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Mekong erosion, hydropower development and sediment trapping by the reservoirs

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Erosion occurs from soil surface due to the kinetic energy of raindrop and surface flowing water. The energy of flowing water causes down cutting of the land, which results from soil migration and forest cutting. Bare land shows easy erosion behavior, and loose soil has greater potential for erosion than the vegetated land.

In the twenty-first century, the demand of energy for consumption is increasing. Hydropower is one of the cheaper sources for energy. These dams threaten the risk of livelihoods and food security of millions of people who depend upon the river's resources. People living near to Mekong basin depend on the fish as main source of food.

The main purpose of thesis was to study the erosion pattern at Mekong River, sediment transport, the sediment trapping by the reservoir. The study was accomplished by the help of mathematical modelling based on the data of soil, water and geography. For this study EIA ltd has provided Integrated Water Resource Management (IWRM) model, Mekong model and input data. The first task was to test the sensitivity of the model specific parameters and to calibrate model parameter where output result flow and TSS (total suspended sediment) concentration match the measured result. The second task was to calculate sediment yield at Chiang Saen, 3S and Kratie. Reservoir sediment trapping efficiency was calculated from the model and also by using Brune's model for comparative study.The results of this thesis show that the dam construction is the most important factor for sediment flux trapping. A sharp decrease in the sediment flux is due to the upstream dam construction.

Keywords	Watershed, Erosion, Precipitation, Suspended Solid, IWRM model, Total suspended sediment, Sediment load, Sediment trapping, Brune's equation

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LIST OF ABBREVIATIONS

DEM	Digital elevation model
EIA	Environmental Impact Assessment
GAME-T	GEOSS anaMahasri Experiment in Tropics
GIS	Geographical Information System
GLC	Global Land Cover
IWRM	Integrated Water Resource Management
LPB	LuangPrabang
MMF	Morgan, Morgan and Finney
MRC	Mekong River Commission
NCEP	National Centres for Environmental Prediction
RLGis	River life Geographical information system
T_e	Trapping efficiency
T_{res}	Residence time
T_s	Time series
TSS	Total suspended sediment
SL	Sediment load
3S	Se Kong, Se San and Sre Poke

1 Introduction

Water is the basic need for the life. Humans have utilised water resources for their various purpose. To preserve water resources for different purposes, natural water sources have been modified through construction of canals and dams. Construction of large reservoirs and dams really boosted after the Second World War. Reservoir construction may currently exert the most important influence on land-ocean sediment fluxes (Walling and Fang, 2003 cited in [1]). Transport of sediments is a fundamental feature of the morphology and biochemistry of rivers (Vörösmarty et al., 2003 cited in [1]). Sediments are important transport nutrients from continent to ocean. A big issue in sustainability of reservoirs is sedimentation. By changing the natural sediment fluxes through such activities as reservoir construction, humans have greatly influenced not only the sediment fluxes but also the overall river morphology and ecosystem in multiple ways. The impacts include increased changes in river channel morphology, nutrient transport, carbon sequestration and trace gas emissions due to decomposition of deposited organic materials. [1]

Soil erosion is a process of soil detachment from the soil mass which is transported from upstream to the downstream. The different kinds of factor which cause soil erosion are rain drop, flood, wind, soil type, landscape, and deforestation [2].There is increasing concern about the origin and fate of sediment at Mekong basin. However, research has already been done on the area but further recalibration of the erosion parameters and sediment trapped by the Mekong mainstream reservoir is required. Therefore, this thesis focused on improving the IWRM model for calculating the sediment load and trapping efficiency of the reservoirs.

2 Factors for Erosion

2.1 Soil quality

Soil is divided into three layers, i.e. clay, sand and silt. Clay is top soil which is considered as fertile soil. Erosion of the fertile soil causes a bare area. Clay contains a high amount of organic materials. Soil colloids coagulate in the presence of organic materials and hold soil particles strongly. Clay is the smallest particle, and it can mix with water and can transport to long distances. Sand and silt are heavier than clay; they get settled quicker when the water velocity is less. Sand and silt particles cannot hold tightly; thus, their Infiltration rate higher than that of clay. [3]

2.2 Precipitation

Rain drops falling from the sky have kinetic energy. Soil particles get detached from the soil lump when rain drops strike the ground surface. At the beginning of the rain fall, rain drop causes more soil detachment from the soil surface. When the infiltration is less than rainfall, then runoff starts carrying the loosened soil particles. Heavy rainfall causes flooding, and it carries the loose soil particles along. Water velocity also helps in cutting soil surface. [3]

2.3 Vegetation / Non-vegetation

Soil erosion is stronger in non-vegetated land than-in vegetated land. Vegetation helps to hold the soil particle, but bare land which has no vegetation, can be directly affected by the rain water. Vegetated land has higher infiltration rate than no-vegetated land. Roots of plants help to bind the soil particles therefore, it also holds the water. To prevent soil erosion, bare land must be vegetated. Dense forest shows less soil erosion.

2.4 Topography

The topography of a watershed area determines the surface runoff. Runoff increases when the slope is steeper the infiltration rate also decreases due to increase of slope, this is due to fact that water does not get time to infiltrate into the soil because water flows down the base. Thus, longer slope length is more susceptible to high rate of erosion during heavy rains than shorter slope length. [3]

3 Sediment transport agents and transport mechanism

Any particulate matter which is deposited as a layer of solid particle on the bottom of the water is called sediment. Carrying of the solid particles from one place to another under the water movement is called erosion. It is the process of particle entrainment from a higher elevation to a depositional basin at a lower elevation.

3.1 Media of Sediment Transport

There are several agents which help to transport particles from one place to another. These agents are described in the following subsections. [4]

3.1.1 Water

Water is one of the important agents in eroding and transporting the particles. Sediments are carried due to water motion occurred in rivers, oceans, lakes and seas, due to currents and tides.

3.1.2 Air: Wind

Air a low density and low-viscosity fluid. Wind blowing on land can transport dust and sand large distances.

3.1.3 Gravity

Gravity is an earth force which also helps the sediment to move down slope. Generally slope surface such as hill slopes, scarps, cliffs and continental boundaries are more likely to transport heavy particles such as, sand, gravel, and boulders. Sediments transported by gravity include rock falls, debris flows, and turbidity currents. When there is high concentration of sediment in water, the mixture forms a debris flow.

3.1.4 Ice: Glaciers and icebergs

Ice is a high-viscous fluid which can transport large amount of debris. Freezing and thawing cause breakdown of the rocks. When the flow of the current is small coarse particles transported down the slope by gravity force. An Ice glacier plays significant role in moving detritus in polar ice caps and mountain areas.

3.2 Particle entrainment and suspension

Depending upon the velocity of water, particles get transported or settled. In Figure 1 shows the relationship between velocity and the particle size movement. The lower left corner of Figure 1 shows erosion of unconsolidated mud starts at a flow velocity of 5 cm/s, and consolidated mud starts at a flow velocity of 120 cm/s. The upper part of the diagram shows the erosion and transport of the particle. The lower right area shows the deposition of the bedload. In between erosion and deposition areas the flow can sustain bedload transport. The rise in erosion threshold for particles finer than sand expresses the increasing cohesion between grains as size is reduced through the silt and clay size range [5]. Once the particle starts transporting with the water current, fine silt and clay are held in suspension in currents slower than those associated with channel flow and are typically carried with the flow throughout the river. [6]

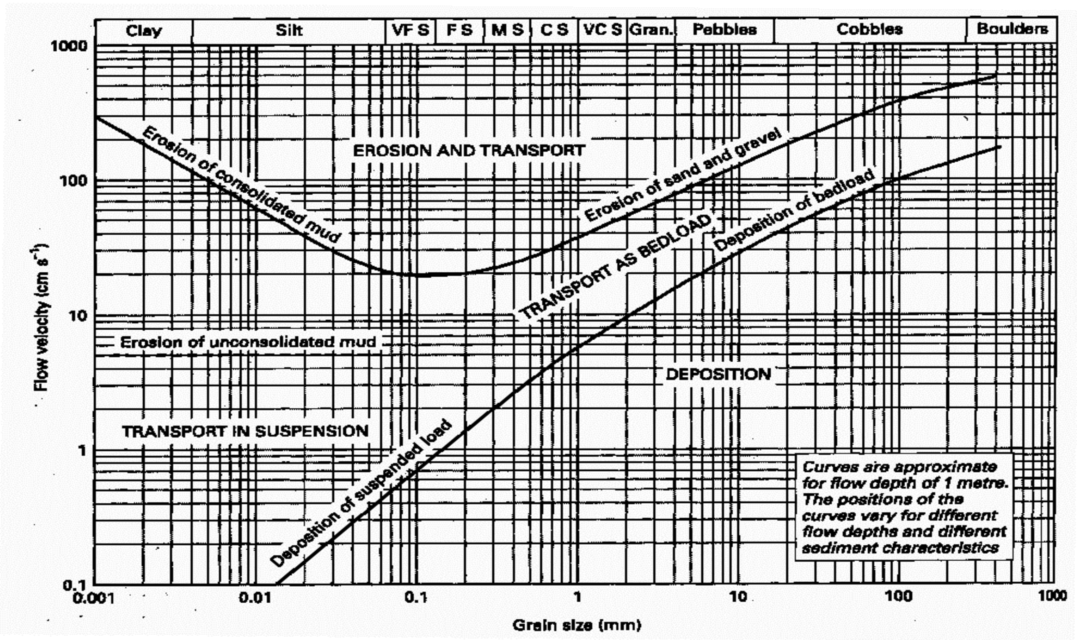

Figure 1. Hjulstrom diagram. The curves show the relationship between the velocity of a water flow and the transport of particles [6].

The Hjulstrom diagram is based on experimental work rather than on natural channels, but it shows the principals involved. Entrainment is the process of starting the particles of sediment moving- the opposite of settling [5]. The principle of Hjulstrom experimental work is summarised below:

- Sediment particles are transported when the flow velocity is high and settled down at low flow velocity.
- High flow velocity is required to move heavier sediment, but medium sand can move at lowest velocity.
- Silt and clay are cohesive in nature, which means they stick together and higher velocities are needed to transport them.
- Once in motion, fine particles can travel a long distance even when the velocity falls.

- Coarse particles such as boulders and gravels can be transported only at high flow velocity.
- Bed load can be suspended at high flow velocity and transported at low flow velocity.

3.3 Sediment movement in water bodies

Sediment movement in water is divided in to three types:

1. Bed Load
2. Suspended load
3. Dissolved load

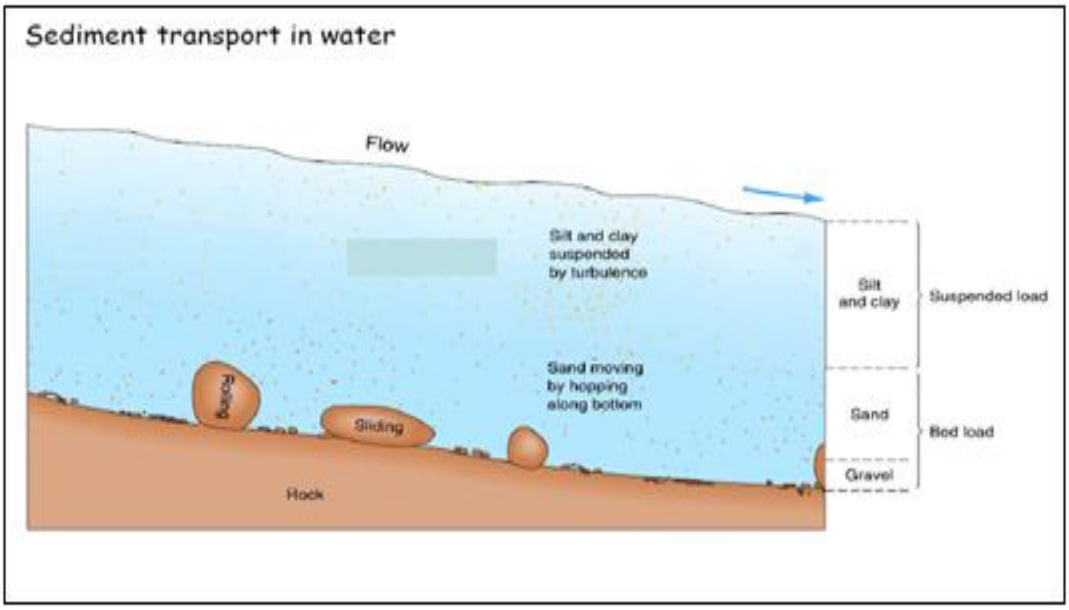

Figure 2. Schematic diagram of different types of sediment load are carried in the downstream [3].

