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ORIGINS AND CHARACTERISTICS OF STREAMFLOWS FROM HEADWATERS FORESTED WATERSHEDS IN THE MOUNTAINOUS REGION OF NORTHERN TAIWAN

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ABSTRACT The origins and characteristics of streamflows for mountainous headwaters watersheds in northern Taiwan are discussed to help facilitate better planning of watershed protection and soil conservation projects for improved land and water management. Hydrograph analysis, field observation and a comparison of rainfall intensities with infiltration capacity/saturated hydraulic conductivity of soils, indicate that the origins of stormflows for these headwaters forested watersheds appear to be resulting from hydrologic processes and mechanisms associated with mixed surface-subsurface pathways. Low flow generation mechanisms are discussed in relation to differences in low flow magnitudes and recession rates between small and large watersheds. The quantities of annual water yield, monthly flows, low and peak flows and their temporal variability are discussed.

INTRODUCTION

Headwaters forested watersheds contribute nearly all the flow for reservoirs that supply water for northern Taiwan's heavily populated and developed low-lying plain areas. However, during heavy rainstorms in the May-October typhoon season, the reservoirs and low-lying downstream areas are also often detrimentally affected by the sediment-laden floods originating from mountainous headwaters watersheds that are prone to soil erosion and landslides as a result of steep terrain, weak geologic formations and/or improper landuse practices. Therefore, it is important to manage these upstream areas with proper landuse practices and soil conservation measures where necessary to ensure stable and favorable watershed conditions for optimum regulation of streamflow. Knowledge of hydrologic characteristics of these upstream watersheds is required for proper assessment of landuse practices and sound design of conservation projects. This paper describes and discusses the origins and characteristics of streamflows from headwaters forested watersheds in northern Taiwan (Figure 1).

METHODS

Study Area

The Shi Men Reservoir Basin (SMRB) is located in the headwaters area of the Ta Han River in northern Taiwan (Figure 1). Shi Men Reservoir, with a storage capacity of 315×10^6 m^3, is the major reservoir in the Ta Han River for power generation, irrigation, municipal and industrial water supply requirements. The topography of the 763 km^2 watershed is steep and mountainous. Some quantitative physiographic features of the SMRB and two small tributary watersheds are given in Table 1.

The study area receives abundant torrential rains and strong winds during the May-October typhoon season; cool, moist northeast monsoonal winds during the winter; and warm, moist southwest monsoonal winds in the summer. As indicated by data from the Yu Feng climate station located within the SMRB the mean annual temperature is 18.6°C. The relative humidity is normally between 70 and 85 %. The average class A pan evaporation is 1010 mm annually. The mean annual rainfall at this station averages 2 440 mm with about 70 % occurring in the May-October typhoon season. On average, there are 140 rainy days per year and more than 10 rainy days for every month except October, November and December (Table 2).

The bedrock underlying the watersheds is mainly of slate formation. The soil type is mainly a Brown podzol of silty loam and sandy loam with high infiltration capacities. The watersheds are mostly covered by forests of coniferous species in the high elevation areas (> 1400 m) and hardwood species in the lower elevation valley bottoms.

Analysis

Watershed physiographic and hydrometeorologic information as well as results from field observation and other soil hydrologic studies are analyzed to describe and discuss the origins and hydrologic characteristics of streamflows from forested catchments located within the SMRB. Included in the analyses are data from (1) two experimental watersheds, SM-1 and SM-2 (Figure 2), (2) seven hydrometric stations maintained by the Water Resource

