Hydrologic Behavior and Land Use Characteristics of Some Catchments in Asia

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Abstract

Initial results from two MSEC catchments and three sub-catchments from 2000 to 2002 were analyzed to establish baseline information on the relationships of land use characteristics and hydrologic behavior. Based on one- to three-year annual hydrographs, previous stream classifications were validated. The streams of Mapawa Catchment and Rambutan sub-catchment were both reclassified as ephemeral while those of Dong Cao Catchment, and Tegalan and Kalisidi sub-catchments are perennial and intermittent, respectively, as initially classified. There were no observed consistent relationships between land use and annual runoff coefficients within each of the five catchments and sub-catchments. The variations in annual direct runoff coefficients among catchments and sub-catchments could hardly be attributed to differences in their present land use. It is surmised that such variations are more related to their differences in geology and soil classification. Analysis of storm hydrograph behavior of the Mapawa Catchment showed that there is practically no base flow even if about 95 percent of its annual rainfall of 2,400 mm has infiltrated and possibly percolated below ground surface. Percolating water does not come out in its stream but is added to the water table that flows to the Alanib River downstream. The same conditions could be true in the case of the Babon Catchment and its three sub-catchments. In spite of relatively lower porosity and a smaller fraction of rainfall infiltrating and percolating down the soil profile, a year-round base flow occurs at the Dong Cao stream. Presumably, an impermeable layer lies just below its streambed so the water table can easily rise above it. More years of field data monitoring are needed to come up with conclusive results

Introduction

Quantitative field data on the environmental impacts of different land uses are indispensable information to guide extension workers in advising farmers on conservation farming techniques and for planners and decision-makers to formulate appropriate and implementable policies for the sustainable development and management of our natural resources. Such information is also very useful for engineers for the proper design of water control structures for irrigation, flood control, and soil and water conservation, and for the validation and improvement of runoff and sediment yield prediction models.

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Inter alia, the more significant environmental impacts of land use and cover type modifications are hydrologic in nature (Figure 1). Specifically, these include variation in runoff, groundwater quantities, and sediment yields. In most of the less-developed countries, however, there is a dearth of factual data on the effects of land use on the hydrologic behavior of a catchment. Indeed, the ongoing catchment studies in six Asian countries being conducted via the Management of Soil Erosion Consortium (MSEC) program under the International Water Management Institute (IWMI) are a move towards addressing such data gaps.

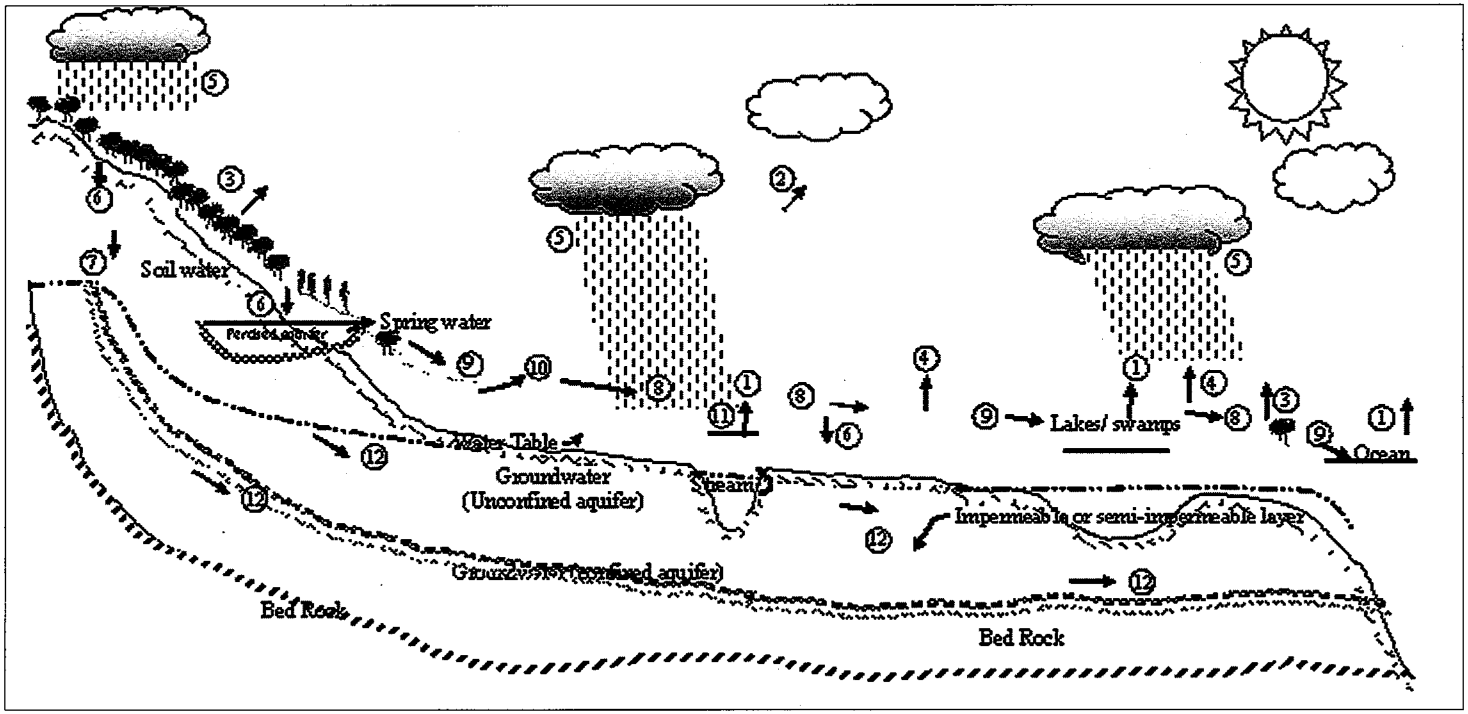
This paper attempts to analyze the initial results of the MSEC catchment studies that are relevant to the assessment of the hydrologic impacts of land use.

