LITERATURE REVIEWS

1. <u>Land use evolution and water resource situation in the tropics</u>

1.1 Land use evolution

Land use changes throughout human civilization are an evolving process that is obviously constrained by environmental factors such as soil characteristics, climate, topography, and vegetation. But it also reflects the importance of land as a key and finite resource for most human activities including agriculture, industry, forestry, energy production, settlement, recreation, and water catchments and storage. Land is a fundamental factor of production, and through much of the course of human history, it has been tightly coupled to economic growth (Richards, 1990). As a result, control over land and its use is often an object of intense human interactions. Human activities that change or maintain attributes of land cover range from the initial conversion of natural forest into cropland to on-going grassland management (e.g., determining the intensity of grazing and fire frequency) (Turner II *et al*., 1993).

According to 'Report of the Asia-Pacific Forestry sector outlook Study' by Asia-Pacific Forestry Commission FAO 1998, the broad changes in land use that have taken place in the Asia-Pacific region since 1961 are presented in Figure-1. The area of land used for agriculture has increased about 170 million ha. (about 13% in total) since 1961. The area used for permanent pasture has increased by 125 million ha (about 15%), arable crops by 30 mill. ha. (about 7%) and permanent crops by 15 million ha over the period. The expansion of permanent crops (only 15 million ha) represents a remarkable 60% increase over 1961 levels that bear major implications for forestry. About two-thirds of the expansion of agricultural land (or 115 million ha) has come from the cultivation of previously unused or barren land (i.e. other land) and the remaining 55 million ha has come from the conversion of forest(crown cover of more than 10% and an area of more than 0.5 ha) and other wooded land (with a crown cover of 5-10% of trees reaching up to 5 meters height at maturity; more than 10% of trees not able to reach 10 meters height; or with shrub and bushy cover of more than

10 %) to agricultural use. The average loss of forest and other wooded land over the period 1961-1994 is calculated at about 1.6 million ha per year. It also shows that the area of forest and other wooded land is increasing in North and South Asia, while most major losses are occurring in Southeast Asia.

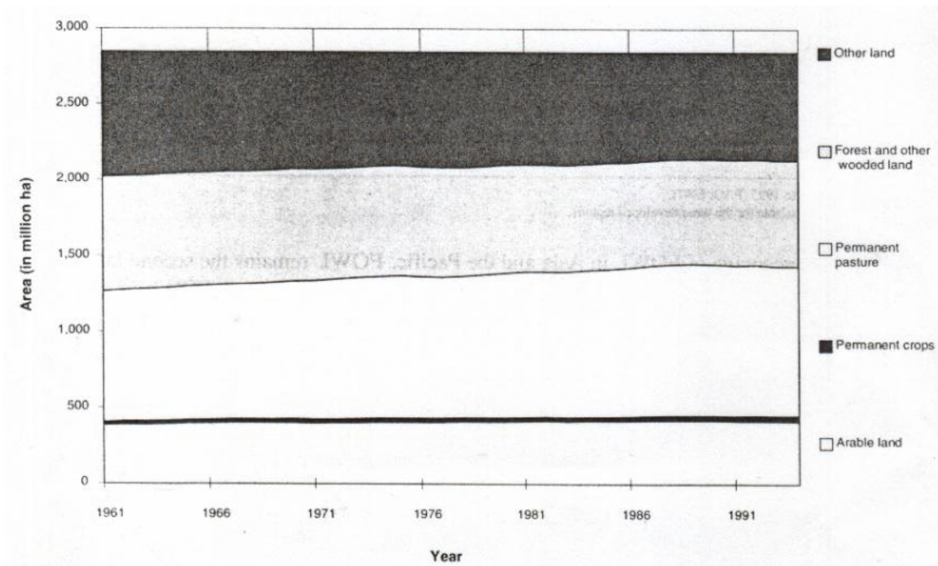

Figure 1 Trends in land use in the Asia-Pacific region, 1961-1994.

Source: FAO (1998)

Prospects of land use evolution as analyzed in the above report (shown in Table1) indicate that the need to produce more food for region's increasing population will drive continued expansion of the area of arable land, while the high profitability of permanent crop will encourage an expansion in cropping area by about one-third from 1994 levels. Together, these changes will take about 36 million ha away from other land uses. A large proportion of this expansion in agricultural and permanent crops will take place in North and Southeast Asia. In contrast, the area of permanent pasture is expected to decline by 48 million ha or less than 5 %. In some countries this will be driven by conversion of pasture to higher value land uses and in others, the loss will result from farmers abandoning pastures due to low profitability, soil erosion or other problems. In terms of forest and other wooded land it is expected that past deforestation rate will continue and that about 17 million ha of forest and other wooded land will be converted to other land uses (mainly arable land and permanent crops) by 2010. It is also expected that most of this conversion will take place in Southeast Asia.

Table 1 Estimated changes in land use in the Asia-Pacific region, 1994-2010

Land use type	Area in 1994 (million ha)	Estimated areas in 2010 (million ha)	Change 1994-2010 (million ha)	Change 1994-2000 (%)
Arable land	404	413	+9	+2.2
Permanent crops	51	78	+27	+52.9
Permanent pastures	974	926	- 48	- 4.9
Forest and other wooded land	806	789	- 17	- 2.0
Other land	613	640	+27	+4.4

Source: FAO (1998)

According to data compiled by Richards and Flints (1994), Forest cover in Northern Thailand declined from 62% to 40% and agricultural land increased from 2.3 % to 23% during the 100 years ending in 1980 (Table 2).

It was due to clearing of small patches of vegetation for agriculture rather than as extensive, contiguous vegetation removal (Fox *et al*., 1995). In case of Sam Mun watershed of Chiang Mai Province he showed that patch number and edge distance increased 94% during period between 1954 and 1983, while mean patch area decreased by 62%. He also noted that as in other tropical areas though the rate of deforestation has leveled in the recent period, forest fragmentation has continued to increase.

