ESTIMATION OF SOIL LOSS FROM
THE UPPER RAJANG SUB-CATCHMENT IN SARAWAK,
MALAYSIA DURING THE DEVELOPMENT OF THE
BAKUN HYDROELECTRIC PROJECT

by

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<th>Description</th>
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<tr>
<td>%</td>
<td>Percent</td>
</tr>
<tr>
<td>°C</td>
<td>Degrees Celsius</td>
</tr>
<tr>
<td>asl</td>
<td>Above sea level</td>
</tr>
<tr>
<td>cm, m, km</td>
<td>Centimeter, meter, kilometer</td>
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<tr>
<td>CTTC</td>
<td>Centre for Technology Transfer and Consultancy (UNIMAS)</td>
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<tr>
<td>CWR</td>
<td>The Center for Water Research at the University of Western Australia</td>
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<tr>
<td>DANIDA</td>
<td>Danish International Development Assistance</td>
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<tr>
<td>dbh</td>
<td>Diameter breast high</td>
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<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
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<td>GIS</td>
<td>Geographic Information System</td>
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<tr>
<td>ha</td>
<td>Hectare</td>
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<tr>
<td>HEP</td>
<td>Hydro-electric Project</td>
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<tr>
<td>HWRU</td>
<td>HaNoi Water Resources University</td>
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<tr>
<td>mg/l</td>
<td>Milligram per liter</td>
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<td>MW</td>
<td>Megawatt</td>
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<td>RP</td>
<td>Reservoir preparation</td>
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<tr>
<td>s</td>
<td>Second</td>
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<tr>
<td>SAMA</td>
<td>Joint Venture of Consultants: Lahmeyer International, Fichtner, Dorsch and Motor Columbus</td>
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<tr>
<td>SESCO</td>
<td>Sarawak Electricity Supply Corporation</td>
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<tr>
<td>tonne</td>
<td>Metric ton = 1000 kg</td>
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<tr>
<td>UNIMAS</td>
<td>Universiti Malaysia Sarawak</td>
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<td>USLE</td>
<td>Universal soil loss equation</td>
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Abstract

Changes in the land use and land cover; especially biomass removal, timber harvesting and agricultural activities in the Bakun catchment during the development of Bakun Hydro-electric Project (HEP) have resulted in considerable soil loss from the area. The objective of this study is to estimate soil loss from the Upper Rajang Sub-Catchment during the development of the Bakun HEP by using sediment rating curve. Rating curves were constructed for six scenarios using TSS and water level data collected during a field work and those compiled by the Sarawak Hidro Sdn. Bhd. Suspended sediment yields in the catchment were calculated based on equations created from the rating curve and water level data for 2003 and 2004. Sediment yield is taken to be the sum of suspended sediment yield and bed load, the latter being estimated as 20% of sediment yield. The results for suspended sediment yields for the 'best fit' scenario were 36.87 and 40.20 million tonnes in the year 2003 and 2004 respectively. Taking into consideration the bed load contribution, the annual sediment yields in the catchment were 46.09 and 50.25 million tonnes respectively. The result in this study is not very different when compared with the results of an earlier estimated reported in Bakun HEP EIA (1995). Estimation of soil loss and sediment yield in the catchment is relevant to the overall assessment of the effects of the project development. Appropriate mitigation measures to minimize the soil erosion and sediment yield on the drainage system, especially the effects to the reservoir in the future, were also highlighted in this dissertation.
Abstrak

Chapter 1

INTRODUCTION
Chapter 1: Introduction

1.1. Background

1.1.1. Erosion

The degradation of soils is a serious problem in developing countries, especially in highland, forest and river catchment areas. Soil degradation is one of the greatest challenges facing mankind and its extent and impact on human welfare and the global environment are greater now than ever before (Lal and Stewart, 1990). Water erosion is the main degradation process, while human activities, the reduction of plant cover, and the nature of the parent material are the main causes of soil erosion (Lopez and Albaladejo, 1990). A review of the impacts of soil degradation found that 1.2 billion ha (almost 11% of the vegetative area in the world) have undergone moderate or worse degradation by human activity over the last 45 years (World Bank, 1992).

