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Streamflow Modeling for a Small Watershed using Limited Hydrological Data

S. Chuenchooklin

***Abstract*—**This research was conducted in the Pua Watershed whereas located in the Upper Nan River Basin in Nan province, Thailand. Nan River basin originated in Nan province that comprises of many tributary streams to produce as inflow to the Sirikit dam provided huge reservoir with the storage capacity of 9510 million cubic meters. The common problems of most watersheds were found i.e. shortage water supply for consumption and agriculture utilizations, deteriorate of water quality, flood and landslide including debris flow, and unstable of riverbank. The Pua Watershed is one of several small river basins that flow through the Nan River Basin. The watershed includes 404 km^2 representing the Pua District, the Upper Nan Basin, or the whole Nan River Basin, of 61.5%, 18.2% or 1.2% respectively. The Pua River is a main stream producing all year streamflow supplying the Pua District and an inflow to the Upper Nan Basin. Its length approximately 56.3 kilometers with an average slope of the channel by 1.9% measured. A diversion weir namely Pua weir bound the plain and mountainous areas with a very steep slope of the riverbed to 2.9% and drainage area of 149 km^2 as upstream watershed while a mild slope of the riverbed to 0.2% found in a river reach of 20.3 km downstream of this weir, which considered as a gauged basin. However, the major branch streams of the Pua River are ungauged catchments namely: Nam Kwang and Nam Koon with the drainage area of 86 and 35 km^2 respectively. These upstream watersheds produce runoff through the 3-streams downstream of Pua weir, Jao weir, and Kang weir, with an averaged annual runoff of 578 million cubic meters. They were analyzed using both statistical data at Pua weir and simulated data resulted from the hydrologic modeling system (HEC–HMS) which applied for the remaining ungauged basins. Since the Kwang and Koon catchments were limited with lack of hydrological data included streamflow and rainfall. Therefore, the mathematical modeling: HEC-HMS with the Snyder's hydrograph synthesized and transposed methods were applied for those areas using calibrated hydrological parameters from the upstream of Pua weir with continuously daily recorded of streamflow and rainfall data during 2008-2011. The results showed that the simulated daily streamflow and sum up as annual runoff in 2008, 2010, and 2011 were fitted with observed annual runoff at Pua weir using the simple linear regression with the satisfied correlation R^2 of 0.64, 062, and 0.59, respectively. The sensitivity of simulation results were come from difficulty using calibrated parameters i.e. lag-time, coefficient of peak flow, initial losses, uniform loss rates, and missing some daily observed data. These calibrated parameters were used to apply for the other 2-ungauged catchments and downstream catchments simulated.

***Keywords*—**Streamflow, hydrological model, ungauged catchments.

S. Chuenchooklin, is with the Department of Civil Engineering, Faculty of Engineering, Naresuan University, Phitsanulok, 65000 Thailand (phone: 66-5596-4095; fax: 66-5596-4000; e-mail: sombatc@nu.ac.th)

I. Introduction

The Pua River, one of the small watershed of the Nan River Basin and directly connect to the Nan as a tributary, is located in Nan Province in north region of Thailand with a catchment area of 404 square kilometers (km^2) as shown in Fig. 1. The study area covers a district : Pua District, 9-subdistricts : Phuka, Sakad, Silalang, Sathan, Woranakhon, Pua, Chaiwatana, Jedichai, and Ngang were chosen for study with emphasize on hydrological and flood change. The Pua is the main river used as the water source for agriculture in this area, but there is a high variation of flow between rainy and dry season. The direction of water flow via from the East in the Phuka national park to the West and meet the Nan River at Ban Sala, Jedichai subdistrict.

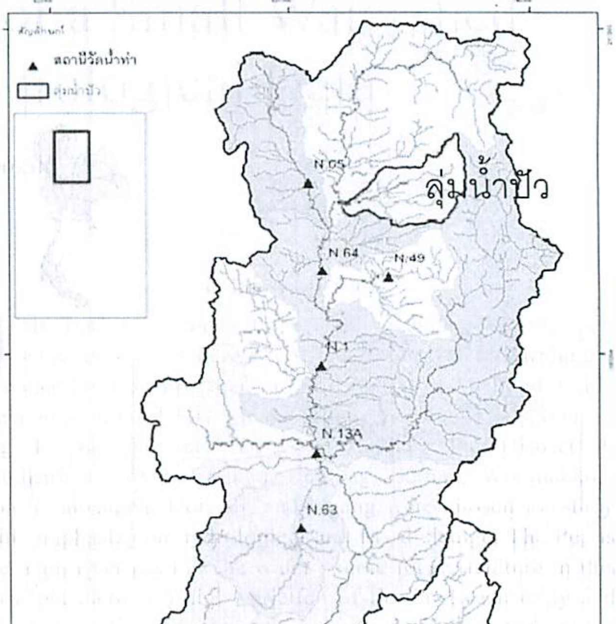

Fig. 1 Map of study area in the Upper Nan River Basin and hydrological observation stations upstream of Sirikit Dam