Table 2 Land cover change in Northern Thailand

Land cover types	Years				
	1880	1920	1950	1970	1980
Forest /Woodland	0.620	0.570	0.514	0.466	0.400
Secondary	0.343	0.385	0.390	0.412	0.349
Agriculture	0.023	0.033	0.078	0.106	0.233
Other	0.013	0.012	0.019	0.016	0.018

Note: values given as fraction of total land cover

Source: Richards and Flints (1994)

Based on the data of Office of Agricultural statistics, Ministry of Agriculture and Cooperatives, Tangtham *et al*. (1999) showed that forest area in the Mae Klong river basin decreased from 13,783 sq. km in 1981 to 11,995 sq. km in 1995 i.e., about 13% decrease. About 73% of mangrove forest existed in 1981 was found reduced at 8.74 sq. km in 1995. Unlike forest area about 10% of farmland was reported to increase from 3.15 mill. rai in 1981 to 3.45 mill. rai in 1995. Opposite to this situation, population growth of 34% was found from 1979 (1.3314 mill.) to 1997 (1.7873 mill.) i.e., about 1.8% per anum. The converted forest area owned by one person was estimated at 2.45 rai/head during the past 20 years and the farmland area was about 1.97 rai/head in 1995. The above scenario implied that the area of about half rai (0.56 rai) per head was left abandoned. Forest area depletion and increased farmland in relation to population growth as illustrated by Tangtham *et al*. (1999) are presented in Figure-2. Based on this trend it was estimated that the land needed for upland agriculture (since lowlands have been fully utilized by various kinds of cropping) would be 3.87 mill. rai in year 2010.

1.2 Water resource situation

Water, rather than the land, is the defining element of Southeast Asia, where the human relationship to water has long formed the basis of existence (Rigg, 1992). A severe limitation exists in the uneven distribution of precipitation (only important renewable resources) in this region. Some regions have excess some have shortage. An indication of the amounts of water in some tropical countries is shown in Table 3.

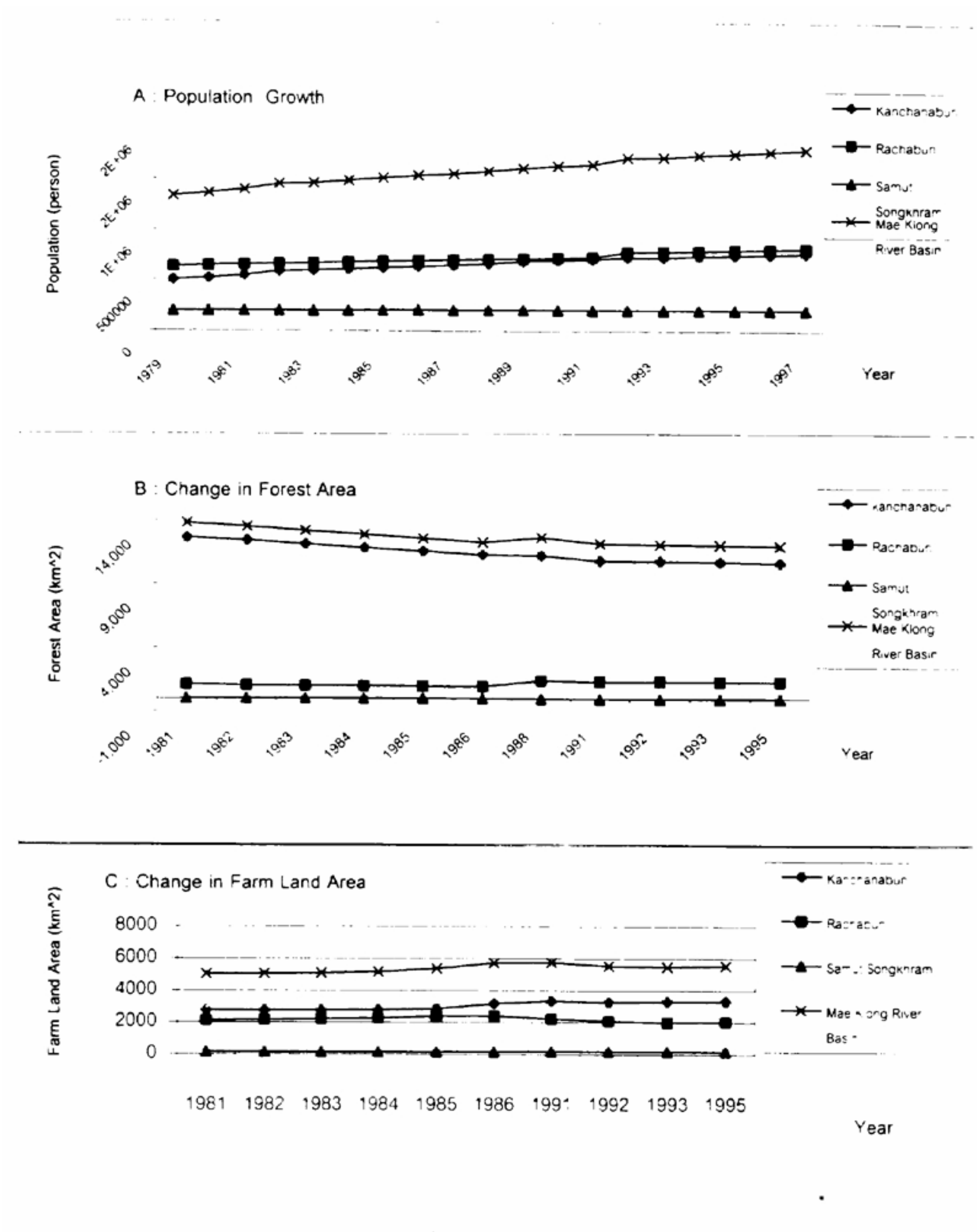

Figure 2 Population growth during 1979 – 1997 (A) and Change in forest area (B) and change in farmland area (C) during 1981 – 1995 in Mae Klong River Basin.