MSEC Methodology of Hydrologic Data Monitoring

The hydrologic data being monitored and the measuring devices used in all the six MSEC catchments are listed in Table 1. Figure 2 shows a typical instrumentation layout in a catchment area. Regular field monitoring of possible change in the land use and cover types is being done in each catchment. Specific farming activities are also noted including soil and water conservation measures being practiced or introduced by the project.

Table 1. Hydrologic data and the measuring devices used in MSEC catchment monitoring

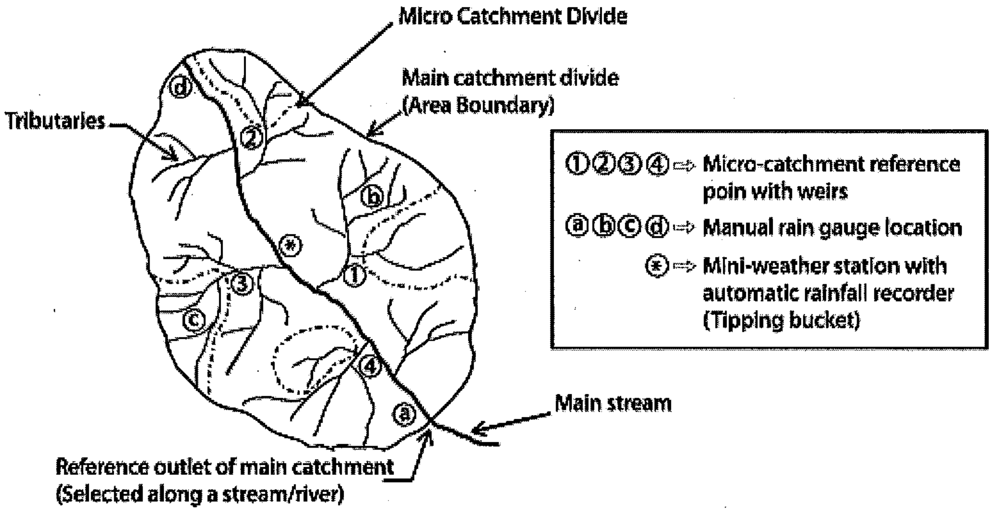
Hydrologic dData	Measuring instrument per catchment
a. Precipitation (i) total daily rainfall (ii) rainfall intensity	• 5-8 mManual rain gauges • 1 automatic meteorological station (AMS)
b. Runoff sStream flow, or water yield	• Flume or cCompound sharp-crested weir (contracted rectangular weir with V-notch). Water level is being measured by a staff gauge and an automatic water level recorder (see Figure 1) with data logger
c. Sediment load/yield (i) Bed load	• Approach channel of the weir (see Figure 1) Sserves as a bed load sediment tank or interceptor. Such trapped sediments are considered bed load. Every Aafter every sediment-producing storm rainfall, water is drained from the tank and then the bulk sediment volume is measured. A sample is taken out and oven-dried in the laboratory to get the dry mass density. This density multiplied by the bulk volume is the total sediment dry mass for the storm.
(ii) Suspended load	• Initially, no common sampler was used. Others just used manual scooping with can samplers or series of sampling cans at different levels in the weir approach channel. • ICRISAT-design automatic pumping type samplers were delivered to most catchments during the last quarter of 2001 but not all have beenwere installed.



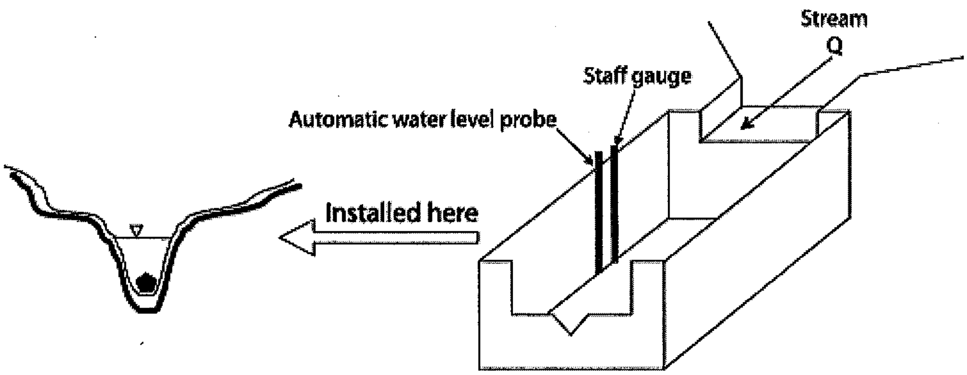
Notes:

1 = Evaporation from water surfaces (oceans, lakes, rivers, dams, canals)
2 = Raindrop evaporation
3 = Transpiration from plants
4 = Evaporation from moist soil
5 = Precipitation/rainfall
6 = Infiltration through soil surface
7 = Percolation
8 = Surface runoff or direct runoff
9 = Soil erosion and sediment transport
10 = Interflow
11 = Total runoff (or streamflow or water yield)
12 = Groundwater flow

Figure 1. The hydrologic cycle



a) Plan view of catchment showing instrumentation location.



b) Stream cross-section at reference outlet (where runoff or stream flow and sediment load / yield ar being measured)

c) Typical compound weir (sharp-crested and contracted rectangular weir with sharp-crested V-notch) for measuring streamflow and sediment load (installed at reference outlets)

Figure 2. Typical MSEC catchment hydrologic instrumentation for monitoring rainfall, streamflow and sediment load

The field data relevant to this paper were requested from the results of the different MSEC-participating countries. Additional information was extracted from the progress and cross-country reports, and technical papers presented during the 6th (2001) and 7th (2002) MSEC meetings held in Hanoi, Vietnam and in Vientiane, Laos, respectively.