From the engineering perspective, soil erosion is defined as a general destruction of soil structure by the action of water and wind. It is essentially the smoothing process with soil particles being carried away, rolled and washed down by the force of gravity (Beasley, 1972). Rainfall is the prime agent of soil erosion, whereby the rain's runoff will scour away, loosen and break soil particles and then carry them away, thus leaving behind an altered bare earth surface (Wischmeier et al., 1978). The impact of raindrops on the soil surface can break down soil aggregates and disperse the aggregate material. Lighter aggregate materials such as very fine sand, silt, clay and organic matter can be easily removed by the raindrop splash and runoff water; greater raindrop energy or runoff amounts might be required to move the larger sand and gravel particles. Soil movement by rainfall (raindrop splash) is usually greatest and
most noticeable during short-duration, high-intensity thunderstorms. Although the erosion caused by long-lasting and less-intense storms is not as spectacular or noticeable as that produced during thunderstorms, the amount of soil loss can be significant, especially when compounded over time.

Runoff can occur whenever there is excess water on a slope that cannot be absorbed into the soil or trapped on the surface. The amount of runoff will increase if infiltration is reduced due to soil compaction, crusting or freezing. Runoff from the agricultural land may be greatest during spring months when the soils are usually saturated, snow is melting and vegetative cover is minimal.

In Malaysia, there are many soil erosion prone zones especially hilly areas at the newly established oil palm plantation and along the riverbanks. In the case of slope, an altered bare surface of the slope with sheet, rill and gully erosion features will cause instability of the slope. This situation will gradually cause slope failure or landslide as commonly known. The soil erosion phenomenon is basically the function of the erosivity of the soil (Roslan, 1992).

1.1.2. Sediment Yield

Several of the impacts stemming from the construction process and earthworks at work sites are predictable and mitigable to a significant extent through careful site planning, supervision and application of best management practices. A number of other impacts are expected to be residual. Progressive construction and use of access roads and camps in rugged and steep topography intersected by many watercourses would initiate unavoidable erosion and sedimentation in the reservoir area. Removal of biomass in this environment would increase the risk of accelerated erosion and
sedimentation over a larger area. Following biomass removal, the sediment yield in the catchment also increases rapidly. Removal of biomass would also unavoidably affect the terrestrial and aquatic resources within the reservoir area.

Insoluble matter in suspension is one of commonest forms of pollution, being recent in river and reservoir. All rivers and reservoir, even those which are relatively unpolluted, contain suspended matter consisting of natural silt, sand, etc, derived from the stream bed and banks. There are several reasons why suspended solids are objectionable in a stream, among which are:

- They interfere with self-purification by diminishing photosynthesis and by smothering benthic organisms,
- Reduce reservoir storage capacity,
- They can result in the reduction of fish and other aquatic species,
- They are unsightly and are a nuisance aesthetically,
- They can also cause mechanical problem to installations such as pumps, turbines,
- They can affect navigation in waterway through sedimentation and shallowing of river bed, etc.

The soil erosion related problems should thus be identified to enhance understanding and to minimize effects. Soil loss estimation in relation to changing discharge in the watershed provides vital information on this issue.
1.2. The Study Site

The proposed study area is located within the Balui sub-watershed of the upper Rajang River Basin in the interior of Sarawak. The Bakun catchment area is located between latitudes 1.5°N and 3.0°N and longitudes 113.5°E and 115.3°E. The catchment upstream of the dam site covers an area of about 1.5 million hectares (ha). The watershed and river are respectively the largest (44,200 km²) and the longest (>900 km) in Malaysia and the Balui or Upper Rajang sub-watershed represents 34% of the entire Rajang watershed.

1.3. Objectives of the Study

A set of research projects can be initiated in relation to the development of the Bakun HEP dam with the aim of producing data and information useful for an integrated approach to river basin and land use management. The present study focuses on the following objectives:

a) Estimation of soil loss from the Upper Rajang Sub-Catchments during the development of the Bakun HEP

b) Soil loss estimation in relation to changing discharge in the watershed.