Source: Tangtham *et al*. (1999)

Table 3 Water resources in some tropical countries

Country	Population, 1990 (10^6 people)	Annual internal renewable resources 1990 (10^3 m^3 a^{-1} $person^{-1}$)	Annual river flows from outside country ($m^3 a^{-1}$)
Bangladesh	115.6	11.7	1000
India	853	2.17	235
China	1139	2.47	0
Australia	16.9	20.5	0

Source: McCaffrey (1993)

Bangladesh has excess water in the wet season causing flood each year while shortage of water in the dry season causing drought another. Australia has excess water in the north and north-east and large deserts in the center. The more serious water shortages during the next few years are expected to occur in parts of south, west and central Asia and regions where the density of populations is growing rapidly (Wild, 2003). The aquifers in most countries have been depleted by high withdrawal and low recharge rates, and significant draw down problems exist. Increased runoff in some river basins can cause deleterious effects such as greater flooding, water logging, and salinity. More than 25% of the irrigated land in the Indus basin already is affected by water logging and salinization (Hillel, 1991). Freshwater availability in the coastal regions is likely to undergo substantial changes as a result of a series of chain effects. So in order to have optimum quantity, good quality and good timing of water, watershed management along with improving runoff management and irrigation technology (e.g., river runoff control by reservoirs, water transfers, and land conservation practices) have now become a crucial task for the watershed manager and hydrologists.

Vudhivanich, *et al*. (1998) stated that Mae Klong river basin with its drainage area of about 30,800 sq. km and two large reservoirs namely: Srinagarin and Khao Laem is annually generating tremendous amount of water and feeding to 2.97 million rai of the “Greater Mae Klong Irrigation Project”. Annual run off reaching to

Srinagarin and Khao Laem basins ranges from 25-50 % and 55-80 % of annual rainfall respectively (Sugiyama, *et al*., 1998). Although it indicates large amount of inflow to support multiple purpose activities planned for this project, inadequate water supply for downstream-irrigated paddy cultivation and domestic uses is still persisted (Tangtham, *et al*., 1999). Vudhivanich *et al*., (1998) investigated that the water demanded by various surpass downstream of Mae Klong Basin was 6,363 mcm per year. Of this figure about 2180 mcm for wet season and 4,210 mcm for dry season were used for 2.64 million rai and 2.40 million rai in wet and dry season cultivation respectively. The total annual released water of 7,983 mcm was thus supposed to meet all the downstream requirements.

Tangtham *et al*. (1999) opined that Land use and water is integrated development issue due to their reciprocal effects as land use is water dependent and water quality and quantity are impacted by land use. Several water reservoirs planning in developing countries are still developed with paying less attention to this interaction. Forest, land and water resources have been separately planned and managed by departments within the same ministry using their own planning units.

2. Watershed management concept

Essential to the success of watershed management is a clear understanding of some of its basic underlying concepts. This part endeavors to define key terms and principles that are relevant to watershed management.

2.1 Watershed definitions

Brooks *et al.* (1992) defined watershed as a topographically delineated area of land from which rainwater can drain as surface runoff through a river system with a common outlet, which could be a dam, irrigation or domestic water supply off-take point or where the river discharges into a large river, lake or sea. In Asia, the land area located above 8% slope is operationally considered as watershed area. Land above 30% slope is considered upper watershed. Thus conventionally accepted watershed area of Asia is 900 million hectares or 53 % of the landmass. (Magrath and Doolette, 1990).

The term 'watershed' is synonymous with 'river basin', 'drainage area' and 'catchment'. The term 'watershed' is often used in reference to large watersheds (usually over 100,000 ha). In contrast, 'catchment' usually refers to smaller watersheds (ranging from less than 1,000 ha to 100,000 ha).

A watershed is a self-contained system consisting of intricately interacting biotic and abiotic components and often of several linked ecosystems or portions of a number of ecosystems.

A watershed is not necessarily an upland or mountainous landform; it may occur in a lowland setting, and the land surface may be a major site for residential, commercial, industrial, agricultural, educational, experimental, environmental and forestland uses. Many of these uses are often conflicting and competing with each other for limited watershed land resources. Watersheds are a major source of nutrients and pollutants, which are deposited in lakes, coastal areas and rivers.

2.2 Watershed management approach

Watershed management tries to bring about the best possible balance in the environment between natural resources on the one side and human and other living beings on the other. It generate benefits for the people of both on-site and off-site of watershed area so that increasing population can have adequate basic needs and better quality of life including more water, more land and productive soil, good forest land, good food, good house and better environment (Brooks *et al.*1992).

Two characteristics distinguish watershed management from other resource management:

- Upstream use of resource affects downstream area.
- Intimate linkage exists among the resource uses: soil, water and forestry of a watershed (White, 1994).

Both of these characteristics require coordinated and interdependent action in the utilization of these resources. In the past, watershed management was synonymous to soil conservation. Today it is more synonymous with poverty alleviation and sustainable development of upland watersheds for the welfare of the upland populations or land users. Watershed management is seen in its entire complexity, where interrelated factors and their interactions are considered with the objective of poverty alleviation and food security of the upland populations.

3. Impact of land use changes on streamflow and it's timing

In this part literature upon the definition of streamflow and its timing, run-off and rainfall relationship, impact of land use changes upon them are reviewed.

3.1 Defining streamflow

According to Linsley *et al.* (1982) and Black (1991) water flows to streams by three processes:

1) Overland flow (or surface runoff),
2) Interflow (or subsurface storm flow) and
3) Ground water flow (base flow)

Overland flow involves water that travels over the ground surface to a stream channel. Interflow involves water that infiltrates into the upper soil layers and moves laterally until it enters a stream channel. Both overland flow and interflow, combined called storm flow, come from the unsaturated zone above the water table.

Flow discharge from saturated zone beneath the water table is known as ground water flow. When they are in the stream collectively called streamflow.

In most forested watershed the rate at which water can infiltrate into the soil is greater than the rate of rainfall. Therefore, overland flow is relatively rare or is limited to areas with shallow, degraded soils or saturated areas in a watershed. In contrast, interflow is common, especially in areas with thin, porous soils that become saturated during storms or in areas where subsurface soil pipes or macro pores have developed (Swanson et al., 2000).

3.2 Rainfall-runoff relationship

Rainfall and runoff have been recognized as important factors causing soil erosion for a long time. A number of investigators have attempted to develop rainfall-run-off relationship that can be applied to watershed under various conditions. One of the simplest and well-known models for characterizing the relationship between rainfall and run-off as developed by Mulvaney (1851), which allows for the prediction of the peak flows (Q_p) is follows:

$$Q_p = CIA$$

Where, C = Runoff coefficient that varies with land use

I = Rainfall intensity of chosen frequency for a duration equal to time of concentration t_c (mm/hr^{-1})

t_c = Time of rainfall at the remote portion of watershed to travel to the outlet in minute

A = Watershed area (km^2).

