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Influence of Rainfall Distortion on Hydrograph Lag Time of Naturally Full-Covered Hill-Evergreen Forest Watershed in Mountainous Land

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ABSTRACT

The research is aimed to study influence of rainfall distortion on hydrograph lag time in three periods of normal climate (1966-1987), transition (1988-2008) and climate change (2009-2015) over the first-order stream watershed covering natural hill-evergreen forest in mountainous land. The results found the total average annual rainfall 2,046.5 mm from the periods of 2,084.1 mm (plus another fog drift 2.3% of annual rainfall) for 1966-1987, 2,021.8 mm for 1988-2008 and 1,993.3 mm for 2009-2,015; falling 155 rainy days; humidity ranging 58.5-89.7%, pan evaporation 3.1 mm/day; average temperature 16.7-23.3 ^{o}C with extreme maximum 35 ^{o}C and minimum 4.5 ^{o}C, and wind speed 5.4-22.6 km/hr. Measuring streamflow was approximately 1,2233 MCM/km^2 which divided to wet flow 57% and dry flow 43%. Accordance with 3-period rainfall of normal climate (1966-1987), transition (1988-2008), and climate change (2009-2015) played vital role in decreasing lag time 18, 13, and 9 hours due to the distortion of rainfall quantity but the first-order stream watershed covering with dense-nature hill-evergreen forest was still functioned on its flow regime without interruption. The abundances of organic matter, clay minerals, high soil porosity, deep soil profile and plant cover over 80% are regulated to rainwater absorption for continuously feeding streamflow all the year, even the driest and wettest years.

Keywords: Watershed hydrology; First-order stream watershed; Hydrograph lag time; Soil water

1. Introduction

Thailand is located on the latitudes 5*37' N-20*28' and longitudes 97*21'E-105*37' which belongs to the zone of tropical rainforest and identified as high annual rainfall approximately 1,700 mm (ranging between 800 to 10,000 mm) and converting into rainwater 800,000 MCM per annum, the highest in the south and the least in the northeast. The Royal Irrigation Department identified this annual rainwater to evaporation 70% (600,000 MCM), and streamflow 30% (200,000 MCM) which is kept about 40,000 MCM by the sixteen storage dams in the whole country. Since the year of 1990 up to present time, the distribution of rainfall were increasing intensity and longer duration in some period of the years and in some parts of the areas, but the average annual rainfall water still narrow variation. Significantly, the excessive rainwater are still expected to influence on shorter traveling time for both surface runoff and soil water flow from headwater down to lowlands which related to forest cover, the traveling time of both flows the surface runoff and soil water are shorter periods that causes flash flood whenever the occurrences of high intensity and longer duration of falling rain. The return flow unavoidably occurs by the role of return flow to sweep all toxicants from elements, soluble and non-soluble organic matters and debris as well as pathogens in which they are surely contaminated to stream water (Forest service, 1977; Streeter and Phelps, 1925; Vargaftik *et al.,* 1996; UN, 1953; Oliver *et al.,* 2016; Poff *et al.,* 1997; Gburek and Folmar, 1999; Cheng *et al.,* 2002).

In principles of tropical watershed management is identified as keeping water in soil and keep soil in place. Naturally, the tropical soils, especially mountainous headwater and normally covering with hill-evergreen forest, are deep together with friable-loam structure texture, high content of organic matter and high soil porosity. Such properties of tropical forest soils are characterized as high water holding capacity by organic matter, finer particles (clay particles) and soil pores (particularly pore size between diameter 30 to 70 microns of top soils). This is the reason why hill-evergreen forest soil is able to absorb water 5 to times in oven-dry weight. (Baver, 1965; Baver *et al.,* 1972). The aforesaid researches in the past indicated that the first-order-stream mountainous watershed covering with forest is able to feed water continuously to stream. In doing so, the soils have to covered with plant cover eligibility for maximizing water holding capacity by surface coating, soil porosity storing, and chemical combining in order to make the feeding water to stream prolonging beyond the usual time (technically called as hydrograph lag time). In hydrological point of view, hydrograph lag time (sometimes called as lag time) is defined as the difference between the time when half the rainfall of each falling storm and the time coordinate of the centroid of resulting runoff. Actually, lag time reflects the efficiency of the basin channels and subsurface flow network to deliver runoff to a downstream point in the stream channel. Hence, a significant change in lag time should indicate some degree of alteration in the watershed structure. However, a change in flow regime may or may not cause degradation of drainage, depending on the nature and severity of the alteration (Dunne and Leopold, 1978; Leopold, 1981; Kittredge, 1948; Hill *et al.,* 2014). Making lag time longer by increasing soil porosity is very necessary in tropical countries (Forest Service, 1976; Baver *et al.*, 1972; Berhanu *et al.*, 2015; Berkowitz *et al.*, 2011; Brooks *et al.*, 2013; Chunkao, 2008; Dunne and Black, 1970; Gburek and Folmar, 1999; Rothacher, 1971; Niedzialek and Ogden, 2012; Oliver *et al.*, 2016).

To make support the above statement, the objective of this research is aimed to learn the role of first-order stream of highland watershed covering with dense hill-evergreen forest in 'keeping water in soil and keeping soil in place' for providing the optimum quantity, desirable quality, and flow regime regulation all the year. The research results are also expected to protect flash flood as well as to apply for integrated water management at the present and future time.

2. Selection of Study Area

Kog Ma watershed research station (KMWRS), under control of Department of Conservation, Faculty of Forestry, Kasetsart University, has been selected for Mountainous Watershed Management Research since 1963 by taking the first-order stream watershed covering with dense hill-evergreen forest as the experimental area of 10.4 hectares between elevation of 900 to 1,650 mMSL (Doi Pui summit) on the average slope about 45%, and nearby Bhuping Palace in Chiangmai northerly Thailand as shown in Figure 1. Also, KMWRS watershed shape and size as originated from granitic rock type and deep soil one part of Doi Pui -Mae Sa National Park, Department of National Parks, Wildlife and Plant Conservation, Ministry of National Resources and Environment, Thailand.

