Mekong River Commission

Technical Support Division
Information and Knowledge Management Program

Component 4: Modelling

Draft Working Paper

The SWAT Model
for Sediment and Nutrient Simulation
in the Mekong River Basin

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CONTENTS AMENDMENT RECORD

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1. Introduction

The Hydrological Model (SWAT), the basin simulation model (IQQM) and Hydrodynamic model (iSIS) has been officially selected to use as the Basin Simulation Package of the Decision Support Framework (DSF) since year 2001.

The Initial SWAT has been set-up by Water Utilisation Project (WUP) and the consultant for the Lower Mekong River Basin from China-Lao Border down to Kratie in Cambodia, the SWAT was also applied for the tributaries around the Great Lake in Cambodia. The major purpose for using the SWAT inside the DSF is for estimating the sub-basin runoffs by providing historical climatic records. In March 2004, the consultant handed over to MRC the DSF package including the SWAT Model set-up and calibration and since there the DSF has been applied for assessments of various development scenarios.

The SWAT Models were reset-up and recalibration by MRCS Modelling Team in year 2005 for the area upstream of Kratie and in mid-2006 for the area around the Great Lake over the period 1985-2000. The model was revised in order to represent more existing topological conditions by diving into smaller sub basins and closer to the real land cover and soil conditions of the basin. Year 2007, The SWAT in Upper Mekong Basin was set-up to simulate flow from China by considering the effect from snow and dam in China. The SWAT model 2005 was setup with baseline data from year 1985 – 2000 with the Topography, land use from year 1997 and 2003 and uses a version of the SWAT code from 2003. Then the SWAT baseline model (SWAT2005) was complete set-up whole Mekong River Basin and has been used at MRCS and among riparian country to support for Basin Development Planning.

In year 2012, MRC Programme and member country requested the updating of the baseline models and period of simulation for MRC models, therefore the Modelling Team have been worked on the expansion of simulation period since early of year 2013. The Hydro-met data up to 2006/7/8 from member countries has been assembled to support the update of SWAT calibration and baseline. The effort have been put to review climate/hydrological data, checking quality of data, re-schematization with the update river network (2010) and location of proposed dam, set-up SWAT model on ARCGIS with more detail on DEM 50 m and HRU.

The SWAT models (SWAT2013) over period 1985-2008 currently is enhancing capacity to simulation not only flow both will be included sediment and nutrient simulation. The model will be used as the standard hydrological models in a number of MRCS studies including the Council Study, FMMP Climate sensitive flood management, CCAI/FMMP Basin wide Studies on Flood Management including the Cambodian Floodplain and Vietnam delta, future BDP work etc.

2. The Data Available and Analysis

The data available through the MRCS could be used for the modelling as this data had to be available to all the riparian countries where such data was insufficient, use has been made of public domain global datasets.

The basic inputs to the SWAT model include the following:

- Topography data/Digital Elevation Model
- Land Cover/Land Use data
- Soil data
- Time-series of daily climatic data including maximum and minimum temperature, relative humidity, solar radiation and wind speed.
- Time-series of daily rainfall data throughout the basin
- Time-series of gauged flow
- Reservoir Data

The detail of dataset already describes in The SWAT flow application report (Modelling Team, 2014) and in this report will discuss only sediment and nutrient dataset.

2.1 The Sediment and Nutrient monitoring station

The data available through the MRCS was collected and documented in working paper "The Sediment and Nutrient Data Available for the DSF model Simulation" (Modelling Team, 2015). The summary of number station as below;

Available Sediment station

- Hymos database
    - o available 60 stations mainstream : 9 stations Tributary 51 stations
- EP database
    - o available 70 stations mainstream : 8 stations Tributary 62 stations
    - o Exclude 61 stations in Mekong Delta (no SWAT in Cambodia Floodplain and Mekong Delta)
- DSMP database
    - o available 11 stations mainstream : 10 stations Tributary 1 stations
    - o Exclude 6 stations in Mekong Delta (no SWAT in Cambodia Floodplain and Mekong Delta)

Available Nutrient (Nitrogen and Phosphorus) station

- EP database
    - o available 70 stations mainstream : 8 stations Tributary 62 stations
    - o Exclude 61 stations in Mekong Delta (no SWAT in Cambodia Floodplain and Mekong Delta)

After checking the length of data then only some station that has enough record of data was selected for further check QA/QC and using for SWAT calibration in Area 0 – A9

Selected Sediment station

- Hymos database : mainstream : 8 stations Tributary 21 stations
- EP database: mainstream : 7 stations Tributary 16 stations
- DSMP database : mainstream : 10 stations