When the bed shear stress exceeds a critical value, sediments are transported in the form of bed-load and suspended load (Figure 2). Bed load are the heavier particles which transport by rolling, sliding and saltating (bouncing) over the river bed. During the bed-load motion, the moving grains are subjected to hydrodynamic forces, gravity force and inner-granular force. Suspended load are of fine-grained clays and silts and some sands. This sediment is transported inside the water column as the water flows downstream. Dissolved loads are dissolved ions in the solution that are transported within the stream movement. [7]

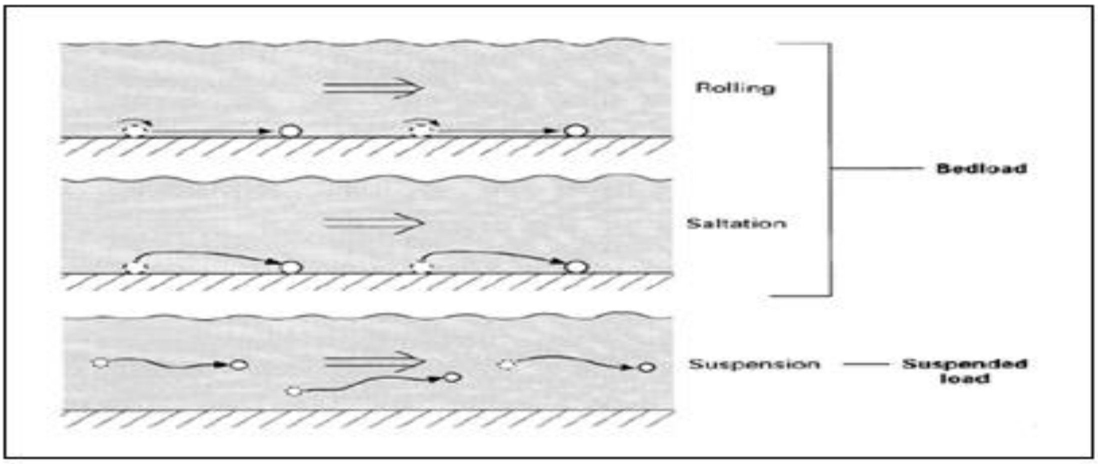

Figure 3. Mode of transport in a flowing fluid, with increasing flow velocity [4].

Figure 3 demonstrates the mode of transport in a flowing fluid with increasing velocity. Fine particle are transported by being suspended in the moving water column. Sand particle does not remain suspended in the water for long time. Thus, it is transported in as series of short jump (i.e. saltation). The particles are picked up by the water current and settle down when the flow is less than settling velocity. This process of transport is called saltation. Bigger particles such as gravels cannot be suspended in the water. These types of particles are transported by rolling. Streams in the mountains have a high current, but not much volume of water. Such stream can transport large particles, but not much sediment. On the other hand, a major lowland river generally has a lower current, but very large volume. This kind of stream has a low competence, but enormous capacity. [4]

3.4 Cohesive sediment Transport

Cohesive sediments are composed of clay-sized materials. The fine grain particles have a strong inter particle force due to their surface ionic charges. Sediment is considered as cohesive if the particle diameter is less than 60 µm. Cohesive sediments consist of inorganic and organic materials. They have a tendency to bind together to form large and low density flocks. The transport and settling characteristics of fine-grained cohesive and coarse-grained non-cohesive sediments follow a different pattern. Coarse-grained sediment undergoes simultaneous erosion and deposition when transported under a constant bed shear stress. In case of fine-grained cohesive sediment, erosion and deposition occur when subjected to certain bed shear stress. [8]

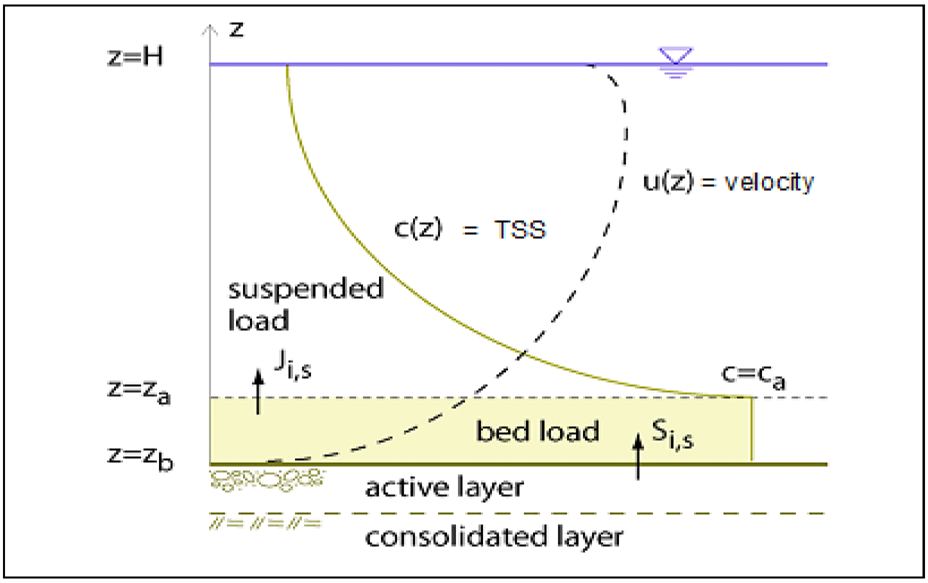

Figure 4. Non-cohesive sediment transport and net sediment flux at bed boundary.

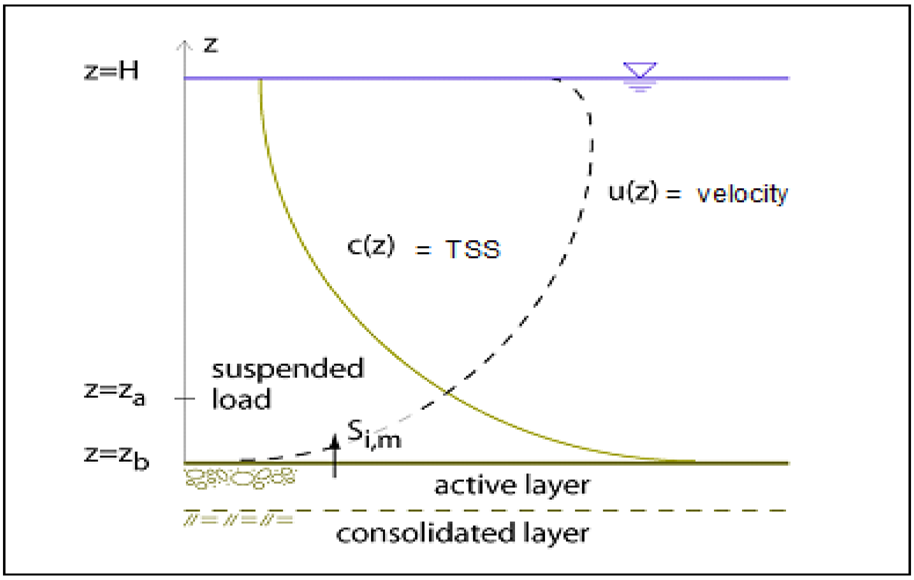

Figure 5. Cohesive sediment transport and net suspended flux at bed boundary.

In Figure 4 and Figure 5 the sediment transport and net suspended flux at bed boundary are presented for non-cohesive and cohesive sediment transport, respectively. [9]

4 Watershed Erosion model

The integrated water resource management (IWRM) model uses the simple empirical erosion formula created by Morgan Morgan and Finney (1984 cited in [9]). Soil particles are detached when the raindrop force or erosive force of flowing water is more than the soil attachment force. Model describes the erosion model in two parts. The model compares the total detachment by raindrop (F) and surface runoff (H) with the transport capacity of the runoff (TC).The proposed model is shown in Figure 6.

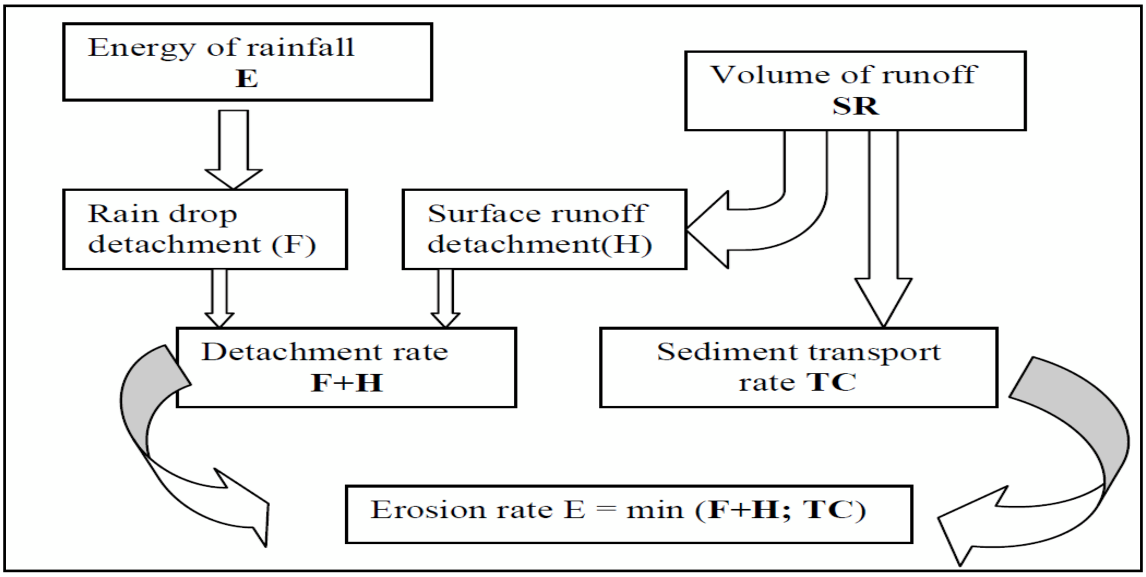

Figure 6. Erosion formula proposed by Morgan, Morgan and Finney.

The equations used in IWRM model are presented below.

Water Phase

$$E = R(11.9 + 8.7log_{10} \ (I))$$

E= Kinetic energy of rain fall (J/m^2)

R= daily rainfall (mm)

I= intensity of erosive rain, (mm/h)

IWRM model calculates the surface runoff (*SR*). The standard annual formulation which is not used in the IWRM-model is expressed as follows:

$$SR = \ R \ exp(-R_c/R_0)$$

SR= volume of surface runoff (mm)

R= annual rainfall (mm)

R_0= annual rain per rain day (mm) = R/R_n , where n is the no of rain days in the year.

R_c= soil moisture storage capacity.

$$R_c = 1000 \times MS \times BD \times EHD(E_a/E_p)$$

R_c= soil moisture storage capacity

MS= the soil moisture content at field capacity (%.w/w)

BD= the bulk density of the soil (Mg/m^3)

EHD= the rooting depth of the soil

E_a/E_p= the ratio of actual to potential evapotranspiration.

Soil Phase

$$F = 10^{-3} \times K \times KE$$

F= rate of soil detachment by rain drop (kg/m^2)

K= soil detachability index (g/J)

KE= total energy of the effective rainfall (J/m^2)

$$KE = E^{-0.05\ A}$$

KE= total energy of the effective rainfall (J/m^2)

E= Kinetic energy of rainfall (J/m^2)

A= percentage of rainfall contributing to permanent interception and stem Flow

The IWRM model modifies (*A*) on the basis of the leaf area index which in turn depends on annual vegetation cycles for each use class.

$$H = 10^{-3}(0.5 \times COH)^{-1} \times SR^{1.5} \times \sin(S) \times (1 - GC)$$

H = rate of soil detachment by surface runoff (kg/m^2)

COH = cohesion of the soil surface (KPa)

SR = volume of surface runoff (mm)

S = slope (deg)

GC = fraction of ground (vegetation) cover (0-1).

$$TC = 10^{-3} C_f SR^2 \sin(S)$$

TC = the transport capacity of the runoff (Kg/m^2)

C_f = crop or plant cover which can be adjusted to take account of different tillage practices and levels of crop residue retention.

The estimates of the soil particle detachment by raindrop impact, F and by surface runoff, H are added together to give a total detachment rate. This is then compared with the transport capacity of the surface runoff and the lesser of the two values is the annual erosion rate:

$$E = min[(F+H), TC]$$

E = annual erosion rate (Kg/m^2),

F = soil particle detachment by raindrop (Kg/m^2)

H = soil particle detachment by surface runoff (Kg/m^2) and

TC = the transport capacity of the runoff (Kg/m^2).

As indicated above the IWRM model formulation differs in some points from the MMF model. The differences are:

- IWRM-model includes formulation for snow-melt erosion
- Surface runoff is obtained from IWRM-model hydrological component
- Vegetation state (leaf area index) modifies the total effective rainfall energy.

5 Area Background and Data used for model Construction

5.1 Description of the model test area

Mekong River is a trans-boundary river in Southeast Asia. The river runs through China's Yunnan province, Burma (Myanmar), Laos, Thailand, Cambodia and Vietnam shown in Figure 7.