The Pua Watershed situated in the Upper Nan River Basin in Nan province, Thailand. Nan River originated in Nan province that comprises of many tributary streams to produce as inflow to the Sirikit dam provided huge reservoir with the storage capacity of 9510 million cubic meters (Fig.1). The common problems of most watersheds [1] were found i.e. shortage water supply for household and agriculture utilizations, deteriorate of water quality, flood and landslide including debris flow, and unstable of riverbank [2]. The research reported in this paper aimed to analyze the hydrological parameters relevance to the river discharge as supply water using the hydrological modeling system (HEC-HMS) [3] and river analysis system (HEC-RAS) [4] to simulate streamflow and flood studies with shortage of observation data, which will be benefit for further efficient water management.

II. Materials and Methods

The study area of the Pua watershed includes 404 km^2 representing the Pua District, the Upper Nan Basin, or the whole Nan River Basin, of 61.5%, 18.2% or 1.2% respectively. The Pua River produces all year streamflow supplying the Pua District and an inflow to the Upper Nan Basin. Its length approximately 56.3 kilometers with an average slope of the channel by 1.9% measured. A diversion weir namely Pua weir bound the plain and mountainous areas with a very steep slope of the riverbed to 2.9% and drainage area of 149 km^2 as upstream watershed while a mild slope of the riverbed to 0.2% found in a river reach approx. 20 km downstream of this weir, which considered as a gauged basin. However, the major branch streams of the Pua River are ungauged catchments namely Kwang, and Koon with the drainage area of 86, and 35 km^2, respectively. These upstream watersheds produce runoff to the 3-streams downstream of Pua weir (Pua river), Jao weir (Kwang river or Namkwang), and Kang weir (Koon river or Namkoon), respectively, with an averaged annual runoff of 578 million cubic meters and supply to the Nan River. The Royal Irrigation Department (RID) take responsibility to manage only the Pua weir since the completion of construction to the operation and maintenance scheme with full annual budget at present time due to the medium scale project. Unfortunately, the others small-scale irrigation project (SSIP) has transferred to the local administration office to do the maintenance and extension work with shortage of budget and data recording.

There are continuously recorded daily data of rainfall from inside and outside the watershed operated by the Thai Meteorological Department (TMD) with location mostly at the district offices namely Pua (28042), Thawangpha (28073), and Phuka national park (28164), and from the Department of Water Resource (DWR) at Ban Nafang (090201). There is a continuously daily data recording at Pua river with gauging station namely : Nafang (090201) which is situated at 19.21°N and 100.95°E upstream of the Pua weir conducted by DWR. The daily recorded of water stage at the Pua weir conducted by RID with the period of water delivery according to the water schedule only. The aerial rainfall based on Thiessen polygons used to generate from point to aerial rainfalls. Most side-flows of the river are ungauged catchments; therefore a hydrologic modeling system : HEC-HMS [3] using daily rainfall recorded from TMD and DWR was applied as the uniform lateral inflow based on Snyder's synthetic hydrograph for each specific reaches in the river analysis system model : HEC-RAS [4] from 2008 to 2011. The simulation results from the models were validated with previous recorded of gauged data at midstream of the Pua river at N50 (Ban Rong; RID) in 1994. Unfortunately, it stopped recording of river stage since 1995. The hydrological modeling system and river analysis map are showed in Fig.2 and Fig.3, whereas Reach-1 is the Pua River, and Kwang, Koon, HuaiLa-Pood, and Pua-Ngang are lateral inflows to the Pua, no any gauging station at the outlet point yet was reported. The calibration of hydrological parameters in HEC-HMS i.e. peak coefficients (C_p), peak lags (t_p), and loss rates etc. Initial transposing unit hygrograph's parameters for the Nan sub-basins in Thailand [5], [7] and calculation results using typical Snyder's transformed model formulae [6] used for HEC-HMS shown in (1) and (2). Finally, the hydrological parameters from model optimization presented and fitted with observed data for gauged catchments in HEC-HMS. The upstream (u/s) discharges via the Pua weir result by observation and produced from HEC-HMS applied as u/s boundary condition of Reach-1 in HEC-RAS.