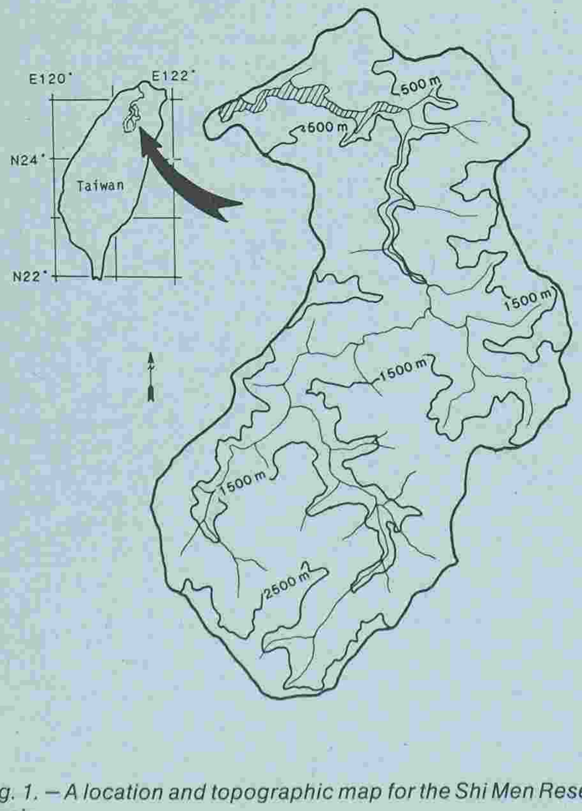

Fig. 1. – A location and topographic map for the Shi Men Reservior Basin.

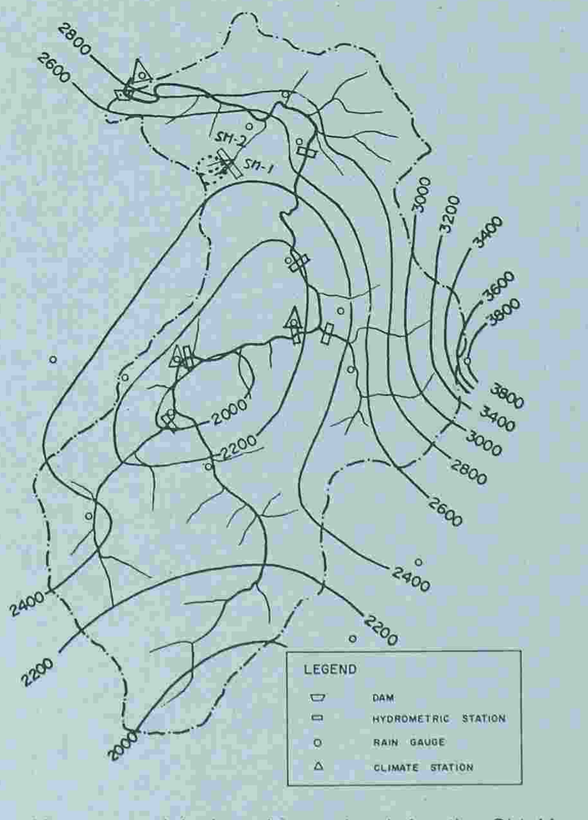

Fig. 2. – Mean annual isohyetal map (mm) for the Shi Men Reservior Basin.

Table 1. – Physiographic Characteristics of the Shi Men Reservoir Basin and Two of It's Many Tributary Watersheds.

	SMRB	SM-1	SM-2		SMRB	SM-1	SM-2
Area (km^2)	763	0.655	0.699	Total Stream Length (km)	352	1.0	1.1
Mean Elevation (m)	1417	1266	1184	Drainage Density (km/km^2)	0.462	1.54	1.57
Average Slope (%)	52.6	45	42	Orientation	N	NNE	E

Table 2. – Climatic Characteristics of the Study Area as Indicated by Data from the Yu Feng Climate Station Located at 770 m Elevation.

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Ave. Temp. (°C)	12	13	16	19	21	23	24	24	22	20	16	13	18.6
Ave. Humidity (%)	79	82	84	82	83	83	79	80	81	79	78	77	81
Rainfall (mm)	90	135	224	175	302	342	234	325	278	175	85	75	2440
Ave. Class A Pan Evaporation (mm)	56	53	67	77	86	96	124	117	100	100	73	63	1010
Ave. Rainy Days	9	12.5	14.2	14.1	15.7	16.2	12.4	13.4	11.6	6.1	7.8	7	140

Commission (WRC), (3) three weather stations and (13) thirteen rain gauges, as well as (4) results from relevant hydrologic studies in the adjacent areas. The lengths of available records differed with hydrologic variables analyzed.