Selected Nutrient (Nitrogen and Phosphorus) station

- EP database
  - Nitrogen mainstream : 8 stations Tributary 12 stations
  - Phosphorus mainstream : 8 stations Tributary 15 stations

2.2 Approach for the data analysis

The process to analysis Sediment/Nutrient Dataset describe below:

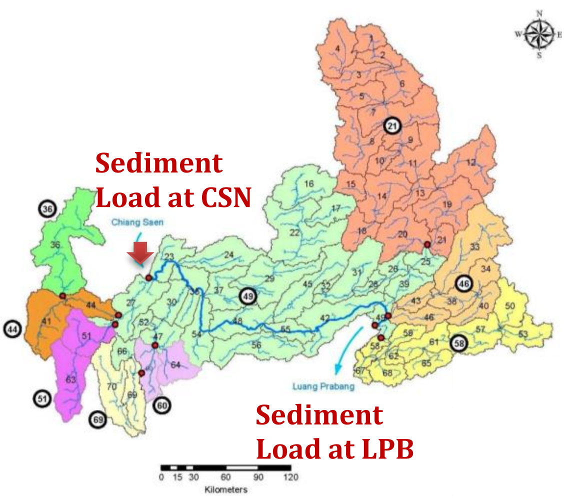
(1) Check quality and consistent of data as detail in QA/QC (Report 1, WQ data analysis).
(2) Sediment concentration (mg/l) collected in monthly (2-3 times/month for HM and 1 time/month for EP) will be used to estimate Sediment Load (Ton) using Loadest software for create sediment rating curve.
    a. By providing the daily flow, we can estimate daily load (both sediment and nutrient). However based on measurement do in monthly basis because of many of uncertainty in the system, therefore the estimate load will be summary in monthly.
    b. Loadest software will calculated correlation of flow and sediment concentration when data are available in term of "Sediment Rating Curved" then will apply these rating curve to estimate the daily sediment load from the daily flow.
    c. The evaluation of "Sediment Rating Curved" will be check for each monitoring station, before using for SWAT calibration.
(3) Sediment yield (Load per catchment area) will be calculated at each monitor station in tributary to check the possibility of sediment production and will used as guidance to estimated sediment supply to the Mekong Mainstream.
(4) Guidance of Potential sediment production in the Lower Mekong River Basin based on GIS analyses and sediment monitoring result from DSMP project will be used for verify the Load estimation.
(5) The result from each monitor station will be considered for using case by case.
(6) The similar approach will be used for nutrient (total nitrogen and total phosphorus)

The details are describe in Report "The Sediment and Nutrient Data Available and Analysis for DSF Model Simulation in the Lower Mekong Basin"

The steps to estimate sediment Load for using in process of SWAT calibration on the Mekong mainstream are:

(1) The Sediment Load from Tributary between Chiang Saen - Kratie

- Load at Key Monitoring station i.g. CSN, LPB, CKN, NKI, NKP, MDH, KCM,PKS, STT and KRE from year 1985 -2008 will calculated from "Sediment Rating curved"(relation between flow & Sediment Load) that created from DSMP correlation year 2009-2013
- The different of load from each station will be used to calibrate related parameter inside the SWAT sub area. For example; SWAT Area 2 can start to calibrate load from CSN – LPB by using Load at CSN (from DSMP eq) as inlet and calibrate result of load at Luang Prabang (from DSMP eq) as target.



The SWAT model for each area can use the similar concept as flow calibration, using Observed Load (from loadest estimation) to be inlet then calibrated the area between 2 key monitoring stations.

(2) Sediment Load at Chiang Saen used from EP dataset that cover study period (1985-2008) and downscale up based on compare data from 2009-2013 between EP and DSMP dataset. The load at Chiang Saen will be target to calibrate SWAT A0 (Upper Mekong) and A1 (China – Laos Border to Chiang Saen). Once the calibration at Chiang Saen is look reasonable, then the SWAT calibration model will be connected.