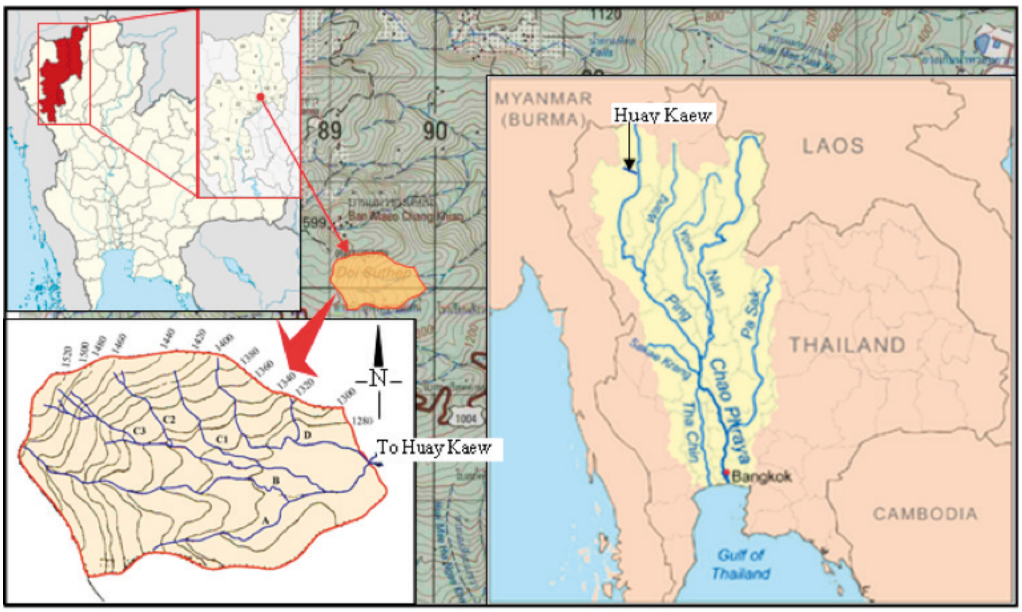

Figure 1. Location of Kog Ma Watershed Research Station (KMWRS) inside the Hill-Evergreen Forest the Highland Area of Doi Pui - Mae Sa National Park adjacent to the City of Chiang Mai, Thailand.

3. Methodology and Instrumentation

3.1 Installation of climatic station and rain gage

The standard climatic station has of KMWRA been installed at elevation 1,200 mMSL (ranging 950-1,650 mMSL) in which it is included the manual 8-inch standard rain gage, weighing-type automatic 8-inch rain gage, wet-bulb and dry-bulb thermometer in instrument shelter, ambient air thermometer, 5-level soil thermometer, 120-cm diameter evaporation pan, 3-cup anemometer, and sunshine recorder as indicated (Figure 2). Besides, the total watershed area used to installed dispersedly another 27-vertical-tilted rain gages around the KMWRS area in order to evaluate the rain-gage density and to be perpendicular to earth exist or to the sloping surface. Nevertheless, the experiments were installed wedge-type rain gages under forest canopy for measuring throughfall, interception, making gutter around tree trunks for measure stemflow, Then after an interception can be determined from the different between gross rainfall and throughfall plus stemflow as well as amount of fog drift which is identified as the total amount of moisture, mist, and drizzle as falling rain.

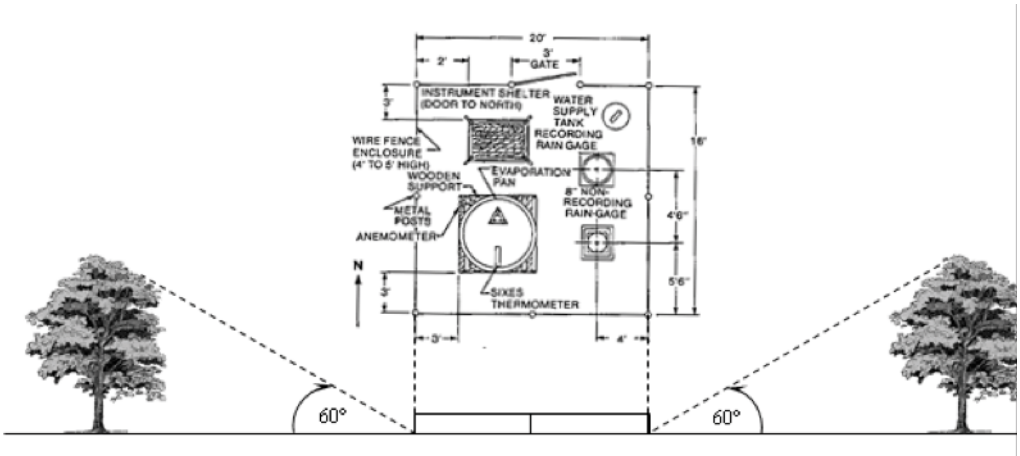

Figure 2. KMWRS climatic station as installed on the 60-degree angle between ground floor and treetop including meteorological instruments.

3.2 Construction of 120-V notch weir dam

The dam site at the outlet of Huay-D sub-watershed was selected to construct the sharp 120-V Notch weir on the size of width (5 m), length (12 m), and depth (1.2 m between the dam bottom and lower level of 120-V Notch weir) with the storage capacity of about 72 cubic meters together with dredging the stilling well and connecting to water body in storage dam as shown in Figure5, At that time, the automatic water level recorder had been installed for measuring the height of water level and using the derived equation (2) for calculating discharge. Actually, water height has been continuously recorded since one year after the KMWRS project starting-up in 1964, and also the manual staff gage were inside of stilling well in order to measure directly water height in storage dam by 6-cm connecting concrete pipe. In so far, the 120-V Notch weir has been continuously measuring flow, but there were some interruption period due to long-using automatic recorders and robbery events. Besides, the 120-V Notch weir is presumably used not only for storing water but also for collecting annual sediment yields from Huay-D main stream.