Another model modified from the equation of Frye and Runner (1970) for expressing the changes of runoff caused by changes of rainfall amount is as follows:

$$Q_A = a\,P^{b}\,f_c$$

Where Q_A = Annual runoff generated by a watershed having forest cover of f with annual rainfall of P (m^2S^{-1})

a,b,c = Constant values indicating influence of watershed morphologic condition, annual rainfall and forest cover on runoff generation respectively.

Based on the historical runoff discharge data and annual rainfall in Khao Yai National Park Area, Ruangpanit and Tangtham (1982) derived equation representing the run off-rainfall relationship caused by land use changes (percentage of existing forest areas), where all parameters were found highly significant in increasing run off discharge for all watershed of Khao Yao National Park. The equation is as follows:

$$RD = -27.38 + 0.0292\,DA + 0.0067\,RAIN + 0.1321\,EFA$$

$$r_{RD.DA} = 0.62;\quad r_{RD.\,RAIN} = 0.29;\quad r_{RD.\,EFA} = 0.23 \text{ and } R = 0.78$$

where $_{RD}$ = Predicted annual run off discharge in cms

$_{DA}$ = Drainage area in km^2

$_{RAIN}$ = Observed basin average of annual rainfall in mm.

$_{EFA}$ = Existing forest area in drainage basin in percent

$r_{RD.DA}$; $r_{RD.\,RAIN}$; $r_{RD.\,EFA}$ = Correlation coefficient between run off discharge with drainage area, annual rainfall and percentage of existing forest area respectively.

The relationship between runoff and rainstorm events were observed by Tangtham (1998) in various types of exotic species plantations with narrow terracing on steep terrain of Doi Angkhang Highland Project, Chiangmai, Thailand. Data were collected from 4X15 m runoff plots 2, 3, 7 years after the plantations were established. The results showed a good correlation between storm rainfall and rainfall energy (El $_{30}$ index) with R^2 ranges from 0.86 to 0.99. A very small increase of R^2 was found in all plots in year 7 and a little increase of R^2 was obtained when the rainfall factor was added in to the regression analysis. He concluded that narrow bench terracing and the vegetation recovery greatly reduced both rainfall and runoff energy on the steep terrain.

Ruangpanit (1971) studied the effect of percent crown cover on runoff on twelve rectangular sample plots located on the 20 to 25% southwest-facing slope of the hill evergreen forest at an elevation of 1,350 m at the Doi Pui, Kog Ma Watershed Research Station, Chiang Mai Province, Northern Thailand. He showed that runoff increased with increasing amount, duration and intensity of rainfall and varied inversely with percent crown cover, increasing rapidly when the crown cover was below 70% and remaining nearly constant when crown cover was 70% or greater.

3.3 Flow timing indicators

Streamflow timing as defined by Court (1961, 1962), Satterlund and Eschner (1965) and Sopper and Lull (1970) is described below:

Streamflow timing indicators are primarily categorized into two main parameters, i.e., the "Flow Date" and the "Flow Intervals".

Flow Date: It is defined as the date on which a given flow volume of a year has passed.

Flow Interval: It is defined as the shortest number of the consecutive days that account for high flows and the longest number of consecutive days that account for low flows.

The "Flow Dates" are further categorized as follows:

Half-flow date: The date on which half of the streamflow has passed.

First and Third quartile flow dates: The dates on which ¼ th and ¾ th of the stream flow of a year has passed respectively.

The " Flow intervals" are further categorized as follows:

Half-flow interval: The shortest rainy season period that includes one half of the annual run off.

Quarter flow interval: The shortest rainy season period that includes one quarter of the annual run off.

For "low flows", run off intervals are also defined as follows:

Five percent flow interval: The longest period, usually in dry season, that accounts for 5 percent of annual flow.

One percent flow interval: The longest period, mainly in dry season, that accounts for one percent of annual flow.

As there are several factors causing changes in flow dates and flow intervals, which include the month that highest rainfall occurs, the amount of annual rainfall, amount of rainfall in each month and the changes of land use within the watershed, it is therefore hard to detect which factor or factors significantly affecting upon variations of momentary peak date, half flow date and any particular flow interval. Although the measures of streamflow timing parameters have been attempted since 1961, only few studies used these parameters for describing stream flow regimen.

Ruangpanit and Tangtham (1982) investigated the impact of land use evolution on streamflow timing where it was assumed that within a given period of consecutive years e.g. 5 years period, the average flow volumes of each of those given periods would be treated by the same rainfall characteristics. Only the changes in land use within any given period was then presumed to be a main factor causing the change in stream flow timing. With the above assumption, cumulative flow volume of each date were calculated starting with 1st date of April as the first day of the year (Thailand Water Year).

Cumulative flow volume of the last date of last month (March) was assigned as 100%. Cumulative flow volumes of each date along with their percentage rates were then plotted in graphic paper. Resulting diagram representing cumulative values of each date were adjusted for determining flow dates and flow intervals. The method of deriving streamflow timing was illustrated by the following hypothetical curve of cumulative flow volume in Figure 3.