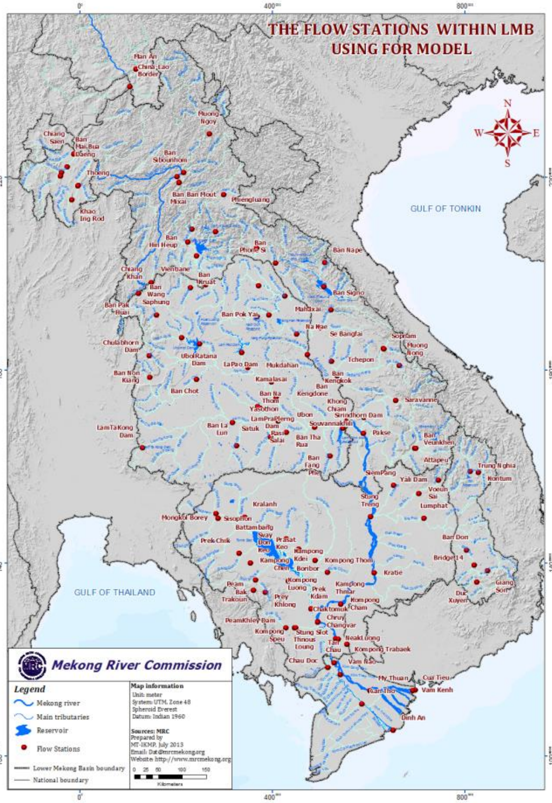
Runoff Location:	**Sediment Station Location:**	**Nutrient Station Location:**
	**on going**	**on going**

Figure 2 -1: Location of Monitoring station in Lower Mekong Basin for SWAT model

3. SWAT Sediment and Nutrient Process

The Soil and Water Assessment Tool (SWAT) is a small watershed to river basin-scale model to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds. The Soil and Water Assessment Tool (SWAT) is a public domain model jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research, part of The Texas A&M University System. SWAT for Mekong River Basin was setup on ArcSWAT 2012 that work on ARCGIS Interface, process of Model Set-up as shown in Figure 3.1-1

More detail on watershed delineation by SWAT software can be found from "User's Guide for ArcGIS Interface for SWAT2012".

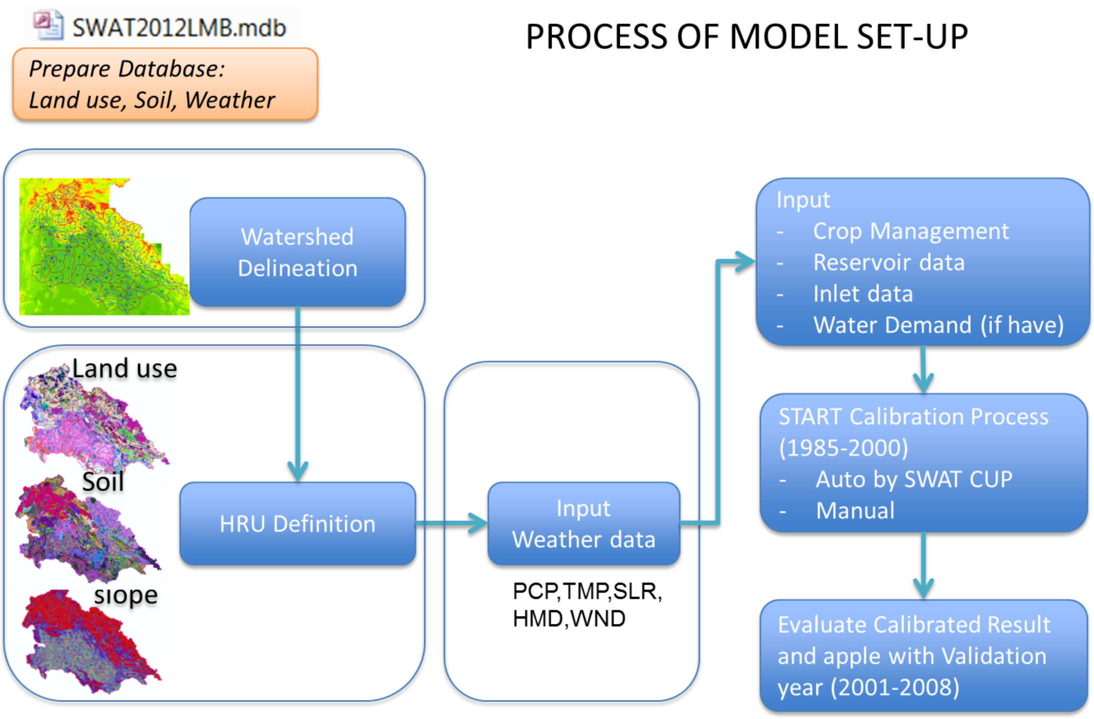


Figure 3.1-1: Process of SWAT Model Set-up

In this report will summarize only part of Sediment and Nutrient only; the process in SWAT model was divided to be two parts i.e. Land phase and Channel Process.