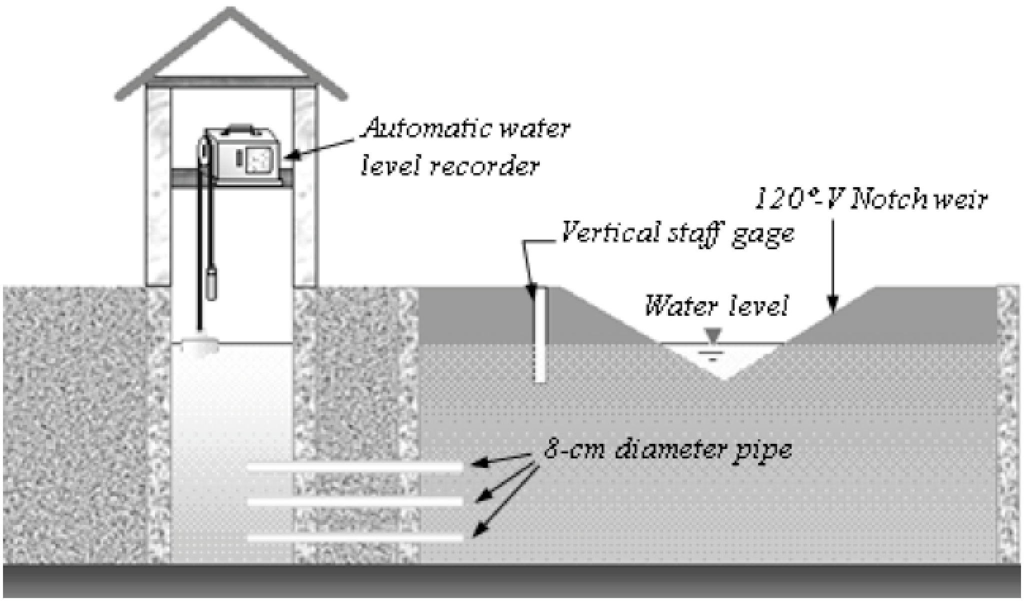

Figure 3. Sketching V-Notch weir to connect with drilling well by 8-cm diameter pipe and installed automatic water level recorder for measuring continuously streamflow of first-order stream.

3.3 *Forest ecology study*

Forest inventory was applied line plot system with areal size of 0.1 hectare (plot radius 17.85 m), 7 lines (100-m between lines, and 40-m between plots) by using Huay-D main stream as the main line), in order to find out plant species diversity in both the horizontal distribution and forest profile. Each plot was randomly placed on 2 x 2 m plot for identifying undergrowth including ground-floor mosses, likens, climbers and seedlings (less 1.3-m height); 5 x 5 m plot for identifying saplings (greater 1.3-m to 5.0-m height but less 30-cm DBH); and the whole 0.1-ha plot for identify trees (greater 5.0-m height and great 30-cm DBH) for studying on soil, water and plant relationships. In so far, there were the study on the percentage of plant cover in various topographical characteristics by photographically techniques, plant cover relation to soil losses by using soil erosion plot techniques, and concerning with influences of plant cover to soil and water losses regarding intercepted evaporation and surface runoff as shown in Figure 4. For updating data, the forest ecology was studied in every 5 years for only first period (1966-1987) on both dry and summer period.

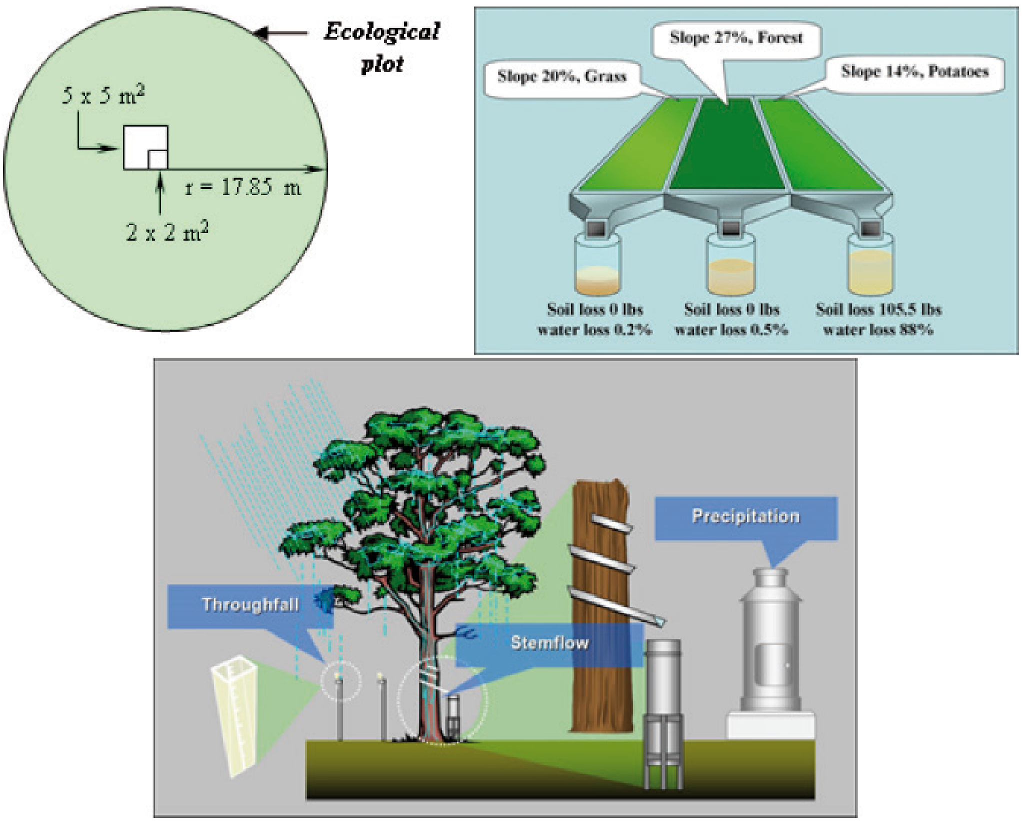

Figure 4. Measurement of quantitative ecological inventory, soil erosion plot, streamflow, throughfall and interception in Kog Ma hill-evergreen forest before infiltrating and percolating into sub-surface soils and flowing down to feed the streamflow.

3.4 Streamflow discharge formula

The water quantity as the streamflow is the most important that has to be measured in order to take it for managing water resources. The method how to measure streamflow as expressed in the following formula:-

Q = VA --------------(1)

where

Q = streamflow discharge, cms

V = flow velocity, m/s

A = cross-sectional area of stream, m^2

In practical point of view, V (flow velocity) can be obtained by using current meter to measure directly in the field (by selecting 50-100 m-long reach of stream), while A (cross-sectional area of stream) has to be determined at the same measuring point. V-notch weir is another method in flow measurement for small watershed, normally less 50 m^2, but the angle of V-notch weir is applied by 90-V and 120-V notch weirs for low and high flow measurement in which the equation (1) can applicable for 120-V notch as shown in equation (2):-

Q = 2.56 H 5/2 ------------(2)

where

Q = discharge of stream, cms

H = water height over weir crest,

Long term flow measurement of small head watershed (area less 1 m^2) covering with dense hill-evergreen forest found annual water quantity about 50% of annual rainfall (more or less 2,000 mm). While the larger size of watershed (greater than 100 m^2) produced streamflow approximately 30% of annual rainfall, another 70% of rainwater escaped to sky as evapotranspiration and about 5% of them using for plant growth, also small part to be kept as subsurface water.