Results and Discussion

Table 2 shows the locations and basic descriptions of two main catchments (Mapawa in Philippines and Dong Cao in Vietnam) and three sub-catchments (Tegalan, Rambutan, and Kalisidi in Indonesia). Their observed respective annual precipitation, runoff (or water yield), and sediment yield from 2000 to 2002 are given in Table 3.

Annual Hydrograph Behavior and Stream Classification

Based on its annual hydrograph, a stream or river of a catchment may be classified as *perennial*, *intermittent* or *ephemeral* (Wanielista, 1990; Subramanya, 1984; and Linsley *et al.* 1949). If the water table is below the streambed, the groundwater "gains" water and such a stream is referred to as an *influent stream*. If the groundwater is "losing" water to the stream, the latter is called an *effluent stream* (Figure 3). A perennial stream is one which always carries some flow throughout the year. It is either an effluent stream all year round or is continuously gaining water from perennial springs upstream. An intermittent stream is one with limited contribution from groundwater. It may be effluent during the wet season, but becomes influent during the dry season. A stream which does not have any base flow contribution is referred to as ephemeral. It becomes dry soon after the end of the storm flow.

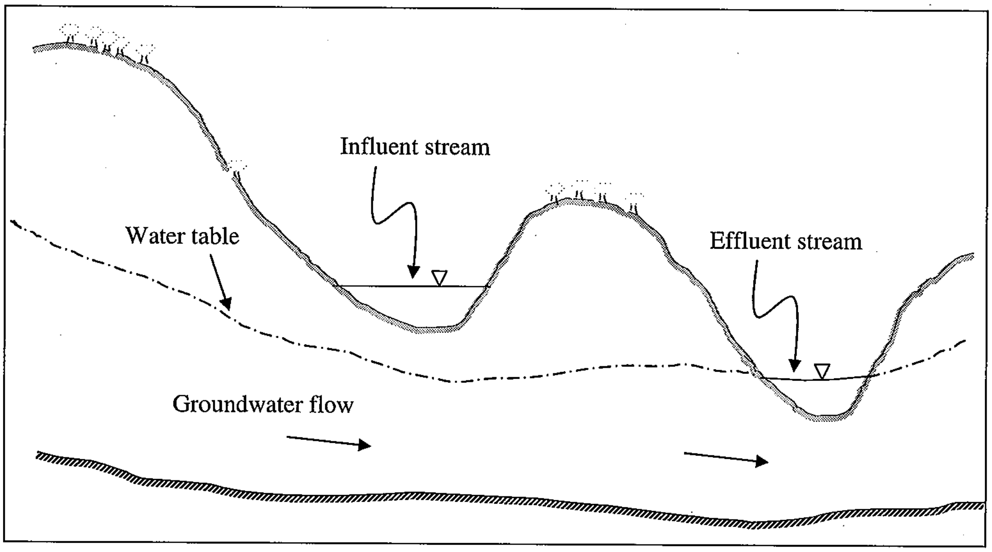


Figure 3. Influent and effluent streams

Accurately determined stream classification based on daily or weekly rainfall-runoff discharge variations at the initial stage of a study is very informative base data. It could serve as an indicator of evaluating the long-term impacts of watershed modification. Depending on the catchment's geological, soil, and topographic characteristics, its stream may shift from one type to the other if significant land use change and soil conservation measures are effected.

Measured at its main weir, the Mapawa Catchment was initially classified (Maglinao *et al.*, 2001) as intermittent. After plotting its weekly runoff in 2001 (Figure 4), however, it appeared

Table 2. Location and description of some MSEC study catchments in Asia

	Mapawa (Philippines) Main weir (MW)	Dong Cao (Vietnam) Main weir (MW)	Babon (Indonesia) Rambutan	Tegalan	Kalisidi
Province	Bukidnon	Hoa Binh	Semarang	Semarang	Semarang
Coordinates: Latitude	08?02'50" N	20?57'40" N	07 20' S	07 20' S	07 20' S
Longitude	125?56'35" E	105?29'10" E	110 E	110 E	110 E
Catchment area (ha)	84.5	45.5	0.9	1.1	13.0
Elevation (m)	1,080-1,505	125-700	390-510	391-510	392-510
Slope range (%)	15-20	40-60	22-25	45-47	22-55
Geology	Basalt, pyroclastic	Schist	Basaltic lava	Basaltic lava	Basaltic lava
Soil order/sub-group	Ultisols	Ultisol	Audic Dystropepts	Audic Dystropepts	Audic Dystropepts
Stream classification	Ephemeral b	Perennial	Ephemeral c	Intermittent d	Intermittent d

a Source: (Maglinao et al., 2001)
a Originally classified as intermittent (Maglinao et al., 2001)
c Originally described as intermittent (Agus et al., 2002)
d As reported (Agus et al., 2002)

Table 3. Annual precipitation, runoff (or water yield) and sediment yield of some MSEC catchments in Asia.

Catchment name and code	Area (ha)	Annual precipitation (mm)				Annual runoff or water yield (mm)				Annual runoff coefficient (%)				Annual sediment yield (tons/ha)			
		2000	2001	2002	Ave.	2000	2001	2002	Ave.	2000	2001	2002	Ave.	2000	2001	2002	Ave.
Mapawa, MW a	84.5	2,270	2,907	2,103	2,448	96.70	78.00	-	87.35	4.30	2.70	-	3.57	3.80	4.80	1.10	3.23
Dong Cao, MW b	45.5	1,224	2,501	1,171	1,632	647.00	1,286.00	770.00	901.00	52.80	51.40	65.80	55.21	0.64	9.14	3.46	4.41
Babon c																	
a. Rambutan	0.9	-	3,062	3,104	3,083	-	6.14	95.00	50.57	-	0.20	3.10	1.64	-	0.01	0.15	0.08
b. Tegalan	1.1	-	3,161	2,924	3,042	-	162.00	151.00	156.50	-	5.10	5.20	5.14	-	10.78	9.58	10.18
c. Kalisidi	13.0	-	3,234	3,104	3,169	-	104.00	425.00	264.50	-	3.20	13.70	8.35	-	1.92	8.00	4.96

a Source: (Ilao et al., 2002)
b Source: (Toan et al., 2002)
c Source: (Agus et al., 2002