1. Land Phase

Sediment and Erosion (sources: SWAT manual):

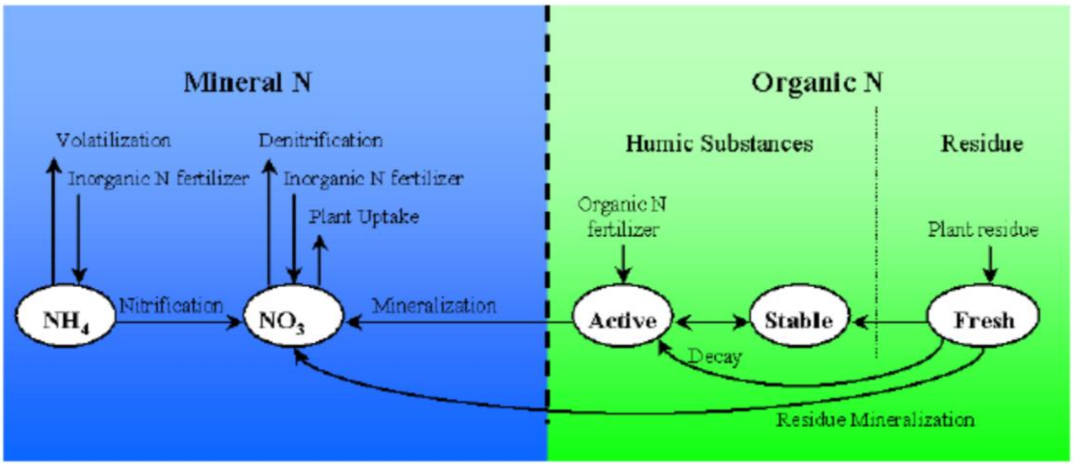
Erosion and sediment yield are estimated for each HRU with the modified Universal Soil Loss Equation (MUSLE). While the USLE uses rainfall as an indicator of erosive energy, MUSLE use the amount of runoff to simulate erosion and sediment yield. The substitution results in a number of benefits: the prediction accuracy of the model is increased, the need for a delivery ratio is eliminated, and single storm estimates of sediment yields can be calculated. The hydrology model supplies estimate if runoff volume and peak runoff rate which, with the subbasin area, are used to calculate the runoff erosive energy variable.

The crop management factor is recalculated every day that runoff occurs. It is a function of above ground biomass, residue on the soil surface, and the minimum C factor for the plant. Other factor of the erosion equation are evaluated as describe by Wischmeier and Smith (1978)

Nutrient (sources: SWAT manual):

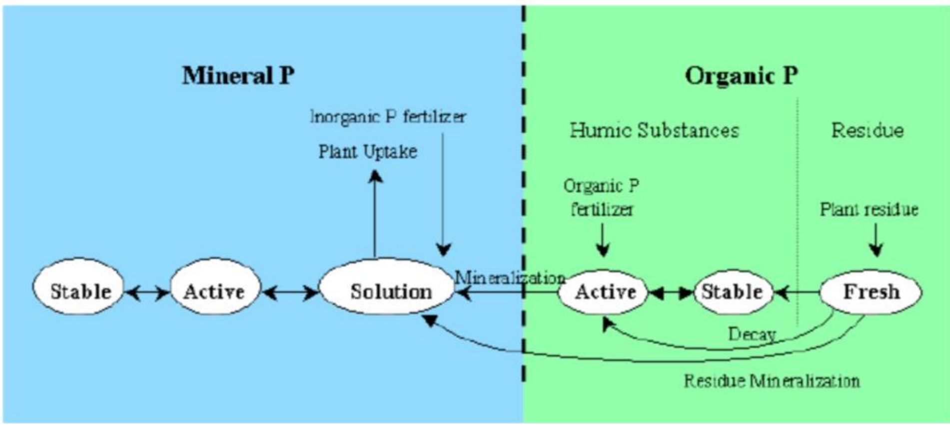
SWAT tracks the movement and transformation of several forms of nitrogen and phosphorus in the watershed. In the soil, transformation of Nitrogen from one form to another is governed by the nitrogen cycle. The transformation of phosphorus in the soil is controlled by phosphorus cycle. Nutrients may be introduced to the main channel and transported downstream through surface runoff and lateral subsurface flow.

Nitrogen: The different processes modelled by SWAT in the HRUs and the various pools of Nitrogen in the soil are depicted in Figure. Plant use of nitrogen is estimates using the supply and demand approach, in addition to plant use, nitrate and organic N may be removed from the soil via mass flow of water. Amounts of NO3-N contain in runoff, lateral flow and percolation are estimated as products of the volume of water and the average concentration of nitrate in the layer. Organic N transport with sediment is calculated with a loading function developed by McElroy et al. (1976) and modified by Williams and Hann (1978) for application to individual runoff events. The loading function estimates the daily organic N runoff loss based on the concentration of organic N in the top soil layer, the sediment yield, and the enrichment ratio. The enrichment ratio is the concentration of organic N in the sediment divided by that in the soil.



