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Watershed Degradation and Hydro-ecological Role of the Western Forest Complex (WEFCOM) of Thailand

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Abstract

Factors contributing to watershed degradation in general and specific to southeast Asia and particularly to Thailand are described as background for connecting to the status of natural resources degradation in Thailand as well as the western region in terms of forest, land and water resources changes during the past decades. The results from observation and assessment as probable effect of watershed degradation caused by forest fragmentation and land-use practices and cabbage growing with pesticide application on water yields are briefly discussed. The general features and the hydro-ecological role of the WEFCOM are described and analysed based on the observed and assessed effects obtained from the northern and western regions. The conservation plan of the WEFCOM originally proposed by the project together with that stemed from this study was also presented.

Keywords : watershed degradation, hydro-ecological role, western forest complex

1. INTRODUCTION

Thailand, by nature, is a forest land. A century ago, over 80% of the country was covered with the forests which fed a vast natural network of rivers, lakes and streams, most of which had water year-round and myriad wildlife. It has been known that less than 25% has good forest cover recently. Many tributaries are drying up and much of its wildlife and indigenous plants has vanished. The worse is that most of its forests are fragmented, surviving in residual pitches like small terrestrial islands in a sea of human settlement. Only some of those patches are large enough to have fully functional ecosystems. The most are too small or too disturbed or have lost its hydro-ecological roles as well as many wildlife species. (SNF.et.al.,*undated*)

During the past four decades, Thailand have implemented eight National Economic and Social Development Plans (NESDP) in the hope that our national economy and social status could be improved in great prosperity. At the end of the 8^{th} NESDP, the Government had learnt that the decades of economic development which proceeded the recent economic crisis in this country as well as in many others did not guarantee a good quality of life of Thai and a healthy environment. It seems to be realized by the recent and the coming regimes of government that environmental degradation will clearly jeopardize prospects for continued growth of economy and social security in this country as well as this region and would have severe consequences on the poor who suffer most from worsening environmental condition.

It was stated by the World Bank Group (http : // wbln 0018. worldbank.org/eap/eap.nsf/ cf 72f4c306958369852567c9007.......) that "in rural area, rapid loss of natural forest cover, scarcity of water, increased pressure on fisheries, and eroded soils directly impare the income and welfare of poor, who tend to depend on the environment of both their sustenance and livelihood. If the current trend continues, the key role of the agriculture, forestry, fisheries, and tourism could play in these diminished, both in terms of direct sources of livelihood for rural people and indirectly through to other value-added activities"

Thailand has experienced this suffering situation and it should be about time that Thai people have to turn his and her interests in only monetary aspect of country's development and play more role in taking care of their environment so that natural resources degradation could be reduced and it, in turn, would enhance their quality of life.

This paper aims at informing (1) factors contributing to natural resources degradation using watershed to reflect the consequential impacts, (2) degradation of natural resources in

Thailand emphasizing on the western region, (3) effects of forest and soil resources utilization on water resources degradation, and finally (4) the important role of the Western Forest Complex in eco-hydrological maintenance for the western region and the country as a whole.

2. FACTORS CONTRIBUTING TO WATERSHED DEGRADATION

As has been known by watershed scientists that there are many factors that act cumulatively and synergistically to contribute to watershed degradation. Revenga et.al. (1998) stated that these factors include : (1) physical modification, (2) habitat degradation, (3) water use, (4) pollution, and (5) loss of freshwater biodiversity. The FAO (1994) reported that watershed degradation in South Asia comprises elements of (1) deforestation, (2) soil erosion, and (3) adverse changes to river flow regimes and sediment content. Degradation caused by these factors was described by the World Resources Institute and could be summarized as follows :

2.1 Physical alteration of inland water systems

Structural modifications, such as dams, flood control, and channelization, change the dynamics of aquatic ecosystems, fragment existing systems, and join previously unconnected ones. In many cases these structural modification have made more land available for producing corps which have played a key role in global food security. However, altering the structure of a river can also bring about costly changes, such as decline in fish catches, loss of fresh biodiversity, increase in frequency and severity of flood, and loss of soil nutrients in the flood plain.

Reducing the flow of fresh water to the sea, dam can also lead to the intrusion of salt water into previously fresh surface water and groundwater-- rendering them undrinkable. It was also recorded that the recent floods along large rivers such as the Mississippi River have been substantially higher than they would have been before flood control structures confined the river a narrow channel (Watersheds of the World – Revenga et.al.,1998).

2.2 Habitat degradation and watersheds

It was stated by World Resources Institute (Revenga,et.al., 1998) that land utilization such as deforestation, mining, grazing, agriculture, industrialization, and urbanization all degrade rivers, lakes, wetlands, and the watersheds they drain in ways that make the less able to support life and of provide valuable ecosystem services.

Habitat degradation from logging and extensive agriculture, for example, increase soil erosion and therefore siltation of rivers, reservoirs, lakes and coastal waters. The excessive siltation then affect downstream communities by increasing the frequency of floods, imparing hydropower and navigations, and choking streams and coastal habitats.

Besides those afforementioned factors, Goodloe (2002) pointed out using this longer than 44 years experiences in New Mexico watershed management that excessive numbers of livestock and forest fires and the coming popular activity of off-road vehehicles are also of prime important factors causing watershed degradation.

2.3 Water use and watersheds

Human societies recently use more water for irrigation, domestic consumption, and urban and industrial uses, two-third of it for agriculture. It was reported in the Watersheds of the World (Revenga et.al.,1998) that the amount of freshwater withdrawn has risen 35-fold in the past 300 yrs for USA. In many areas, groundwater is now withdrawn far faster than it can be recharged.

So much water is diverted from large rivers like the Colorado and the Ganges that little if any reaches the sea during the dry season, with harmful effects on inland and coastal habitats, fisheries, and people. China's Huang He (Yellow River) is so heavily used that the lower reaches were without water for 2/3 of 1997. Lake Chad, in Africa's Sahel region, has shruk by

75 percent in the last 30 years because of drought and diversion for agriculture, to the detriment of this important inland fishery.