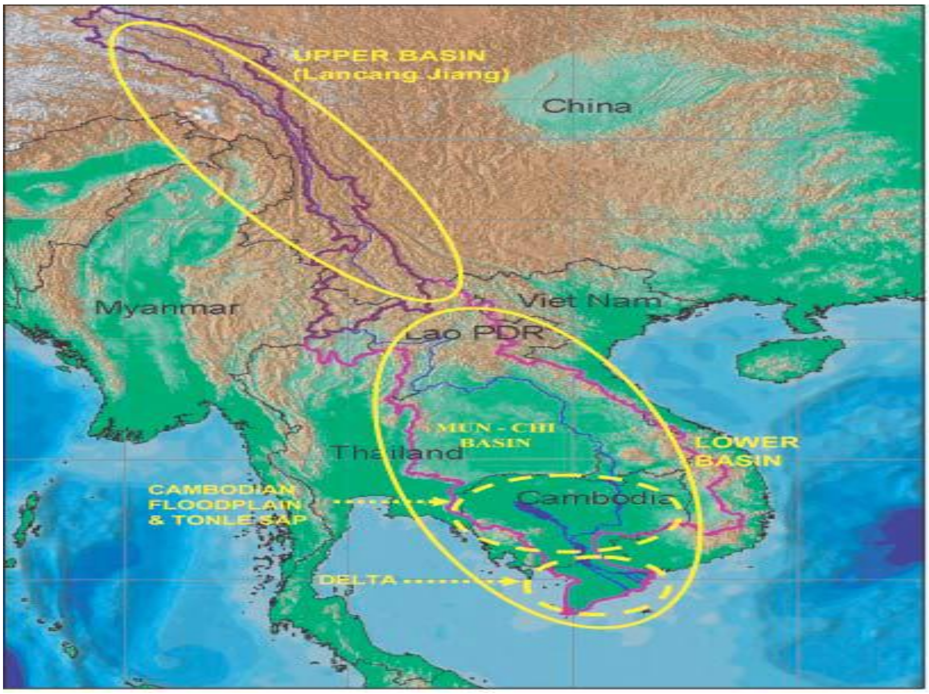

Figure 7. Mekong River Basin broad geographical regions. [15]

In the northern part of the river basin upland there are mountains over 5000 m and alpine climate, and southern part of the basin consists of larger tropical floodplains. The basin is usually divided geographically into Upper Mekong Basin and Lower Mekong Basin, with the division point at Chiang Saen. The upper basin, from the headwater to approximately Chiang Saen, is steep, and falls from an elevation of above 4500 m to an elevation of about 500 m over a distance of 2000 km, with an average slope of 2 m km^{-1}. In the lower basin, from Chiang Saen to Kratie River, elevation drops from 500m to few tens of meters over the distance of 2000 km, the average slope being 0.25 m km^{-1}. After Kratie to downstream, the river bed is more or less flat, reaching the South China Sea after a distance of 500 km with a fall in elevation of 15 m, the average slope being 0.03 m km^{-1}. (Mekong River Commission, 2005 cited in [10])

In the lower part of Mekong Basin, the climate is mostly tropical savannah and monsoon. The wet season starts from early May to October and the dry season starts from November to April. Most of the precipitation occurs during summer. The precipitation of the upper part is slightly different to that of the lower basin. Because of high altitude in the upper basin, precipitation during winter falls mainly as snow. [10]

5.2 Mekong basin characteristics

The Mekong River is one of the major rivers in the South-East Asia. The Mekong river basin is 785,000 km^2large. The average daily flow is about 15, 000 m^3/s. Some of the Mekong Basin Characteristics are summarised in Table 1 [9].

Table 1. Mekong basin characteristics.

Basin	Mekong River Basin
Area	785,000 km^2
Average outflow	15,000 m^3/s
Lakes(% of area)	0.8 % (dry season)
Extent EW	1560 km
Extent NS	2800 km
Outflow	South China Sea
Elevation range	0 – 6200 m
Average yearly precipitation	1600 mm (model value)
Average evaporation	940 mm (model value)
Highest point	6740 m (Kawagebo peak)

5.3 Mathematical modelling approach

The model uses data and calculates the result by using mathematical formula. It also helps in making predictions about the future. The model uses data based on geographical information system (GIS) based data. There are so many GIS-based models in the market. This thesis project used the integrated water resource management (IWRM) model. In this thesis the model used flow data, land use, soil type and elevation to calculate soil erosion, sediment transport and sediment trapping. The input data was arranged in time series (T_s). The mathematical model can also use for agriculture, irrigation, crop development, fishery, land management, and forestry.

5.4 Mekong River model construction

The various data were needed to analyse watershed erosion. Model was constructed using five layers. They were digital elevation model (DEM), land use, soil type, rivers and river data. Precipitation data were used to estimate rainfall-runoff erosive factor and soil and land use type data were to predict the soil erodibility factor [11].The DEM layer was used to calculate slope length and slope steepness factor.

5.4.1 Digital elevation model grid layer

A digital elevation model is a space grid of elevation points. The X-axis and Y-axis represent the area location, and the Z-axis represents the elevation of that location.

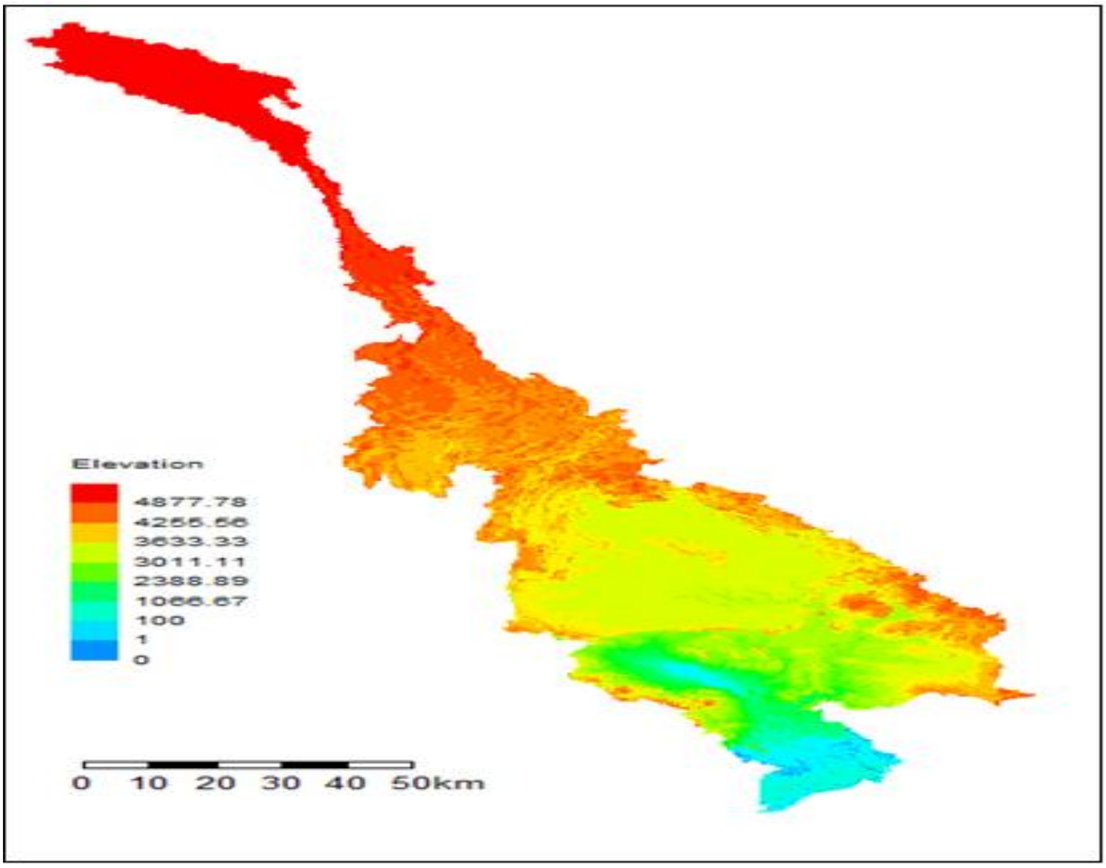

Figure 8. DEM layer of Mekong river basin

Figure 8 is a DEM layer taken from the model. The color difference shows the elevation. The box size of the grid is 5 km. The highest elevations which are above 5000 are shown in deep red color. Thus the upper most part of the Mekong River is depicted as a high altitude. Illustrates heights that are above zero but outside the boundary is zero.

5.4.2 Soil type classification grid layer

Soils were classified on the basis of their hydrological behaviour. According to soil type, different parameters were set in the model such as infiltration and erosion. The soil classes and their explanation are listed in Table 2, and the distribution of soil type in the Mekong river basin is illustrated in Figure 9.

Table 2. Soil classes

Model class	Title	Explanation
1	Water	Permanent water body
2	Acrisol	Subsurface accumulation of clays, low base saturation
3	Histosol	Organic Material
4	Argic	Argic/Ochric horizon, sand on top, clay below
5	Ferrisol	Deep strongly weathered soil
6	Alluvial	Permanent or temporary wetness
7	Lithosol	Limited soil development
8	Cracking	Hard when dry, plastic when wet

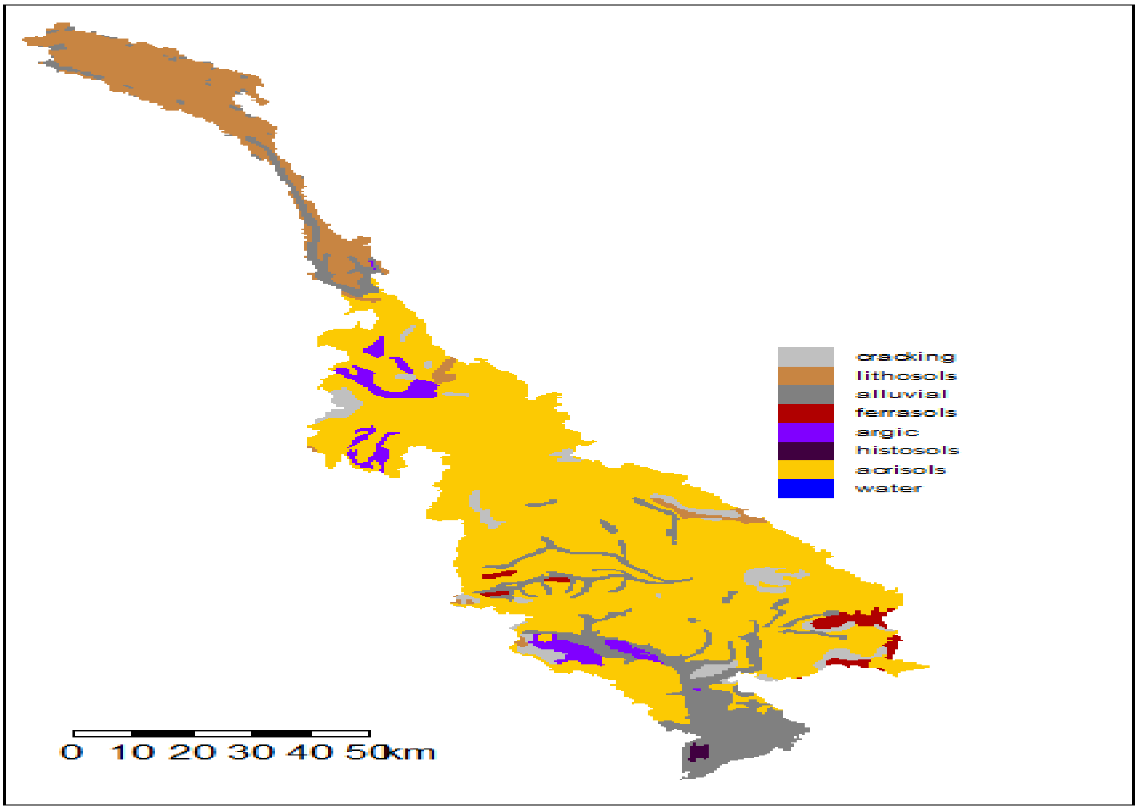

Figure 9. Soil types in the Mekong river basin

5.4.3 Land use grid layer

The land use type were simplified for the model computation from the previously established classes by Global Land Cover 2000 Project (GLC2000) shown in Table 3 [12], thus reducing the number of land use classes in the Mekong basin. The reclassification is shown in Table 4 with the percentage of area in each class.

Table 3. Land use classification by GLC2000

GLC2000	Explanation	Reclassified
1	Tree cover, broadleaved, evergreen	3
2	Tree cover, broadleaved, deciduous, closed	2
3	Tree cover, broadleaved, deciduous, open	2
4	Tree covered, needle-leaved, evergreen	3
5	Tree covered, needle-leaved, deciduous	2
6	Tree covered, mixed leaf type	2
7	Tree covered, regularly flooded, fresh water (and brackish)	7
8	Tree covered, regularly flooded, saline water	7
9	Mosaic: Tree cover/ Other natural vegetation	2
10	Tree cover, burnt	4
11	Shrub cover, closed-open, evergreen	4
12	Shrub cover, closed-open, deciduous	4
13	Herbaceous cover, closed-open	4
14	Sparse Herbaceous or sparse Shrub cover	4
15	Regularity flooded shrub and/or Herbaceous cover	7
16	Cultivated and managed areas	6
17	Mosaic	6
18	Bare Areas	4
19	Water Bodies (natural & artificial)	1
20	Snow and ice (natural & artificial)	9
21	Artificial surfaces and associated areas	8

Table 4. Land use Classes in Mekong Basin

Class number	Title	Number of grid cells	Percentage
1	Water	243	0.75%
2	Deciduous forest	4309	13.22%
3	Evergreen forest	4983	15.29%
4	Shrub and grassland	11212	34.40%
5	Irrigated agriculture	0	0.00%
6	Agriculture	11745	36.03%
7	Floodplain	0	0.00%
8	Glacier	105	0.32%

