PHYSICAL AND ECONOMIC IMPACTS OF SEDIMENTATION ON FISHING ACTIVITIES: NAM PONG BASIN, NORTHEAST, THAILAND

Presented By

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ABSTRACT

Using aerial and LANDSAT data a dynamic land use model of the Nam Pong Basin has been developed. The model simulates erosion that results from conversion of watershed land to alternative uses. Erosion values are passed to a linked reservoir model where they are converted to turbidity levels. Operated together the two models simulate changes in quantity and quality of fish production resulting from increased turbidity levels. Simulation of alternative management scenarios predicts continued increases in sedimentation leading to drastic reductions in fishing income levels. Restrictions on number of fishing families and protection of critical watershed areas are necessary to protect the long-term sustainability of the reservoir fish production system.

Key Words: Erosion, Turbidity, Watershed Management, Simulation Modeling, Clearcutting, Over-fishing, Thailand

CAPTIONS OF FIGURES

FIGURE 1. Nam Pong Basin in Northeast Thailand.

FIGURE 2. Land Use in Nam Pong Basin, 1983.

FIGURE 3. Overall Stucture of the Fishery Submodel. Arrows show major linkages between the key components considered in the conception.

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INTRODUCTION

Rapid economic development in Southeast Asia has magnified human pressure on tropical forests. Demand for timber, for minerals and for new agricultural land has resulted in the destruction of large areas of Asian forests. Without proper land management and protection, intensification of economic activities has resulted in increased soil erosion. Recognition of the magnitude of this problem has led to a resurgence of concern about soil erosion and policies to control it. Boggess and Heady [1], Burt [2], Ervin and Ervin [3], and White [4] have published recent articles that examine different aspects of the impacts of soil erosion and soil control measures. In general, these articles have been concerned with erosion's effects on soil productivity and the resulting long-term implication for agricultural production. However, while long-term soil productivity in Asia is important, even more critical are shorter-term problems of eutrophication, increased turbidity and reduction of effective life span of major multipurpose reservoirs throughout the region [5]. As stated succinctly by Griffin and Bromley [6], the benefits of reduced agricultural runoff are improved environmental quality. By concentrating on likely impacts of various actual or proposed soil erosion control policies with a strong focus on long-term soil productivity, researchers have tended to ignore many activities that are related to improved environmental quality. Even studies by southeast Asian researchers such as the TURA Institute [7] and Glankamsorn and

Charooppat [8] have been concerned about erosion as it affects present or future agricultural production and not about its impact on overall environmental quality.

Addressing some of the problems identified by Park and Shabman [9], this paper examines physical and economic impacts of nonpoint pollution from erosion on the larger off-farm environment. The focus is on the flow of suspended sediment into water channels and the resulting increased turbidity and sediment deposits within downstream reservoirs. The paper utilizes a set of linked simulation models to study the impacts of erosion from clearcutting of the watershed on production of fish in the Nam Pong Reservoir in Northeast Thailand (Figure 1). Using dynamic models of the Nam Pong watershed, the reservoir formed by the Ubolratana Dam, and the community of fishing families, the magnitude of actual economic losses resulting from forest clearing is determined. The final section of the paper discusses long-term environmental and economic implications and presents alternative management strategies.

STUDY AREA

In Thailand soil erosion is particularly severe in the Northeast due to illegal logging and to slash-and-burn cultivation. Population growth in the region (over 2.5%) and the recent introduction of cassava for export has accentuated this phenomena. The Department of Land Development of the Royal Thai Government (RTG) has estimated that 33% of the land in the Northeast exhibits signs of severe to very severe erosion.