The origins of stormflows in these headwaters region were investigated by hydrograph analysis, field observations and a comparison of rainfall intensities with infiltration capacity/saturated hydraulic conductivity of soils. Low flow generation are discussed with regard to the differences in recession rates and low flow magnitudes between small and large watersheds.

Investigations are made into rainfall and streamflow characteristics, rainfall-runoff relationships. The quantities of annual water yield, monthly flows, low flows, peak flows and their temporal variability are discussed. Emphasis is placed on peak flows and low flows because of their particular importance to water management and conservation projects.

RESULTS AND DISCUSSION

Rainfall

Based on available rainfall data during the 1953-85 period, the average annual rainfall in the SMRB is 2440 mm (Figure 2), ranging from 1394 mm in 1964 to 3135 mm in 1985. Heavy rainstorms normally occur annually during the May-October typhoon season with daily totals exceeding 300 mm not being uncommon and hourly maximums often over 50 mm. The calculated annual maximum daily rainfalls of different return periods are presented in Table 3.

Annual and Monthly Flows

Based on discharge data at the Hsia Yun hydrometric station during the 1953-85 period, the mean annual streamflow is 36 m^3/s, equivalent to a mean annual water yield of 1822 mm in depth over its drainage area of 623 km^2. The mean annual streamflow for a newly established station further upstream at Shiuruan (with more recent data up to 1985) is 6.9 m^3/s or 1840 mm of mean annual water yield over its drainage area of 119 km^2.

The variations in annual water yield (Q) were related mainly to the variations in annual rainfalls (P) as illustrated by the following seven regression equations for various gauged watersheds respectively:

Shiu-Ruan $y = 1.058\ (x-638)$
Yu-Feng $y = 1.058\ (x-530)$
Shan-Kuang $y = 1.185\ (x-614)$
Kao-Yi $y = 1.075\ (x-492)$
Hsia-Yun $y = 1.175\ (x-579)$
Shi-Men $y = 1.145\ (x-659)$
Ling-Chiao $y = 0.706\ (x+212)$

Seasonal and monthly distribution patterns of streamflows are similar for small and large watersheds. Streamflow follows the rainfall pattern closely. Approximately 80% of the annual streamflow occurs during the May-October typhoon season (Figure 3).

Table 3. – Maximum 1-day Rainfall Amounts (mm) of Various Return Periods Averaged Over the Shi Men Reservoir Basin.

	Return Period (Years)					
	2	10	25	50	100	200
Max. 1-day Rainfall (mm)	265	590	791	956	1133	1323

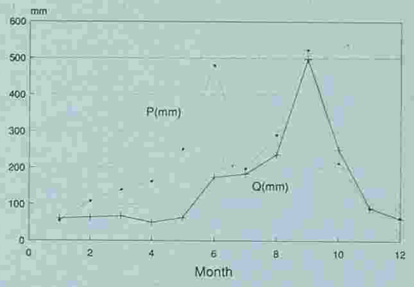

Fig. 3. – A comparison of mean monthly rainfall (P) with streamflow (Q) for the watershed above the Hsia Yun hydrometric station.

Peak Flows and Storm Flows

Peak flows during storm periods range from 0.15 to 7 $m^3/s/km^2$ with a mean of 1.2 $m^3/s/km^2$ for the SM-1 experimental watershed and from 0.13 to 6 $m^3/s/km^2$ with a mean of 1.5 $m^3/s/km^2$ for the SM-2 experimental watershed. These peak flow magnitudes are similar in size to those of the larger watersheds of the WRC network stations in the SMRB. Peak flows of various return periods at the Shi Men hydrometric station are given in Table 4.

Annual peak flows usually result from heavy typhoon rainstorms with total amount often exceeding 300 mm and intensities frequently well over 30 mm/h. The stormflow amounts of 24 selected rainstorms calculated using Hewlett's method of fixed separation slope (Hewlett, 1982) for the SM-1 and the SM-2 experimental watersheds varied from above 1 mm to well over 350 mm. The close relationship between stormflow amount (SF) and rainfall amount (P) for these two experimental watersheds are illustrated by the two regression equations derived from 29 stormflow events shown below (Lu, Cheng and Yang, 1984).