2.4 Pollution and watersheds

It was stated in the Watersheds of the World by Revenga et.al. (1998) that the increased load of wastes and exacerbated by the loss of water withdrawn by people's activities has reduced the capacity of rivers to assimilate or flush pollutants from the system. The water that finally returned streams and rivers after irrigation is severely degraded by increased toxicity, excess nutrients, salinity, higher temperature, pathogen population, sediments, and lower dissolved oxygen.

Fertilizer and pesticides from agriculture are major pollutants. Chemical pollutants are also released directly from industrial and municipal sites, and indirectly as runoff from farms, home, roads, and cities. Toxic chemicals are also carried long distances by air currents, and many ultimately find their way into rivers and lakes.

2.5 Loss of freshwater biodiversity

As mentioned above, physical alteration, habitat degradation, water withdrawal, and pollution all contribute directly or indirectly to declines in freshwater species. In addition, the incursion of non – native, or allien, species and the mismanagement of inland fisheries are other factors contributing to the loss of freshwater organisms. Allien species may prey on native species , compete for food and breeding space, disrupt food webs, and even introduce new diseases. The spread of these species is a global phenomenon, one that is increasingly aided by the growth of aquaculture and by shipping and commerce.

2.6 The causes of watershed degradation in Thailand

The Watershed Management Division of RFD (http://www.forest.go.th/nrco/english/wshmd.htm) reported that the main causes of watershed degradation in Thailand are conversion of forest lands to agricultural land, forest fire, logging operation and other activities such as road construction, mining, over grazing and pesticides and fertilizer application.

The ongoing losses of forest cover in Thailand over the last 3 decades from about 53 percent in 1961 to approximately 25 percent in 1998. The depletion of forest areas has mainly been caused by conversion of forest to agricultural lands to provide subsistence food for rapidly increased population as well as rapid agronomic expansion for commercial crops. Due to the areas in the lowlands are limited effecting form rapidly increasing population, lowland Thai population have encroached forest areas into the mountainous land. In addition, Hilltribes settled in the mountainous watersheds have been practiced shifting cultivation (slash and burn practice) for their livelihood. Shifting cultivation has been the main cause of watershed degradation resulting on soil erosion, soil fertility reduction, sedimentation on downstream areas and reservoirs.

In the past, the cultivated land in the upper watershed areas were mainly for subsistence food. However, in the last few decade, the cultivated lands have been converted to commercial crop incorporation with increasing population which have rapidly caused forest destruction, The population living in the highland mountainous areas in 1997 were 991,122 people in 4,374 grouping villages within 20 provinces mainly in the northern region (Public Welfare Department at : http://www.hadf.org/thailand.htm). About 1 million was recently approximated to reside in those mountainous lands. (http://hadf.org/enlish/hilltribe/hilltribe.html).

The agricultural practices particularly the rapid expansion for commercial crops on the sloping upper watershed areas are major cause of watershed degradation. The widespread deforestation for commercial agriculture caused not only increasing surplus runoff, soil erosion, siltation in rivers and other damaging downstream areas, but also water contamination. The forest fire is mainly caused by slash and burn for shifting cultivation, collecting forest products, hunting etc. It is not only damaged forest trees but also ground covers and surface soil. These will decrease infiltration capacity and resulting in surplus runoff and soil erosion.

Road construction particularly on the upper slopping watershed area is also one of the major cause of soil erosion, landslide, sedimentation, and water quality in the downstreams. In addition, local landless people penetrated into the forests along the roadside and encroaching forests for agricultural practices, and finally settledown in the forest areas.

3. DEGRADATION OF NATURAL RESOURCES IN THE WAESTERN REGION

3.1 The degradation of the forest resources

Trace back to 1961, western region of Thailand was covered by 71.50 percent of forest area. At that time, inland forest area remained in Ratchaburi, Kanchanaburi, Supanburi, Petchaburi and Prachubkhirikan as detected by landsat imageries at about 64.81, 91.32, 37.72, 76.0 and 79.12 percents of the respective provincial areas. Twelve years later, the inland forest area of the respective provinces calculated basing on the landsat-5 remained at 36.10, 69.54, 13.96, 58.41 and 50.22 percent of its provincial area, a tremendous decrease of forest resources which ever occurred during the past 3 decades. The western region has lost more than 50 percent of its forest resources from 1961 to 1998. For the rugged terrain of headwater source of Mae Klong watershed, about 41% of forest in Kanchanaburi boundary have been lost during the mentioned period. Degradation of forest land during the past 3 decades is shown in Table 1. Besides the legal logging by the concessionair in early 1960 – 1980, the illegal land encroachment by those ethic groups migrated from the neighboring country as well as the increasing local population were those factors affecting forest degradation (Pragtong, 2001).

3.2 The degradation of the soil resources

Study on soil resource degradation was rather limited in the experimental area or in some part of the western region. Also it was concentrated on agricultural area of the lowland with very few information for the upland agriculture. Intensive study on the physical and hydraulic properties of soil under various kinds of land use in Mae Klong watershed experiment area was carried out by Deesaeng et.al. (1997). Only partial study results are summarized in Table 2. It was concluded by the investigators that conversion of forest for agricultural practices caused the top soil to loss and left only subsoil which inherently has a finer texture and subsequently resulted in lower BD and higher in total porosity.

Regarding soil hydraulic properties, at any matric potential energy, water content in soil under cultivation was higher than that under other land use condition due to its finer texture and greater porosity. However, soils under cultivation contains micro-pores which, in turn, cause less amount of available water to plants while those soils in the forest and plantation contain medium and macro-pores which soil water could be made available for plant more than that in cultivated soil. Plowing top soil could increase saturated hydraulic conductivity but the lower rate of K_s beneath the plowing depth could be existed as shown in Table 2 (Bt2). Converting forest for agriculture without improving its physical properties could degrade K_s in which greater amount of runoff could occur in cultivated land.