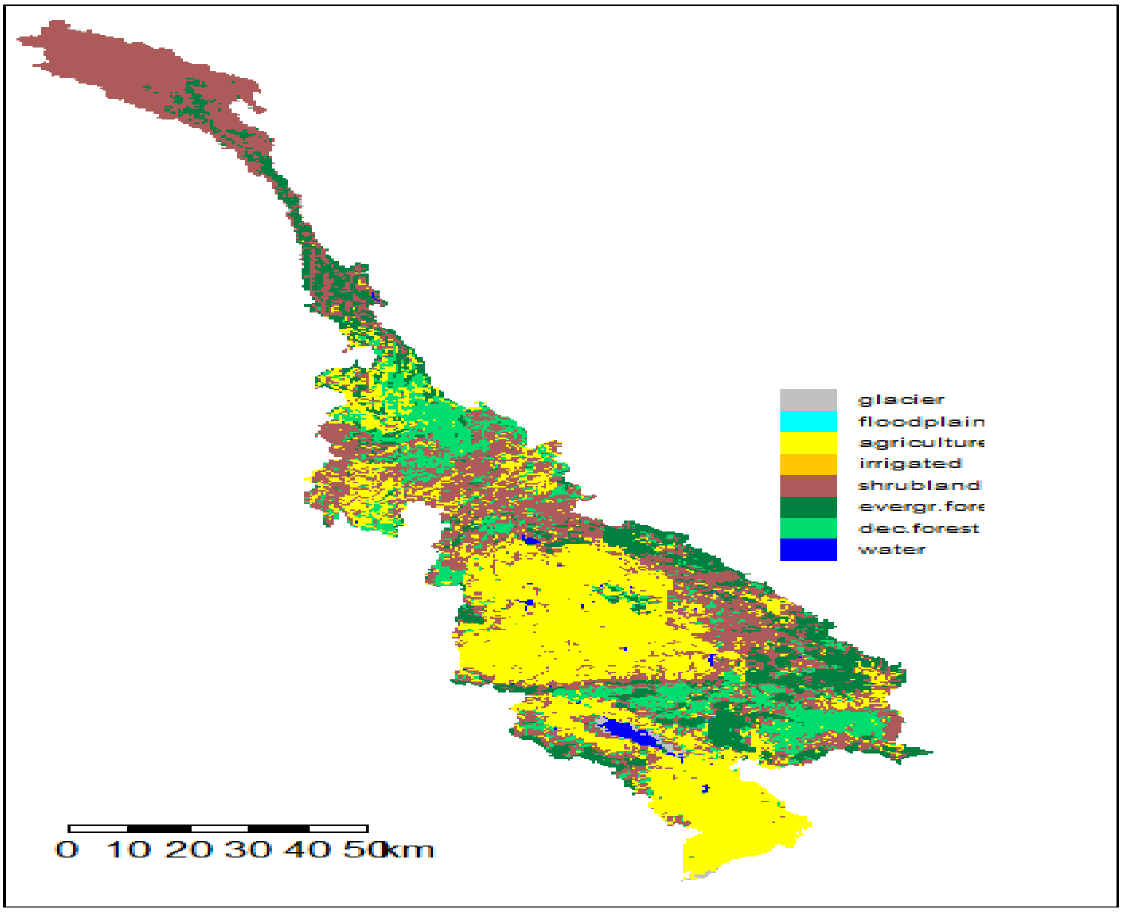

Figure 10. Land use data for Mekong river basin

Table 4, shows that the number of grid cells for irrigated agriculture and floodplain is zero. According to Table 4, 36.03% of land in the Mekong river basin is used for agriculture, and 34.4% of the land is covered by shrubs and grassland. In total, 70.43% of the land is either agriculture land and shrub and grassland. The percentage of Glacier is the smallest: 0.32%.

5.4.4 River Data

All geographical data was first transformed into 5 km grid size. The river data was created from the digital elevation model, land use model, soil data model and rivers. The elevation data was lowered by 10 m in the grid box and the main river channel for flow network computation in order to achieve the connection of the tributaries. The outflow point is the lowest point in the DEM and is located at the boundary of the DEM. The compute flow layer from lowest point was constructed from GeogrComp – Flow. River data layer was created by selecting the flow layer and Dem layer. A Computation parameter Specific discharge of 10 l/s/km^2 was defined for creating river data. Figure 11 illustrates the Mekong River generated by using the IWRM model.

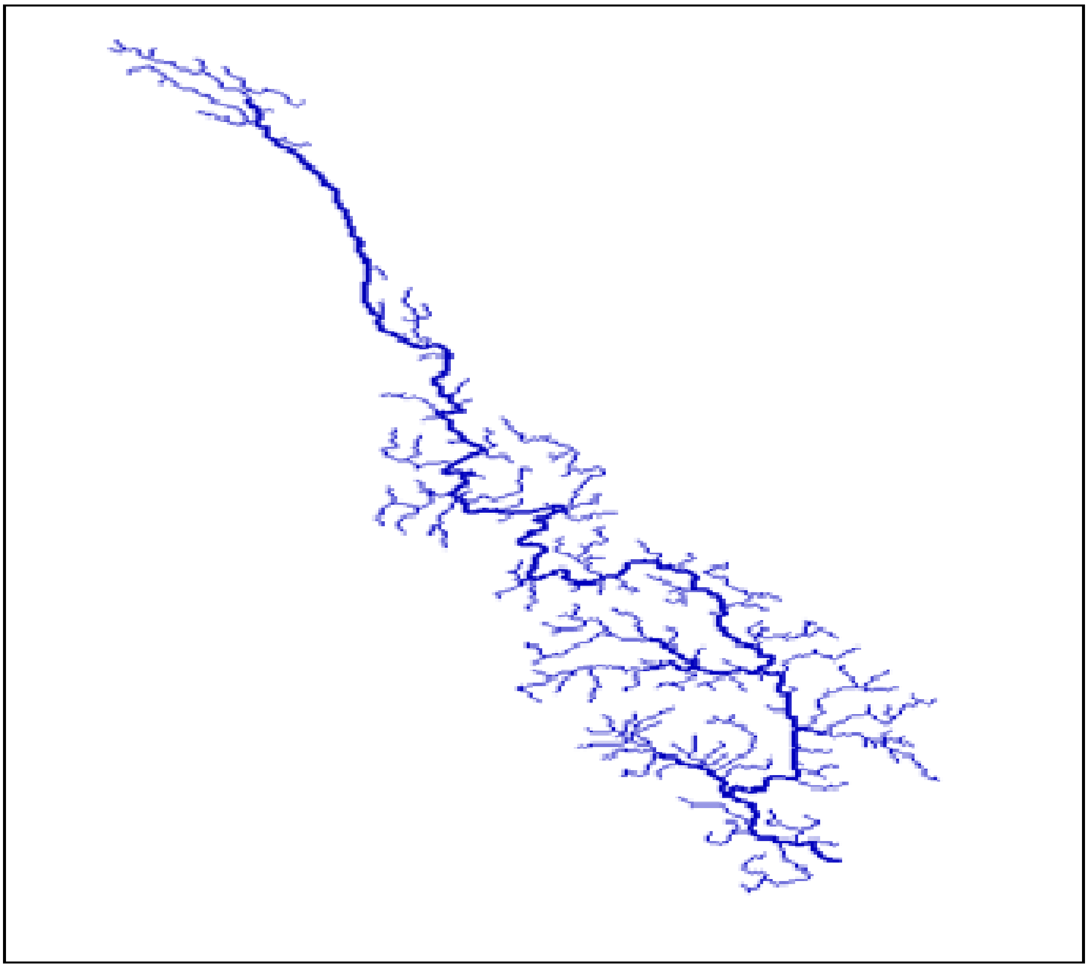

Figure 11. Mekong River generated by using IWRM model.

5.5 Meteorological Data

The Meteorological data contain precipitation and temperature data. There were 212 weather station included in the Mekong basin. Few weather stations are located outside the catchment area. The locations of the weather stations are shown in Figure 12. The weather stations are illustrated as blue boxes.

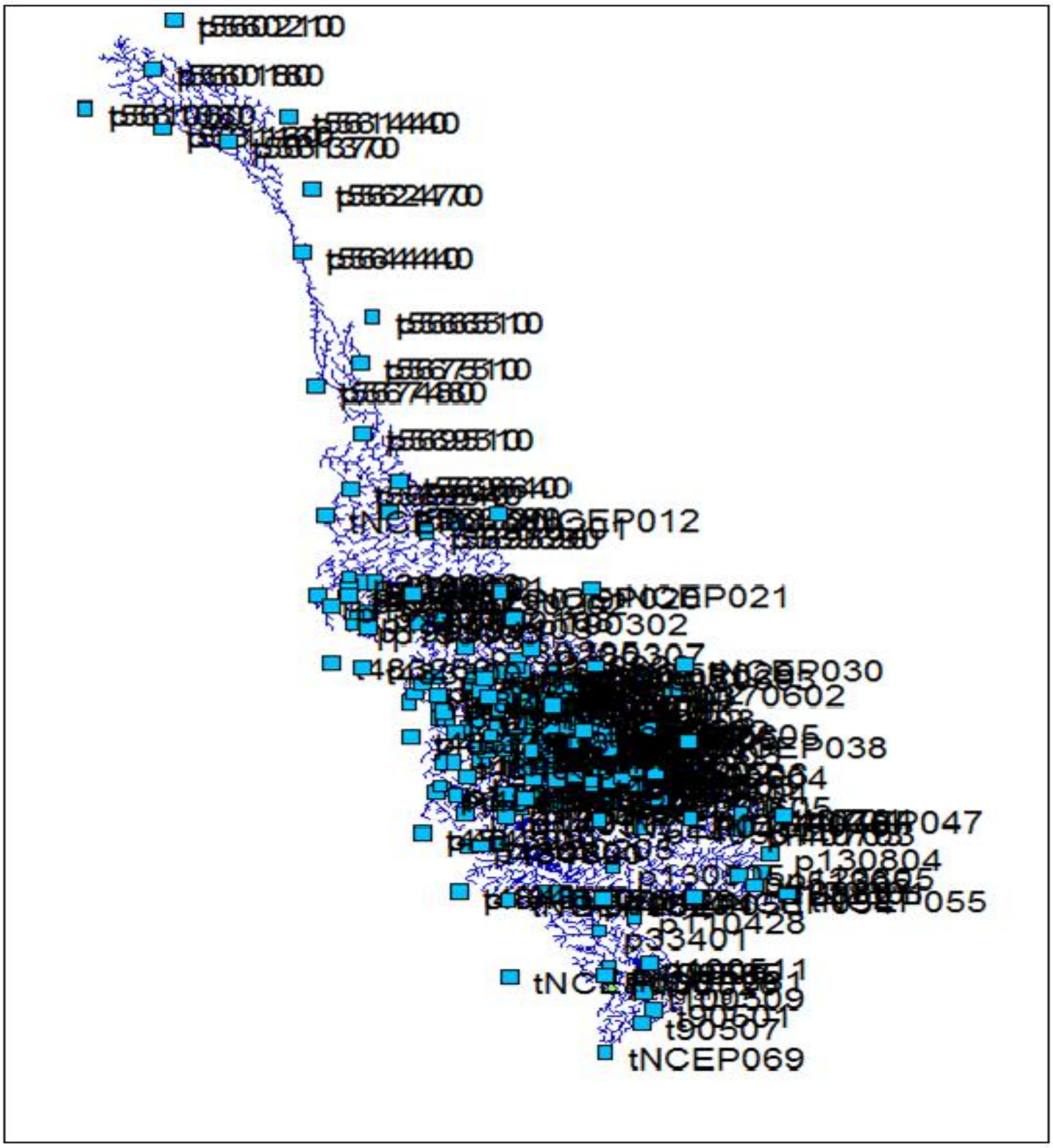

Figure 12. Meteorological weather stations at Mekong basin

5.5.1 Precipitation Data

Precipitation data were obtained from GAME-T. The model also used NCEP reanalysis II meteorological data [9]. Rainfall data from the weather station was from 1985 to 2005. The precipitation was measured in millimetres (mm). Figure 13 shows the precipitation data of one of the weather stations (p150504) which lies near to Pakse Mekong Laos. The graph shows the time series data of rainfall from 1985 to 2005.

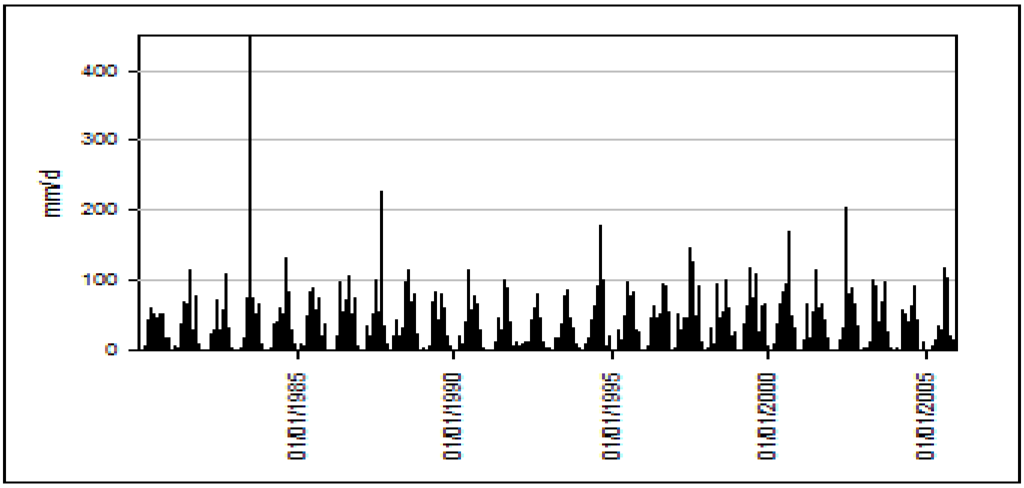

Figure 13. Precipitation at the weather station p150504 near Pakse Mekong Laos

The model needs at least one point having precipitation data and at least one point having temperature data to run the model. If there are several file containing precipitation and temperature, the data file must have same variables. In the model, the precipitation distribution is done by interpolation. The model uses interpolation type 4. It uses 3-point interpolation multiplied by height correction. The height correction was set at 0.0002.