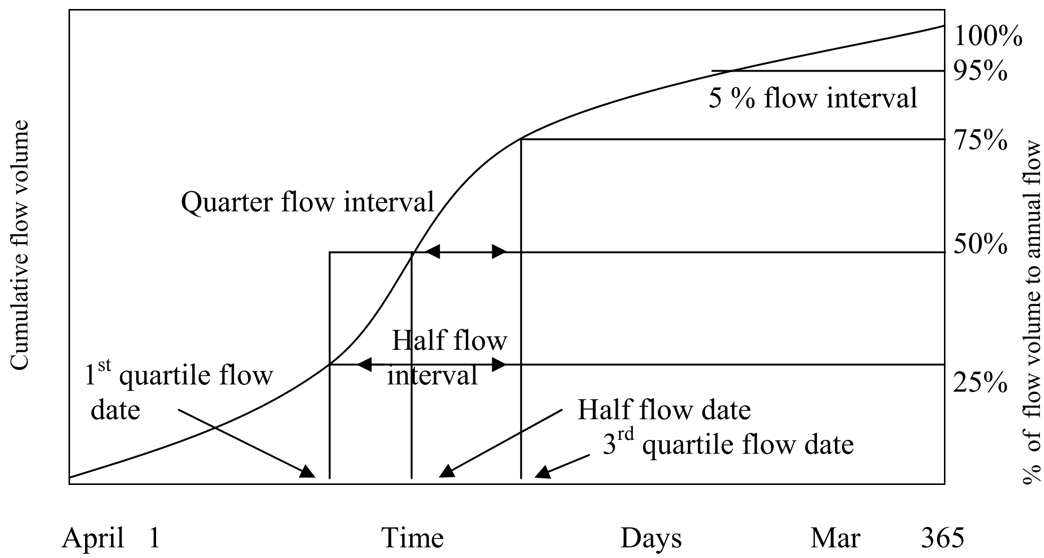

Figure 3 Hypothetical curve of cumulative flow volume for deriving streamflow timing.

3.4 Land use change impact upon streamflow and it's timing

Theoretically it is considered that increased interception and increased dry season transpiration will increase soil moisture deficits and reduced dry season flows. On the other hand, increased infiltration under natural forest will tend to higher soil water recharge and thereby will increase dry season flow (Calder, 1998). Bosch (1979) stated the same as early one that Pine afforestation on former grass land not only reduces streamflow (440 mm) but also reduces dry season flow (1.5 mm). Robinson *et al*. (1997) supported the later one that drainage activities associated with plantation forestry increased dry season flows. Similarly, Calder (2004) observed the same from the studies in the upland of U. K., but he also observed from the studies in South Africa that dry season flows reduced in similar proportion to annual flows and recent studies indicated that most forests reduced dry season flows.

A study conducted by Boonywat and Susanpoontong (1996) in Yom river basin of Northern Thailand revealed that under the situation of change in forest area from 75.29% to 53.84% over the period 1973-1994 into agricultural and urban areas, average annual rainfall and stream flow had continuously trended downwards with the decrease trend of runoff potential from 13.8 to 10.1 % of annual rainfall. However the wet flow trended to increase during the rainy season from 79.3 to 80.3 % while the dry flow decrease from 20.7 to 19.7%. The rainfall - streamflow relationship was significantly in direct proportion to each other. More frequent flooding during the rainy season and drought during the dry season was expected to occur. However, the water shortage in the dry season seemed to be more serious due to the increasing water demand by domestic and agricultural uses than due to effects of land use changes.

Soukhathammavong (1997) compared the statistics of river flow of Nam Tan watershed (Area-2, 297 sq. km) of Lao PDR in 1992-1994 with that carried out in 1970-1973 and concluded that streamflow for the dry months (November to May) has a decreasing trend (up to 64.8%) which might be due to land use changes in the catchments area, particularly slash and burn practice and deforestation for other purposes. He also stated that streamflow of the Nam Tan River for the dry months could not meet the demand for the dry season target irrigation area of 200 ha and the same would be happened for the wet season target irrigation area of 2,000 ha because of the decreasing streamflow during dry spells.

Chunkao and Tangtham (1972) studied the streamflow characteristics of Huai Kok Ma watershed in Northern Thailand, which covers an area of about 0.879 sq. km with steep slope, deep, and porous soil having high organic matter and moisture content. The hydrograph of this watershed was found like overturned ‘V’ shape because of maximum rainfall (146.5 mm) recorded during 20 and 21 May 1970 in seven year’s period. On 20 may 1970 when the rain began at 7.00 p.m. the rising limb of hydrograph rapidly increased owing to heavy rainfall and the peak also suddenly responded to the rainfall amount. When the rainfall ceased at 9.00 to 10.00 a.m. on 21 May 1970, the streamflow clearly decreased and the hydrograph was increased again after the following rainstorm. The antecedent rainfall was 98 and 45 mm on 14 and 16 May respectively. The result showed that when rainfall exceeds soil water capacity in hill evergreen forest, streamflow could rapidly increase. Therefore, the destruction of hill evergreen forest may cause unusually higher runoff and the higher peak of hydrograph than natural forest one because soil properties were changed and permeability and sorptivity also decreased.

Niyom (1980) investigated streamflow characteristics of forest and shifting cultivation area in the sandstone and shale basement of undulating topography at the Sakaerat Environmental Research Station (SERS) of Northeastern Thailand on three sites namely-Huai wanasart and Huai Kokphet for the representative of forest areas, Huai Phae for mixed land use and Huai Tayoo for shifting cultivation area. He summarized that the potential of annual surface water of Huai Wanasart, Huai Kokphet, Huai Phae and Huai Tayoo is 3800, 1200, 304000 and 446000 m^3 km^{-2} yr^{-1} respectively with the average of 202,300 m^3 km^{-2} yr^{-1} or approx. 16.4 % of rainfall. Annual flow period of each watershed indicated at Huai Wanasart, Huai Kokphet and Huai Phae perennial streams were 6, 8, 7 months respectively. For Huai Kokphet water flow showed occasionally after a big rainstorm only. Lag time of all types of land use approximated separately 18 and 6 hours at Huai Wanasrt and Huai Phae, and 90 and 30 minutes at Huai Tayoo and Huai Kokphet.

Chamroonrat (1994) studied the watershed rehabilitation effect on streamflow characteristics at the same site as Niyom (1980). He found the potential of annual surface water after 10 years watershed rehabilitation (1983-1992) of Huai Wanasart, Huai Kokphet, Huai Nakhem and Huai Tayoo was 23,880, 720, 279,800 and 108, 780 m^3 km^{-2} (1.77, 8.09, 0.06 and 20.81 % of rainfall) respectively. He also concluded that forest rehabilitation remarkably caused an increase in soil moisture storage and decreased in streamflow partly due to non-uniform rainfall period even though it showed higher amount of rainfall in dry period than the previous record.