Preliminary study on the effect of change of tropical forest on soil environment by Chunchaay et.al. (1993) also revealed that top soil thickeness, color and hardness of cultivated area were distinctly different form forest soils. Numbers of root in forest land was observed to be more than that in cultivated area. More rainwater was retained by agriculture soil than that in forest soil. The moisture in soil can be more utilized by eucalyptus than by cassava. It was also found that subsoil of cultivated area in Kanchanaburi was reduced 1-3 folds due to greater in bulk density while rather uniform for soils in northern provinces. The CEC of Ca, Mg, K and Na of upper soil layer of forest soil both in northern and in Kanchanaburi are higher than those of cultivated land.

It can be therefore concluded that soil properties in terms of physical, hydrological, hydraulic and chemical have been degraded in some extent whenever forest land have been converted for agricultures. Fortunately, most of the forest lands in this region are under national parks and wildlife sanctuaries systems, slow rate of change is thus expected. Unless intensive conservation could be strictly implemented, soil resources in this region would be then sustainable.

Table 1 : Forest resorures degradation in western region of Thailand during 1961 to 2000

Provincial Area	Province																Western Region	
	Ratchaburi		Kanchanaburi		Supanburi		Samut Sakorn		Nakhan Pratom		Petchaburi		Prachubkhirikhan		Sumut Songkhram			
Sq. km :	5169.02		19,408.20		539.66		858.41		2165.24		6220.65		6366.92		409.01		41,137.11	
Million Rai :	3.25		12.18		3.35		0.54		1.36		3.89		3.98		0.26		28.81	
Remaining forest area in year 1951-1998 was interpreted from Landsat-5 (TM) : scale 1 : 250,000																	*Excluding Mangrove Forest	
Year ;	M.Rai	%	M.Rai	%	M.Rai	%	M.Rai	%	M.Rai	%	M.Rai	%	M.Rai	%	M.Rai	%	M.Rai	%
1961	2.11	64.81	11.12	91.32	1.26	37.72	-	-	0	0	2.96	76.00	3.15	79.12	-	-	20.6	71.50
1973	1.17	36.10	8.47	69.54	0.47	13.96	-	-	0	0	2.27	58.41	1.99	50.22	0.37	14.40	14.37	49.87
1975	-	-	-	-	-	-	0.1156	-	-	-	-	-	-	-	-	-	-	-
1976	0.95	29.34	8.38	68.86	0.46	13.73	-	-	0	0	1.97	50.60	1.46	36.73	0.3	10.79	13.22	45.88
1978	0.81	24.84	8.33	68.41	0.45	13.59	-	-	0	0	1.77	45.40	1.10	27.75	0.022	8.40	12.46	43.25
1979	-	-	-	-	-	-	0.0901	-	-	-	-	-	-	-	-	-	-	-
1982	0.66	20.34	7.76	63.73	0.422	12.60	-	-	0	0	1.56	40.11	0.899	22.60	0.020	7.68	11.30	39.22
1985	0.91	28.31	7.23	59.34	0.386	11.53	-	-	0	0	1.42	36.50	0.869	21.84	0.038	11.53	10.82	37.55
1988	0.89	27.41	7.02	57.66	0.380	11.34	-	-	0	0	1.397	35.91	0.860	21.61	-	-	10.54	36.62
1989	0.888	27.36	7.011	57.58	0.379	11.33	-		0	0	1.396	35.90	0.859	21.60	-	-	10.53	36.56
1991	0.835	25.72	6.769	55.59	0.376	11.24	-		0	0	1.387	35.66	0.829	20.84	-	-	10.20	35.39
1993	0.823	25.35	6.714	55.14	0.372	11.10	0.0113	2.09	0	0	1.367	35.14	0.794	19.96	0.0057	2.22	10.07	34.95
1995	0.820	25.23	6.671	55.09	0.369	11.01	0.0113	2.09	0	0	1.357	34.88	0.787	19.77	0.0054	2.07	10.00	34.72
1998	0.816	25.10	6.579	54.01	0.353	10.53	0.0106	1.96	0	0	1.340	34.45	0.767	19.27	0.0071	2.73	9.85	34.21
2000 Landsat TM) (1:50,000)	1.038	31.93	7.374	60.54	0.391	11.67	0.0211	3.96	0	0	2.105	54.11	1.435	36.05	0.0153	5.88	12.38	42.97

Source : Royal Forest Department (2002). Forestry Statistics. Planning Division, RFD. Ministry of Agriculture and Cooperatives.

Table 2 : Summarized Soil resource degradation investigated in the Mae Klong headwatershed Experimental Station Kanchanaburi , Western Thailand

Soil properties : of surface soil at Bt_1	Natural forest	Teak Plantation	Epil-epil *(Leuceana leucocephala)* Plantation	Cultivated area
Physical properties :				
- Depth (cm)	20-30	20-42	12-32	11-22
- PD. ($Mg.m^{-3}$)	2.54	2.45	2.41	2.55
- BD. ($Mg.m^{-3}$)	1.49	1.39	1.30	1.10
- Porosity (%)	41.35	43.36	46.11	56.69
- Texture	SC	SCL	SL	C
Pore size distribution :				
- < 0.2 μ	0.19	0.17	0.21	0.33
- 0.2 – 60 μ	0.10	0.06	0.09	0.05
- > 60 μ	0.18	0.26	0.19	0.21
Hydrologic capacity : (vol.of H_2O,% in 0- Bt_1 depth at potential energy :)				
- 0 kPa	46.84	48.12	49.60	58.67
- 1 kPa	32.56	31.45	33.37	40.94
- 3 kPa	29.59	28.73	31.27	38.48
- 10 kPa	29.26	23.41	27.89	36.81
- 33 kPa	21.80	19.33	24.12	34.24
- 100 kPa	19.15	16.84	21.71	32.65
- 1500 kPa	18.55	16.53	21.47	32.50
θ_{AWC} (% by vol)	6.71	6.88	6.42	4.31
Hydraulic properties K_s (10^{-6} ms^{-1}) at soil horizon :				
Horizon :	A 22.17	Ap 35.65	Ap 12.55	Ap 124.74
	Bt_1 10.80	Bt_1 3.60	Bt_1 9.18	Bt_1 111.79
	Bt_2 8.92	Bt_2 4.79	Bt_2 21.56	Bt_2 4.62
	Bt_3 7.74	Bt_3 2.10	C 115.30	Bt_3 0.15
	Bt_4 0.93	Bt_4 1.83		Bt_4 0.08
	Bt_5 0.34	Bt_5 9.26		Bt_5 0.05
	Bt_6 0.90			Bt_6 0.07