5.5.2 Temperature Data

Temperature data was used to calculate the evaporation rate. The temperature data file contains daily minimum and maximum temperature daily. The model also used NCEP Reanalysis II methodological data. Temperature was distributed to all grid cells by interpolation. The model use interpolation type 3, which uses three point interpolation and additive height correction. The height correction was set at -0.006. The temperature data used was collected from the weather stations are listed below.

- (GAME-T) minimum temperature (daily)
- (GAME-T) maximum temperature (daily)
- (NCEP) minimum temperature (daily)
- (NCEP) maximum temperature (daily)

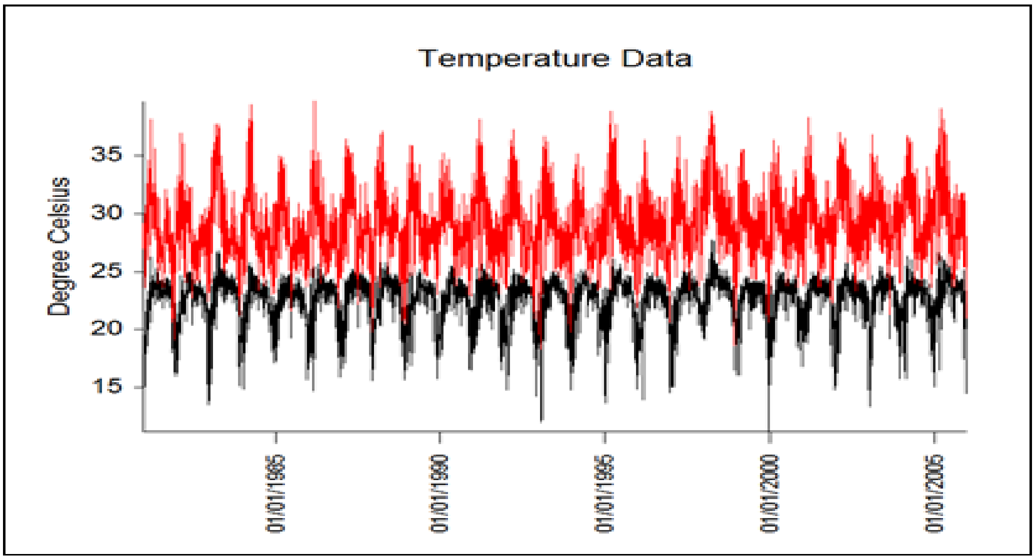

Figure 14. Maximum and minimum temperature data from weather station tNCEP053

5.6 Hydrological Data

The out flow points selected in the model is shown in the Figure 15. The output point produces the desired variables time series result.

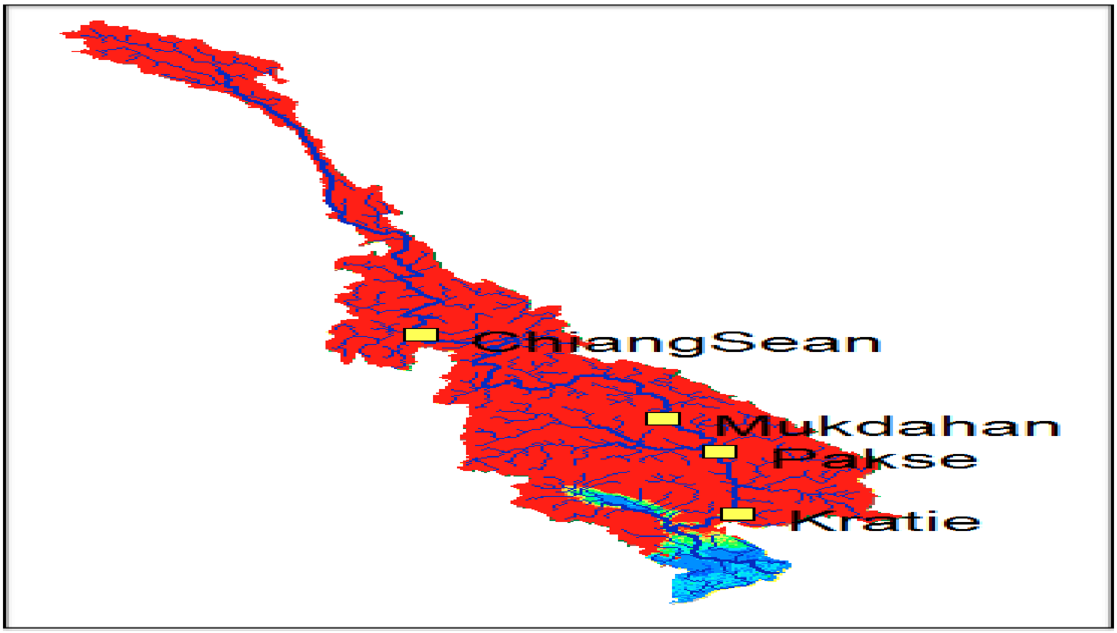

Figure 15. Mekong river Ts (time series) output measurement points selection

The Ts (time series) output were placed according to test area. At each Ts output point, different time series output variables can be obtained. In the model, different Ts output variables were selected, such as river discharge, TSS (Total suspended sediment) concentration, TSS load, reservoir discharge, reservoir water volume and reservoir water level.

6 Sediment trapping by reservoirs

Reservoirs are constructed for hydropower development and other purposes such as agriculture and fishery. The reservoir results in sediment trapping. Sediments have a high nutrient content which is used in downstream for fish development and agriculture. Sediment can block intakes in reservoirs and damage tunnels or turbines. One of the most effective techniques to remove these sediments is the flushing technique. Reservoir construction also blocks fish migration to downstream.

6.1 Mekong Hydropower development

At present, only 10 percent of the estimated hydroelectricity potential in the Lower Mekong Basin is developed [13]. Figure 16 shows dams at the Upper Mekong Basin (UMB).China’s construction of dams on the Lancang (or Upper Mekong), where, five mega dams have already been built, eight are underway and several are being planned in Tibet and Qinghai.

Figure 16.Mainstream dams at Upper Mekong basin.[14]

In October 2012, International Rivers went to investigate the current status of dam building on the Lancang River are shown in Figure 16. [14]
The dam status is as follows:

Blue:	Completed (6)
Red:	Under construction (4)
Pink:	Site preparation (5)
Green:	Planned (5)
Yellow:	Cancelled (2)

According to Cronin and Hamlin report [15], China is constructing a massive cascade of eight dams on the upper half of the Mekong and plans for up to 12 dams on the Lao, Lao-Thai and Cambodian stretches of Lower Mekong mainstream. The completed Xiaowan Dam and Nuozhadu dams have some of the world's largest reservoirs of 15 and 22 million cubic kilometres, respectively. It will each serve as giant cisterns for three lower dams that do not have enough storage capacity to maintain electricity production in exceptionally dry period.

6.2 Reservoirs at Mekong Basin

Figure 17 shows reservoirs at the Mekong basin. For sediment trapping calculations, the model needs to locate reservoirs. The reservoir's monthly flow and the volume-area data are needed for study reservoir trapping.

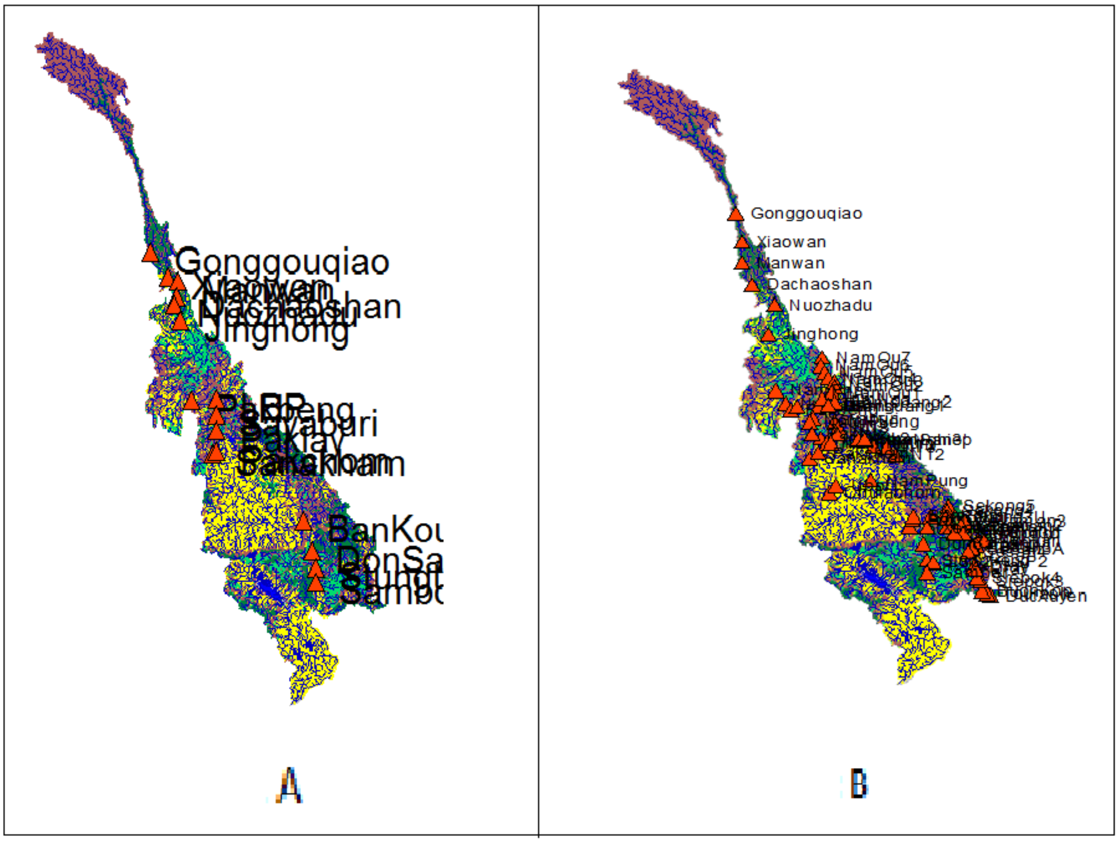

Figure 17. Planned and existing reservoirs in the Mekong Basin (A) at the mainstream of the Mekong Basin;(B) at mainstream and sub–basin of the Mekong Basin.

In Figure 17 planned and existing reservoirs are not categorised because the software does not have option to categorise the reservoirs. For the reservoir trapping study Figure 17 A has been used in this thesis. Figure 17 B have 71 reservoirs and it requires a considerable amount of work to study an individual reservoir. According to the compiled information of the existing and planned reservoirs (Fu and He, 2007; King et al., 2007; Kummu and Varis, 2007; Mekong River Commission, 2008), there were 28 large register dams in the Mekong Basin by the end of year 2008. The total active storage capacity of the existing reservoirs is approximately 8.6 km^3or 1.7% of the annual discharge of the Mekong, 505 km^3 based on Shiklomanov (1999 cited in [1]). In addition, there are 14 reservoirs under construction and 92 planned for the sub-basins with the total active storage capacity of 91.4 km^3. The Sambor reservoir, Cambodia, is the largest reservoir that is planned to be constructed in the Lower Mekong Basin part of the main stream.[16]

6.3 Reservoir trapping modelling

Reservoir sedimentation is the process of deposition of sediment into a reservoir formed after a dam. There are many causes of reservoir sedimentation, such as water-shed, sediment and river characteristics. Reservoir trapping is the capturing of the sediment fractions. These sediment fractions are clay, silt and sand. IWRM-model dam sediment trapping is calculated by using following methodology: [9]

- Reservoir net sediment settling rate is given separately for three sediment fraction (clay, silt and sand)
- Reservoir sediment mass balance is formed based on sediment in- and out-flows and net sedimentation in the reservoir
- It is possible to give different trapping efficiency coefficient for each reservoir.

6.4 Calculation of trapping efficiency by using modified Brune equation

A modified Brune equation present by Vörösmarty et. al. (2003 cited in [16]) was used to estimate the trapping efficiency. Equation 2 is applicable for reservoir volumes, V_i, larger than 0.5 km^3 [17].To calculate T_e, residence time was calculated by dividing the total active storage capacity with the discharge.

$$\Delta T_{res} = \frac{\sum_1^{nj} V_i}{Q_{res}} \qquad (1)$$

$$T_e = 1 - \frac{0.05\,\alpha}{\sqrt{\Delta T_{res}}} \qquad (2)$$

Where,

T_{res}	residence time
V_i	storage capacity
Q_{res}	discharge at the location.
α	curve constant

The Brune equation cited in [16] is probably a most widely used method for estimating the sediment retention in reservoirs. In the Figure 18, the Brune equation curve plots T_e to reservoir C/I.