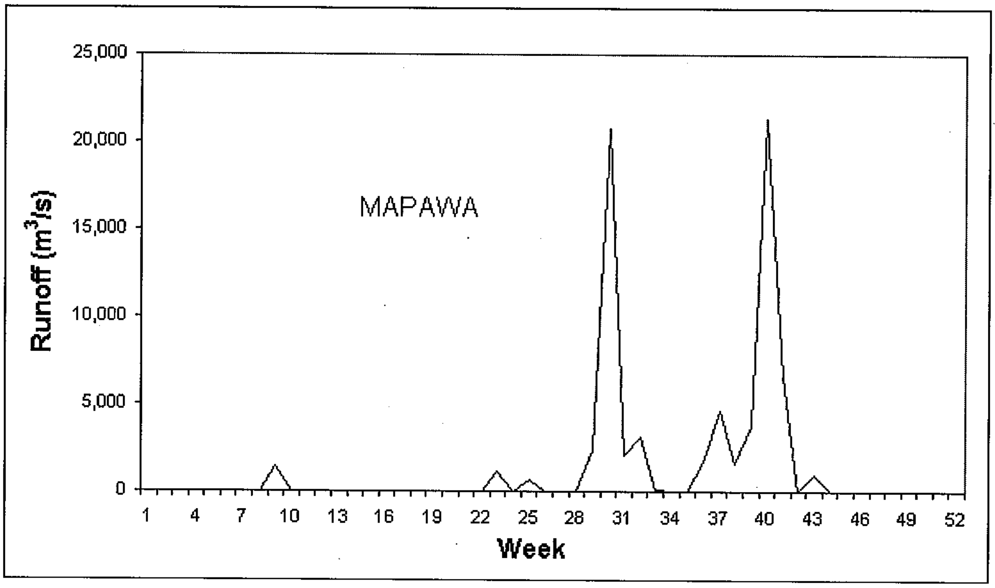


Figure 4. Annual runoff hydrograph of Mapawa main catchment for 2001

that it was more of an ephemeral type than intermittent. Monthly runoff data for the Dong Cao main weir from 2000 to 2002 (Figure 5) prove that it is indeed perennial as initially classified by Maglinao *et al.* (2001). The sub-catchments of Rambutan, Tegalan, and Kalisidi were reported by Agus *et al.* (2002) as having intermittent flow. Based on their monthly runoff discharges as shown in Figure 6, however, it appears that the Rambutan sub-catchment may be classified as ephemeral. A plot of their daily or weekly rainfall-runoff discharge relations from 2000 to 2002 may validate these observations.

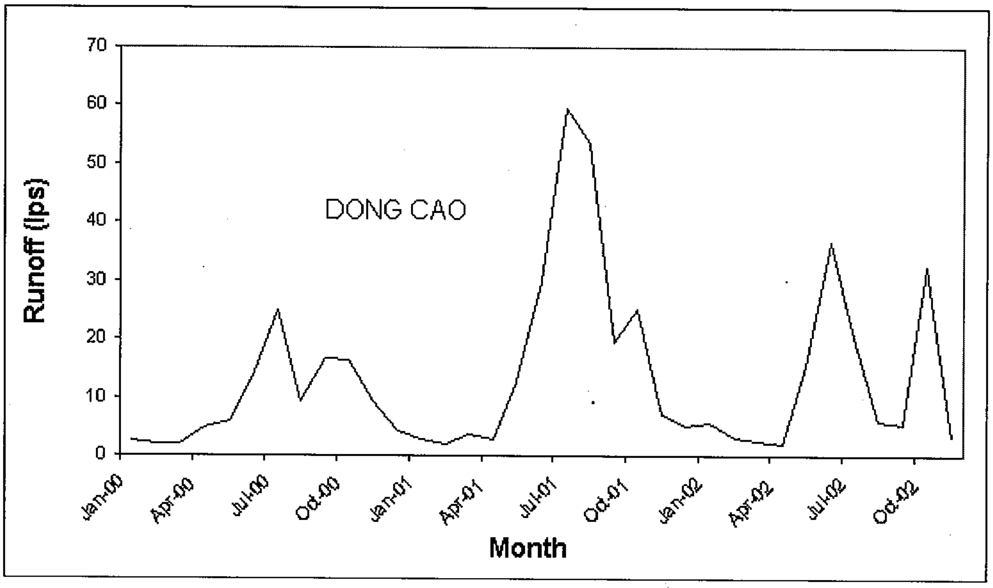


Figure 5. Annual runoff hydrograph of Dong Cao main catchment (2000 to 2002).