Source : modified from Deesaeng et.al. (1997)

3.3 The degradation of water resources

Water resources degradation can be considered in terms of water quantity, quality and flow timing. As has been known that removal of forest or other vegetation can sharply reduce water retention and increase erosion which results in reduced water availability in dry seasons and more silttation downstream as well as more frequency of floods in wet season. Excessive chemical substances form agricultural activities as well as pollution from urbanization and also industrialization can degrade water qualities and even make unusable for human needs.

It has been fortunately for those who are residing in the western regional watersheds of Thailand since there have been relatively abundant water resources after 1994 when the water resources systems in the Mae Klong basin have been highly developed (Satoh, et,al.,1999). Analysis of the relationship between suspended sediment yield and forest cover situation in the Mae Klong river basin led Maita et.al (1999) to conclud that "if the forest land upstream is converted to agricultural land and other land use, more sediment would be produced in upstream areas than in downstream areas because sediment production is more active in the headwater region that contains many steep slopes than the downstreams." Among the three sub – basins of Mae Klong watershed, Lam Phachi – the highest crop land ratio with most finely divided stream network, produced roughly twice the annual mean suspended sediment yield (540 ton/mcm) while the Khwae Noi and Khwae Yai yielded about 244 and 273 ton/mcm annually.

4. PROBALE EFFECT OF WATERSHED DEGRADATION ON WATER YIELD

4.1 Effect of forest fragmentation on flow regulation

Investigation on forest fragmentation effect on water quantity and quality is rarely found for the western region of Thailand. Many researches on the effect of deforestation on water yield have been carried out and published but mainly using existing forest area in a watershed as variable in determininig water yields in terms of water quantity, quality and timing. Among these researches, Warapongsittikul (2002) determined the effect of forest fragmention on water yield regulation on the purpose of attempting to find out optimal size of massive forest cover which can regulate water yield under watershed management policy for maintaining watershed ecosystem functions. Based on the lag time from 437 storm hydrographs which were influenced by patches of forest area in watershed , rainfall characteristics and physiography of watershed under wet and moist soil condition, the derived models for determining lag time under moist soil condition are as follows:

$$LT_m = 468.44 MFC^{0.0845} SL^{-0.2541} Dd^{-1.1648} \; ; \; R^2 = 0.7704 \, , \, F = 50.32^{**} \quad \ldots\ldots(1)$$

$$LT_m = 3239.1 PA^{-0.1867} Pn^{-0.2717} SL^{-0.1450} Dd^{-2.8005} \; ; \; R^2 = 0.7814 \, , \, F = 39.33^{**} \quad \ldots\ldots(2)$$

and $$LT_m = 33.5488 PA^{-0.7523} Pn^{-0.0921} SL^{-0.7887} DA^{1.1502} \; ; \; R^2 = 0.7699 \, , \, F = 36.81^{**} \quad \ldots\ldots(3)$$

where,

LT_m = lag time according to the definition of The Mirago Geography Grosary (is the time diference between when heavy rainfall occurs and when peak discharge occurs) for moist soil condition (in minutes)

MFC = massive forest cover in percent of watershed area.

SL = watershed mean slope (%) = $\sum S / N$ = (summation of slope in each pixel (%) calculated from Erdas Imagery software / number of pixels)

Dd = drainage density ($km.km^{-2}$)

PA = patch area under cultivation in percent of watershed area (%)

Pn = numbers of patch under cultivation

DA = watershed area (sq.km) determine using GIS techiques

In order to determine the effect of human activity in using upland for farming and living as patches that cause fragmentation of forest area , equation (3) was suggested since all independent parameters can be simply determined by GIS techniques.

Considering from the afformentioned equations , it could be stated that with respect to a particular watershed number of patch size utilized for farming on upland watershed would shorten the lag time of flow which could be affected on flash flood and / or increasing flood peak rate. Although the investigation was based mainly on watershed in the north , physiographic features and the ways of using upland in the western region would reflect the same manner.

4.2 Effect of watershed degradation on peak flow

when watershed resources in from of forest and soil were degraded, the hydrological behavior could be changed in some extent. Effect of deforestation on such hydrological function have been investigated in northern Thailand but rather few in the western region especially for small watershed where it could be feasible to develop small reservoirs in the future. The following study although does not directly reflect hydrological change for the western region caused by watershed degradation , the results obtained from various locations of selected watersheds could be beneficial for discussion on watershed degradation in relation to peak flow characteristics for watersheds in western region.