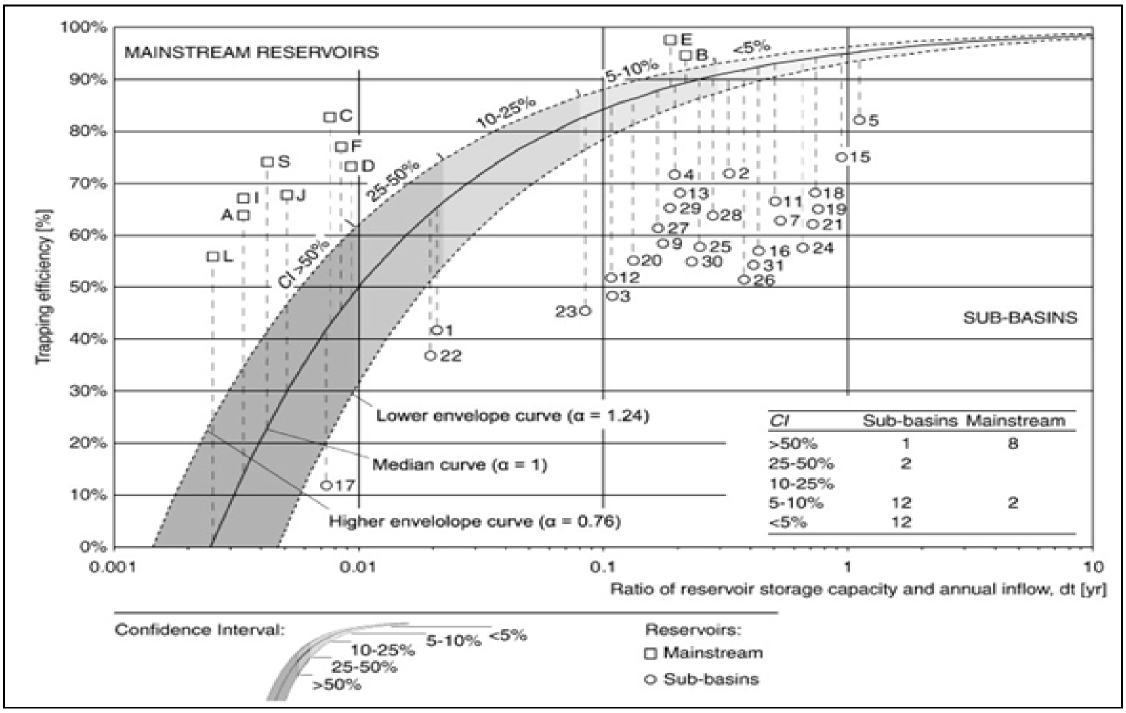

Figure 18. Empirical Brune curve show sediment trapping efficiency as a function of capacity-inflow ratio. [9]

The empirical Brune curve in Figure 18 shows sediment trapping efficiency as a function of volume-inflow ration. Volume-inflow ratio is called residence time. The higher the residence is, the more sediment is trapped and the less sediment is released. The Brune model starts sediment trapping when the residence time is above 0.001, 0.0025 and 0.005 (Unit is year) for the higher envelope, the median envelope and the lower envelope, respectively. The modified Brune equation used to calculate trapping efficiency is not applicable for some reservoirs whose volume is less than 0.5 km^3.
In the Brune's method of calculating trapping efficiency, α has three different values which develop three envelope curves where the lower envelope curve (α value is 1.24) is used for fine grained sediment, median envelope curve (α value is 1) is used for mixed grained sediment and the higher envelop curve (α value is 0.76) is used for highly flocculated and coarse sediment.

The estimated T_e values according to the Brune equation were estimated equal to or higher than the T_e values according to Churchill (1948 cited in [18]), but in general, the two values were similar (Trimble and Carey, 1990 cited in [18]). Although the use of the Churchill curves may give a better prediction of T_e than Brune's curves, it is very difficult to obtain the input data for calculating the sedimentation index. This is the reason why Brune's approach is used so extensively as opposed to that of Churchill.

6.5 Trapping efficiency calculation by the IWRM model

To know the reservoir sedimentation load, it is more informative to know reservoir trap efficiency (T_e). T_e is the proportion of the incoming sediment that is deposited in a reservoir and is expressed in percentage.

$$T_e = \frac{v_i - v_o}{v_i} \times 100 \qquad (3)$$

Where, v_i is the inflowing sediment load and v_o is the outflow sediment load. T_e is estimated from inflow and outflow of sediment, it is actually dependent on several parameters, including sediment size, distribution; the time and rate of water inflow to the reservoir; the reservoir size and shape; the location of the outlet structure and water discharge schedules [18]. In the scenario simulations, it is assumed that net sediment rate is same as theoretical settling rate for each sediment fraction. [9]

7 Model Sensitivity Analysis and Calibration

7.1 Model sensitivity analysis of flow and erosion

The aim of the sensitivity analysis was to check how much the output changes in relation to model parameter changes. For this purpose to make the sensitivity analysis easier and result clearer, only one type of land and one type of soil was used. In sensitivity analysis, flow parameters and erosion parameters were changed and analysed. The list of parameters selected to check flow and sediment solid load are listed in Table 5.

Table 5. Parameters affecting flow and erosion

	Parameter	Unit	Lower and upper limit	Explanation
1.	Rainmult	Non-dim	0.7 – 1.3	Precipitation correction
2.	Petcorr	Non-dim	0.6 -1.3	Evaporation correction
3.	Laimethod	Non-dim	1 -4	Method for leaf area calculation
4.	Laimin	Non-dim	0 -8	Minimum leaf area
5.	Laimax	Non-dim	0 -8	Maximum leaf area
6.	Pbare	Non-dim	0 -1	Fraction of bare area
7.	Pcanopy	Non-dim	0 -1	Fraction of high vegetation
8.	KSD	g/J	0 -10	Soil splash detachment

The base line values for eight parameters are shown in the Table 6. The Outflow point was selected at Kratie. The model was run for two year; the start date 1 January 1999, and the end 31 December 2000.From the outflow point cumulative, a baseline and a peak were calculated for flow and total suspended sediment (TSS) load. The cumulative flow for the year 2000 was 7321 m^3/y; the base flow was 14610 m^3/s and the peak flow 67616 m^3/s. The cumulative TSS load for the year 2000 was $8.91*10^{10}$ kg, the base load $7.85*10^7$ kg/day and the peak load $1.10*10^9$ kg/day.

Table 6. Sensitivity analysis test result

Parameters	Base Value	New Vale	Change	Cumulative Flow	Base flow	Peak flow	Cumulativ	Base TSS	Peak TSS
			%	%	%	%	%	%	%
Rainmult	1	1.3	30%	45.48%	26.70%	48.03%	66.62%	63.16%	57.10%
Petcorr	0.6	1	67%	-23.16%	-16.29%	-18.83%	-18.60%	-20.26%	-9.65%
Laimethod	1	1.5	50%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Laimin	0.5	1	100%	-12.96%	-11.20%	-5.11%	-10.04%	-4.00%	-2.84%
Laimax	3	5	67%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Pbare	0.3	0.8	167%	0.00%	0.00%	0.00%	170.12%	171.16%	169.79%
Pcanopy	0.1	0.5	400%	0.00%	0.00%	0.00%	15.66%	27.15%	9.58%
KSD	0.5	1	100%	0.00%	0.00%	0.00%	98.85%	98.21%	99.41%

The new value for the parameter was changed one at a time and the model was runs for two years. In the Table 6, Rainmult shows a 45.48 % increase in cumulative flow and a 66.62% increase in cumulative sediment load, when a base value is increased by 30%. When Petcorr increases by 67% there is a decrease of 23.16% in cumulative flow and a decrease of 18.60% in cumulative sediment load. Laimethod and Laimax do not show any change in flow and sediment load when increased by 50% and 67%, respectively. An increase in laimin also shows a decrease in flow and sediment load. Pbare, Pcanopy and KSD show no change in flow but increase in sediment load when the parameter value is increased. Pbare and KSD play a significant role in increasing the sediment load. Sensitivity analysis gives a guideline for model calibration. Detailed sensitivity analysis detail calculations are shown in appendix 1.

7.2 Calibration steps

The IWRM model hydrological calibration is a quite laborious task. The following steps were followed to make the task easier.

- The time step was set in “Model/Computation parameters”: uses smaller time steps; e.g. 1 or 2h, increases the time and checked the model result until the result start to deviate; especially focused on the ‘dtriver’ and ‘dtlake’ time step.
- ‘Result/Comparison options’: the model calibration time series point and corresponding discharge measured file were set.
- In the ‘Data/ time series (Ts) output point’, the corresponding measured (e.g. river discharge, TSS concentration, TSS load) files were checked.
- Selected ‘Model/Run’ menu. Defined the start and end dates of the model run. Weather data should be available from all the stations for the selected period. Measured discharge or TSS concentration should be available at least for part of the simulation period.
- Compare the model results with measured file. ‘Result/Flow comparison’, ‘Ts output/TSS concentration’. The resulting time series window shows the computed and observed result. The ‘Report’ window shows statistical fit (r^2) and average observed and computed result.
- The model parameters changed to obtain better fit.

7.3 Model Calibration

First measured flow was compared with computed flow. The match was evaluated subjectively. The measured and computed flows were compared. Secondly sediment model was compared with measured sediment load with computed sediment load. The different initial parameter used in the model was obtained from the EIA Ltd. Model. Mukdahan TSS measured concentration was taken as a reference point for the model sediment concentration calibration point. The model was calibrated by using the observed flows from the period 1990 to 2000. For model calibration, the sediment data from MRC mainstream sediment monitoring stations were used. The several outflow points were placed in the model but the study was done at Chang Saen and Kratie basin. The main parameters taken in account for soil erosion were as follows:

1. Land use parameters / vegetation/ laimethod, laimin and laimax (vegetation growth and leaf area index sheltering ground)
2. Surface model/ pbare (fraction of bare land area; used only when value was negative; otherwise from leaf area; for instance -0.8 means 20% of land area is bare and exposed to rain)
3. Surface model/ pcanopy (fraction of high trees of vegetation)

4. Soil parameters/Erosion/ksd (erosion detachment parameter, higher value with larger bare area implies more erosion)

Figures 19, 20 and 21 show comparisons between computed and measured river discharge. The red line shown in the figures measured flow and the black line is computed flow. Statistical fit (r^2) values for the flow are 0.62, 0.89 and 0.88, respectively. The measured and computed flow at Mukdahan and Kratie is fitted 90%.