The nitrogen cycle is key to biomass production, which in turn impacts ET and sediment yield. The nitrogen cycle is complex; it is generally not possible to validate these routines outside a research setting. Of particular importance are the total applied nitrogen fertilizer and losses due to plant uptake, and volatilization and denitrification. Soils contain a large amount of organic nitrogen in the form of organic matter. Large changes in initial and final nitrogen contents (in particular organic n) may indicate under or over fertilization during the simulation.

Phosphorus: The different process modelled by SWAT in the HRUs and the various pools of phosphorus in the soil are depicted the figure. Plant use of phosphorus is estimated using the supply and demand approach, in addition to plant use, soluble phosphorus and organic P may be removed from the soil vis mass flow of water. Phosphorus is not a mobile nutrient and interaction between surface runoff with solutions P in the top 10 mm of soil will not be complete. The amount of soluble P remove in runoff is predicted using solution P concentration in the top 10 mm of soil, the runoff volume and a portioning factor. Sediment transport of P is simulated with a loading function as described in organic N transport.



The phosphorus cycle is of particular interest in watersheds with significant animal manure application. Soils contain a large reservoir of both mineral and organic phosphorus. Large increases in mineral phosphorus content during the simulation often result from overfertilization with either commercial or manure phosphorus sources. This also means that phosphorus concentrations in runoff also increase during the simulation period. Plant uptake is the dominant loss pathway for soil phosphorus under most conditions.

2. **Routing Phase**

Sediment Routing: The transport of sediment in the channel is controlled by the simultaneous operation of the two processes, deposition and degradation. The equations have been simplified and the maximum amount of sediment that can be transport from a reach segment is a function of the peak channel velocity. Available stream power is used to reentrain loose and deposited material until all of the material is removed. Excess stream power causes bed gradation. Bed degradation is adjusted for stream bed erodibility and cover.

Nutrient Routing: Nutrient transformations in the stream are controlled by the in-stream water quality component of the model. The in-stream kinetics used in SWAT for the nutrient routing are adapted from QUAL2E (Brown and Barwell, 1987). The model tracks nutrients dissolved in the stream and nutrients adsorbed to the sediment. Dissolved nutrients are transports with the water while those sorbed to sediments are allowed to be deposited with the sediment on the bed of the channel.

SWAT Model Parameter

After flow calibration for all 10 SWAT model (detail refer to SWAT flow report), the sediment parameter will adjust and follow with nutrient parameter.

Parameter related with Sediment

Process	Variable name		Definition	Min value	Max value
Reservoir	res	Res_NSED	Normal sediment concentration in the reservoir	1	5000
		Res_SED	Initial sediment concentration in the reservoir	1	5000
		Res_D50	Median particle diameter of sediment [um]	1	10000
Land Process	sol	USLE_K (1)	USLE equation soil erodibility (K) factor	0	0.65
	mgt	USLE_P	USLE equation support practice	0	1
	bsn	ADJ_PKR	Peak rate adjustment factor for sediment routing in the subbasin (tributary channels)	0.5	2
		SPEXP	Exponent parameter for calculating sediment reentrained in channel sediment routing	1	1.5
		SPCON	Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing	0.0001	0.01
		PRF	Peak rate adjustment factor for sediment routing in the main channel	0	2

Parameter related with Sediment

Process	Variable name		Definition	Min value	Max value
Channel Process	rte	CH_BNK_TC	Critical shear stress of channel bank (N/m2)	0	400
		CH_BED_TC	Critical shear stress of channel bed (N/m2)	0	400
		CH_BNK_KD	Erodibility of channel bank sediment by jet test (cm3/N-s)	0.001	3.75
		CH_BED_KD	Erodibility of channel bed sediment by jet test (cm3/N-s)	0.001	3.75
		CH_ERODMO(..)	Jan. channel erodibility factor	0	1
		CH_COV1	Channel erodibility factor	-0.05	0.6
		CH_COV2	Channel cover factor	-0.001	1
		CH_BED_D50	D50 Median particle size diameter of channel bed sediment (µm)	1	10000
		CH_BNK_D50	D50 Median particle size diameter of channel bank sediment (µm)	1	10000
		CH_BED_BD	Bulk density of channel bed sediment (g/cc)	1.1	1.9
		CH_BNK_BD	Bulk density of channel bank sediment (g/cc)	1.1	1.9
		CH_EQN	Sediment routing method	0	4
		CH_SIDE	Change in horizontal distance per unit vertical distance	0	5
		CH_S2	Average slope of main channel	-0.001	10