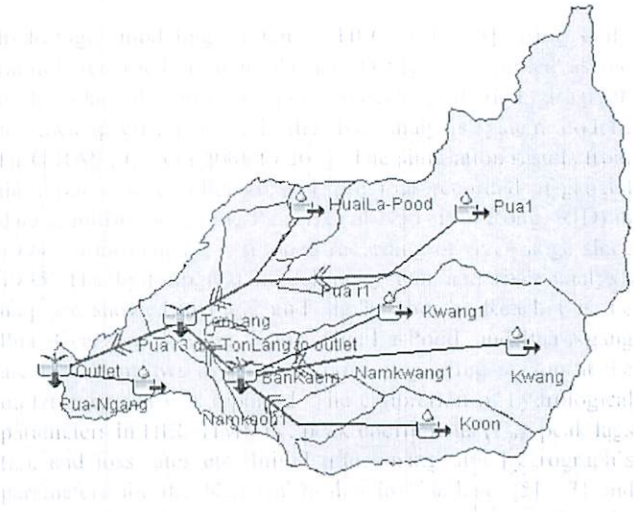

Fig. 2 Schematic map used in HEC-HMS include overall Pua watershed, and catchments namely : Pua1 (u/s of Pua weir), Kwang (u/s of Jao weir), Koon (u/s of Kang weir), HuaiLa-Pood, Kwang1, Pua-Ngang; stream layouts namely : Pua r1, Pua r2, Pua r3, Namkwang1, Namkoon1; and junctions namely : Bankaem (Koon-Kwang meeting point), Tonlang (Kwang-Pua meeting point), and Outlet (Pua-Nan meeting point)

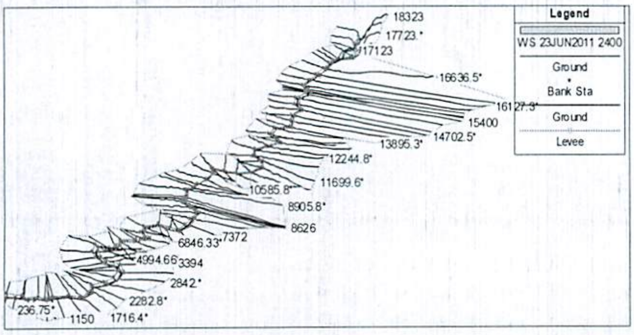

Fig. 3 Plan view of the Pua River's geometry with cross-sectional profiles at every 300-m step length in HEC-RAS model

Steps using HEC-HMS and HEC-RAS were described as follow :-

1. Run HEC-HMS using Pua basin's characteristics (using optimization trial results with observed and HMS's production at some hydrological gauges), observed rainfall for each gage, and discharge productions for main stream and tributaries include junctions and outlet from Pua basin to Nan River.
2. Run HEC-RAS using HEC-HMS results of discharge at main stream (Pua reach-1) and tributaries as lateral side flow of Pua, shape of Pua River i.e. cross-sectional profiles (generated from observed to 300-m interval), inline structures (bridges and weirs) and hydraulic parameters (Manning's n-values calibration resulted at gauging station : N50 in 1994 and flood observed by sight in 2010).

The process using trial n-value showed with the flow chart of the existing study was applied HEC-RAS model for computing water surface profiles at each cross-sectional profiles of the river system (Fig. 4).

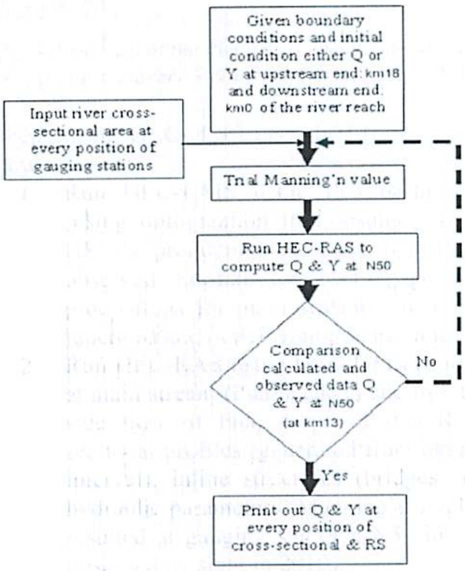

Fig. 4 Flow chart using for the calibration of water surface profile's n-values in open channel