In case of water resources management, the total flow has to be separated by flow separation technique in order to obtain surface flow, subsurface flow (soil water flow) and groundwater (base flow) in which they are very much necessary to point the direction of watershed management, especially conditioning soil physical properties available for keeping rainwater for feeding creek, stream, and river all the year.

3.5 Determination of soil characteristics

To fulfill philosophy of watershed management on “keep water in soils, keep soils in place in order to decrease wet flow, and increase summer flow”, soil samples were taken at depths of 0-5 cm, 5-15 cm, 15-30 cm, 30-50 cm and 0-50 cm, on triangle soil pits along with composite sampling techniques for analyzing the properties of soil physics, soil chemistry, soil biology, soil erodibility, soil erosion, plant cover relation to water loss-gain and soil erodibility, soil water storage capacity, soil filtration and percolation processing in relation to soil nutrient and its cycling and nutrient availability to the downstream areas. Also, its infiltration capacity was determined by infiltration lysimeter at the middle of north and south aspects for three plots each

3.6 Soil water relations

It is understandable that precipitation in tropical zone is naturally identified in form of only liquid in terms of rainfall, hence it must be kept in soils underneath of the surface, that is, soil porosity, coating on surface of soil particles, and in form of chemical-combined water in soil. Such issues have been raised to determine soil moisture of KMWRS study site by collecting soil samples at foothill, middle, and highest elevation, and also at depth of surface (LFH-layer 20 cm), A-horizon 40 cm, and B-horizon 90 cm 50-cm. Conducting of water in soils was determined on soil structure (friable), gravel (7%), bulk density (0.50-1.26 g/cc), soil porosity (50%-60%), pH (5.2-5.3), CEC 7 meg/100 g), sand (60%), silt (15%), clay (39%), soil water holding capacity (5 times of oven-dry soil), and infiltration rate (112 cm/hr), normal status of nutrient elements (N,P, K, Ca, Mg, Na, Fe and Mn) as well as very low quantity of heavy metals (Pb, Hg, and Cd).

4. Results and Discussion

4.1 Climatic Conditions

The research results for 50-yr record (1966-2015) found average annual rainfall 2,084.1 mm extreme minimum monthly 2.1 mm in February and extreme maximum monthly 400.5 mm in September with maximum rain-a-day 183.5 mm in September 1973), and doing exist rain falling every month with 155 rainy days over the small first-order stream watershed under fully dense cover of natural hill-evergreen forest as shown in Table1. The average annual of 50-yr rainfall 2,084.1 mm seems higher than the average rainfall (1,700 mm) of the whole Kingdom because KMWRS watershed is located between the elevation 950 mMSL to 1,650 mMSL of fog belt zone comprising of high atmospheric moisture and mist enhanced the relative humidity in the air found the average of 78.8% (extreme maximum 89.9% approaching to 100% in wet period and extreme minimum 58.5% approaching less 50% during dry period). It could be remarkable that the 50-year record found rain-a-day rainfall not beyond 150 mm until September 1973 (183.5 mm). In other words, the year 1973 might be the turning point of rain falling in mountainous watershed before gradually increasing above 185 mm in 1983 and 1987 and finally coming above 200 mm in 1995, 2013 and 2014 in which they were the causes of flooding in Chiangmai lowlands before continuing to down-north, the central and Bangkok. Even though the falling rain was high amount and its intensity, there is never surface runoff occurring in the KMWRS watershed due to higher infiltration rate of hill-evergreen forest soils along with high soil water holding capacity (approximately 5-12 times of oven-dry weight soils) likewise natural reservoir to provide water yields to streams and downstream areas without any interruption.

Accordance with KMWRS watershed has been located in the fog belt with the existence of high atmospheric content in form of fog drift which is measurable about 2.3 % of average annual rainfall. This amount of fog drift as caught by tree canopy distributes in to interception, throughfall, and stemflow before falling down to surface soils, infiltration, percolation, and soil holding water towards feeding streams (Al-Faraj and Schols, 2014; Sutterlund, 1972; Forest Service, 1976; Berkowitz *et al.*, 2011; Brooks *et al.*, 2013; Colman, 1953; Hill *et al.*, 2014; Niadzialek and Okden, 2012; Oliver *et al.*, 2016). However, the influences of fog belt and fog drift still showed in low rate of pan evapotranspiration approximately 3.1 mm/d (average monthly 94.13 mm and annual 1,129.5 mm) due to low ambient temperature with ranging 4.5 ^{o}C to 35.5 ^{o}C, low wind speed (5.4 km/hr to 12.6 km/hr) as illustrated in Table 1.

Table 1. Characteristics of climate in tropical hill-evergreen forest as measured during 1966 to 2015 (49 years) at Kog Ma Watershed Research Station in Chiang Mai, Thailand

Month	Rainfall			Temperature (ºC)					Relative humidity (%)	Wind velocity (Km/hr.)	Pan Evap. (mm)
	Average Month rainfall (mm)	Max. rain a day (mm)	No. of rainy day (days)	Ext. max.	Ext. min	Mean	Aver. Max	Aver. Min			
Jan.	23.5	69.0	2	26.5	5.0	17.2	21.8	12.6	70.4	9.2	90.2
Feb.	2.1	19.5	1	20.0	8.5	18.9	25.0	14.9	60.5	10.9	119.1
Mar.	31.2	82.5	2	35.5	12.5	22.7	22.7	17.9	58.5	12.6	171.2
Apr.	67.1	61.5	7	35.3	11.5	23.3	28.1	18.5	66.7	10.7	158.6
May	277.0	140.8	20	32.4	13.0	21.8	25.3	18.2	83.4	9.4	113.2
Jun.	247.6	105.5	21	32.4	13.9	20.8	23.6	18.0	86.8	8.2	78.3
Jul.	313.1	116.0	23	28.3	13.9	20.4	22.4	17.8	88.3	9.4	70.0
Aug.	400.1	103.4	26	27.0	12.8	19.6	22.5	17.5	89.6	9.6	69.0
Sep.	400.5	183.5	25	27.0	12.2	20.3	23.1	17.5	89.5	5.4	69.5
Oct.	203.9	105.3	18	28.3	11.7	19.5	22.9	16.8	86.2	6.1	67.3
Nov.	84.9	136.9	7	29.0	8.0	18.3	21.6	15.0	82.0	6.6	58.9
Dec.	33.1	73.0	3	29.0	4.5	16.7	20.7	15.2	78.0	6.6	64.2
Total	2084.1	-	155	-	-	-	-	-	939.9	104.7	1129.5
Aver.	173.7	-	-	-	-	20.0	23.7	16.6	78.3	8.7	94.13
Extreme	400.5	183.5	26	35.5	4.5	-	-	-	89.6	12.6	171.2

Remarks: Maximum and Minimum a-day rains found once during 1966 throughout 2015 at the same as air Temperature but they were different from 1966-2015 average of average monthly rainfall, rainy days, relative humidity, wind velocity and pan evaporation

4.2 *Forest Ecology*

The results from forest inventory found the natural-homogeneous green plant cover over first-order stream KMWRS watershed has been identified as hill- evergreen forest, Catanopsis as the dominant species and abundance with ground-floor and climbers, undergrowths, seedlings, saplings, and trees as illustrated in Table 2.