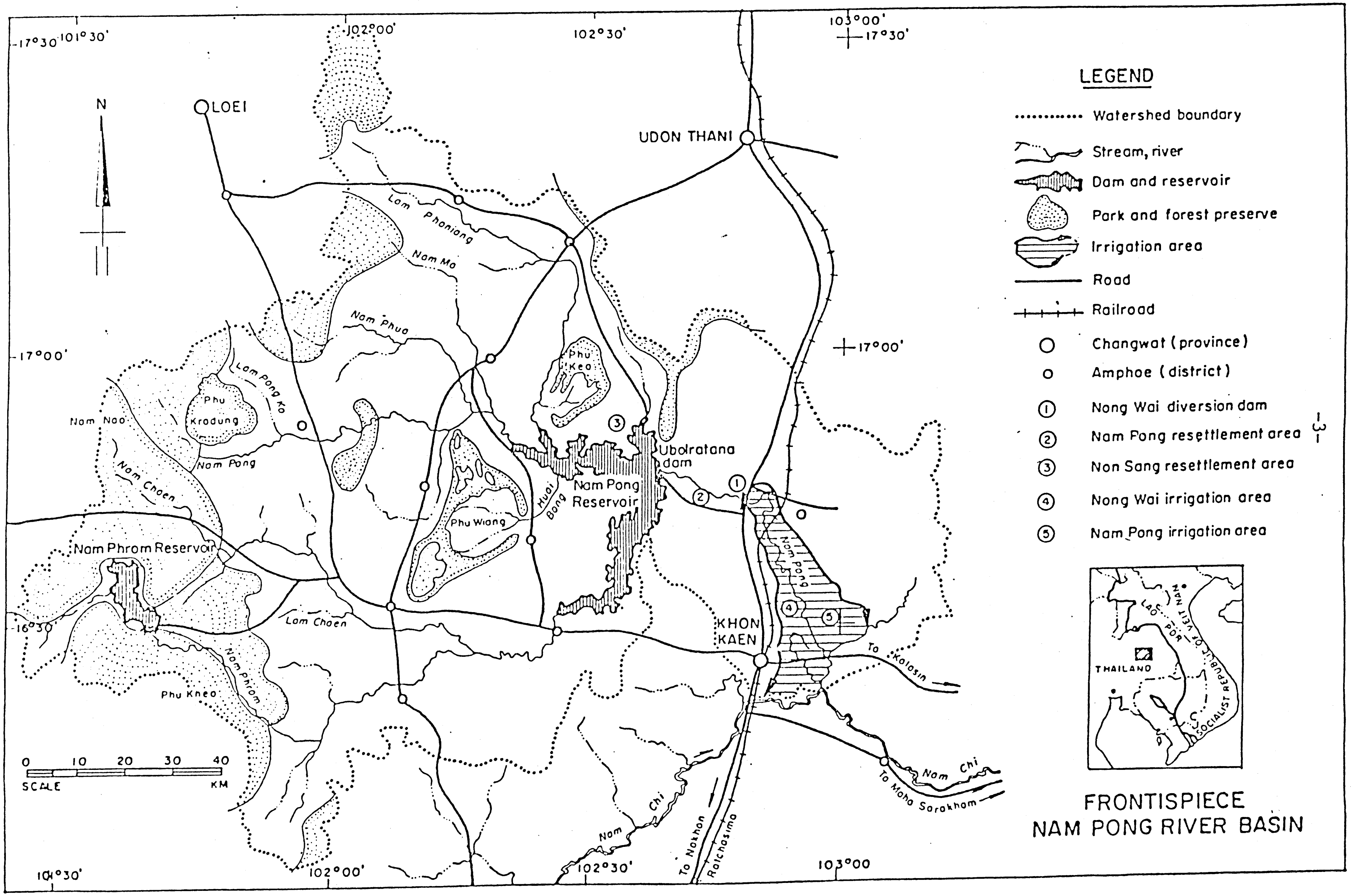

FIGURE 1. Nam Pong Basin in Northeast Thailand.

Clearcutting of forests has been particularly damaging in the watershed areas of the major rivers, the Mun and the Chi, that originate in the Northeast and eventually flow into the Mekong River in Kampuchea. The Nam Pong Basin with its 12,560 square kilometer (km^2) watershed is the largest in the Northeast and is the major source of water for the Chi River. The catchment area of the Nam Pong Basin, which ranges from 200 to 1,500 meters above mean sea level, is drained by many streams and rivers. These eventually join to form the Nam Pong River just above the site of the Ubolratana Dam.

Since 1965 when the dam was completed there has been extensive forest destruction in the watershed. Primitive slash-and-burn agriculture, illegal cutting of trees for poles, lumber and charcoal making as well as exploitative logging techniques have destroyed large areas of the forests. Between 1965-75 forest land in the upper basin declined by 4,698 km^2. Table 1 details the evolution of land use in the Upper Basin between 1965 and 1982. From this table it can be seen that the majority of the deforested land has been converted to agricultural land even though much of it has relatively steep slopes and poor soils.