Wittawatchutikul (1997) studied the streamflow characteristics of Huai Hin Dard watershed and found that streamflow of forest area was about 19.38 % of annual rainfall; the lateral flow from upper horizon, lower horizon and the base flow were 3.50,28.86 and 67.64 % respectively. After changing to para rubber plantation, the streamflow was about 57.33 % of annual rainfall. The surface runoff, lateral flow from upper horizon, lower horizon and base flow were 42.52, 15.38, 20.31, and 21.79% of total stream flow respectively.

A simulation study of the seven largest storm events within the rainfall collection period in Northern Thailand (Ziegler and Giambelluca, 1996) indicated that during large rainstorms, overland flow on roads is greater than that from the agricultural related lands. In swidden based hill slopes, roads are linear features that with low infiltration rates channel overland flow quickly/directly to the stream channel.

Through data collected from small farm catchments ranging from 1 to 3 ha under semi-arid black soil region of Karnataka, India Adhikari *et al*. (2003) showed that maximum rainfall and runoff was occurred in the month of September followed by October and June. Annual run off was as high as 119 mm in 25 year return period suggesting that the area is prone to sever soil erosion due to high percentage of runoff. Effect of crop cover on runoff was not much pronounced. There was found minimum water deficit (24.9 mm) and maximum soil water availability (0.71 AE/PE) in the month of September followed by October and November.

Tangtham and Yuwananont (1996) investigated that land use changes by decreasing forest area from 50% to 25% in the upper part and 32% to 17% in the entire Pasak river basin of Thailand increased quantity of wet flow in the upper Pasak and almost no effect in the lower part of basin. It was also observed that about 92% of annual flow was occurred in wet period while only 8% flowed in dry season.

Bruijnzeel (1990) urged that infiltration capacities were critical in how the available water was partitioned between runoff and recharge leading to dry season flows. It was also concluded by Bruijnzeel (2004) that total annual water yield was seen to increase with the percentage of forest biomass removed, with maximum gains in water yield upon total clearing. Actual amounts were differed between sites and years due to difference in rainfall and degree of surface disturbance. As long as surface disturbance remains limited, the bulk of the annual increase in water yield occurs as base flow (low flow), but often rainfall infiltration opportunities are reduced to the extent that ground water reserves are replenished insufficiently during the rainy season, with strong decline in dry season flows.

4. Impact of land use changes upon soil erosion and sedimentation

This part endeavors to deal with soil erosion process, factors influencing upon it, sediment yield estimation, and impact of land use changes upon it:

4.1 Soil erosion process

Soil detachment and transport are the basic processes of soil erosion. Soil particles detached from the soil mass by raindrop impact and runoff are transported down slope. The processes involved as described by Hudson (1995), Morgan (1995), and Marshall *et al*. (1996) are as follow:

The first process is the detachment of mineral grains or small aggregates from larger aggregates caused by impact of large, fast-falling raindrops. Some of the soil particles are splashed into the air and on a hill slope fall predominantly downhill. Ellison 1944 showed that striking raindrops act like miniature bombs, detaching soil particles and throwing them in the run off. Infiltration of water is reduced as the large pore spaces become blocked by collapse of the larger aggregates and deposition of the splashed particles. When the rainfall intensity is greater than the infiltration rate, water runs off the soil surface.

The second process is the transport of some of the detached particles in the run off water. As it flows downhill with its suspended load the runoff water may detach and transport more particles as shown in Figure 4:

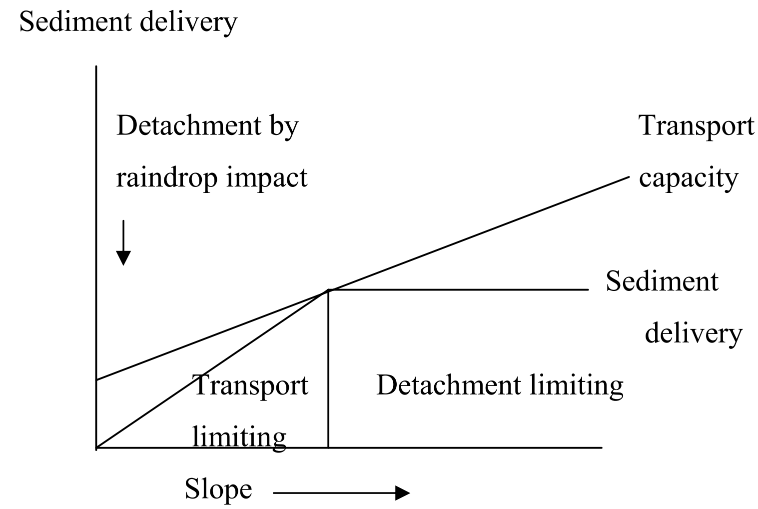

Figure 4 .Schematic representation of the process of particle detachment and transport in relation to slope inter-rill areas.
Source: Gordon et al. (2004)

The flow, initially as a sheet over the soil surface (inter-rill flow), becomes concentrated in small channels called rills that coalesce into larger and deeper rills as the flow becomes turbulent. Ekern (1950) showed the same also as it greatly adds to the rate of soil transport. The suspended load is deposited when the flow rate decreases either because the slope decreases, or because there is vegetative cover or some other form of protection. Heavier particles of coarse sand, gravel or rock debris are rolled and bounced along the streambed as bed load. Both suspended sediments and bed load have important effects on the life expectancy of reservoirs and on the maintenance of irrigation systems. Sediment flows are critical indicators of the effectiveness of watershed management.

On a long, unprotected slope or with a prolonged, severe storm the rills tend to join together and the turbulent flow produces gullies. Whereas rills can be eliminated by cultivations, gullies require special treatment.). It is measured as a concentration such as milligrams per liter or as turbidity, which is an optical measurement of the water's ability to diffract light and is expressed as nephelometric turbidity units (Stednick, 1991).

Sediment enters the stream system through erosion processes. To achieve stream stability, equilibrium must be sustained between sediment entering the stream and sediment transported through the channel. A land use activity that significantly changes sediment load can upset this balance and result in physical and biological changes in the stream system (State of Idaho, 1987).