Based on 13 small watersheds of different landform and landuse, Klinkularb (2002) analysed the relationship between peak flow rate and parameters representing drainage morphology and land use practices through the CN curve originally developed by USDA and rainfall characteristics via rainfall intensity, the multiple non linear model for high mountain watersheds, hilly watersheds and hill-undulating watersheds were derived. They are :

- High mountain watersheds : (when CN > 50)

  $q_p = 6.42 \times 10^{61} A^{0.23869} CN^{-36.544} I^{0.55693}$; $R^2 = 0.4496$; F = 5144.32**

- Hilly watersheds : (when CN = 40-50)

  $q_p = 7.89 \times 10^{23} A^{0.34849} CN^{-14.852} I^{0.3143}$; $R^2 = 0.8167$; F = 19.31**

- Hill – undulating watersheds : (when CN < 40)

  $q_p = 7.284 \times 10^{3} A^{0.72557} CN^{-4.}50879 I^{1.665633}$; $R^2 = 0.7129$; F = 6.62**

where ,

q_p = peak discharge ($m^3.s^{-1}$)

A = drainage area (km^2)

CN = curve number

I = rainfall intensity ($mm.hr^{-1}$)

4.3 Effect of Headwater Catchment Degradation on Water Qualities

4.3.1 Effect on water physiochemical quality and aquatic macroinvertibrates communities

It has been perceived by scientists as well as the farmers that converting headwater forest resources for annual crop cultivation without any conservation measures produces tremendous amount of suspended sediment. Study on the effect of such activity on chemical qualities of water and on aquatic life in rather few. Sangpradub et.al.(1997) carried this kind of research in the Nam Choen head watershed in the northeast of Thailand where forest and soil resources degradation have been recognized by the northeast people. The investigators found that degradation of Nam Choen headwater was evident by water physiochemical parameters and benthic macroinvertibrates. The water quality in the forest land sites was less degraded than at bared sites. The apparent degradation of water quality in this catchment was caused by clearing for agriculture. The streams covered by forests were less affected by surface runoff, resulting in high DO and low BOD level.The macroinvertibrate analysis more accurately reflected these impacts. The species richness and abundance in the disturbed sites was less diverse than those in the pristine sites. The degree of fauna composition in disturbed areas varied according to the extent of land clearing. More detail on richness and abundance of aquatic life can be found in the above mentioned reference.

4.3.2 Effect of cabbage growing and pesticide application on soil and water quality degradation

Cabbage growing on upland area of northern as well as western Thailand has been controversial on water quality degradation aspect. There have been few investigation on the effect of cabbage growing, which usually needs pesticide application, on water quality of headwater sources. Ounok (2002) carried out the research with the aim at modeling the movement of pesticide (cypermethrin) from cabbage growing area to stream channel and downsteam. Based on 26 storm rainfalls observed at small watershed of Mae Chaem basin in northern Thailand, the model derived for estimating storage of cypermethrin in soil for the first and second application was expressed as :

$$[\triangle s_i]_1 = 2.56\, R^{-7.39\times10^{-6}}\, \triangle s_{i-1}^{\,0.0843}\, D_1^{\,2.86\times10^{-6}}\, e^{-1.47\times10^{-6}\lambda} \; ; R^2 = 0.96$$

$$[\triangle s_i]_2 = 797.91\, R^{-3.21\times10^{-5}}\, \triangle s_{i-1}^{\,-1.48\times10^{-3}}\, D_2^{\,-3.88\times10^{-6}}\, e^{-3.72\times10^{-6}\lambda} \; ; R^2 = 0.922$$

where ,

$[\triangle s_i]_1$ and $[\triangle s_i]_2$	=	amount of cumulative cypermethrin in soil at the day i for the first and second date of application (gm/ha)
R	=	cumulative rainfall amount after date of application (mm)
$\triangle s_{i-1}$	=	storage of cypermethrin in the previous day (gm/ha)
D_1 and D_2	=	day after cypermethrin application for the first and second application date
λ	=	slope length of cypermethrin movement (meters)

To estimate pesticide contamination in streamwater, the ratio of Cypermethrin observed at outlet (1200 meters from the cabbage growing area) and amount of cypermethrin storage in soil and cabbage (which is named as Cypermethrin delivery ratio ; CyDR ,%) was modeled using storm rainfall amout (mm),day after cypermethrin application (days) and storage of Cypermethrin in cabbage growing area of the previous day ($\triangle s_{i-1}$; gm/ha). The model was derived as ;

$$CyDR = 6.324\times10^{-4}\, R^{1.485}\, D^{-1.062}\, \triangle s_{i-1}^{\,0.640} \quad ; R^2 = 0.772$$

The results indicated that with about 400 gm/ha of cypermethrin application, It contaminated in surface runoff and sediment in the range of 0.003-0.0498 mg and transported to the outlet at a range of 0.2820 – 639.8 mg . The maximum storage of cypermethrin in cabbage was 224 mg and in soil of about 4532 mg.

4.4 Effect of irrigation on water quality

As has been previously mentioned that water that finally returned to rivers after irrigation could severely degraded by increased toxicity and excess nutrients. In the Mae Klong basin, Kwanyuen et.al.(1999) investigated the effect of Thamaka Irrigation Project on 12 water quality parameters namely : temperature , EC , turbidity , pH , concentration of nitrate , ammonia , phosphate , and chloride ,TS ,TDS , BOD and SAR. It was found that the water quality was acceptionally good and the drainage water quality was deteriorated just a little but the overall quality was still much above the standard of water quality for natural water resources and irrigation water. It was also stated that the main source of pollution for the Mae Klong basin is from wastewater from community , town , and city along the riverbanks followed by agriculture and industrial wastewater.

5. HYDRO-ECOLOGICAL ROLE OF THE WESTERN FOREST COMPLEX (WEFCOM)

5.1 Thailand's Largest Forest Conservation Area

Covering 18,730 sq.km., the Western Forest Complex (WEFCOM)- situated at Lat :13°00'-18°00' and Long : 96°15'-100°15' in western region, It is Thailand 's largest surviving tract of forest land as well as being the largest conservation area in mainland S.E. Asia. It retains most of its native flora and fauna (only rhinos and vulture are known to be extinct) and it encompasses many waterways which supply three of Thailand 's six river systems;- the Chao Phraya, the Mae Klong and the Salween. The complex comprises 17 conservation areas (11 national parks, 6 wildlife sancturies) and span six provinces: Kanchanaburi, Kampaengphet, Uthaithani, Nakhonsawan, Supanburi and Tak.(Sueb Nakhasathien Foundation, *undated*)

5.2 Biophysical Features of the WEFCOM

The WEFCOM contains all the forest formation (except the coastal one) of continental Southeast Asia: hill-evergreen, seasonal (or dry) evergreen, mixed deciduous and dry deciduous forest as well as variations such as pine forest, bamboo grove and savana.Most precipitation comes from the southwest monsoon and ranges from 2,500 mm on the western side where rain falls longer than 6 months to 1,200 mm in the east where it rains for 4-5 months. Soils vary from red-brown clays in the west where the substrate is mostly limestone to sandy podzolic soils in the east where the substrate is mostly granite.