Erosion resulting from illegal forest destruction has increased sediment discharge into the reservoir. Data indicate that prior to impoundment (1964) over 950,000 tons of sediment were carried in the Nam Pong at the dam site annually. In 1978, the Electricity Generating Authority of Thailand (EGAT) carried out a post-impoundment sediment survey. Results of that survey indicated approximately two million tons of sediment were being deposited in the reservoir. In addition to reducing the overall economic life of the

Table 1. Land Use Changes in Nam Pong Basin from 1965 to 1982.

Land Use Categories	Area (km^2) 1965	1975	1982	Area Changes (km^2) 1965-82
Urban and Built-up Land	17.50	18.75	26.25	+8.75
Agricultural Land	2,499.50	6,954.00	7,801.50	+5,302.00
Forest Land	9,998.50	5,300.00	4,533.00	-5,465.50
Water Resources	95.25	288.00	200.00*	---
Total Watershed Area	12,560.75	12,560.75	12,560.75	

* LANDSAT imageries taken during dry season (January).

reservoir, increasing sediment inflow also appears to be a significant factor in explaining the change in fish composition in the reservoir, particularly the rapid increase of Corssica goniognatnus, a low value fish regarded by many as an obnoxious fish [10].

MODEL SPECIFICATION

Models used in this study are an offshoot of the second and third phase of the Nam Pong Environmental Management Research Project (NPEMRP). Phase II of the NPEMRP carried out a series of detailed scientific studies to identify and measure environmental and socio-economic impacts resulting from the construction and operation of the Ubolratana Dam [11]. Phase III's objective was to construct an integrated management oriented simulation model of the Nam Pong Basin. The final integrated model consists of four interacting submodels encompassing the dynamics of water management, land-use patterns, socio-economics, and reservoir fisheries [12].

As the Phase III land-use model did not provide information on sediment and water outflow by actual location, a detailed watershed submodel was developed. This model was linked to the reservoir fishery model developed for Phase III after the model was modified to reflect the impact of turbidity on fish fry survivability. Finally, the models are driven by a population submodel that represents the fishing community gaining its livelihood from the reservoir.

Watershed Model

As mentioned earlier, during the last 18 years the watershed has been extensively clear cut. In order to document these changes black and white photographs of 1:50,000 and 1:15,000 were taken in 1965 and 1972, respectively, and LANDSAT imagery from 1975 and 1983 were used to classify land use over time. Four broad land use categories were used: (1) urban and built-up land, (2) agricultural land, (3) forest land, and (4) water resources. The agricultural and forest land categories were divided further into sub-categories. A random ground truth survey was conducted to verify these uses [13].

Overlying the watershed map with a grid of 70 km. by 50 km. has made it possible to convert the map to a digital computer model [14]. Each grid point is coded to indicate the major economic activity in that area. In addition, they are coded to designate subwatershed location and distance to nearest water channel or body. To illustrate, Figure 2 details land use patterns existing in 1983 as well as indicating changes since 1975. Using these digital maps, it is easy to visualize, and measure, the changes in economic use resulting from continued cutting in the watershed.

Based on the maps of the different years, utilizing the universal soil loss equation (USLE) modified to fit the size of the grid, annual soil loss is calcualted for each grid point [15].

As sediment cannot move into the reservoir unless the streams or rivers are flowing into the reservoir, it is assumed that the annual soil loss for a subwatershed area is distributed on a monthly basis as a function of monthly