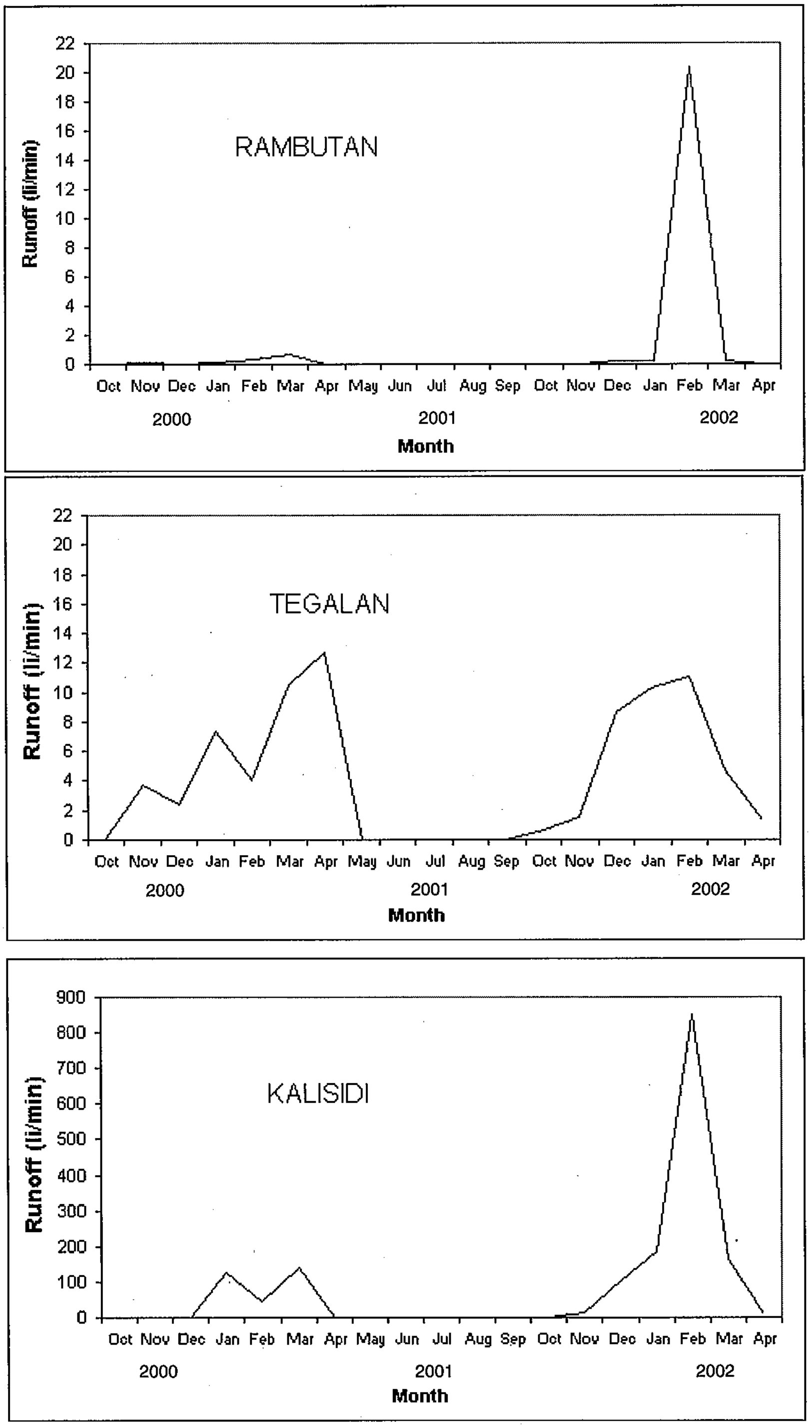


Figure 6. Annual runoff hydrographs of the Rambutan, Tegalan, and Kalisidi micro catchments (October 2000 to April 2002)

The probability of the above intermittent and ephemeral streams becoming perennial with the introduction of soil conservation measures is worth investigating. This may include further validation of the geology, soil order, and sub-group, and whether the stream is influent or effluent. Sample boring down the soil profile to determine sub-surface porosity and permeability and soil water dynamics may have to be done. MSEC-Laos has done much to this effect.

Behavior of Runoff Coefficients

Runoff, streamflow, and water yield are synonymous terms which all refer to the total water (combined surface or direct runoff and base flow as illustrated in Figure 7) passing the gauging station, such as weirs or flumes, of a given catchment or micro catchment. The ratio of the annual runoff to the annual precipitation is the annual runoff coefficient which may be expressed in decimal or in percent. It is called the direct runoff coefficient if the numerator is the surface or direct runoff. From the viewpoint of sustainable soil and water conservation in general, the smaller the direct runoff (DRO) coefficient is, the better, as this means a higher fraction of the precipitation is added to the soil water storage and eventually may recharge the groundwater or aquifers. A low DRO coefficient also implies relatively lower surface runoff, hence lower erosivity and capacity to transport eroded soil downstream.