The topography is seldom level with altitudes ranging from 150 m(MSL) to highest peak 1,960 m. Temperature vary from 0 ^{0}C in the highland at night in the cold season to a daytime high of 40 ^{0}C in the hot season. Because of this physical diversity, these western forests support a mixed mosaic of habitats with a correspondingly diverse flora and fauna.

5.3 The Ecological Role of the WEFCOM

5.3.1 Forest types and distribution

The most recent data on the forest area in the WEFCOM interpreted from **Landsat** by the Technical Division of the WEFCOM Management Project, RFD is shown in Figure 1 and Table 3. Based on the above mentioned source of data, mixed deciduous forest is the largest proportion in the WEFCOM boundary (30.4%) followed by the degraded (hill + dry) evergreen forest (24.8%) and secondary growth/bamboo forest (23.8%), the other smaller patches of forests consist of dry evergreen (7.2%), hill evergreen (5.4%), dry dipterocarp (2.1%) and savannah (1.6%). The pine and swamp forests, even a very small area (0.10% and 0.02%) occurring, but they are very interesting and not much is known for these two forest type. For the pine forest, it was stated by the WEFCOM Project, after the rapid ecological assessment (REA) of the vegetation that , these forests seem to be on the brink of disappearing because of the forest fire and the change in climate. It is a fact that several thousand years ago, the climate was drier and pine forest were wide spread in Thailand. The swamp forest is more or less flooded all year round so trees have adapted to the most conditions and formed large buttresses Calophyllum sp. and and tandanus still roots.

These evergreen mountain forests on elevation above 1,700 MSL are subject to strong winds and harsh condition results often in stunt growth and the forming buttress. It makes these forests very fragile and disturbances, espectcially fires might result in the collapse of these stil little knowm ecosystems and will be replaced with secodary growth and grassland. This type becomes more and more fragmented as result of encroachment. So far over 900 species of trees, shrubs and herbs have been categorized in database. A few species are, so far, not found outside the WEFCOM.

At the figure of 19,648.3 sq.km as total area of the WEFCOM, about 875.1 sq.km. or about 4.44 percent is agricultural area. The agricultural area will be extended more and more in the future by many reasons, e.g., more development projects, contradictory land-use policies, civil strife in Mynmar that gives rise to refugees, by illegal land encrochment, hunting and logging and also by the failure to involve local people in forest and wildlife protection.

5.3.2 A Source of wildlife and natural wealth

With variety of forest vegetation and the ecological diversity, this area endows with a wealth of animals. Among them, 1,000 vertebrates species or a half the number known for Thailand exist in the WEFCOM. These vertebrates include: 156 mammal species, 490 birds species, 41 reptiles and over 180 species of fish. These figures do evoke the areas awesome biodiversity and ecological wealth. In addition, this area supports the world 's largest and smallest land mammals (the elephant and the bumblebee).

5.3.3 The role in maintaining people's quality of life

The WEFCOM can be viewed as a place to be appreciated by visitors in many ways. It is a natural library or recreation and spiritual sustenance. For those who are living and farming in the west and west-central Thailand, it is also valuable for its role in maintaining the local climate (including air and water quality) which improves the quality of life. More important, the western watersheds help regulate the local supply of fresh water, ensuring that it is available year-round from surface waterways and underground aquifers. The later role will be deseribed in the next sections.