4.2 Factors affecting soil erosion and sedimentation

Site properties that affect erosion processes include vegetation cover, soil texture, soil moisture, and slope, among others (Falletti, 1977; Renfro, 1975). The sediment load of streams (both suspended and bed load) is determined by such characteristics of the drainage basin as geology, vegetation, precipitation, topography and land use. According to Stevan *et al*. (1986) the four principle factors affecting soil erosion process are climate, soil characteristics, topography and ground cover, which form the basis of the Universal Soil Loss Equation (USLE). The USLE is a method for quantifying the interaction of factors to estimate the tonnage of soil loss per year.

4.2.1 Climatic factors

Climate affects erosion potential both directly and indirectly. Directly, rainfall is the driving force of erosion. It dislodges soil particles and runoff carries in particles away. The erosive power of rain is determined by rainfall intensity and droplet size which is indicated by Law and Parson (1943) in the form of following equation:

$$D50 = 2.23 * I^{0.182}$$

Where D50 = Median drop size

I = Intensities in inches per hour

Wischmeier and Smith (1978) have found that the best single rainfall related to soil loss is the product of total rainfall energy of a storm and it's maximum 30 min. intensity i.e., called rainfall – erosion index. On an individual storm basis, the rainfall erosion index explained 72-97 % of the variation in erosion for bare soils.

Indirectly yearly distribution of rainfall and temperature determines the extent and growth rate of vegetation that is the most important form of soil erosion control. Vegetation provides ground cover to the soil and protects it from erosion.

4.2.2 Soil characteristics

Based on Steven *et al.* (1986) the following four soil characteristics are important in determining soil erodibility: Soil texture, organic matter content, structure and permeability:

Sand, silt and clay are the three major classes of soil particles. Soil which is high in sand content are said to be coarse textured. Because water readily infiltrates into sandy soils, the runoff and consequently the erosion potential is relatively low. Clay because its stickiness binds soil particles together and makes a soil resistant to erosion. However once fine particle are eroded by heavy rain or fast flowing water, they will travel great distances before settling.

Organic matter consists of plant and animal litter in various stages of decomposition. Organic matter improves soil structure and increases its permeability, water holding capacity and soil fertility. Organic matter in an undisturbed soil or in a much covering a disturbed site reduces erosive impact of raindrops, runoff and erosion potential so on.

Soil structure is the arrangement of soil particles into aggregates. It largely affects soil water and soil-air relations through its influence on pore space, air-holding capacity and thus infiltration capacity. Compaction of soil results in lowest infiltration of water, compel water to run off. Erosion hazards increases with increase run-off. Loose granular soils absorb and hold water, which reduces runoff and encourages plant growth.

Soil permeability refers to the ability of the soil to allow water and air to move through the soil. Soil texture, structure and organic matter all contribute to the permeability. Soils with high permeability produces runoff at a lower rate than soils with low permeability, which minimizes erosion potential. The water content of a permeable soil is favorable for plant growth, although it may reduce slope stability in some situation.

4.2 3 Topography

Slope length and slope steepness are critical factors in erosion potential, since they determine the large part the velocity of runoff. Long continuous slope allow run off to build up momentum. The high velocity runoff tends to concentrates in narrow channels and produces rills and gullies.

a. Percent slope

Several studies have reported increased erosion with increasing percent slope. Smith and Whitt (1957) proposed the following equation:

$$R = 0.10 + 0.21\, S^{4/3}$$

Where

R = Relative loss of soil in relation to a unit loss of a 3% slope

S = Percent slope.

In cases where it is difficult to get a relative figure such as the amount of soil that might be expected to be lost on a 3% slope, an additional equation has been suggested:

$$A = 0.43 + 0.3\, s + 0.043\, s^2$$

Where A is the soil loss in tons per acre and s is the percent slope.

b. Slope length and gradient factor

Topographic or slope length and gradient factor play vital role in soil losses from any activities and treatment on-site of watershed. To determine the value of slope length and gradient factor or 'LS' factor is a target for estimating soil loss. Wischemeier and Smith (1978) proposed the following equation for estimating LS factor:

$$LS = (\lambda_m / 22.13)^m \ (65.41 \sin^2\alpha + 4.56 \sin\alpha + 0.065)$$

or $$LS = \lambda_m \ (0.0076 + 0.0053_{s} {}_{++0.00076\ s}{}^{2})$$

Where

$L = (\lambda_m / 22.13)^m$

$S = (65.41 \sin^2\alpha + 4.56 \sin\alpha + 0.065)$

λ_m = Slope length in m

m = Exponent (0.5 for slope>5%, 0.4 for 3.5-4.5%, 0.3 for 1-3%, and 0.2 for <1%)

α = Angle of slope.

Wischemeier and Smith (1978) recommended that this equation should be applied to the area with slope length between 8-90 m and slope gradient between 3-18%.

3.2.4 Ground cover

The term "ground cover" refers principally to vegetation, but it also includes surface treatments placed by man such as mulches, Jute netting, wood chips and crushed rock. Vegetation is the most effective form of erosion control. No manmade products can approach it in long-term durability and effectiveness. Vegetation control runoff velocity and holds soil particles in place and shields the soil surface from the impact of falling rain (Steven *et al*., 1986).

4.3 Sediment yield predictions

Sediment yield is defined as the total sediment outflow from a catchments over some unit of time, usually one year (Gordon et al., 2004). Its measurement is necessary in watershed management in order to find out the sediment sources for protection. Accuracy in predicting the space needed for sediment storage is important because overestimation adds unnecessarily to the cost of structure and underestimation shortens the useful life of the structure and the services associated with it (Holeman, 1975). In the same manner inaccurate sediment yield prediction causes the failure in watershed management, particularly water quality control (Rainfro, 1975; Dunne and Dietrich, 1982). In order to estimate average annual sediment yield the accurate basic procedures used in Soil Conservation Service of U.S.A depending on the environment and data available are – 1) gross erosion and sediment delivery ratio determination 2) predictive equations 3) suspended load measurement and 4) sediment accumulation measurement. Glymph (1975) modified and developed these into four predicting procedures:

4.3.1 Sediment rating curve - flow duration method

This method requires concurrent field measurement of streamflow and sediment to establish the relationship between parameters of streamflow and sediment quantity. Though it is difficult and expensive to obtain the required data for the large number of sites potentially of concern by this method (Glymp, 1975), estimating sediment concentrations from discharge data is a widely used approach in hydrological practice (Gordon et al., 2004).