$SF_1 = 0.752P_1 - 13.28$
or $SF_1 = 0.752\ (P_1 - 17.6)\ (n = 29,\ r^2 = 0.946)$
$SF_2 = 0.826P_2 - 17.38$
or $SF_2 = 0.826\ (P_2 - 21.0)\ (n = 29,\ r^2 = 0.962)$

Similar close relationships between stormflow and rainfall have also been found for other small forested watersheds located in a nearby area south of the SMRB (Hu 1986).

Annual peak flows can be from 500 to well over 1000 times the annual minimum flows. This large variation in flow magnitude is a common feature of many streams in Taiwan and indicates the need to build reservoirs for flow regulation to meet the demands of water users.

Stormflow Generation Mechanisms

Analyses of rainfall intensities of various return periods and soil infiltration capacities indicate that the Horton's infiltration-exceeded overland flow (Horton, 1933) seldom occur in the forested watersheds of Taiwan (Cheng and Hsia, 1988). However, despite the apparently rare occurrence of overland flows, the flow responses of these forested watersheds generally are still very flashy. This fast response is illustrated by the rapid changes in streamflow rates of the Siuruan watershed to an extreme heavy rainstorm in August, 1985 (Figure 4). It is interesting to note that for this 1985 event, the 787 mm storm over 36 h resulted in 584 mm of stormflow. If we assume all this

Table 4. – Annual Instantaneous Peak Flows of Various Return Periods at the Shi Men Hydrometric Station.

Hydrometric Station	Drainage Area (km^2)	Annual Peak Flows of Various Return Periods, m^3/s/km^2 2 yr	5 yr	10 yr	25 yr	50 yr	100 yr	200 yr
Shi Men	763.4	2.62	4.91	5.24	5.89	7.61	11.4	11.8

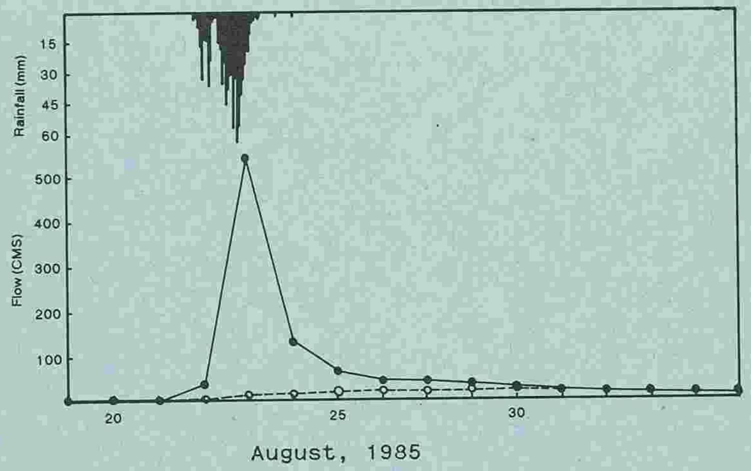

Figure 4 The response of streamflow to a rainstorm in August, 1985 for the watershed above the Siuruan hydrometric station.

stormflow was generated by the infiltration-exceeded overland flow as defined by Horton (1933) the average infiltration rate for the soils would have been less than 6 mm/h. This is much lower than the infiltration capacities of 50 mm/h or greater reported in the literature (e.g. Lu and Yang, 1979) for forest soils in nearby areas. Therefore, subsurface flows must play an important role in generating stormflows.

During typhoon torrential storms, localized overland flow has been observed in the study watersheds on wet areas along stream channels, in depressions and in other areas with shallow and high density soils. Therefore, peak flows in the study watersheds are best described as resulting from stormflows through mixed surface-subsurface pathways. However, the exact processes associated with stormflow generation in the study watersheds require closer examination.

Characteristics and Origins of Low Flows

Low flows of tributary watersheds of the SMRB may occur anytime from December to about the middle of March or April, when rainfalls to these forested watersheds are at their lowest. Low flow data of hydrometric stations in the SMRB show that low flow magnitudes and recession constants for the large WRC network watersheds are higher than for the two small experimental watersheds. These differences can be related to the low flow generation mechanisms.