It is remarkable to point out that the profile of forest is classified into 5 stories (trees, saplings, seedlings, undergrowth, and ground-floor). Actually, the ground plants are composed of undergrowth (mostly newly sprouts, pheatophytes, climber, herbs, etc) and ground-floor plants (mostly likens, ferns, biofilms, etc.) as shown in Table 2. Besides, there was no trespass and walk-in visitors but only collection of mushrooms in wet season and medicinal plants in dry period could be occasionally found in this study area. In other words, this study area was naturally existed high numbers of tree density, index of diversity, basal area, and height (see Tables 2, 3 and 4).

Table 2 Tree density as obtained from ecological study plots in hill-evergreen forest of Kog Ma watershed as located between elevations of 1,000-1,650 m MSL.

Altitude, m	Density, trees/ha					Total	Seedling (no./ha)	Ground plant (no./ha)
	Size class (DBH; Diameter at Breast Height in centimeter)							
	I	II	III	Saplings				
	(>66)	(<66 – 33)	(<33 – 17)	(<17 – 5)	(<5)			
1,000	12	92	260	539	1,172	2,075	43,200	33,200
1,100	55	102	55	321	1,201	1,734	10,000	89,600
1,200	11	156	100	300	722	1,289	86,000	35,600
1,300	11	110	288	710	1,042	2,161	7,600	129,200
1,400	11	44	177	855	1,022	2,109	7,600	391,800
1,500	-	-	180	909	3,242	4,331	11,800	105,200
1,600	-	44	143	942	663	1,792	13,200	179,600
Total	100	548	1,203	4,576	9,064	15,491	179,400	964,200
Ave.	14	78	172	654	1,295	2,213	25,600	137,700

Table 3. Tree size distribution as found from quantitative ecological investigation in KMWRS hill-evergreen forest headwater of Huay Kaew creek upper Ping river

Character Trees	DBH ≥ 4.5 cm	DBH <4.5 cm H >1.30 m [1/]	H <1.30 m [1/]
No. of tree/plot	726 (770)	24 (-)	75 (88) (168)*
Tree density (no./ha)	726 (770)	3750 (-)	46,875 (55,000) (105,000)*
No. of species	70 (83)	19 (-)	29 (5) (5)*
Index of diversity (H)	5.14 (5.56)	4.12	4.33 (5.05)
Percent of basal area/ha	0.377 (0.384)	0.008 (-)	-
Average height (m)	14.20	2.73	0.91

Remark : [1/] Under canopy plots.

Note Base on a 100 m x 100 m samples plot for tree over 4.5 cm DBH, four 4 m x 4 m sample plots for under 4.5 cm DBH, but taller than 1.30 m , and sixteen 1 m x 1 m sample plots for trees below 1.30 m in height. Figure in parentheses include climber and ( )* include herbs.

Table 4. Tree density, basal area, and height of KMWRS hill-evergreen forest as located in Huay Kaew sub-watershed of Ping river basin

Quantitative characteristic	Hill-evergreen forest
No. of species	38
Tree density (no./ha)	1,014
Percent of basal area/plot	0.2816
Average height (m)	9.00

Obviously, the density of plant cover was shown in the fog belt zone which indicated high efficiency of drizzle capture by leaves, twigs, flowers, fruits, and tree trunks to form the fog drift before falling to the ground. In principles, the more the crown density is the more the amount of fog drift. So, the dense hill-evergreen forest is sensitively able to catch the drizzle in form of small drop size of precipitation in the atmosphere. This is another benefit of dense hill-evergreen forested headwater to withdraw atmospheric moisture as a part of precipitation instead of only rainfall. However, the 25-year average amount of fog drift over KMWRS hill-evergreen forest was about 2.3 % of average annual rainfall (above 2,000 mm) as occurred normally in wet period of the year.

Looking at forest ecological data as shown in Tables 2, 3 and 4, the first-order stream headwater as covered by dense hill-evergreen forest is the target plant cover for healthy and wealthy watershed management in terms of continuously water supplying to stream and main rivers. This condition should be concerned with soil properties not only high water absorptivity but also plenty of plant nutrients for healthy hill-evergreen forest over first-order stream KMWRS watershed which includes details in the previous sections.

4.3 Soil Characteristics

Field survey and laboratory, the soil of KMWRS first-order stream watershed is generated from granite rock type along with depth of 0-20 cm for LFH-layer, 20-60 cm for A-horizon, 60-150 cm for B-horizon, and greater 150 cm for effectiveness together with organic content of 13.05, 4.30, 1.43 and 6.0%, respectively (see Table2). The soil structure was identified as friable for horizons, and sandy clay loam as their soil texture (comprising of clay 21.40%, 26.67%, 29.13%, and 25.00%), while soil porosity found at LFH-layer 67.7%, A-horizon 62.5%, B-horizon 52.43%, and effectiveness 50%-60%. Those characteristics of soils provide very high infiltration rate up to 112 cm/hr (approximately 20 mm/sec) as the same as making soil water holding capacity about 10, 6, 3 and 5 times of their oven-dry weight as shown in Table 5.