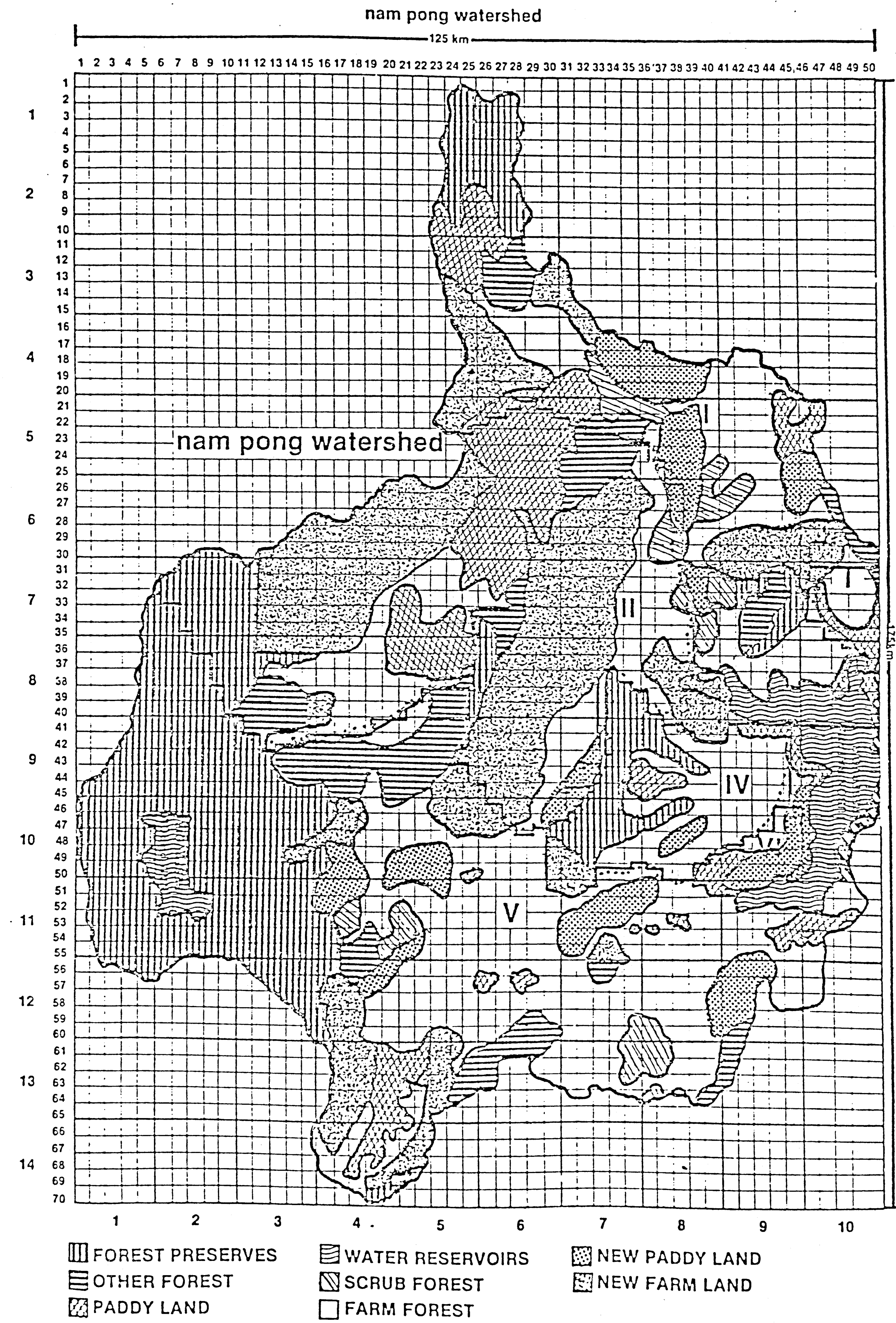

FIGURE 2. Land Use in Nam Pong Basin, 1983.

flow from that area into the reservoir. This relationship is quantified in equation 1.

$$SED_{ij} = \sum_{i=1}^{6} \sum_{J=1}^{7} \sum_{k=1}^{3500} USLE_{ijm} * DR_k * \frac{INFim}{TINF_i} \quad m=1...12 \qquad (1)$$

where

- i = six different subwatersheds
- j = seven different economic activities
- k = 3,500 grid points in the watershed
- m = twelve different months
- $USLE_{ikm}$ = soil loss for each grid point as a function of subwatershed (rainfall) and economic activity
- DR_k = delivery ratio for each grid point calculated as $1/(d)^a$ of the distance (d) to the nearest water channel or body when a equals 1.45.
- INF_{im} = monthly inflow for each subwatershed
- $TINF_i$ = annual inflow for each subwatershed.

Using equation 1 and historical rainfall and monthly water inflow data, sediment inflow into the reservoir is calculated. Table 2 presents predicted values for selected years. Inflow values for 1969 and 1976 correlate closely with measured values. Values for 1990 are developed from historical trend data assuming that the remaining forest land, encompassing national park land, wildlife reserves and critical watershed area for the Nam Phrom Reservoir, will be approximately 3,500 km^2. After calculation sediment and water inflow values are passed to the reservoir model.