1.4. Significance of the Study

Sediment which reaches streams or watercourses can accelerate bank erosion, clogging of drainage ditches and stream channels, silting of reservoirs (reduce reservoir storage capacity), damages to fish spawning grounds and depletion of downstream water quality. Pesticides and fertilizers, frequently transported along
with the eroding soil can contaminate or pollute downstream water sources and recreational areas. Because of the potential seriousness of some impacts, the estimation of soil loss is necessary. The estimation is useful, among others in understanding the sources, predict the trend of erosion and support further studies.

Soil loss and transport in the upland watershed are difficult to measure, and may go unnoticed until it is a severe problem. Deposition is often easier to identify and measure. Water samples collected at downstream locations can be used for sediment analysis for the assessment of cumulative sediment yield for all the catchments in the watershed or river basin. The research is intended to:

- Describe the total suspended solids (TSS) measurement methods, and to develop a relationship between daily discharge (or water level) and daily TSS. From the daily TSS readings, the total yield of the TSS for the whole year can be determined.

- Discuss the chronological changes of sediment yield of the upper Rajang catchment.

- Make recommendations on implementation of an integrated watershed management approach with respect to management of soil base on changing of soil loss over different years.
Chapter 2

LITERATURE REVIEW
2.1. History of the Bakun HEP Project

The Bakun Hydroelectric Project (Bakun HEP) in Sarawak, with a proposed generation capacity of 2,400 MW, is located on the Balui River about 37 km upstream of Belaga Town in the State of Sarawak, Malaysia.

The implementation of the hydro project was initially privatized to Ekran Berhad in 1994 and the preliminary works and river diversion works commenced in 1995. However, the economic slowdown beginning in 1997 had forced the project to be shelved. Later in 2000, the Government reinstated the project and vested all the rights of Ekran Berhad to Sarawak Hidro Sdn. Bhd. (SHSB). In the meantime, the river diversion works continued and were completed and handed over to SHSB at the end of April 2001.

On 1st June 2001, the construction of the upstream auxiliary cofferdam was awarded to Global Upline Sdn. Bhd. and the work was completed in June 2002.

Further construction of the dam and ancillary facilities (the main civil works) was offered to Malaysia-China Hydro Joint Venture on 8 October 2002. The main civil works is scheduled to be completed by 22 September 2007 while the reservoir impoundment is planned to commence earlier i.e. on 1 January 2007.

The reservoir of the Bakun Hydro Dam by virtue of the topography and relief will be elongated and dendritic in shape, spanning over the Batang Balui, Sg. Murum, Sungai Bahau and Sungai Linau. The reservoir will lie between the base elevation of 34 m asl at the dam site and maximum operating level of elevation of 228 m asl, encompassing an area of 69,640 ha, with a corresponding perimeter of
about 2,000 km. This Reservoir preparation (RP) comprise inventory, perimeter
survey and marking, biomass removal planning, partial biomass removal over the
entire reservoir and complete biomass removal of a 100 km reservoir rim between
elevation 180 m asl and 228 m asl identified for future use.

Biomass removal forms the main activity of the reservoir preparation. Complete
biomass removal of the entire Bakun Dam reservoir is not practical or feasible
due to its immense size. As such, as recommended by the environmental
consultants in the EIA report, only selective or partial biomass removal of the
reservoir for all trees down to 15cm dbh will be carried out. The complete biomass
removal at certain zone of the shorelines is to be implemented for the following
reasons:

- to ensure that the quality of water of the reservoir will improve; and
- to make sure that the future development and use of shoreline and
  reservoir may not be hindered.