For small headwater streams like the SM-1 and SM-2 experimental watersheds with steep slopes, the low flows appear to be mainly sustained by the soil water drainage rather than by the saturated groundwater reservoir (Hewlett, 1961; Bowles and Riley, 1978). The soil drainage contribution to low flows becomes relatively less significant as drainage area increases, because larger watersheds contain more deeply incised channels of higher order which tap groundwater storage. In other words, groundwater flow which may depend on rainfall over a relatively long period is a more important low flow contributor to a large watershed than to a small one. In addition, low flows of larger streams also include contributions from headwater tributary streams which drain mainly soil profiles. Therefore, larger streams should carry not only higher but also more sustained low flows than smaller streams.

Streamflow Correlations Between Adjacent Watersheds

The close relationships of streamflow characteristics between two nearby watersheds are one of the common features that exist for forested upstream watersheds in the SMRB. Regression equations and their 95% confidence limits were derived individually for annual and monthly water yields, annual peak flows, stormflow amounts, peak flow magnitudes and rising times to determine whether sufficient correlations exist between the SM-1 and SM-2 experimental watersheds so that streamflow changes as a result of proposed logging over one of them can be assessed properly. The results (Table 5) show that for those streamflow parameters analyzed the two experimental watersheds are closely correlated, suggesting good pre-logging calibrations. Close correlative relationships also exist between several WRC network watersheds located immediately south of the SMRB (Hu, 1986).

CONCLUSIONS

Streamflows of watersheds in the SMRB show large variations with regard to time and are strongly governed by heavy torrential storms during typhoon season. Streamflows correlate closely with rainfalls. The study watersheds are closely correlated for many streamflow parameters, suggesting that environmental factors governing the hydrologic processes within these watersheds are relatively similar. Therefore, data from short-term hydrometric stations or miscellaneous flow measurements, if used together with relevant data from nearby long-term WRC network data, can be very useful in estimating flow characteristics by correlation analysis.

Stormflows in the study watersheds appear to be resulting from flows through mixed surface-subsurface pathways. However, the exact processes associated with stormflow generation require closer examination.

For small, steep headwater streams in the study area, the low flows appear to be mainly sustained by the soil water drainage rather than by the saturated groundwater reservoir. Soil drainage contribution to low flows becomes relatively less significant as drainage area increases, because larger watersheds usually contain more deeply incised channels of higher order which tap groundwater storage. In other words, groundwater is a more important low flow contributor to a large watershed than to a small one. In addition, low flows of larger streams also include contributions from headwater tributary streams which drain mainly soil profiles. Therefore, larger streams should carry not only higher but also more substained low flows than smaller streams.

Table 5. – Streamflow Relationships between Two Adjacent Small Tributary Watersheds (SM-1 and SM-2) in the Shi Men Reservoir Basin.

Streamflow Parameter	Regression Equation, Coefficient of Determination (r^2) and Number of Observation (n) Equation	r^2	n
Stormflow Amount (SF, mm)	$SF_2 = 1.163\ SF_1 - 7.842$	0.988	29
Peak Flow (PF, m^3/s/km^2)	$PF_2 = 0.841\ PF_1 + 1.191$	0.967	29
Time to Peak (TP, h)	$TP_2 = 0.916\ TP_2 + 0.226$	0.982	29

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PRECIPITATION AND RUNOFF IN ARID – MOUNTAINOUS REGIONS A CASE OF CENTRAL AND SOUTHEAST OF IRAN

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ABSTRACT The aim of this paper is to present a general information about the hydrometeorological features of Iran and to establish a relationship between the mean annual flow as well as the peak annual flood and related drainage area in arid mountainous regions similar to those in Iran. To achieve the aim the hydrological characteristics of Iranian Plateau are described and for two different arid parts of the country,the above mentioned relationships are derived.