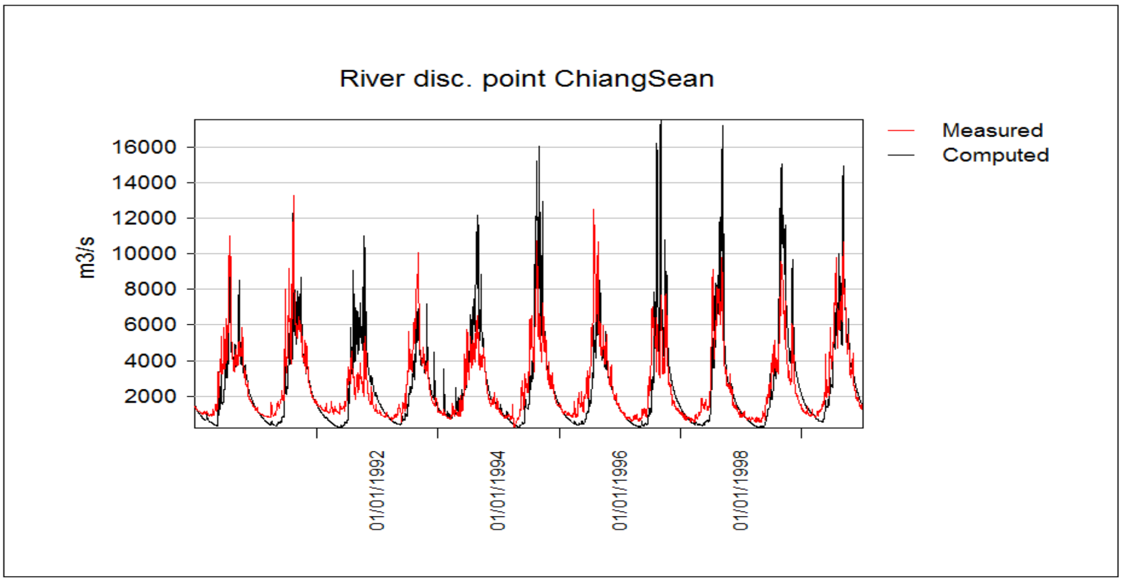

Figure 19. Measured and computed flow at Chiang Saen River from 1990 to 2000

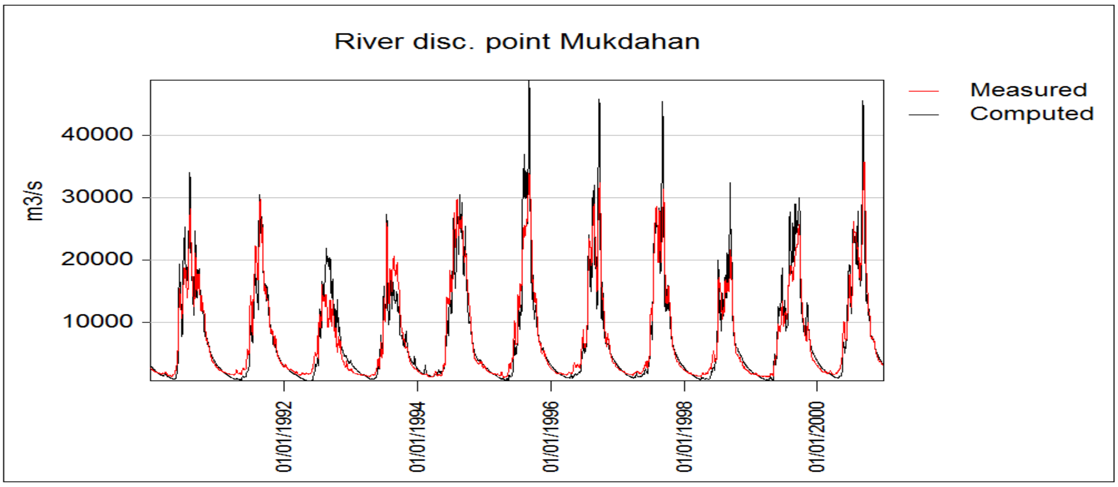

Figure 20. Measured and computed river discharge at Mukdahan from 1990 to 2000

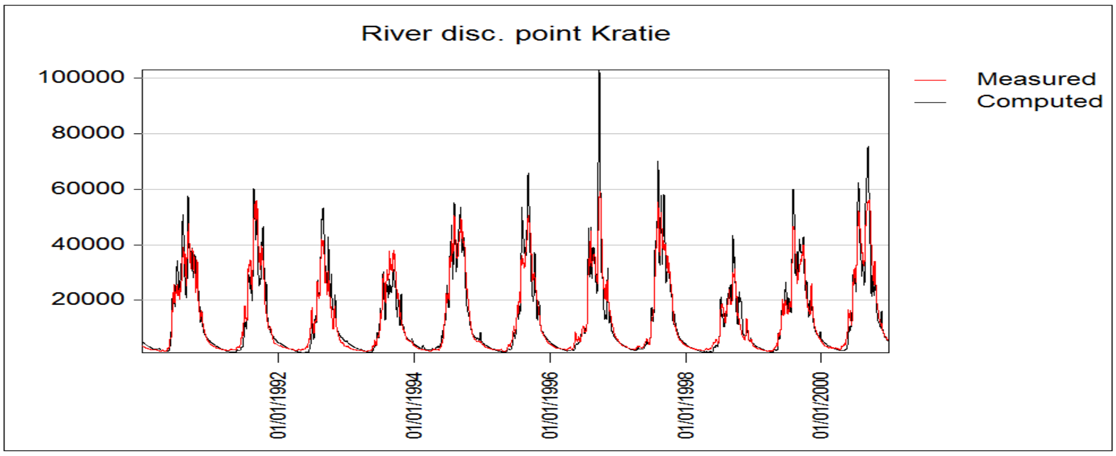

Figure 21. Measured and computed discharge at Kratie River from 1990 to 2000

Figure 22 shows a comparison between the computed and measured sediment load from 1990 to 2000. The measured TSS concentration available for the Chiang Saen River was not accurate and Kratie does not have measured TSS concentration data. So, for the model calibration measured Mukdahan TSS concentration was used to compare the computed TSS concentration.

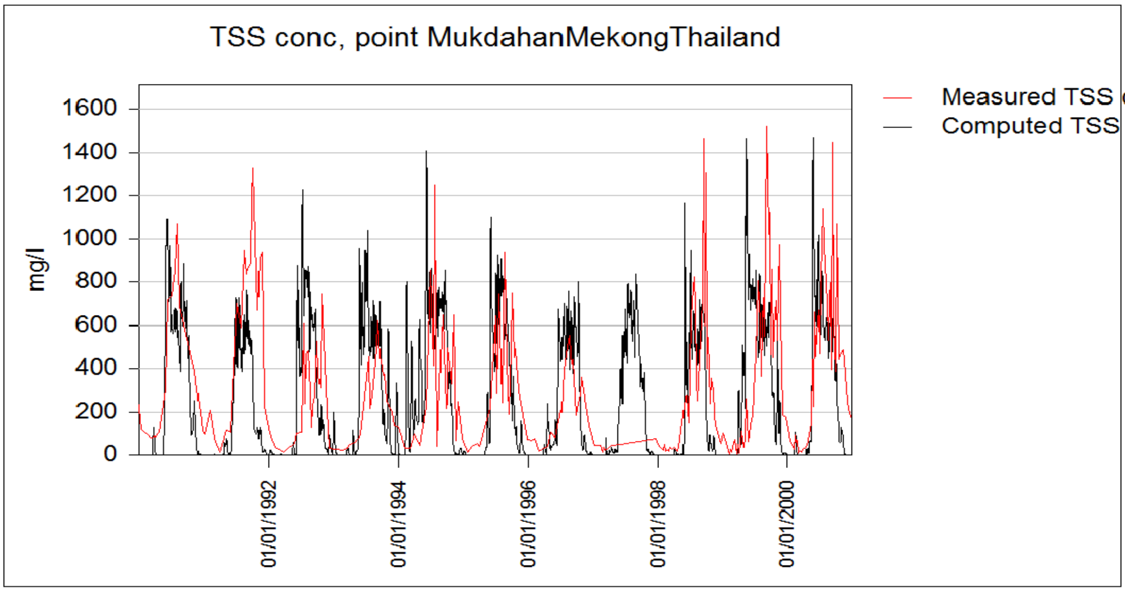

Figure 22. Measured and computed TSS concentration at Mukdahan River from 1990 to 2000

For further calculations, flow was multiplied with TSS concentration to get TSS load. The use of sediment concentration was not justified so further changes in parameter value were needed to achieve required amount of sediment load.

8 Result and Discussion

8.1 Flow Statistics measured and simulated result

In order to study river discharge three Output Ts points was selected. Chiang Saen Ts point which collect all the water coming from UMB, Mukdahan output Ts point is located in Thailand and Laos border and Kratie output Ts point which is located in Cambodia. Finally the river flows through Vietnam and end to South China Sea.

Table 7. Flow statistics at the Chiang Saen, the Mukdahan and the Kratie River from 1990 to 2000

Location	Average flow (m3/s)		Maximum flow (m3/s)		Minimum flow (m3/s)	
	Simulated	Measured	Simulated	Measured	Simulated	Measured
ChiangSaen	2644.29	2638.78	10472.20	8071.29	267.09	496.93
Mukdahan	7678.40	7676.87	31938.70	26816.70	678.41	1331.29
Kratie	13491.90	13299.40	54593.30	50580.20	1231.08	1736.15

Table 7 shows flow statistics. Kratie River is located at the lower Mekong basin and it collects whole Mekong water. Thus it has high flow rate. Chiang Saen River is located atupper Mekong basin and it collects water from small part of China border. The flow at the Chiang Saen River is much low than that of the Kratie River. The Dam flow is maintained according to average flow rate. In the monsoon season, the river out flow is higher than average flow rate but in the dry season, the flow remains constant to average flow.

8.2 Estimated TSS load

Sediment load is calculated by using formula flow multiplied by total suspended sediment concentration. The Chiang Saen River is located at the upper Mekong basin; its TSS load measured shows the total load coming from China. Kratie River calculates the TSS load of whole Mekong basin. The Figure 23 shows computed daily sediment load in kg/d at Kratie, Mukdahan and Chiang Saen River. The annual sediment load of Figure 24 was calculated from Figure 23. The unit is million tonnes/ y.

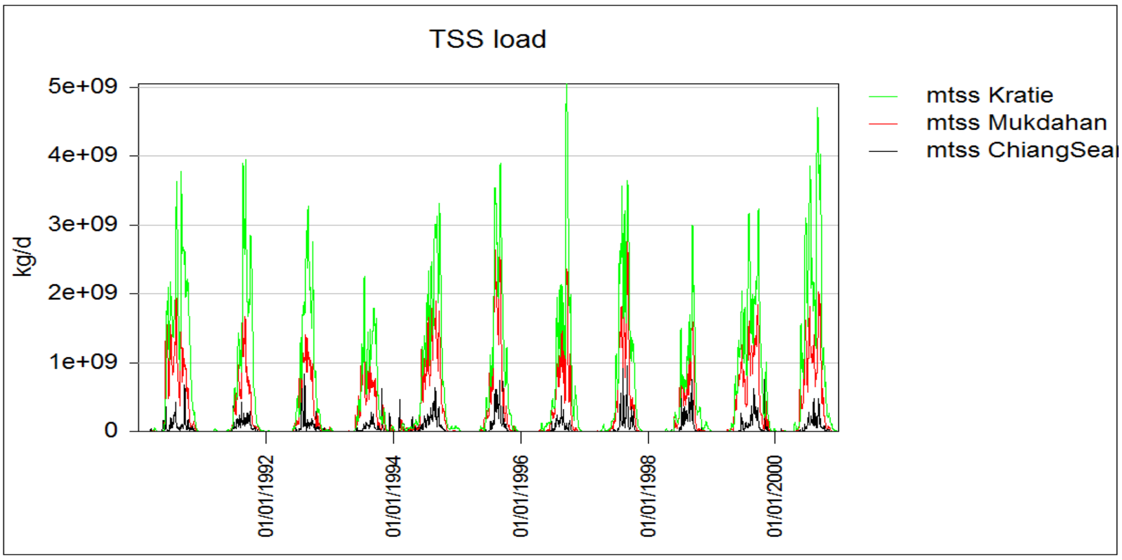

Figure 23. Computed TSS load at the Chiang Sean, the Mukdahan and the Kratie River from 1990 to 2000

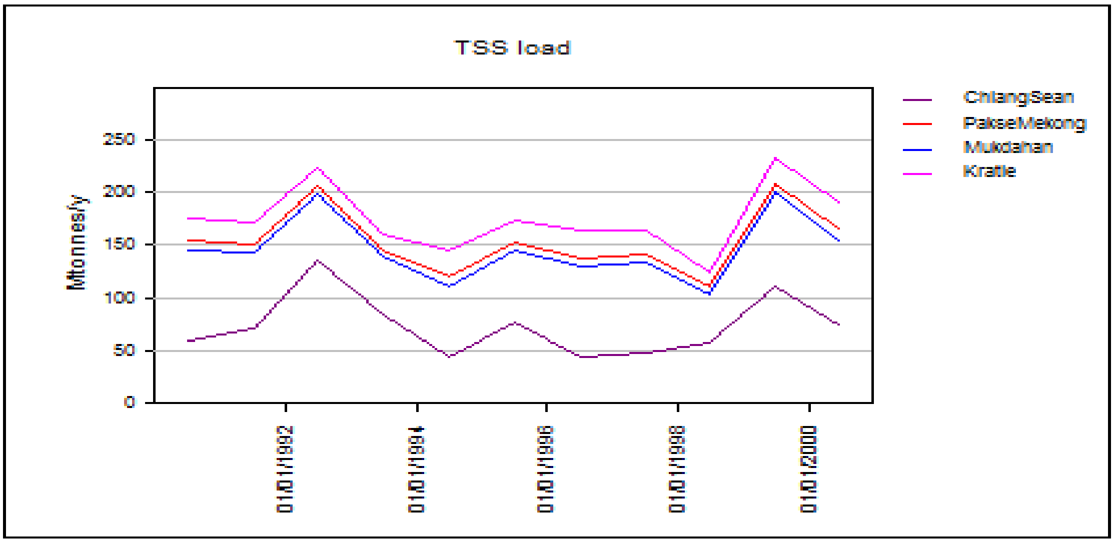

Figure 24. Yearly sum TSS load at the Chiang Sean, the Mukdahan, the Pakse and the Kratie River from year 1990 to 2000

First, model was computed without using the reservoir to calculate TSS load at the selected output point in the model (Figure 15). The model was computed from 1990 to 2000. The TSS load unit is million tonnes/ y. Total yearly, the Kratie River TSS load varies between 114 and 223 million tonnes/ y. The average annual load is 165 million tonnes/ y. The Chiang Saen River TSS load variability ranges from 43 to 134 million tonnes/ y. Most of the Chiang Saen River TSS load is coming from the Chinese border. The average annual sediment load is 71.04 million tonnes/ y. The Chiang Saen contribute 43% of TSS load, Central highland in Vietnam -3S (Se Kong, Se San and Sre-Pok sub-basins) contributes 11% and the rest of the TSS load is 46% from Thailand

and Laos. Sarkkula, J.et.al. [9] report China contributes 55% (91 million tonnes/ y) sediment load, the 3S contribute 11% (18 million tonnes/y) and the rest contribute 34% (56 million tonnes/y). Kummu et al. [1] report state that the majority of the Mekong sediment originates from two areas: Lancang sub-basin contributes 65% and the 3S area in Vietnam contributes approximately 13% of the sediment load. The difference between the Kratie and the Pakse sediment load is approximately equal to that of the 3S region and the difference between the Pakse and the Chiang Saen sediment load is approximately equal to the remaining sediment load.

Table 8. Yearly TSS loads from different basins. No reservoirs included in the simulation.

	Yearly TSS load without using reservoirs (million tones/ y)			
	ChiangSaen	Mukdahan	Pakse	Kratie
1990	58	139	147	163
1991	69	138	145	162
1992	134	195	202	215
1993	84	136	140	154
1994	42	107	114	136
1995	73	138	146	163
1996	43	124	132	152
1997	45	127	134	152
1998	54	99	104	114
1999	109	196	202	223
2000	71	147	157	177
Total	781	1546	1621	1810
Annual Average TSS Load	**71**	**141**	**147**	**165**

In Table 9 average annual TSS loads are presented after calibrating the model and comparing them with those of Sarkkula, J.et.al. [9]. The report presented average annual sediment load from 1990 to 2000.