Summarily speaking, the characteristics of hill-evergreen soil are prominently identified as loamy sand, depth 120-200 cm, infiltration capacity (fp) 112 cm/hr, soil porosity about 50%, water holding capacity 5-10 times of oven-dry weight soil, high nutrient content, and low heavy metal content. Hydrological, the dense-natural and undisturbed hill-evergreen soils of the first-order stream watershed is hydrological functioned as "natural water reservoirs" or "spongy land" for keeping percolated water before gradually self-releasing to streams or rivers all the year even extreme drought in late 2015 (August-December) and early 2016 due to high content of organic matter in soils, high soil porosity for storing infiltrated and percolated water, deeper soil profile, water holding capacity and others that bring about to have water suppliers to provide streamflow all the year. Besides, there was no response of streamflow whenever rainstorm less 30 mm according to rainwater being absolutely absorption but it was surely seen its response when daily rainfall greater 60 mm. Moreover, loamy sand textured soil of KMWRS hill-evergreen forest was another factor to make soil unstable to keep it in place, this is why soils nearby experimental site have been washed off (UN, 1953; Middleton, 1930; Forest Service, 1976; Berkun, 2005; Cheng *et al.,* 2002; Gburek and Folmar, 1999; Neal *et al.,* 2010; Kittredge, 1948; Baver, 1965; Baver *et al.,* 1972; Hill *et al.,* 2014; Chunkao, 2008).

4.4 Streamflow Characteristics

The 50-record streamflow as measured by 120-V Notch weir was divided into 3 periods; they were 1966-1987, 1988-2008 and 2009-2015 for the periods of normal, transition, and climate change, respectively. Results found annual flow 1.3782, 1.2077 and 1.0839 MCM/km^2 during the periods of 1966-1987, 1988-2008 and 2009-2015 (total average 1.2233 MCM/km^2) as well as wet flow 57% and dry flow 43% of annual flow while the annual rainfall indicated at amount of 2,084.1, 2,021.8, and 1,993.3 mm (total average 2,046.5 mm), respectively as indicated in Table 6.

Table 5. Values of analyzed soil properties of Huay-D first-order stream watershed as generated by old granitic rock parent material (PM), hill-evergreen forest cover (O), cool and wet climate (Cl), mountainous relief (R), and more 1.000 year weathering period (T) over the area of Pui-Mae Sa National Park in Chiang Mai, Thailand

No.	Item	Soil Horizon			
		LFH - Layer	**A - Horizon**	**B - Horizon**	**Effectiveness**
1	Parent Material	granite	granite	granite	granite
2	Soil Depth, cm	0 - 20	20 – 60	60 - 150	150
3	Structure	Very friable	Friable	Friable	Friable
4	Porosity, %	67.7	62.5	52.43	50 - 60
5	Texture, %	Sandy clay loam	Sandy clay loam	Sandy clay loam	Sandy clay loam
	1) Sand	64.45	61.70	59.61	60
	2) Silt	14.15	11.63	11.26	15
	3) Clay	21.40	26.67	29.13	25
6	Basic Properties				
	1) Organic Matter, %	13.05	4.30	1.43	6.0
	2) CEC, meq/100g	11.5	6.4	3.4	7.0
	3) pH	5.3	5.2	5.3	5.2-5.3
	4) Gravel,%	4.15	6.30	9.46	7.00
	5) Color	Dark brown (7.5 YR 3/2)	Dark reddish brown (5 YR 3/4)	Yellowish red (5 YR 4/6)	Dark reddish brown (5 YR 3/4)
	6) Bulk density, g/cc	0.50	0.99	1.26	0.50 – 1.26
	7) Infiltration Capacity, cm/hr.	-	112	-	112
	8) Water Holding Capacity, times of oven–dry weight Soil	10	6	3	5
7	Plant Nutrients				
	1) N (mg/Kg)	5,400	2,600	1,250	3,100
	2) P (mg/Kg)	15.71	9.24	7.53	11
	3) K (mg/Kg)	175.68	125.64	88.83	127
	4) Ca (mg/Kg)	173.12	39.04	28.06	80
	5) Mg (mg/Kg)	536.40	77.60	50.20	222
	6) Na (mg/Kg)	36.28	36.36	33.15	35
	7) Fe (mg/Kg)	15.61	17.26	13.10	15
	8) Mn (mg/Kg)	16.57	11.81	10.43	13
8	Heavy Metals				
	1) Pb (mg/Kg)	0.0013	0.0065	0.0122	0.0066
	2) Hg (mg/Kg)	0.0050	0.0028	0.0037	0.0038
	3) Cd (mg/Kg)	0.0007	0.0367	0.0034	0.0136

Table 6. Average monthly flow during 1966-1978,1998-2008 and 2009-2015 of Huay-D first-order stream KMWRS watershed along with full cover of dense-natural hill-evergreen forest as located in mountainous land inside Sutep Pui - Ma Sa National Park, Chiang Mai northerly Thailand

Month	Average Monthly Flow (MCM/ km^2)				Average Monthly Rainfall (mm.)			
	1966 - 1978	1998 - 2008	2009 - 2015	Ave.	1966 - 1978	1998 - 2008	2009 - 2015	Ave.
Apr.	0.0622	0.0577	0.0520	0.0573	67.1	65.2	56.8	63.0
May	0.0744	0.0775	0.0642	0.0720	277.0	273.4	268.7	237.3
Jun.	0.0797	0.0744	0.0782	0.0774	247.6	246.1	268.4	253.7
Jul.	0.0919	0.0790	0.0901	0.0870	313.1	269.7	257.0	329.9
Aug.	0.1169	0.1091	0.0982	0.1081	400.1	398.2	395.6	398.0
Sep.	0.1734	0.1642	0.1402	0.1593	400.5	402.1	398.2	400.3
Oct.	0.2080	0.1554	0.1426	0.1687	203.9	198.5	190.2	197.5
Nov.	0.1712	0.1380	0.1254	0.1449	84.9	82.6	76.5	81.3
Dec.	0.1358	0.1203	0.1108	0.1223	33.1	312.5	281.5	31.0
Jan.	0.1064	0.0950	0.0882	0.0965	23.5	21.6	20.2	21.8
Feb.	0.0826	0.0724	0.0512	0.0687	2.1	3.2	2.9	2.2
Mar.	0.0757	0.0647	0.0428	0.0611	31.2	29.7	30.6	30.5
Total	1.3782	1.2077	1.0839	1.2233	2,084.1	2,021.8	1,993.3	2,046.5

The average of peak flow was mostly found in either September or October which depended on the antecedent rainfall, mostly a month ahead. Experience from field working can be pointed out that there is no surface flow occurring inside KMWRS watershed because of high infiltration rate and water holding capacity of the hill-evergreen forest soil. Remarkably, the divided periods showed the same trend of perennial streamflow pattern as low flow rate in summer (January to June as dry period) then gradually rising to peak flow in either September or October, then gradually recessing to the summer flow rate as illustrated in Figure 5.