Flaxman (1975) showed the following relationship between sediment yield and discharge which can be used to develop a sediment rating curve:

$$Y = a * X^{m}$$

Where,

Y = Sediment concentration in milligram per liter

X = Discharge in cfs

m = An exponent indicating the average change of sediment load with changes in discharge, not depend on the units used, typically lies between 1.5-3.0 (Knighton, 1984).

a = Co-efficient.

To be able to apply with larger size of watershed area, Dunne and Dietrich (1982) added land use and topographic steepness factors as :

$$S_y = U.Q^n. S^b$$

Where

S_y = Mean annual sediment yield in metric tons/km^2/yr

Q = Mean annual runoff in mm

S = Dimensionless index of topographic steepness.

U = Land use expressed by means of dummy variable

The stepwise multiple regressions for various land use types as investigated by Dunne and Dietrich (1982) are:

1) Undisturbed forest (n = 4)

   $S_y = 2.67 * Q^{0.38}$

   $R^2 = 0.98$

2) Forest greater than agriculture (n=8)

   $S_y = 0.10 * Q^{1.28} * S^{0.47}$

   $R^2 = 0.76$

3) Forest less than agriculture (n=28)

   $S_y = 0.14 * Q^{1.48} * S^{0.51}$

   $R^2 = 0.74$

4) Rangeland (n=5)

$S_y = 4.26 * Q^{2.17} * S^{1.14}$

$R^2 = 0.87$

The above equations reveal that as the density of cover decreases the effects of increasing run-off and topographic steepness are enhanced.

4.3.2 Sediment delivery ratio method

Sediment delivery ratio (SDR) is the ratio or percentage of relationship between sediment yields from watershed and computed gross erosion on the watershed in the same period of time (Glymph, 1975; Renfro, 1975). Maner (1962) found a definite and significant relationship between the sediment delivery ratio and the size of the drainage area above the point of sediment yield measurement. The study was confined to Blackland Prairie area in Texas. The relationship was a non-linear correlation to be computed to obtain the regression equation as follows:

$$\text{Log}_{10} DR = 1.87680 - 0.14191 * \log_{10} A$$

$$R^2 = 0.96$$

where

DR = Estimated sediment delivery ratio, in percent of annual erosion

A = Sediment contributing area in square miles.

Maita *et al*. (1998) analyzed the relationship between suspended sediment yield and watershed characteristics in Mae klong river basin with its three tributaries including Khwae Noi, Khwae Yai and Lam Pachi and estimated suspended sediment rating curves by using water discharge data and sediment load data. The exponent was found to be a positive value of 0.22 in Mae klong river basin which indicated that lowland of the basin has plenty of suspended sediment source rather than the upland because almost all agricultural land exists in lowland and increase with basin area.

Parker and Osterkemp (1995) compiled mean annual suspended sediment discharges from 24 gagged rivers in the United States. Drainage area range from 1.6 to 10^6 km ^{2} and mean annual suspended sediment ranged from less than 5 to over 1480 ton/km^2/yr. Linear and non-linear regression analysis of mean annual suspended sediment and drainage area indicates no statistically significant relationship. At these case factors such as geology, climate, soil, vegetation, land use, stream flow characteristics and river regulation dominate over watershed area in determining sediment.

5. <u>The relationship between land use, streamflow and suspended sediment</u>

Based on the historical records of stream flow and suspended sediment data of 32 watershed years (1964-1981) together with estimated percentage of existing forest areas of Khao Yai national park watershed areas, Ruangpanit and Tangtham (1982) derived equation representing relationship among drainage area, land use change, runoff discharge and suspended sediment in the form below:

$$ASS = e^{(1.714 + 0.011\,RD + 0.003\,DA + 0.0015\,rain + 0.0321\,EFA)}$$

$$r_{ASS.\,RD} = 0.73\,;\quad r_{ASS.DA} = 0.66\,;\quad r_{ASS.\,RAIN} = 0.53\,;$$

$$r_{ASS.\,EFA} = 0.58;\ R = 0.80$$

Where

ASS = Predicted annual suspended sediment in tons

RD = Annual run off discharge in cms

DA = Drainage area in km ^{2}

RAIN = Observed basin average of annual rainfall in mm

EFA = Existing forest area in drainage basin in percent

R = coefficient of multiple correlation

$r_{ASS.RD}$, $r_{ASS.DA}$, $r_{ASS.\,RAIN}$, $r_{ASS.\,EFA}$ = correlation coefficient between annual suspended sediment and run off discharge, Drainage area, annual rainfall and existing forest area respectively.

Applying the prediction equation of run off discharge obtained in runoff-rainfall relationships in the suspended sediment model, the new equation derived is as follows:

$$ASS = e^{(1..391+ 0.00334\ DA + 0.0016\ RAIN + 0.0337\ EFA\ )}$$

All parameters representing watershed characteristics in the above equation (i.e. drainage area (DA), annual rainfall (RAIN), existing forest area (EFA) have positive impact on suspended sediment yield i.e., there were good forest cover in the study area during the study period.

Another study conducted by Tangtham and Lorsiriat (1993) on reservoir sedimentation in Northern Thailand revealed the negative impact of watershed parameters upon suspended sediment yield. The study employed bottom survey data from 11 existing reservoirs to find correlation between the annual suspended sediment and 11 various hydrological, geomorphologic and forest cover parameters including basin annual rainfall (R_a), annual inflow (Q), areal distribution of watershed classes (WSC1-WSC5), surface area of water in reservoir (WSA , % of basin area), basin relief ratio (Sr), channel sinuosity (Si) and remaining forest cover (For; %).

The derived mathematical statistical equation is:

$$RS = e^{(-7.\ 2348 + 2.5386\ In\ Q - 0.00\ 41\ For + k)}$$

Where $k = (\ 4.442\ Sr - 2.4077\ Si - 0.307\ WSA - 0.524WSC1\ )$

In which,

Q = Annual inflow in mcm

DA = Basin area in km ^{2}

Sr = Relief ratio in %

Si = Channel sinuosity in %

WSA = Surface area of water in reservoir %

WSC1 = Watershed class 1

For = Remaining forest cover (%).