Table 9. Comparison average yearly TSS loads from different parts of Mekong Basin. Modeling period is from 1990 to 2000

Place	Average annual TSS load (million tones/y)			
	Sarkkula, J. et al., 2009 report	%	Computed	%
Chiang Saen	91	55	71	43
rest	56	34	76	46
3S	18	11	18	11
Kratie	166		165	

*3S is Sediment load at Kratie subtracted Pakse sediment load

* Central highland in Vietnam -3S (Se Kong, Se San and SrePok sub-basin)

When comparing the results computed by the model with those of Sarkkula, J. et.al. [9], the Chiang Saen TSS load decreases by 20 million tonnes/ y and the TSS load from Thailand and Laos (rest) increases by 20 million tonnes/ y. According to Jorma Koponen, one of the supervisors of this thesis suggested to increase precipitation height correction (maximum height was set 3500 m and changed to 6000 m) the result does not shows much difference, weather station precipitation was manipulated (precipitation increases 10 times) and the result showed the increase in TSS load. The supervisor concluded that UMB soil type need separate classifications therefore; model computed result was taken for further calculation.

8.3 Estimated sediment load existing and planned mainstream reservoirs

Figure 17 shows mainstream reservoirs and sub-basins reservoirs. The model used only planned and existing mainstream reservoirs (Figure 17A). At the Upper Mekong Basin (UMB), there are eight reservoirs of which six reservoirs are included in the model. Ganlanbe and Mengsong reservoirs are not included because the reservoirs data (Reservoir monthly flow and the volume-area data) are not available. In the lower Mekong Basin (LMB), there were 12 proposed mainstream reservoirs where data from 10 mainstream reservoirs were included in the model simulation.

Table 10. Yearly sediment load from different basins with mainstreams reservoirs. The model runs from 1990 to 2000.

	Sediment Trapped by the main stream reservoirs (million tones/y)			
	Chiang Saen	Mukdahan	Pakse	Kratie
1990	7	85	90	44
1991	8	77	82	44
1992	2	63	68	36
1993	1	53	56	30
1994	1	66	71	43
1995	5	69	75	41
1996	1	83	88	48
1997	2	84	88	45
1998	4	48	51	29
1999	2	89	92	49
2000	1	77	84	46
Total	33	795	845	456
Annual average sediment load	**3**	**72**	**77**	**41**

The annual average sediment load in Table 10 was obtained after computing the model by using 16 main stream reservoirs. After comparing Table 9 and Table 10, the decrease in sediment load seems to be due to reservoirs. The model runs from 1990 to 2000, and the result shows that in the UMB 96% of the sediments is trapped by six reservoirs and that the total Mekong sediment decreases by 75%, because of all 16 reservoirs.

8.4 Theoretical Trapping efficiency using modified Brune's equation

Theoretical trapping efficiency is calculated by using Equation 1 and Equation 2 which are presented in section 6.4. Trapping efficiency is calculated by using active storage. The dead storage was not included in the model. Siltation is the process that fills up the reservoir with the time scale of several decades. Here, using active storage in the calculation ensures that TE or T_e value are not impacted significantly on the siltation. Residence time (ΔT_{ms}) is the time water remains in the reservoir. In the UMB residence time (ΔT_{ms}) varies between 0.008 to 0.132 yr and in the LMB residence time varies from 0.001 to 0.01 yr. After the local residence time was calculated, Brune's method was used to estimate the individual reservoir trapping efficiency. In the calculations, the curve constant α was kept at 1, representing the median curve in Brune's method.

Table 11.Trapping efficiency calculation of individual reservoir using the Brune method

General information					*TE* results
		Q_{ms} km^3 yr^{-1}	V km^3	ΔT_{ms} Yr	TE_{ms}
Upper Mekong Basin (UMB) Reservoirs					
1	Gonguoqiao*	28.18	0.18	0.006	0.38
2	Xiaowan*	32.11	4.02	0.125	0.86
3	Manwan*	42.48	0.33	0.008	0.43
4	Dachaoshan*	43.14	0.32	0.008	0.42
5	Nuozhadu*	41.49	5.48	0.132	0.86
6	Jinghong*	42.84	0.40	0.009	0.48
Lower Mekong Basin (LMB) Reservoirs					
7	Pakbeng	97.97	0.51	0.005	0.31
8	LBP	104.29	0.81	0.008	0.43
9	Sayaburi	131.64	0.26	0.002	0.00
10	Paklay	136.92	0.48	0.003	0.15
11	Sanakham	143.24	0.13	0.001	0.00
12	Pakchom	143.42	0.30	0.002	0.00
13	Ban Koup	269.52	0.65	0.002	0.00
14	Don Sahong	310.60	0.21	0.001	0.00
15	Strung Treng	393.35	0.47	0.001	0.00
16	Sambour	395.41	2.20	0.006	0.33

*Existing main stream reservoir, A_{ms}: drainage area at location of a mainstream reservoir,
Q_{ms}: discharge at a mainstream reservoir, V: active storage volume of a mainstream reservoir,
ΔT_{ms}: residence time of a mainstream reservoir, TE_{ms}: trapping efficiency of a mainstream reservoir.

Table 11 shows that trapping efficiency for the sixteen main stream reservoirs varies from zero to 86%.The mainstream reservoir in the UMB have much larger T_e value than in the LMB due to their large storage capacity and smaller discharge. The largest planned reservoirs Xiaowan and Nuozhadu in upper Mekong basin have potential to trap 86% of sediment load. T_e in lower Mekong basin varies between 0% for six run-off-the river dams (Sayaburi and from Sanakham to Strung Treng) to 43% in LPB (Luang-Prabang). T_e is 31% at Pakbeng and 33% at Sambour reservoirs while 15 % for the Paklay.

8.5 Annual average sediment load trapped by reservoirs and its efficiency

Trapping efficiency of dams was calculated by using Equation 3 presented in section 6.5. The incoming sediment is subtracted by out coming sediment from reservoirs. Trapping efficiency is the percentage of sediment trapped.

Table 12. Annual average TSS loads with and without reservoir and percentage of TSS load trapped by the reservoirs.

Main stream Reservoirs	Annual average TSS load		Net TSS load trapped by reservoirs	Trapping Efficiency Of reservoirs
	million tones/ y		Million tones/ y	%
	Before reservoir	After reservoir		
Gongouqiao*	26.14	12.56	13.58	52%
Xiaowan*	18.43	3.27	15.16	82%
Manwan *	41.26	25.51	15.75	38%
Dachaoshan *	25.53	15.38	10.15	40%
Nuozhadu*	16.38	2.79	13.59	83%
Jinghong *	2.79	2.35	0.43	16%
Pakbeng	3.03	2.87	0.16	5%
LPB	2.88	2.72	0.15	5%
Sayaburi	2.83	2.82	0.01	0%
Paklay	2.82	2.70	0.12	4%
Sanakham	2.71	2.70	0.01	0%
Pakchom	2.68	2.68	0.00	0%
Ban Koup	73.54	71.46	2.09	3%
Don Sahong	78.15	71.56	6.59	8%
Strung Treng	73.70	70.78	2.92	4%
Sambour	75.69	34.47	41.22	54%

*Existing mainstream reservoirs

From the Table 8 Xiaowan and Nuozhadu has the highest trapping efficiency 82% and 83%. From the Brune empirical model (Table 9) trapping efficiency of Xiaowan and Nuozhadu shows 83%. However, the model calculated using Equation 3 shows a 52% trapping efficiency for Gonguoqiao and a 54% trapping efficiency for Sambour, while the corresponding figures yielded by the Brune model are 38% and 33% respectively. Compared to the percentage of Brune model, Jinghong, Pakbeng, LPB, and Paklay show lower trapping efficient values calculated by using Equation 3. Ban Koup, Don

Sahong and Strung Treng shows T_e value of 3%, 8% and 4% while, the Brune model shows a T_e value of 0%.

8.6 Impacts of hydropower development at upper and lower Mekong basin

Hydropower is considered a clean source of energy. Hydropower development raises the economy and fulfils rising energy demand of the Mekong riparian countries, especially China, Thailand and Vietnam. The Mekong mainstream dam poses direct future threat to the river, and to the tens of millions of people who depend on it for their food and livelihoods. The China-operated dams already block the flow of nutrient-rich silt and phosphorus that sustains soil productivity, nurtures fisheries and keep the sea at bay in the Mekong Delta. The proposed Mekong dams would block the spawning migration of hundreds of species of important food fish as well as cause the extinction of several species such as the giant Mekong Catfish and fresh water dolphin. In the future, expected threats can be climate change, specifically rising sea levels, shifting rainfalls patterns, drought, flood, costal inundation and salt intrusion. [15]

8.6.1 Positive Impacts

Hydropower dam development accelerates the economy of the people. Dams constructed for hydropower help in increasing flow in dry seasons. It increases the option for irrigation in dry seasons. In the Mekong delta in Vietnam, increasing dry season flow may reduce saline water intrusion, benefiting rice farming and aquaculture. Higher water levels during the dry season may also ease navigational activities in many places.

8.6.2 Negative impacts

The negative side effect of dam construction can cause water flow alteration, sediment load trapping, disturb water ecosystem and several impacts on the environment and the livelihoods of the rural Mekong population. Construction of dams changes the natural flow pattern. It also declines the water quality. Flow pattern changes causes negative impacts on riverine habitats. The slight increase in the dry season flow pattern may flood important ecosystem, whereas decrease in the wet season flow affect biological productivity. Sediment coming from upper Mekong contains silt and phosphorus which is important for agriculture land gets trapped by the dams. Mekong entering to Vietnam, it already forms a delta, leaving no opportunity in dam construction. [19]

9 Conclusion

Understanding natural phenomena is a slow and complicated process. A wide range of tools have been developed for understanding the effects of hydropower development, and for identifying and describing these effects. The IWRM-model developed help to determine the sediment load coming from different parts of the Mekong Basin, the transportation and trapping of sediments by the reservoirs. It also helps in studying the erosion pattern by geographical component such as land use and soil use class. Further, the results from the model help in future dam construction planning, which can minimise the effect on the downstream environment. For the future study, the model results not only yield the environmental challenges but also help in finding possible solutions.

The results of this thesis show that the total sediment load generated at Kratie Basin which is finally going to South China Sea decreases due to dam sediment trapping. The increase in hydropower development will result in a decrease in sediment load, which also shows large impact in hydrology and downstream ecosystem change. Special attention will have to pay on sediment deposition which decreases the reservoir capacity and also decreases the electricity production efficiency.

10 References

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1. Sensitivity analysis result

Parameters	Base Value	New Vale	Change	**Cumulative**	Cumulative Flow	**base**	Base flow	**peak**	Peak flow
			%	**m3/s**	%	**m3/s**	%	**m3/s**	%
Rainmult	1	1.3	30%	**1.07E+07**	45.48%	**18510.87**	26.70%	**100091**	48.03%
Petcorr	0.6	1	67%	**5.63E+06**	-23.16%	**12230.15**	-16.29%	**54885.5**	-18.83%
Laimethod	1	1.5	50%	**7.32E+06**	0.00%	**14610.11**	0.00%	**67616.1**	0.00%
Laimin	0.5	1	100%	**6.37E+06**	-12.96%	**12973.96**	-11.20%	**64159.6**	-5.11%
Laimax	3	5	67%	**7.32E+06**	0.00%	**14610.11**	0.00%	**67616.1**	0.00%
Pbare	0.3	0.8	167%	**7.32E+06**	0.00%	**14610.11**	0.00%	**67616.1**	0.00%
Pcanopy	0.1	0.5	400%	**7.32E+06**	0.00%	**14610.11**	0.00%	**67616.1**	0.00%
KSD	0.5	1	100%	**7.32E+06**	0.00%	**14610.11**	0.00%	**67616.1**	0.00%

Parameters	Base Value	New Vale	Change	**Cumulative**	Cumulative TSS	**Base**	Base TSS	**Peak**	Peak TSS
			%	**kg**	%	**kg/d**	%	**kg/d**	%
Rainmult	1	1.3	30%	**1.48E+11**	66.62%	**1.28E+08**	63.16%	**1.77E+09**	57.10%
Petcorr	0.6	1	67%	**7.25E+10**	-18.60%	**62626110**	-20.26%	**1.02E+09**	-9.65%
Laimethod	1	1.5	50%	**8.91E+10**	0.00%	**78534860**	0.00%	**1.13E+09**	0.00%
Laimin	0.5	1	100%	**8.01E+10**	-10.04%	**75390270**	-4.00%	**1.1E+09**	-2.84%
Laimax	3	5	67%	**8.91E+10**	0.00%	**78534860**	0.00%	**1.13E+09**	0.00%
Pbare	0.3	0.8	167%	**2.41E+11**	170.12%	**2.13E+08**	171.16%	**3.05E+09**	169.79%
Pcanopy	0.1	0.5	400%	**1.03E+11**	15.66%	**99859620**	27.15%	**1.24E+09**	9.58%
KSD	0.5	1	100%	**1.77E+11**	98.85%	**1.56E+08**	98.21%	**2.25E+09**	99.41%

Base line	**flow**	**TSS load**
cumulativ	7320944	8.91E+10
Base	14610.11	7.85E+07
peak	67616.10	1.13E+09