Reservoir and Fishery Model

As sediment values for each major stream are passed to the reservoir model they are changed to turbidity values. Turbidity is a function of waves, wind action, quantity of water flowing into the reservoir, previous

Table 2. Average* Sediment Inflow from the Nam Pong Watershed In the Reservoir (metric tons)

Sub Watershed	Year of Conditions			
	1969	1978	1982	1990
I	66,299	87,747	117,762	145,059
II	246,615	357,349	480,411	562,518
III	494,586	649,071	790,585	1,085,807
IV	90,878	129,458	165,155	191,557
V	336,417	500,353	676,590	923,918
TOTAL	1,234,795	1,723,978	2,230,503	2,908,859

* Average based on 10 years of climatological and streamflow records.

turbidity levels, height of the reservoir and other factors. Given the complexity of this relationship conversion of sediment inflow to turbidiy levels is, at best, only approximate. However, based on field data collected during 1977, 1978 and early 1979, regression relationships between sediment inflow and turbidity levels for the two main inlet areas and the main body of the reservoir were developed.

In addition to calculating turbidity values, the reservoir model also determines the size, area and height of the Nam Pong reservoir. This is done by an input-output algorithm that keeps track of the changes in reservoir storage in million cubic meters (mcm) of water on a monthly basis [17].

The fishery model is designed to capture the dynamics of fish biomass and fishing effort in the reservoir. Fish are divided into four generic groups: large herbivores, small herbivores, large carnivores, and small carnivores with each of the generic groups having three size classes [18]. The model does not attempt to represent in great detail nutrient, phytoplankton, and zooplankton dynamics. Rather, plankton biomass is represented as the main factor contributing to production of herbivorous fish. The model simulates the natural phenomenon that high levels of nutrients in the reservoir generate high levels of plankton production. Three mechanisms are hypothesized as the major contributors to the nutrient pool: (1) area of the drawdown zone, (2) inflow of sediment, and (3) recycling of phosphorous and nitrogen.

Natural mortality among herbivores is a function of density of population. For carnivores, natural mortality is a function of prey ingested

[19]. Survivability of fish fry is also hypothesized to be a function of turbidity levels in the spawning areas [20]. The higher the average monthly turbidity levels, the lower the survivability rates. Harvest rate is determined by a catchability coefficient which is dependent on the level of water in the reservoir and monthly fishing effort that is a function of the number of fishermen operating on the reservoir. The harvest rate is also assumed to be influenced by rainfall, with harvests being greater during periods of heavy rainfall.

Figure 3 details the overall structure of the fishery submodel. The hatched line from turbidity to the four generic fish types reflects the impacts of turbidity on mortality. Actual landing statistics for 1978-80 were used to validate the model.

Fishermen Population

Fishing in the Nam Pong reservoir is unrestricted both to the number of fishermen and also in respect to the number of nets and boats used for fishing. Since 1965 when the dam was closed, the population of fishing families has grown from less than 100 families to more than 3,500 families. By 1980, the number of families within a two kilometer strip around the reservoir was greater than 8,500 families containing more than 51,000 people.

Total commercial catch averaged around 1,850 tons per year between 1969 and 1978. Another 400 tons per year were estimated to have been caught for subsistence use. However, variation in total catch has been extreme, ranging between 1,350 and 2,465 tons per year. As the fishermen population has increased, the catch per effort has declined. Where in 1969