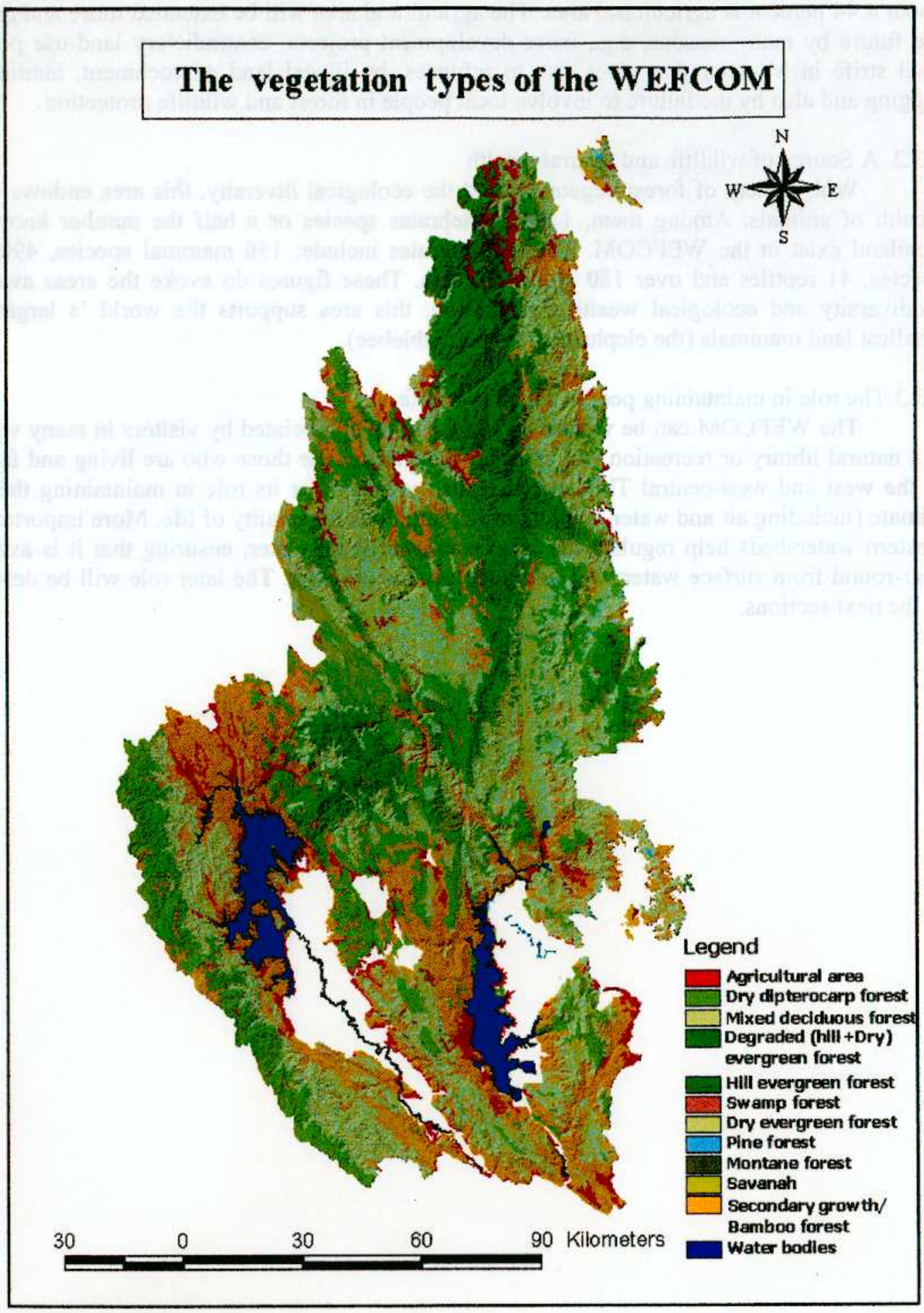

Figure 1: The vegetation type of the Western Forest Complex interpreted from Landsat taken in year 2000 with groundcheck in 2001.

Source : The Wastern Forest Complex Ecosystems Project

Table 3: Forest area in the WEFCOM interpreted from Landsat taken in 2000 with groundcheck in 2001

Forest type	Areal distribution		
	(Sq.km)	Million Rai	Percent
Agricultural area	872.08	1.40	4.44
Degraded (Hill+Dry) evergreen forest	4882.18	7.81	24.85
Dry dipterocarp forest	410.00	0.66	2.09
Dry evergreen forest	1410.76	2.26	7.18
Hill evergreen forest	1053.17	1.69	5.36
Mixed deciduous forest	5982.79	9.57	30.45
Montane forest	14.33	0.02	0.07
Pine forest	20.22	0.03	0.10
Savannah	314.20	0.50	1.60
Secondary growth/Bamboo forest	4684.57	7.50	23.84
Swamp forest	3.91	0.01	0.02
Total area	19648.36	31.44	100.00

Source : Technical Section, WEFCOM Management Project, RFD

5.4 The Hydrological Role of the WEFCOM

5.4.1 The important source of water supply for the western region

Besides ecological role of western forest complex in terms of the diverse in wildlife and tropical vegetation , it encompasses many waterways which supply three of Thailand six river systems; the Chao Phraya (via the Sakaekrang),the Mae Klong (via the Khwae Yoi and Khwae Noi),and the Salween (via the Mae Kasat and Suriya)

The Sakaekrang river enclosed by 5,142 sq.km watershed area covering the main portion of Uthai Thani province and some part of Nakhon Sawan and Kampang Petch provinces. The four tributaries consisting of Huay Mae Wong (2,171sq.km) , Klong Poh (1,211sq.km) ,Huay Tab Salao (1,253 sq.km) and lower Sakaekrang sub watershed (1,557sq.km) drain 1,297 MCM annually to the Chao Phraya River. At present only one large reservoir of 160 MCM namely Tab Salao with others medium and 78 small reservoirs have been operated by the RID. The total area benefited from these projects is about 721,650 rai (6.25 rai = 1 ha)

The Mae Klong basin of 30,837 sq.km covering 8 provinces namely: Kanchanaburi , Ratchaburi, Samut Songkram, partly Supanburi, Nakhon Phrathom, Samut Sakorn, Uthaithani and Tak contributes about 7,973 MCM annually. This treatmendous amount of water drains from 10 sub-basins, they are : Khwae Yai basin (1,445 sq.km), Huay Mae Lamoong (910 sq.km), Huay Mae chan (862 sq.km), middle Khwae Yai (3,380 sq.km), Lower Khwae Yai (4,094 sq.km), upper Khwae Noi (3,947 sq.km),Huay Khayeng (1,015 sq.km), Huay Mae Nam Noi (947 sq.km), Lam Pha chi (2,453 sq.km). and lower Mae Klong floodplain (4,318 sq.km).

The Salween basin in the upper northern covers 29,500 sq.km in which about 17,920 sq.km is in Thailand and some part of Mynmar. Drainage area in Thailand covers 3 provinces: Mae Hongson, Tak and Chiang Mai. Annual runoff discharged from total area of Salween basin is about 112,561 MCM with the rate of 120.8 liters/second/sq.km. The sub-watersheds in Thailand contributes about 85.66 MCM/ annum with the rate ranges from 4.7 -5.5 liters/sec/sq.km. Recently, there have been few projects of reservoir and water pupping for irrigation which feed about 187,000 rai of cropping areas.

All these three main basins in the western region contributed totally about 9,321 MCM/annum to those living and farming downstream area. Althouth treatmendous amount of runoff (112,562 MCM/annum) discharged from 17,920 sq.km of Salween basin, only 86 MCM is discharged from small basin in Thailand. With the high annual rainfall and good condition of forest cover in headwaters which are mainly in the WEFCOM boundary, good quality water and proper timing have been regulated by the WEFCOM ecosystems an the two large reservoirs of Mae Klong basin.