The flow measurement was pointed that the integrity of hill-evergreen forest ecosystems plays the most important role in flow regime not only maintaining high content of organic matter in deep soils to absorb rainwater much more capacity but also capturing wind-carrying fog drift to increase measured rainwater along with less evapotranspiration. Again, the research results found that the first-order stream watershed with full cover of hill-evergreen forest was met the requirement of "keeping water in soil, keep soil in place" which did lead to "decreasing wet flow and increasing summer flow." Also, friable soil of hill-evergreen forest as generating from granitic rock type has illustrated in flow regime that might be changed in size, shape, depth, and form in case of the occurrence of soil erosion after clearing forest cover because of erodible granitic-parent-rock soil. Fortunately, the KMWRS first-order watershed is localization inside Pui-Sutep National Park which is named as protected area to mechanize water flow to lowlands.

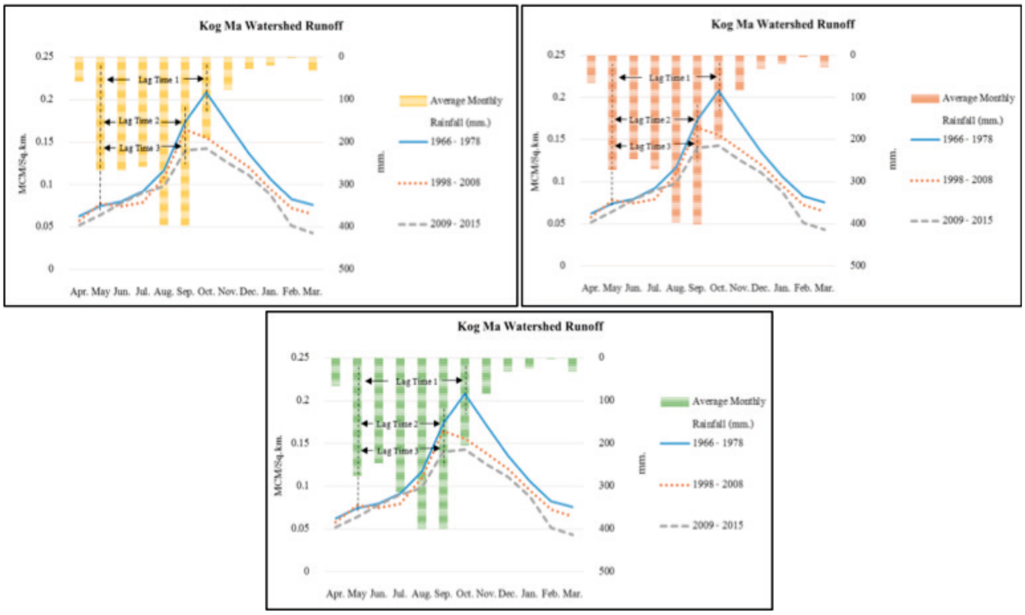

Figure 5. Hydrograph of average monthly flow during 1966-1978, 1998-2008 and 2009-2015 of Huay-D first-order stream KMWRS Watershed in mountainous land at Doi Pui inside Sutep Pui-Sa National Park, Chiang Mai, northerly Thailand.

The annual flow of first-order stream which is the main stream of KMWRS watershed was determined by separated the hydrograph into surface flow (surface runoff), soil water flow (interflow), and groundwater flow (base-flow). There were no surface and groundwater flow, only soil water flow to feed the main stream due to rainwater falling from sky were stored in abundant soil pores belonging to LFH-layer 67.7%, A-horizon 62.5%, B-horizon 52.43%, and effectiveness 50%-60%. Moreover, the rainwater was absorbed by coating on surface of smaller soil particles (particularly clay mineral 21.4%-29.13%) and soil organic matter of LFH-layer 13.05%, A-horizon 4.30%, B-horizon 1.43%, and effectiveness 6.0% in which the soil organic matter could absorbed rainwater 10, 6, 3, and 5 times of oven-dry weight soil. Nevertheless, the total streamflow was evaluated by dividing into wet flow (April to October) approximately 60%, 53%, and 59% (average 57%) of total annual flow and dry or Summer flow (November to March) approximately 40%, 47%, and 41% (average 43%) for normal climate (1966-1987), transition climate (1988-2008), and climate change (2009-2015), respectively (Chunkao, 2008; Brooks *et al.*, 2013; Colman, 1953; Detenbeck *et al.*, 2005; Hill *et al.*, 2014; Kittredge, 1948; Neal *et al.*, 2010; Satterlund, 1972; Lajoie *et al.*, 2007; Berkowitz *et al.*, 2011; Niedzialek and Ogden, 2012). The above results can be brought to conclude that no matter the rainfall distortion the first-order stream headwater is still functioned in continuously providing stream water.

4.5 Lag Time Determination

In hydrological point of view, hydrograph lag time is defined as the difference between the time when half the rainfall of each falling storm and the time coordinate of the centroid of resulting runoff. In practical means, lag time is represented the time required for fifty percentages of the rainfall input into the watershed to produce fifty percentages of the streamflow output. In doing so, the hydrograph lag time from streamflow of KMWRS headwater covering with dense-nature hill-evergreen forest were found approximately 18 hours for normal climate (1966-1987), 13 hours for transition climate (1988-2008), and 9 hours for climate change (2009-2015) as shown in Table 7 and Figure 6.

Table 7. Selected rainstorms of automatic recorder as related to streamflow of first-order stream watershed at Doi Pui mountainous land inside Suthep Pui - Mae Sa National Park in Chiang Mai northerly Thailand

Time	**Stream Flow, cms x 10-2**		
	1966 - 1978	**1979 - 2008**	**2009 - 2015**
0.00	1.7	2.4	1.5
3.00	2.0	3.3	3.6
6.00	6.1	6.5	5.2
9.00	10.0	7.8	13.3
12.00	15.0	14.2	18.4
15.00	18.5	18.4	16.3
18.00	20.9	16.5	14.0
21.00	21.5	10.9	8.2
24.00	20.9	8.3	4.6
3.00	16.0	7.0	4.2
6.00	12.2	6.1	4.0
9.00	6.2	5.3	3.8
12.00	4.0	4.1	3.5
15.00	3.6	3.9	3.2
18.00	3.1	3.6	2.7
21.00	2.9	3.2	2.4
24.00	2.0	3.0	2.1