2.2. Definitions

2.2.1. Soil Erosion

The word erosion is derived from the Latin word *erosio*, meaning "to gnaw away". In
general terms, soil erosion implies the physical removal of topsoil by various
agents, including falling raindrops, water flowing over and through the soil
profile, wind velocity, and gravitational pull. Erosion is defined as "the wearing
away of the land surface by running water, wind, ice or other geological agents,
including such processes as gravitational creep" (SCSA, 1982). The process of
wearing away by water involves the removal of dissolved and solid materials.
Physical erosion involves detachment and transport of soil particles, e.g., sand, silt, clay, and organic matter. The transport may be lateral on the soil surface or vertical within the soil profile through voids, cracks, and crevices. Erosion by wind involves processes similar to those by water except that the causative agent in sediment detachment and transport is the wind (Lal, 1990).

2.2.2. Types of Erosion

Different types of soil erosion can be classified on the basis of major erosion agents. Fluids or gravity is the principal agent of erosion. Wind, rainfall, and running water are the principal agents of soil erosion on arable land in the tropics.

![Diagram of Types of Erosion](Source: Lal, 1990)

Different types of erosion on the basis of major agents involved are shown in figure 2.1. Water erosion is classified into splash, sheet, rill, and gully erosion on
the basis principal processes involved. Splash or inter-rill erosion is caused by raindrop impact. Sheet erosion is the removal of a thin, relatively uniform layer of soil particles. Rill erosion is erosion in small of a thin, channel only a few millimeters wide and deep. Rills are transformed to gullies when they cannot be obliterated by normal tillage. Stream channel erosion and coastal erosion are caused, respectively, by stream flow and ocean waves. Soil movement en masse is caused by gravity.

2.2.3. Sediment

The soil mass removed from one place is often deposited at another location when the energy of the erosion causing agent is diminished or too dissipated to transport soil particles. The term sediment refers to solid material that is detached from the soil mass by erosion agents and transported from its original place by suspension in water or air or by gravity.

The term soil erosion therefore is distinct from soil loss and sediment yield (Wischmeier, 1976; Mitchell and Bubenzer, 1980). Soil erosion refers to the gross amount of soil dislodged by raindrops, overland flow, wind, ice, or gravity. Soil loss is the net amount of soil moved off a particular field or area, the difference between soil dislodged and sedimentation. Sediment yield, in comparison, is soil loss delivered to the specific point under consideration. A field's sediment yield is the sum of soil losses from slope segments minus deposition. The deposition may occur in depressions, at the toes of slopes, along filed boundaries, and in terrace channels.

The combined terms erosion and sedimentation by water embody the process of detachment, transportation, and deposition of sediment by erosive and transport
agents including raindrop impact and runoff over the soil surface (ASCE, 1975). Sediments from one location may be deposited at another site and may eventually reach the ocean following repeated cycles of re-detachment and re-entrainment in rills, channels, streams, river valleys, flood plains, and delta. The process begins with sediment detachment from uplands and ends with an eventual transport to the ocean.

Sedimentation has serious environmental and economic implication. Sedimentation decreases the capacity of reservoir, rivers, and chokes irrigation canals and tributaries. Researchers, especially engineers, consider sedimentation to be a major process of which erosion is an initial step. Fleming (1981) adopts a broader approach by stating that “the sediment problem may be defined as the detrimental depletion by erosion and transport of soil resources from land surfaces and subsequent accretion by deposition in reservoirs and coastal areas”.

2.3. Soil Erosion in Asian Countries

Soil erosion is perhaps the most serious mechanism of land degradation in the tropics in general and the humid tropics in particular (El-Swaify et al., 1982). In the tropics, erosion by water, rather than by wind, assumes the primary importance (El-Swaify, 1993). Various authors, cited by El-Swaify and Dangler (1982) pointed out that available geologic data on erosion of different continents indicate that Asia leads the way with 1.66 tonnes/ha/year, followed by South America, North and Central America, Africa, Europe, and Australia with 0.93, 0.73, 0.47, 0.43, and 0.32 tonnes/ha/year, respectively. These data were derived directly from sediment loads in major rivers. No attempt was made to convert these data to field soil losses. This was corroborated by the fact that the heavily populated regions of Asia possess the highest global sediment loads in their major