$$t_p = 0.75C_t(LL_c)^{0.3} \text{ and } {}_pQ = 2.78A\,{}_pC/{}_{tR}t \quad (1)$$

$$t_p = C_t[LL_c/S^{0.5}]^n \quad (2)$$

whereas : L, L_c are channel and mid stream lengths in km, S is the channel slope, A is catchment's area in km^2, t_p, $_{tR}t$ are basin lag and adjust duration in hr, Q_p is peak discharge in m^3/s, C_t and n are basin coefficient and exponent values with the 3.2663 and 0.19 for this regional study [5], [7], respectively.

The HEC-RAS model was applied existing 19-cross sectional profiles and generated to every 300 m in step length, 2-inline structures with ogee-weirs at km17 (local weir) and km8 (Plan weir), and 2-highway bridges at km15 (route#1080new) and km1 (route#1080old), and previous gauging station at km13 (N50:RID data 1992-94) were modeled as shown in Fig. 3.

III. Results and Discussion

The optimization of gauged hydrological parameters: $_pC$, t_p in HEC-HMS and the result of 4-year observed rainfall and comparison between simulated and observed flow were summarized in Table I. Daily recorded of rainfall and streamflow observation data in 1999 (station 090201, N47, and generated N46 for the calibration hydrological parameters in Pua, Koon, and Kwang's catchments, respectively), 2008 to 2011 as shown in Fig. 5 (Pua1) and Fig. 6 (Koon) used as input in the model. Those comparison results fitted with R^2=0.44.

TABLE I
HYDROLOGICAL PARAMETERS FOR EACH SUB-BASIN IN HEC-HMS

Sub-basin	Area, km^2	L, km	L_c, km	S	t_p, hr	C_p	Infiltration, mm/hr
Pua1*	149	38.0	19	0.0437	18	0.48	0.10
Kwang	86	22.8	12	0.0665	12	0.5	0.05
Koon	35	16.9	8.5	0.0847	9	0.6	0.20
Kwang1	33	7.7	3.8	0.0108	6	0.48	0.05
HuaiLa-Pood	43	8.1	4.0	0.1161	6	0.5	0.05
Pua-Ngang	58	13.5	6.8	0.0615	6	0.5	0.05

Note * with gauging station

Moreover, the hourly-recorded data of rainfall and WSL at Pua weir (Pua1 watershed in HMS) in wet season 2011 was installed. The simulated and observed results showed better fit with those relationship of R^2=0.572 (Fig. 7 and Fig. 8).

The output results of daily or hourly discharge interpreted to water surface level (WSL) during flood periods (15 June-31 October) in 2008 to 2011 (Fig. 9) were used as boundary conditions in HEC-RAS model with roughness coefficients (n-values) in HEC-RAS ranged from 0.03 to 0.04 for main channel, and 0.08 to 0.10 for flood plain. However, there are not any river stage observation at the outlet of the Pua river meet the Nan river yet, the method using generated the recorded WSL data at N64 (approx.30 km d/s of Pua in the Nan river) into the Pua river mount was applied and shown in Fig. 10. The example results of maximum flood with plan view and water surface profile (WSP) of maximum flood in 2011 are shown in Fig. 11 and Fig. 12. The WSL at d/s of Pua resulted by amount of rainfall and influenced from backwater effect with the fluctuation WSL in the Nan River (outlet point) during flood period.