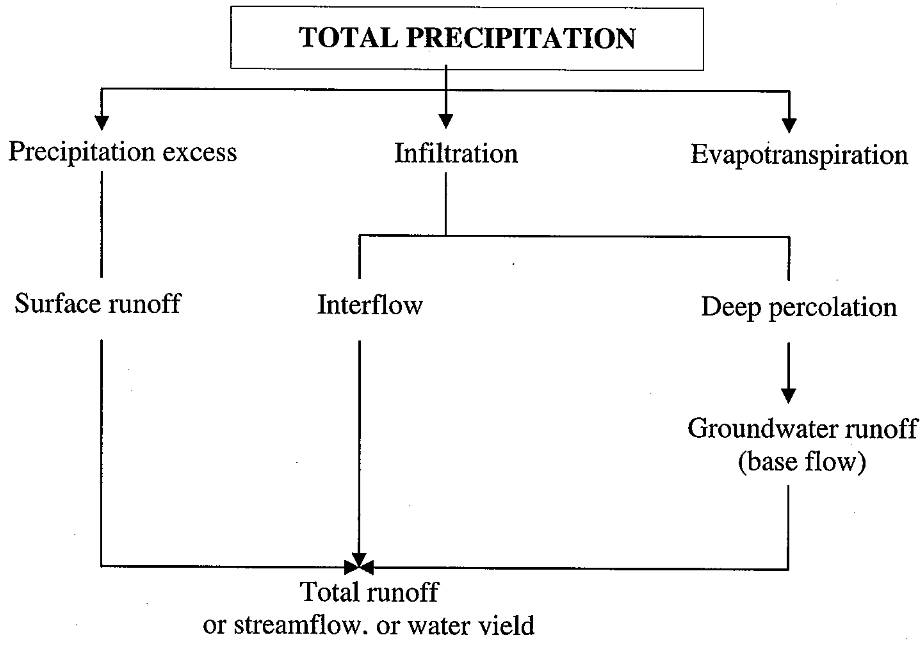


Figure 7. Disposition of total precipitation

Variations of Annual Runoff Coefficients within the Catchment

Table 3 presents the computed two- to three-year annual runoff coefficients of five MSEC catchments and sub-catchments from 2000 through 2002 and their corresponding land use descriptions are shown in Tables 4a and 4b. In general, there appears to be no consistent relationship between land use and annual runoff coefficients. In the Mapawa Catchment, for instance, the percent cropped area increased from 24 percent in 2000 to 27 percent in 2001 (Table 4b), but the annual runoff coefficients decreased from 4.30 to 2.70 percent even if the annual precipitation increased from 2,270 to 2,907 mm. On the other hand, the percentage of annually cultivated area in the Dong Cao Catchment decreased from 36 percent in 2001 to 24 percent in 2002 (Table 4b) but the runoff coefficient increased from 51 to 66 percent. The same inconsistent relationship is also observed for the three Indonesian sub-catchments. There were no significant land use changes from 2001 to 2002 (Table 4a) for the Rambutan and Kalisidi catchments but the runoff coefficients increased by at least 300 percent. While Chaplot *et al.* (2002) found no significant correlation between annual runoff coefficients and land use among initial observations in several MSEC catchment studies, there is still a need for longer years of study before a more reliable conclusion can be made.

Table 4a. Land use conditions in some MSEC catchments for 2001 and 2002[a]

Catchment name	**Surface area (ha)**	**Slope angle S (%)**	**Percent surface area covered per land use[b] C (%)**	**F_a (%)**	**C_p (%)**	**O (%)**	**F_o (%)**
Year 2001							
1. Mapawa (MW)	84.50	14.00	23.67	44.97	16.80	0.00	15.38
2. Dong Cao (MW)	59.52	25.00	28.00	22.00	20.00	30.00	0.00
3. Babon							
a. Rambutan	2.00	12.00	0.00	0.00	0.00	100.00	0.00
b. Tegalan	3.20	14.00	50.00	0.00	0.00	50.00	0.00
c. Kalidisi	38.50	8.00	0.00	0.00	0.00	100.00	0.00
Year 2002							
1. Mapawa (MW)	84.50	25.00	24.79	40.59	7.40	11.83	15.38
2. Dong Cao (MW)	59.52	21.00	5.90	57.70	0.00	0.00	5.20
3. Babon							
a. Rambutan	2.00	12.00	0.00	0.00	0.00	100.00	0.00
b. Tegalan	3.20	14.00	60.00	0.00	40.00	0.00	0.00
c. Kalidisi	38.50	8.00	0.00	0.00	0.00	100.00	0.00

[a] Source: (Chaplot *et al.* 2002)

[b] Land uses: Annual crops (C), fallow or pasture (F_a), crops with conservation practices (C_p), orchards (O) and forest (F_o)

Variations of DRO Coefficients among Catchments

The DRO coefficient of a catchment is best determined from the hydrographs (Figure 8) of its rainfall storm events. For perennial and intermittent streams such as Dong Cao, Tegalan, and Kalisidi (see Table 2), the DRO is estimated by first separating it from the base flow as illustrated in Figure 4. In the case of ephemeral streams like those of the Mapawa and Rambutan catchments, there is practically no base flow so the observed annual flow is totally considered DRO. As such, their annual DRO coefficients are equal to their respective annual runoff coefficients listed in Table 3. Unfortunately, the DRO data for the Dong Cao, Tegalan, and Kalisidi streams are not available. Based on their annual hydrographs in Figure 5, however, a conservative estimate may indicate that the base flow at the Dong Cao main weir could be around 20 percent of the annual precipitation. Thus, for the three-year average, the annual

Table 4b. Land use conditions in some MSEC catchments from 2000 to 2002

Catchment and lLand uses	**Year**		
	2000	**2001**	**2002**
1. Mapawa [a]			
a. Catchment area (ha)	84.5	84.5	84.5
b. Cropped area			
- Percen (%)	24	27	27
- Crops	Corn, potato, Chines cabbage, sweet peas coffee	Corn, potato, Chines cabbage, sweet peas coffee	Corn, potato, Chinese cabbage, sweet peas coffee
c. Other vegetation			
- Percen covered (%)	76	73	73
- Vegetation	Grassland, eucalyptus, bamboo	Grassland, eucalyptus, bamboo	Grassland, eucalyptus, bamboo
2. Dong Cao [b]			
a. Catchment area (ha)	45.50	45.50	45.50
b. Annually cultivated area (ha)	35.68	35.68	24.20
- *A. mangium* intercropped with cassava			
- Cassava intercropped with taro and *A. mangium*	9.23	10.30	0.00
- Arrow root			
- Cassava monoculture	0.00	1.18	0.00
- Fallow	0.00	0.35	0.00
- Natural grasses	16.25	16.78	2.33
c. Forest area (ha)	0.00	0.00	14.80
- *A. mangium*	1020	7.07	7.07
- *Veminia Montana*	2.38	2.38	13.86
- Eucalyptus	0.00	0.00	11.48
d. Land for other purposes (ha)	0.90	0.90	0.90

DRO coefficient could be about 30 percent. Being of intermittent flow, the DRO coefficients of Tegalan and Kalisidi should be close to their annual runoff coefficients in Table 3, which are both less than 10 percent.

Summarizing the above estimates, the average DRO coefficients of Mapawa, Dong Cao, Rambutan, Tegalan, and Kalisidi are roughly 3.6, 27.0, 1.6, <5.1, and <8.4 percent, respectively. Referring to their land use conditions in Tables 4a and 4b, there appears to be no significant differences to account for the variations in their DRO coefficients. These were the initial findings of Chaplot *et al.* (2002) in their correlation study. Only land slope shows significant relations with runoff coefficients. Considering that the average land slope of the Dong Cao Catchment (Table 2) is not too high compared to that of Mapawa, Rambutan, Tegalan, and Kalisidi, there must be some other factors that could explain the big difference in the DRO coefficients of the Dong Cao Catchment compared to the others.