INTRODUCTION

The plateau of Iran is generally above altitude of 1000 meters with two distinct high rugged ranges of mountains ; the Alborz and Zagross which run from northwest to east along the Caspian Sea and from northwest to southeast respectively. Central Iran is relatively lower than the rest of the plateau and is mostly desert. These physical features associated with general directions of wind movement have divided Iran into three major basins, i.e. the Caspian, the Central and the Persian Gulf-Oman Sea basins. Of the above basins, the Caspian Sea basin is directly exposed to moisture moving inland from the sea. The high range of the Alborz mountains prevent most of the Caspian Sea moisture from moving into the Iran plateau, thus creating a very humid region, distinctly different from the rest of Iran plateau. In spite of large amount of precipitation, the occurence of very severe storms is not very common in this region. Moisture from the Persian Gulf and Oman sea has some influence on precipitation in Southern Iran. However, the general direction of the wind prevents them from comming far inland. Occurence of severe storms, however is common in this region. The widespread Central basin which is farther away from the source of moisture is located in the general direction of moist wind blowing inland from Mediteranean Sea after passing over Syria, Iraq and high range of Zagross mountains. The distance from the source of moisture reduces the possibility of very severe storms in Iran. One of the important aim of this paper is to elaborate the relationship between runoff and precipitation as well as runoff and related watershed area in arid – mountainous regions.

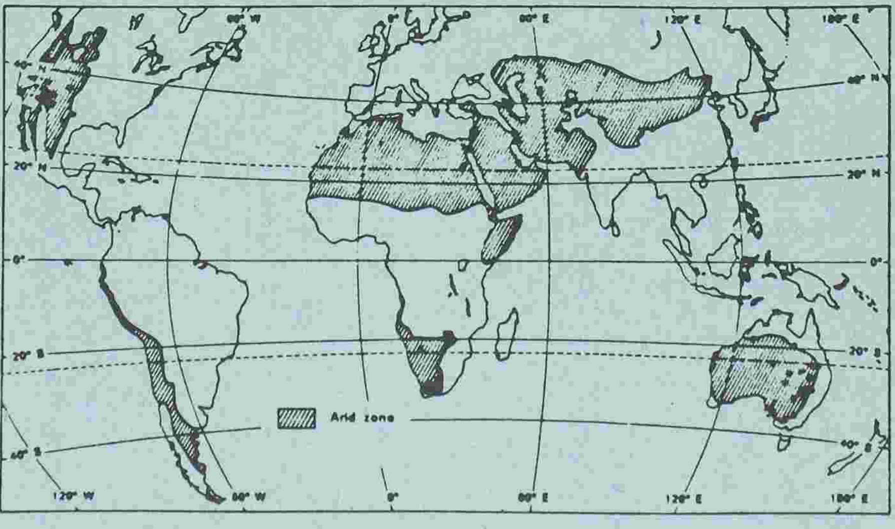

FIGURE 1. – The arid zones.

SOURCE OF MOISTURE AND PRECIPITATION

Precipitation in Iran is a result of Mediterranean depressions which governs the weather patterns of the country throughout the winter and spring seasons.During their passage, these depressions cause rain at low altitude and snow at high elevations. Occasionally, however, these Mediterranean cyclons fail and, following such winter, Iran is faced with severe drought.
In the spring, unstable air masses produce a considerable amount of precipitation over much of the country, in the form of locally scattered convection storms. This is particularly true of the mountain areas of the northeastern and western parts of the country.
Summer is dry everywhere, except along the Caspian littoral. There is practically no rain in the interior deserts and lowlands, but areas along the higher peripherals may experience occasional local showers. The southeast of Iran, especilly the southeastern mountains, are occasionally subjected to Indian monsoonal influence with some summer rain.
Autumn is the transitional season between dry summer and the wet winter. Mediterranean depressions begin to make themselves felt by mid autumn and rains start in many parts of Iran in October. In this season the Caspian littoral receives its maximum seasonal precipitation.
In addition, precipitation in Iran varies considerably with time, both during the rainy season and from year to year. Precipitation frequently departs widely from the mean from year to year, and a several year period of greater than mean precipitation can be followed by a period of several years of less than mean precipitation.
Average annual precipitation in Iran is about 220 mm. The averages vary from less