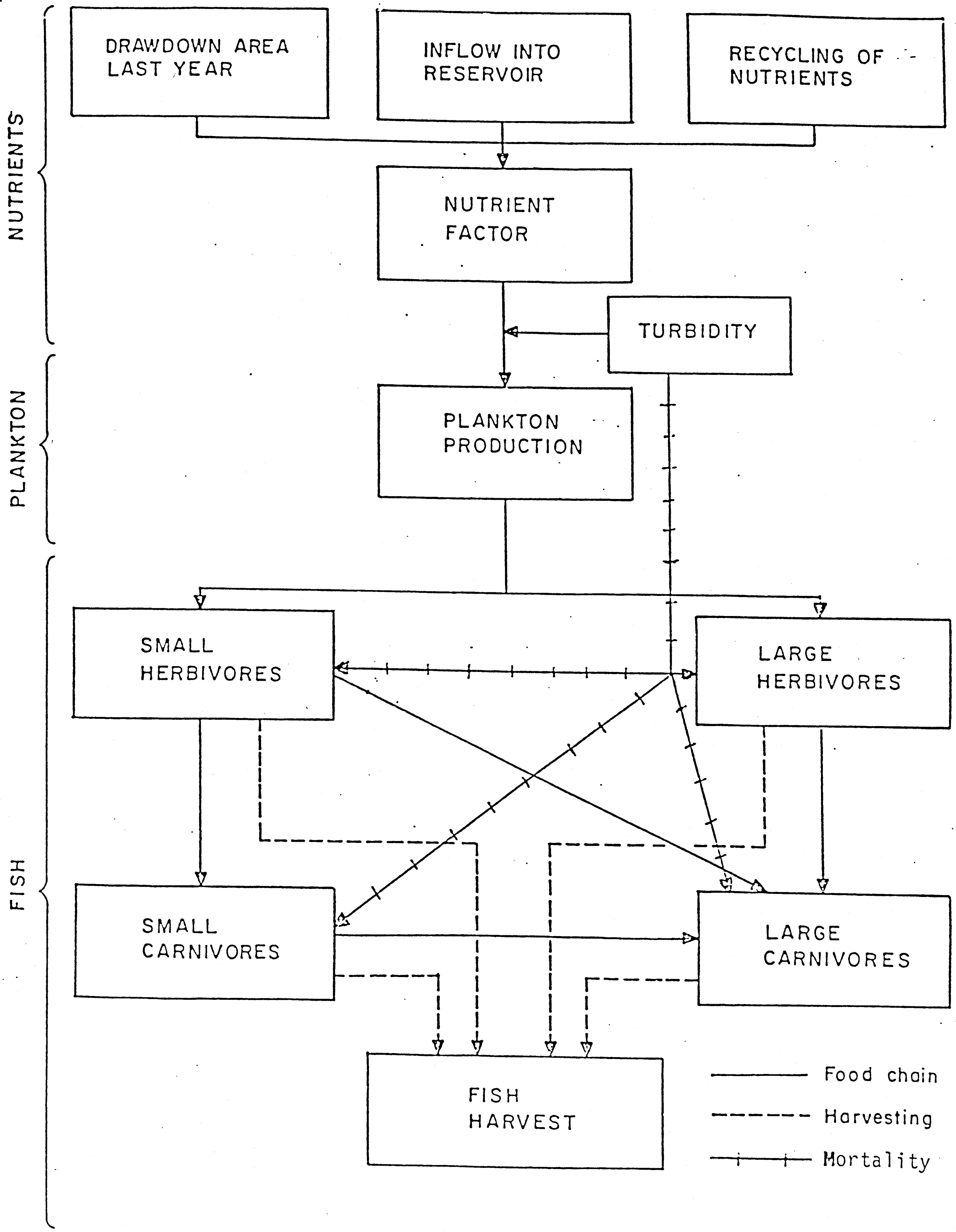

Fig. 3. Overall structure of the fishery submodel. Arrows show major linkages between the key components considered in the conceptualization.

the average annual catch was slightly more than one ton per fisherman, by 1980 the annual catch per fisherman declined to about one-half ton.

SIMULATION RESULTS

The Nam Pong Reservoir has surprised a number of fishery biologists as it turned out to be a very productive system. From 1965 to 1975, even with the significant increase in sediment inflow and resulting higher levels of turbidiy, fish catch continued to average around 1,850 tons per year. However, failure to control clearcutting in the watershed and the number of fishermen fishing in the reservoir is starting to lead to a reduction in productivity. Using the basin wide model it is possible to replicate historical conditions in the reservoir as well as simulating projected future conditions. From the data presented in Table 3, it can be seen that average catch, and therefore economic return, is slowly declining. When economic return is divided by the number of fishermen, the return per unit of effort is also significantly reduced. Primary cause of the decline is the reduced survivability of fish fries due to increased turbidity levels in the Nam Choen and Nam Pong inlets which are the major spawning grounds for the reservoir. Due to increased sediment inflow average turbidity during the spawning season in the inlet areas changed from around 40 turbidity units under 1969 type conditions to around 80 turbidity units under 1978 type conditions and is projected to increase to 140 turbidity units under 1990 type conditions.