One probable reason could be their differences in geology. As indicated in Table 1, Dong Cao Catchment is underlain by a schist formation while the catchments of Mapawa, Rambutan, Tegalan, and Kalisidi are all under a basalt formation. As described by Karanth (1989), crystalline rocks such as granite, gneiss, schist, gabbro, and diabase are practically impervious and impermeable. The porosity of these rocks is confined to minute disconnected interstices within the mineral grains or between the granular fabric.

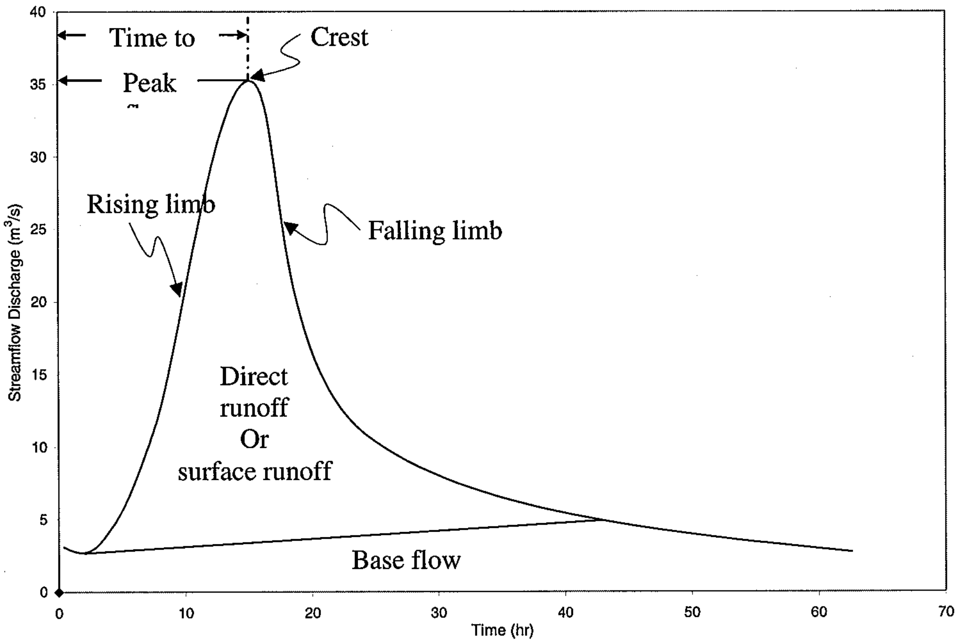


Figure 8. Components of a storm hydrograph

On the other hand, the distinctive geohydrological feature of volcanic rocks such as basalt, according to Karanth (1989), is the significant porosity in the form of interstices in vesicular varieties and pillow lavas, lava tubes, and occasional tunnels. These differences in geological properties of the different catchments may have influenced the topsoil porosity and infiltration rate, hence, the variations in their DRO coefficients which could hardly be explained by their land use alone. Within the Mapawa Catchment, a single ring infiltration test showed that the lowest rate of 35 cm hr^{-1} was observed at the top thin soil layer within a potato-cropped area and the highest rate of 129 cm hr^{-1} at the naturally vegetated surfaces. In the Indonesian catchments, Agus *et al.* (2002) surmised that the low-recorded runoff coefficients could indicate high infiltration capacity of the Inceptisols at the site.

Based on the above discussion, it appears that geological difference is the major reason why about 30 percent of Dong Cao's annual precipitation occurred as DRO while less than 10 percent of the annual precipitation was DRO in Mapawa, Rambutan, Tegalan, and Kalisidi. However, further field validation of the actual geology and soil classification of the above catchments needs to be done.

Storm Hydrograph Behavior

Another hydrologic characteristic of a catchment which could be affected by land use is the storm hydrograph behavior which could be described in terms of its components as shown in Figure 7. The more relevant components in soil and water conservation include the proportions of the direct runoff and base flow, and the peak discharge. Land use which effectively contributes to a significant decrease in direct runoff and peak discharge, and an increase in base flow would then be preferred and should be determined or developed for a given catchment or locality. While it would normally require long years of catchment studies to come up with some conclusive results, baseline data on storm hydrograph behavior in the MSEC catchment studies should be established.

Table 5 shows the estimated values of the relevant storm hydrograph components of some storms in the Mapawa Catchment in 2000 and 2001. Figure 8 shows the hydrograph of one sample storm. With the short period of the study, no significant changes in the hydrograph behavior could be observed. These data will best serve as a baseline reference from which to compare the behavior of future hydrographs in the same catchment as land use changes are effected. No storm hydrograph data were received from the other MSEC-participating countries.

Investigation of Mapawa's 2000-2001 storm hydrographs such as that shown in Figure 8 indicates practically zero base flows. When the weekly runoffs were plotted with time as shown in Figure 4, it is clear that not a fraction of the annual rainfall which infiltrated the ground surface appeared as base flow at the main weir. As such, the stream was classified earlier in this paper as ephemeral.