Parameter related with Nutrient

Process	Variable name		Indicator for	Definition	Min value	Max value
Reservoir	res/lwq	NSETLR1	N	Nitrogen settling rate in reservoir for months IRES1 through IRES2 (m/year)		
		NSETLR2	N	Nitrogen settling rate in reservoir for months other than IRES1 - IRES2 (m/year)		
		PSETLR1	P	Phosporus settling rate in reservoir for IRES1 through IRES2 (m/year)		
		PSETLR2	P	Phosporus settling rate in reservoir for months other than IRES1 - IRES2 (m/year)		
		IRES1		Beginning month of mid-year nutrient settling period.		
		IRES2		Ending moth of mid-year nutrient settling period		
Land Process	bsn	NPERCO	N	Nitrate percolation coefficient NPERCO controls the amount of nitrate removed from the surface layer in runoff relative to the amount removed via percolation	0	1
		P_UPDIS	P	Phosphorus uptake distribution parameter This parameter controls plant uptake of phosphorus from the diffirent soil horizons in the same way that UBN controls nitrogen uptake	0	100
		N_UPDIS	N	Ntrogen uptake distribution parameter Root density is greatest near the surface, and plant nitrogen uptake in the upper potion of soil will be greater than in the lower portion	0	100
		PSP	P	Phosphorus availability index	0.01	0.7

Parameter related with Nutrient

Process	Variable name		Indicator for	Definition	Min value	Max value
Land Process	bsn	SDNCO	N	Denitrification threshold water content Fraction of field capacity water content above which denitrification takes place. Denitrification is the bacterial reduction of nitrate, NO3-, to N2 or N2O gages under anaeroboc (reduced) conditions	0	2
		CDN	N	Denitrification exponential rate coefficient This coefficient allows the user to control the rate of denitrification	0	3
		CMN	N	Rate factor for humus mineralization of active organic nutrients (N and P)	0.001	0.003
		RSDCO	N	Residue decomposition coefficient	0.02	0.1
		PHOSKD	P	Phosphorus soil partitioning coefficient (m3/Mg) Phosphorus soil partitioning coefficient is the ratio of the soluble phosphorus concentration in the surface 10mm of soil to the concentration of soluble phosphorus in surface runoff	100	200
		PPERCO	P	Phosphorus percolation coefficient (10m3/Mg) The phosphorus percolation coefficient is the ratio of the solution phosphorus concentration in the surface 10mm of soil to the concentration of phosphorus in percolate	10	17.5
	chm	SOL_ORGN	N	Initial organic N concentration in the soil layer (mg N/kg soil or ppm)	0	50
		SOL_NO3	N	Initial NO3 concentration in the soil layer (mg N/kg soil or ppm)	5	50
		SOL_SOLP	P	Initial soluble P concentration in soil layer (mg P/kg soil or ppm)	1	25
		SOL_ORGP	P	Initial organic P concentration in the soil layer (mg N/kg soil or ppm)	1	50
Channel Process	wwq	AI1	N	Fraction of algal biomass that is nitrogen (mg N/mg alg).	0.03	0.14
		AI2	P	Fraction of algal biomass that is phosphorus (mg N/mg alg).	0.001	0.04
	swq	RS2	P	Benthic (sediment) source rate for dissolved phosphorus in the reach at 20 °C (mg dissolved P/(m².day)). If routing is performed on an hourly time step (see IVENT in .bsn file), the units of RS2 are converted to mg dissolved P/((m².hr) by the model.	0.001	10
		RS3	N	Benthic source rate for dissolved NH4-N in the reach at 20 °C (mg dissolved NH4-N/(m².day)). If routing is performed on an hourly time step (see IVENT in .bsn file), the units of RS3 are converted to mg dissolved NH4-N/((m².hr) by the model.	0	1
		RS4	N	Rate coefficient for organic N settling in the beach at 20 °C (day ^-1).	0.01	10
		RS5	P	Organic phosphorus settling rate in the reach at 20 °C (day ^-1).	0.001	2