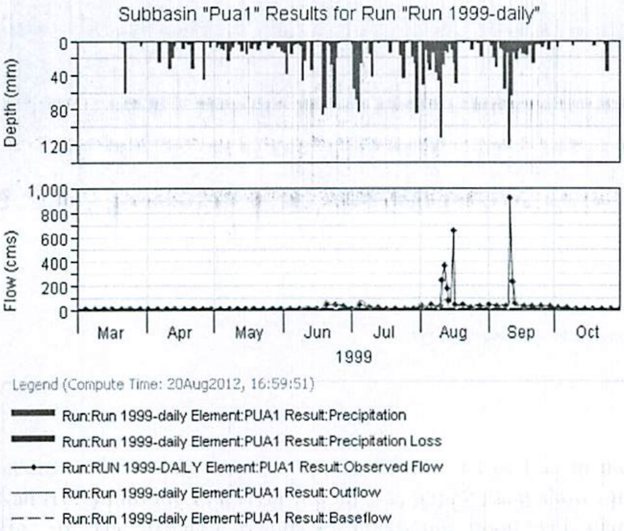

Fig. 5 Observed rainfalls, river flow and simulated flow of Pua1

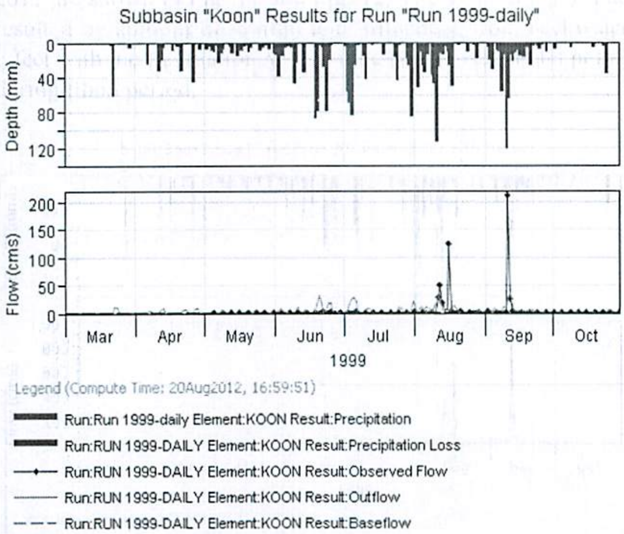

Fig. 6 Observed rainfalls, river flow and simulated flow of Koon

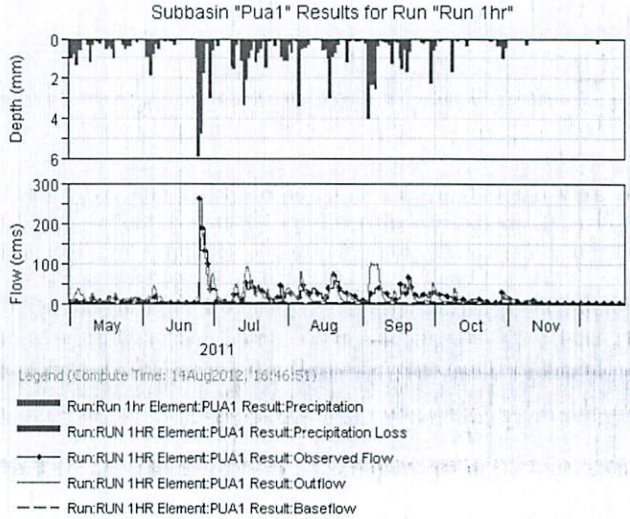

Fig. 7 Observed and simulated results using 1-hr time step in 2011

Project: pua2008-11 Simulation Run: Run 1hr

Start of Run: 30Apr2011, 00:00 Basin Model: pua
End of Run: 20Dec2011, 00:00 Meteorologic Model: pua hyetograph
Compute Time: 14Aug2012, 16:46:51 Control Specifications: Control 2011-1hr

Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (1000 M3)
Pua1	149	173.9	26Jun2011, 05:00	328493.7
Pua r1	149	173.9	26Jun2011, 05:00	328496.7
HuaiLa-Pood	43	66.4	25Jun2011, 02:00	100754.2
Pua r2	192	229.5	26Jun2011, 02:00	429255.1
Kwang	86	113.3	26Jun2011, 00:00	196079.6
Namkwang1	86	113.2	26Jun2011, 00:00	196081.7
Koon	35	51.0	25Jun2011, 04:00	68258.6
Namkoon1	35	51.0	25Jun2011, 05:00	68260.2
Kwang1	33	50.5	25Jun2011, 02:00	77946.9
BanKaem	68	101.3	25Jun2011, 03:00	146207.1
Namkwang2	154	209.2	25Jun2011, 08:00	342291.9
TonLang	346	432.6	26Jun2011, 01:00	771547.1
Pua r3 d/s TonLang t...	346	432.4	26Jun2011, 01:00	771550.8
Pua-Ngang	58	89.6	25Jun2011, 02:00	136245.9
Outlet	404	509.9	26Jun2011, 01:00	907796.8