6. THE CONSERVATION PLAN OF THE WEFCOM

The results obtained from research on the effect of watershed degradation caused by converting forest for agriculture without any conservation measures clearly reflect the important role of forest cover on water yield regulation. With the more demand of good water for domestic use as well as for irrigation in the future, conserving upstream under good condition is of prime important. Fortunately the conservation plan for the WEFCOM has been implemented. The plan comprises of 5 main parts, i.e., (1) Landuse zoning and implementation, (2) strengthen manpower efficiency, (3) research and database development, (4) ecological value promotion and (5) people's participation. The conservation plan is illustratied in Figure 2.

Land suitability classification as has been recommended by Tangtham et.al.(1994) shoud be considered for implementation. For those agricultural areas outside the WEFCOM , intensive conservation practices as well as water management by appropriate irrigation system should be developed for increasing efficiency in using both land and water resources so that the need for upland, which is now under forest cover, for cropping would be less from the increasing regional population.

7. CONCLUSION

Compare to the other regions, watershed degradation in the western region is relatively less even though there have been almost the same driving factors. The rugged terrain and harsh road access in the past resulted in remaining higher percentage of forest cover than other main basins in Thailand. This consits of 18,776 sq.km forest area under the WEFCOM conservation area. Of this figure,it is fortunately that about 18,730 sq. km. are under 11 National Parks and 6 Wildlife Sancturies. Besides the important ecological role in preserving one of the most abundant biodiversity of the world named as " ***The Tenasserim Hill Biogeographic Unit*** " , the WEFCOM also plays an essential role in regulating water yield with proper quantity, good quality and flow timing to the two main basins-the Mae Klong and Sakaekrang and a part of Salween basin. The existing conservation plan of the WEFCOM will help protect the superlative eco-hydrological roles of the western regional watershed. The plan, however, should be modified to meet the increasing population and the global changes in both environmental and economic aspects in the future.

The WEFCOM Conservation Plan

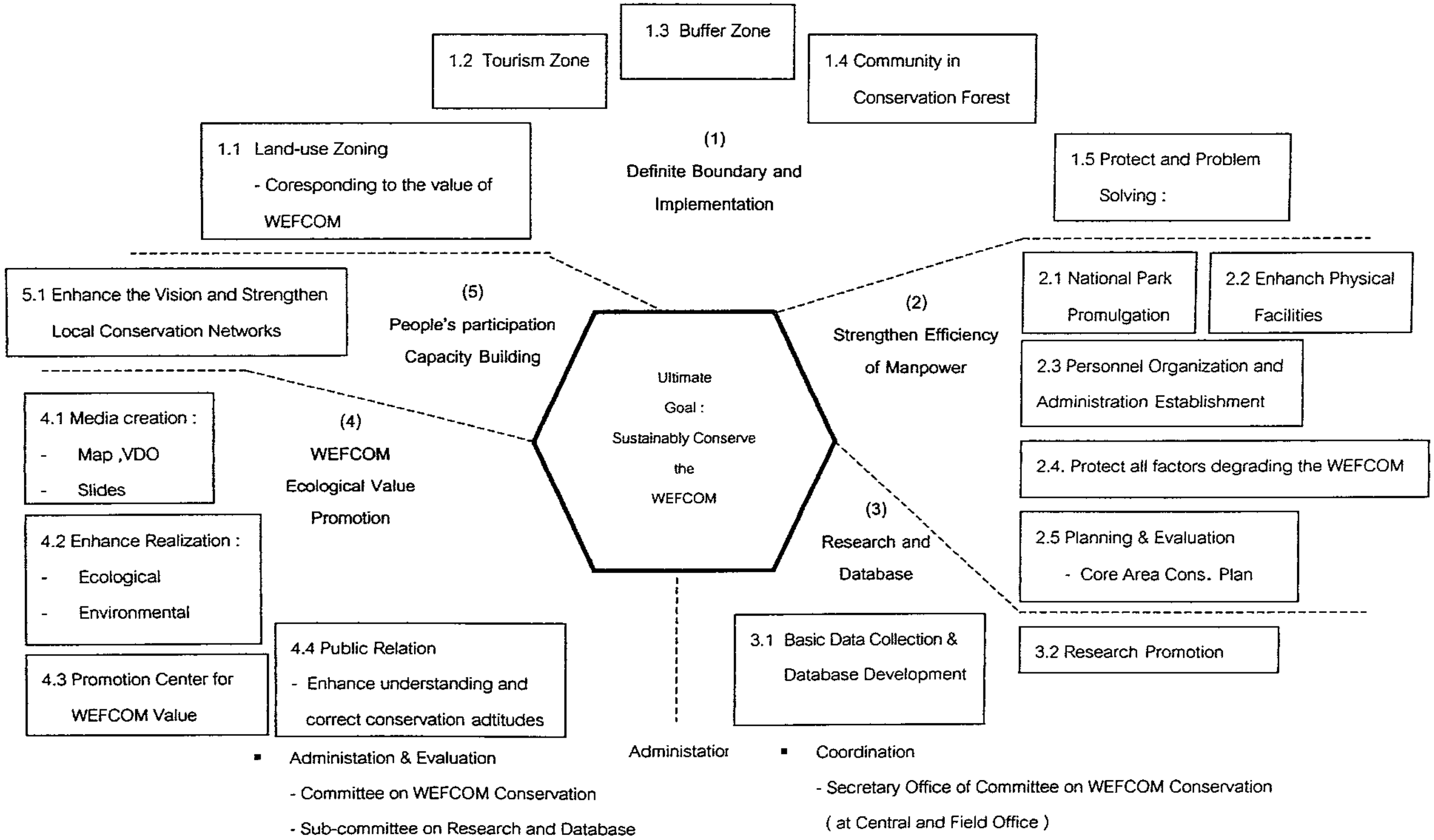

Figure 2 : The WEFCOM Conservation Plan and implementation strategies proposed by the WEFCOM Management Project, RFD

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