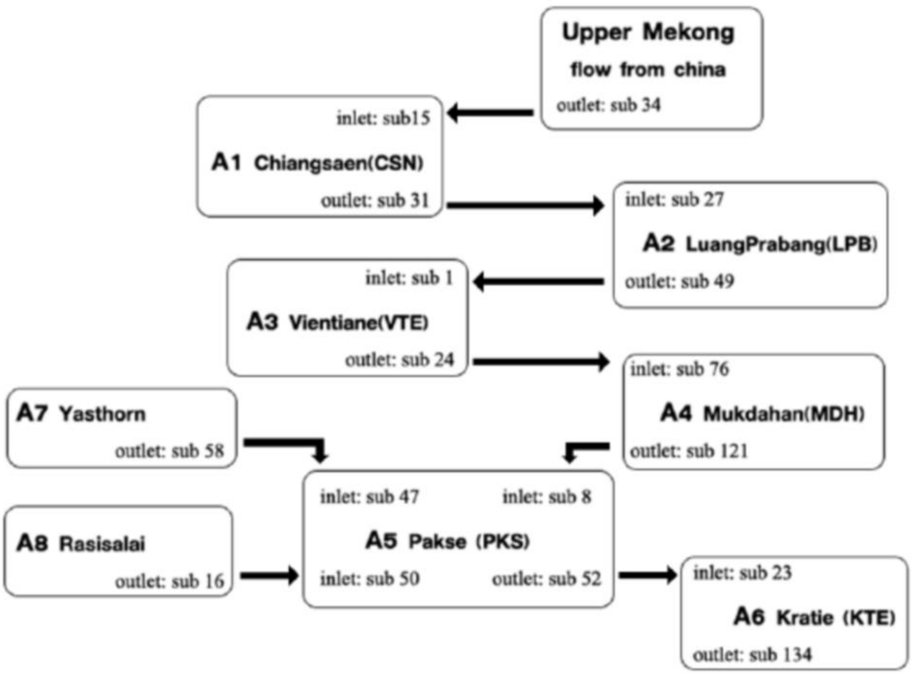
4. SWAT Model Setup and Calibration Process:

4.1 Model Configuration

SWAT model was reset-up to cover all area of Mekong River Basin (Figure 4.1-1) exclude Delta in Vietnam, the model has been split into ten sub-models from Area 0 in Upper Mekong Basin and A1-A9 in Lower Mekong Basin as detail in Table 4.1-1 In addition to the sub-basins in the Lower Mekong Basin, the East Vaico and West Vaico sub-basins in the Mekong flood affected area outside the basin also provide inputs to the hydrodynamic model. The basins were delineated using the SWAT utility. The West Vaico catchment as delineated by the SWAT utility was modified to ensure the boundaries were contiguous with the Prek Chhlong catchment boundaries identified by the Watershed Classification project.

Table 4.1-1: Watershed area of SWAT sub-models in Mekong River Basin

SWAT Sub-Model	River Reach	Area from SWAT Model (sq.km.)	Watershed area (sq.km.)	Remark
A0	Upper Mekong in China	162,300	162,300	Flow to A1
A1	Chinese border to Chiang Saen	31,460	193,760	Flow to A2
A2	Chiang Saen to Luang Prabang	80,100	273,860	Flow to A3
A3	Luang Prabang to Vientiane	30,140	304,000	Flow to A4
A4	Vientiane to Mukdahan	89,900	393,900	Flow to A5
A5	Mukdahan to Pakse	65,720	551,560	Flow to A6
A6	Pakse to Kratie	101,400	652,960	Flow to Kratie
A7	Chi up to Yasothon	47,110	47,110	Flow to A8 Mun
A8	Mun up to Rasi Salai	44,830	91,940	Flow to A5 (Mun + Chi)
A9	Around GreatLake	106,565	106,565	Cambodia/GreatLake
		Total	759,525	