Table 5. Magnitudes of storm hydrograph components for sample storms in Mapawa Catchment (main weir)

Date of occurrence	Rainfall (mm)	Direct runoff m^3	Direct runoff mm	Direct runoff coefficient ratio	Direct runoff coefficient %	Q_p (m^3/s)	t_p (min)
2000							
1. September 24-25						0.55	15
2. October 5-6						0.917	125
3. November 5						0.669	10
2001							
1. September 13-14	33.90	4,127.40	4.74	0.140	14.0	0.826	35
2. September 26-27	35.60	2,997.00	3.44	0.097	9.7	0.186	105
3. October 4-5	22.00	4,563.00	5.24	0.238	23.8	1.122	20
4. October 6-7	22.20	4,806.90	5.53	0.249	24.9	0.927	30
Total/average	113.70		18.95	0.167	16.7		

Note: Q_p = peak runoff
t_p = time to peak

With no base flow appearing at Mapawa's main weir, the next question would be to account for the disposal of the almost 95 percent of the 2,450 mm average annual precipitation which infiltrated the ground surface. The most probable explanation is that being an influent stream (see Figure 3), the water table is lower than the streambed at the main weir throughout the year. Thus the fraction of precipitation at the Mapawa Catchment which infiltrated, percolated, and added to the aquifer does not occur as base flow of its stream at the main weir but possibly to the base flow of the perennial Alanib River which it intersects less than half a kilometre downstream. This relationship of the influent Mapawa stream and the effluent Alanib River may be likened to that shown in Figure 3. The same relationships maybe true for that of the Babon River and the three sub-catchments of Rambutan, Tegalan, and Kalisidi.

For the Dong Cao Catchment case, the fraction of precipitation which infiltrates and percolates down the soil profile keeps the water table always above the streambed at the main weir. A year round base flow is maintained making it a perennial stream. It is more likely that the geological formation exhibits an impermeable or semi-impermeable layer not far below the main streambed so the water table can be easily maintained by the annually infiltrating water. It is also possible that groundwater flow from higher aquifers is contributing to the base flow. Field validation through piezometers, as being conducted at the Lao PDR MSEC catchment, may have to be done to validate these assumptions.

Recommendations

The ongoing MSEC catchment studies are a great contribution towards generating information to show that appropriate land uses could sustain the use of our land and water resources and enhance the environment. However, generation of adequate and reliable information would require longer duration of field data observations.

That hydrologic field data monitoring is quite costly is not a question. The gathering of enormous but unreliable data should therefore be minimized if not totally avoided. Towards improving the reliability of field data, the specific recommendations are as follows:

a. Ascertain the functionality and accuracy of field instruments. Preparation of a field manual on the proper observation, operation, and maintenance of installed instruments could be considered. It should be simple enough to be easily understood by field observers. If necessary, it may be written in the local dialect of a concerned observer.
b. Ascertain the capability and sustainability of field data observers. More than one capable staff member may be needed to minimize data gaps when an observer gets sick or resigns.
c. Occasional checking/verification of actual field data monitoring to ensure uniformity of procedure and reliability of collected information.
d. Use of uniform technical terms and units to avoid confusion and for easy comparison of results with other publications. A glossary of terms and units may have to be agreed upon.
e. The delineation of catchment divides with respect to the actual stream flow gauging stations should be done using topographic maps and re-checked in the field. Some catchment areas being reported are not yet fixed.
f. Consider the inclusion of other indicators of groundwater recharge, specifically the spring water discharge (if some exist within the catchment area) and water table/ piezometric water level variation in all catchments if possible. A common methodology and instrumentation for these indicators is necessary if they are to be monitored.
g. Measurement of gully and stream bank erosion rates and factoring them in the total sediment yield before computing the sheet and rill erosion rate.
h. More detailed characterization of the geology and soil classification of each catchment.

i. Monitoring of variations in soil water, water table, or piezometric level, which is being done at the MSEC-Lao PDR catchment, could also be followed in the other MSEC catchments.

References

Agus, F.; Vadari, T.; Watung, R.L.; Sukristiyonubowo; Valentin, C.; Ilao, R.; Toan, T.D.; and Boonsaner, A. 2002. The effect of catchment size and land management systems on water and sediment yield: case study from several micro catchments in Southeast Asia. Cross-country report presented at the 7th Management of Soil Erosion Consortium (MSEC) Assembly, 2-7 December 2002, Vientiane, Lao PDR.

Chaplot, V.; Chanthavonga, A.; Agus, F.; Boonsaner, A.; Ilao, R.O.; Toan, T.D.; Valentin, C.; and Silvera, N. 2002. Soil erosion and environmental factors: A CIDSS country paper from MSEC catchments. Paper presented at the 7th MSEC assembly, 2-7 December 2002, Vientiane, Lao PDR.

Ilao, R.O.; Duque, C.M.; Villano, M.G.; Quita, R.Q; Tiongco, L.E.; Carpina, N.V.; Santos, B.G.; and De Guzman, M.T.L. 2002. Management of Soil Erosion Consortium (MSEC): An innovative approach to sustainable land management in the Philippines. Final report submitted to the International Water Management Institute (IWMI), January 2003.

Karanth, K.R. 1989. *Hydrogeology.* New Delhi, India. Tata McGraw-Hill Publishing Company Limited.

Linsley, R.K., Jnr.; Kohler, M.A.; and Paulhus, J.L.A. 1949. *Applied hydrology.* New York. McGraw-Hill Book Company.

Maglinao, A.R.; Wannitikul, G.; and de Vries, F.P. 2001. Soil erosion research in catchments: Initial MSEC results in Asia. In Maglinao, A.R. and R.N. Leslie, eds., *Soil erosion management research in Asian catchments: methodological approaches and initial results:* Proceedings of the 5th Management of Soil Erosion Consortium (MSEC) assembly held at Semarang, Central Java, Indonesia, 7-11 November, 2000. International Water Management Institute (IWMI), Southeast Asia Regional Office, Bangkok, Thailand. October, 2001. pp. 51-64.

Subramanya, K. 1984. *Engineering hydrology.* New Delhi, India. Tata McGraw-Hill Publishing Company.

Toan, T.D.; Phien, T.; Orange, D.; Phai, D.D.; Mangin, J.; and Dinh, P.V. 2002. The effect of soil erosion and agricultural practices on farm productivity. Paper presented at the 7th MSEC assembly, 2-7 December 2002, Vientiane, Lao PDR.

Wanielista, M.P. 1990. *Hydrology and water quantity control.* New York. John Wiley and Sons, Incorporated.