Fig. 8 HMS's simulation result using 1-hr time step in 2011

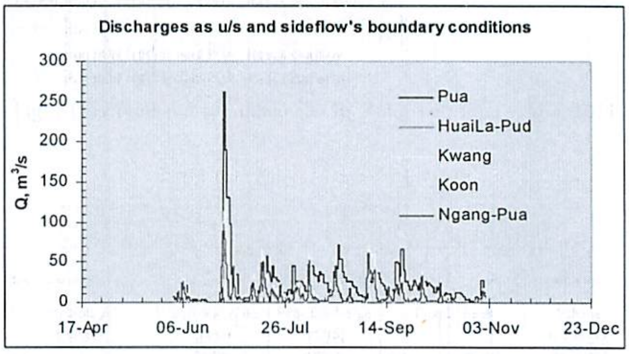

Fig. 9 Discharges in Pua and its tributaries applied as u/s boundary conditions in HEC-RAS in 2011

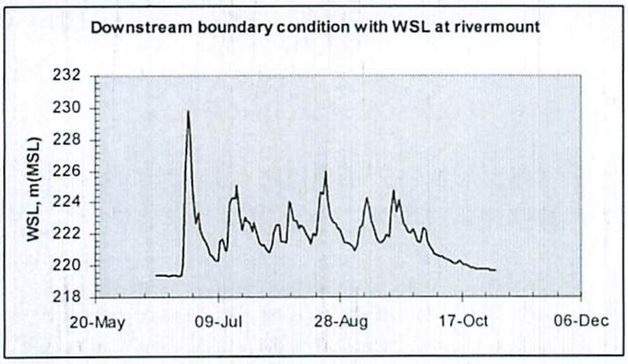

Fig. 10 Daily WSL applied as d/s boundary condition of Pua

The results showed that the simulated daily streamflow and sum up as annual runoff in 2008, 2010, and 2011 were fitted with observed annual runoff at Pua weir using the simple linear regression with the satisfied correlation R^2 of 0.64, 062, and 0.59, respectively. The sensitivity of simulation results were come from difficulty using calibrated parameters i.e. lag-time, coefficient of peak flow, initial losses, uniform loss rates, and missing some daily observed data. These calibrated parameters used to apply for other 2-ungauged catchments and downstream catchments simulated.

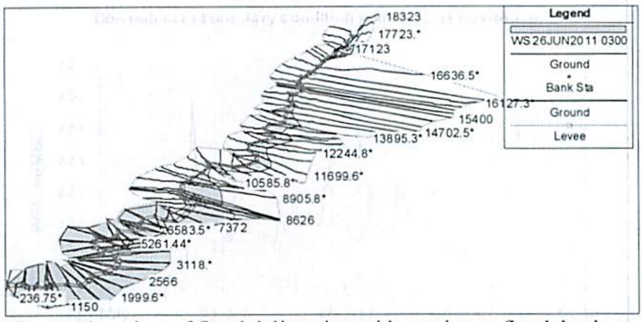

Fig. 11 Plan view of flood delineation with maximum flood depth on 26/06/2011 03:00AM as an example result from HEC-RAS

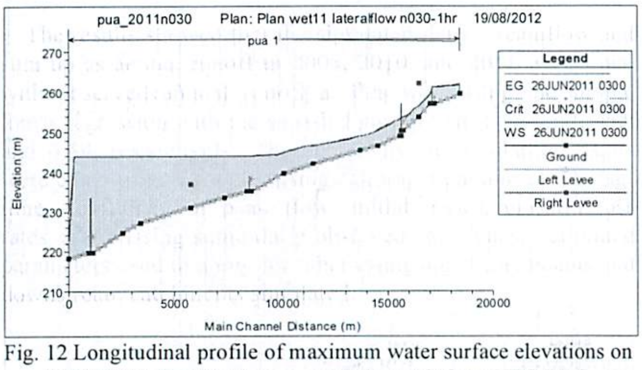

Fig. 12 Longitudinal profile of maximum water surface elevations on 26/06/2011 03:00AM as an example result from HEC-RAS

IV. Conclusion

The results showed that both hydrological modeling system (HMS) and river analysis system (RAS) from USACE could be easily applied for other watershed with lack of hydrological observation data particular WSL. The evidence showed that if the smaller time-step than 1-day of data observation, the result produced from the models would be more fit and efficient application to the field. The effect of changing flood patterns from the change land use should be research to better water management in the basin.

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