Based on historical records the maximum average catchability coefficient (fish caught per kilogram of fish susceptible to being caught per standard unit of effort, fisherman-month) declined from around .0004 in 1969 to .0002 in 1978 [12]. As a result of increased turbidity levels in the reservoir and the consequent decline in productivity of fish biomass, it is estimated that this coefficient will continue to decline. This decline is reflected in the lower annual catch per fisherman which leads directly to a smaller return per fisherman. Data in Table 4 illustrate the economic impacts of the decline in catch per unit effort. Table 4 is based on the assumption that the number of fishermen will continue to increase albeit at a slower rate than in the past. However, at the projected level of economic return for 1990 it is likely the number of fishermen, particularly those that view fishing as a commercial activity, will level off or perhaps even decline. Yet, even with a slight decline in number of fishermen the annual economic return per fishing effort will still be less than half of what it was at lower turbidity levels.

MANAGEMENT ALTERNATIVES

Given that the Royal Forestry Department is not replanting deforested areas in the Nam Pong watershed and that it has proven unable to remove squatters from the land, it seems unlikely that sediment inflow into the lake will be reduced in the foreseeable future. Perhaps the best that can be expected is for sediment inflow to stabilize at an average annual inflow of around 3.0 million tons per year. However, this assumes that the Royal

Table 3. Actual[1] and Predicted[2] Fish Harvest and Economic Returns for Selected Years.

Generic Group	Year of Condition							
	1969		1978		1982		1990	
	Fish Harvest (tons/ year)	Economic[3] Returns (U.S.$/ year)	Fish Harvest (tons/ year)	Economic Returns (U.S.$/ year)	Fish Harvest (tons/ year)	Economic Returns (U.S.$/ year)	Fish Harvest (tons/ year)	Economic Returns (U.S.$/ year)
Small Herb.	1098	277,245	1611	406,778	1107	279,517	799	201,748
Large Herb.	176	106,480	141	85,305	181	109,505	121	73,205
Small Carn.	213	89,140	205	85,792	183	76,586	142	59,427
Large Carn.	165	246,015	106	158,046	89	132,699	66	98,406
TOTAL	1652	718,880	2063	735,921	1560	598,307	1128	432,786

1 Actual (1969 and 1978) from Varikul and Suraswadi (1980).

2 Predicted is an annual average based on 10 years of climatological records.

3 1978 prices.

Table 4. Economic Return per Unit Effort for Selected Years.

	Year of Condition			
	1969	1978	1982	1990
Number of Fishermen	1750	3000	3500	4000
Remaining Forested Area (km^2)	7600	5300	4500	3300
Catch per Fisherman (tons)	.94	.69	.45	.28
Economic Return per Fisherman ($/year)	411	245	171	108

Forestry Department polices at least the 2,500 kms^2 of national parks and wildlife reserves that presently form the major drainage areas of the Nam Pong watershed. If these critical areas are not protected, estimated life of the reservoir, which was originally set at 500 years but has now been reduced to around 200 years, will be reduced even further. Simulation work under Phase III predicts a functional life-span of 157 years if 2,000 km^2 of reserved forests are not maintained and deforestation continues unchecked [12].

Unfortunately, even if sediment inflows are held in the range of 3.0 million tons per year, in order to avoid a collapse of fish production in the reservoir, it is necessary to reduce the population of fishing families and to control overfishing in the spawning grounds. Failure to protect forested area in the watershed above the reservoir, and thus prevent increased sediment inflow, has already reduced gross income from fishing from a maximum of $1.5 million per year (1974) to an average of around $.6 million (in constant 1977-78 prices). Yet, if the number of fishing families continues to exceed 3,500 even this level of income is not sustainable. At a managed fishing level of around 2,500 fishermen, annual gross revenue from fishing will be around $500,000. However, even to sustain incomes at this level, the Department of Fisheries has to develop a system of licensing and controlling access. This requires a strong management effort by the Department of Fisheries which, given their historical stance, will not be easy. Yet without this effort the system will soon collapse from a combination of increased mortality due to high turbidity levels and overfishing.

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