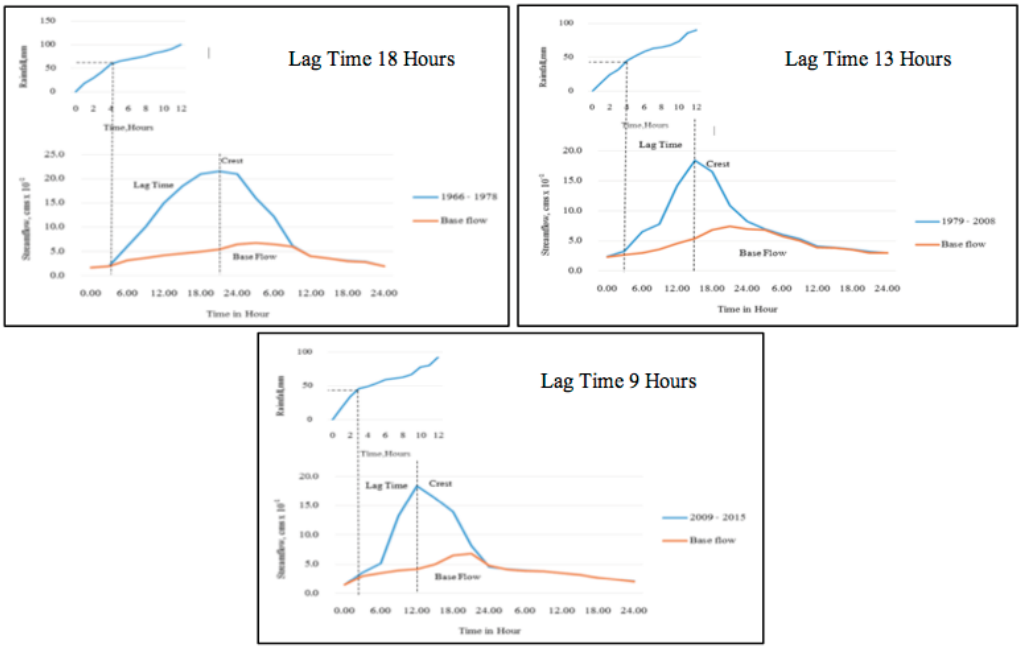

Figure 6. Hydrograph lag time from beginning of falling rain to peak of hydrograph as constructed from measuring flow of 120-V Notch Weir at Huay-D outlet of first-order stream watershed at Doi Pui Chiang Mai, northerly Thailand.

Although the first-order stream watershed ((KMWRS) is protected area belonging to Sutep Pui - Maesa National Park as located in Chiang-mai the lag time was evidently decreased from 18 hours (period of 1966-1987) down to 13 hours (1988-2008) and 9 hours for last period (2009-2015), the causes could be pronounced on climate change, forest encroachment, high intensity and long duration of rainfall, antecedent rainfall soil surface compaction, occasional forest fire (Dunne and Leopold, 1978; Leopold, 1981; Dunne and Black, 1970; Sendek, 1985; Linsley *et al.*, 1988; Hill *et al.*, 2014; Al-Faraj and Schols, 2014; Berkowitz *et al.*, 2011; Niadzialek and Okden, 2012;Oliver *et al.*, 2016).

Evidently, hydrograph lag time of Huay-D first-order stream watershed with full cover with hill-evergreen forest has been 13-15 hours which could be rather long because of high soil water holding capacity (5-10 times of oven-dry soil), more infiltration capacity (greater 112 cm/hr). In reality, lag time is the most necessary in keeping water in soil, the longer lag time is promoting more water supply to the rivers. Therefore, the longer lag time of natural hill-evergreen forest soils could be emphasized that there is no sign of flooding due to high water holding capacity of deeper soils with high content of soil organic matter as the same as high percentage of soil porosity. Although there have been gradually decreased lag time from first period 1966-1987 to second period (1988-2008) throughout third period (2009-2015) according to soils gradually increasing the compaction. If the protective measures were not effective, the lag time could be shorter which might lead to confront with big flood after rain falling. So, the lowland lives and properties have to realize how to manage the expected natural disaster one way or another. It can be pointed out that no matter the climate change, the hydrograph lag time is not influenced at all on flow regime of the first-order stream watershed which is covered by dense-natural hill-evergreen forest in fog-belt highlands.

5. Conclusion

The research on role of first-order stream headwater together with full cover of natural hill-evergreen forest in mountainous land at Doi Pui inside Sutep Pui - Mae Sa National Park in Chiangmai northerly Thailand. Small Huay-D watershed (10.4 acres) was represented the long-term experimental research on the decline of lag time for three periods: 1966-1987 (normal climate), 1988-2008 (transition period), and 2009-2015. The research results found as follows:-

(1) Climate: the climate of Kog Ma Watershed Research Station over first-order stream Huay-D hill-evergreen forest headwater found extreme maximum air temperature 20.0-35.5 oC and extreme minimum 4.5-13.9 oC, mean 16.7-23.3 oC, average relative humidity 58.5-89.7%, pan evaporation 3 mm/day, actual evapotranspiration 3.1 mm/day, average annual rainfall 2,046.5 mm with 155 rain-days, amount of fog drift 2.3% of annual rainfall, wind speed 5.4-12.6 km/hr.

(2) Hill-Evergreen Forest: the ground plants 137,000 trees/ha, seedling 25,600 trees/ha, sapling 1,914 trees/ha, and tree 262 trees/ha along with average height 14.2 m as well as plant cover greater 80%.

(3) Soil Properties: friable and erosive soil, sediment yields 40 t/km^2, sandy loam texture; soil depth 1.5 m; LFH-layer 20 cm, A-horizon 40 cm, B-horizon 90 cm; high infiltration rate (112 cm/hr; organic content 1.43-13.05% by weight; high mineral content in A-horizon; water holding capacity 3-10 times of oven dry weight soils.

(4) Streamflow: the water flow 1.2233 MCM/km2 of average annual rainfall (2,045.5 mm) including wet flow 57% and summer flow 43% of total flow for feeding to perennial streams.

(5) Lag Time: the hydrograph lag time found gradually decreasing from 18 hours for normal climate (1966-1987), 13 hours for transition climate (1988-2008), and 9 hours for climate change (2009-2015) but it still functions on soil water holding capacity of the first-order stream watershed in northern Thailand highlands.

(6) Flow Characteristics: it is ensured that the first-order stream headwater covering dense-nature hill-evergreen forest of KMWRS mountainous land is able to keep continuing flow without interruption.

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