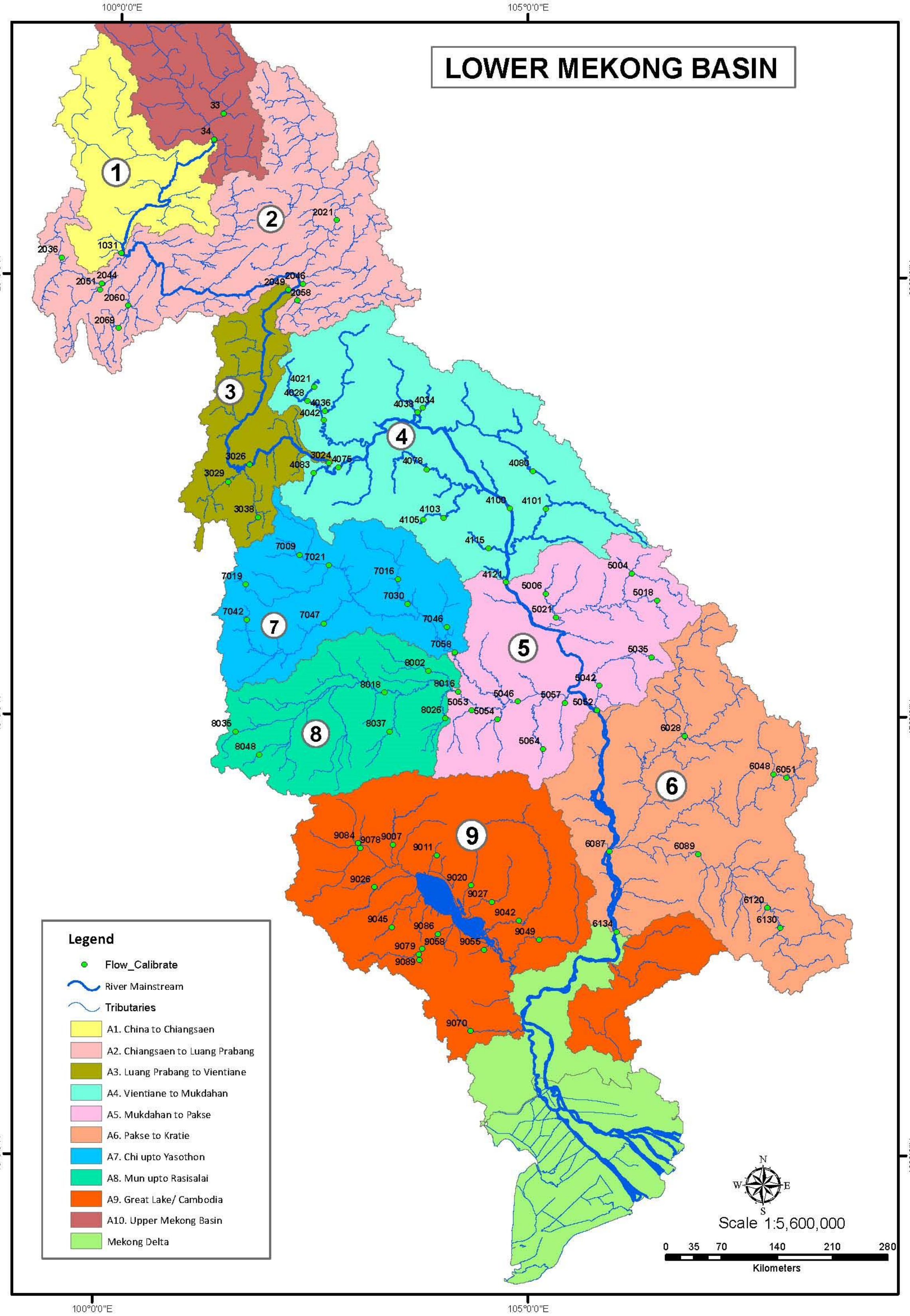


Figure 4.1-1: Boundary of SWAT Models in Mekong River Basin

4.2 Calibration Location

Sediment : There are 28 gauged stations in tributary were modelled for entire Mekong River Basin, with 9 gauged stations on Mekong Mainstream namely Chiang Saen, Luang Prabang, Nong Khai, Nakhon Phanom, Mukdahan, Khong Chiam, Pakse, Stung Treng and Kratie

Total Nitrogen: There are 13 gauged stations in tributary were modelled for entire Mekong River Basin, with 8 gauged stations on Mekong Mainstream namely Chiang Saen, Luang Prabang, Nong Khai, Nakhon Phanom, Khong Chiam, Pakse, Stung Treng and Kratie

Total Phosphorus: There are 15 gauged stations in tributary were modelled for entire Mekong River Basin, with 7 gauged stations on Mekong Mainstream namely Chiang Saen, Luang Prabang, Nong Khai, Nakhon Phanom, Khong Chiam, Pakse and Kratie

Area	***Mainstream***				***Tributary***			
	Flow	*Sediment*	*Total Nitrogen*	*Total Phosphorus*	*Flow*	*Sediment*	*Total Nitrogen*	*Total Phosphorus*
Area 0 :Upper Mekong Basin	0	0	0	0	1	0	0	0
Area 1: China Border to Chiang Saen	1	1	1	1	0	0	0	0
Area 2 : Chiang Saen to Luang Prabang	1	1	1	1	8	5	1	1
Area 3 : Luang Prabang to Vientiane	2	0	0	0	2	1	0	0
Area 4: Vientiane to Mukdahan	3	3	2	2	10	6	3	3
Area 5: Mukdahan to Pakse	2	2	2	2	10	5	3	3
Area 6: Pakse to Kratie	2	2	2	1	6	4	3	3
Area 7: Chi upto Yasothon	0	0	0	0	6	4	2	2
Area 8: Mun upto Rasisalai	0	0	0	0	5	1	1	1
Area 9: Around GreatLake / Cambodia	0	0	0	0	14	2	0	2
Total	**11**	**9**	**8**	**7**	**62**	**28**	**13**	**15**

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SWAT Model Simulation Period is year 1985-2008 with 4 years for warm up model (1980-1984). Model can provided result in Daily that based on flow simulation with daily rainfall and climatic input. The result for sediment and nutrient will evaluate in monthly at the calibration location and whole period will be used for calibration process.

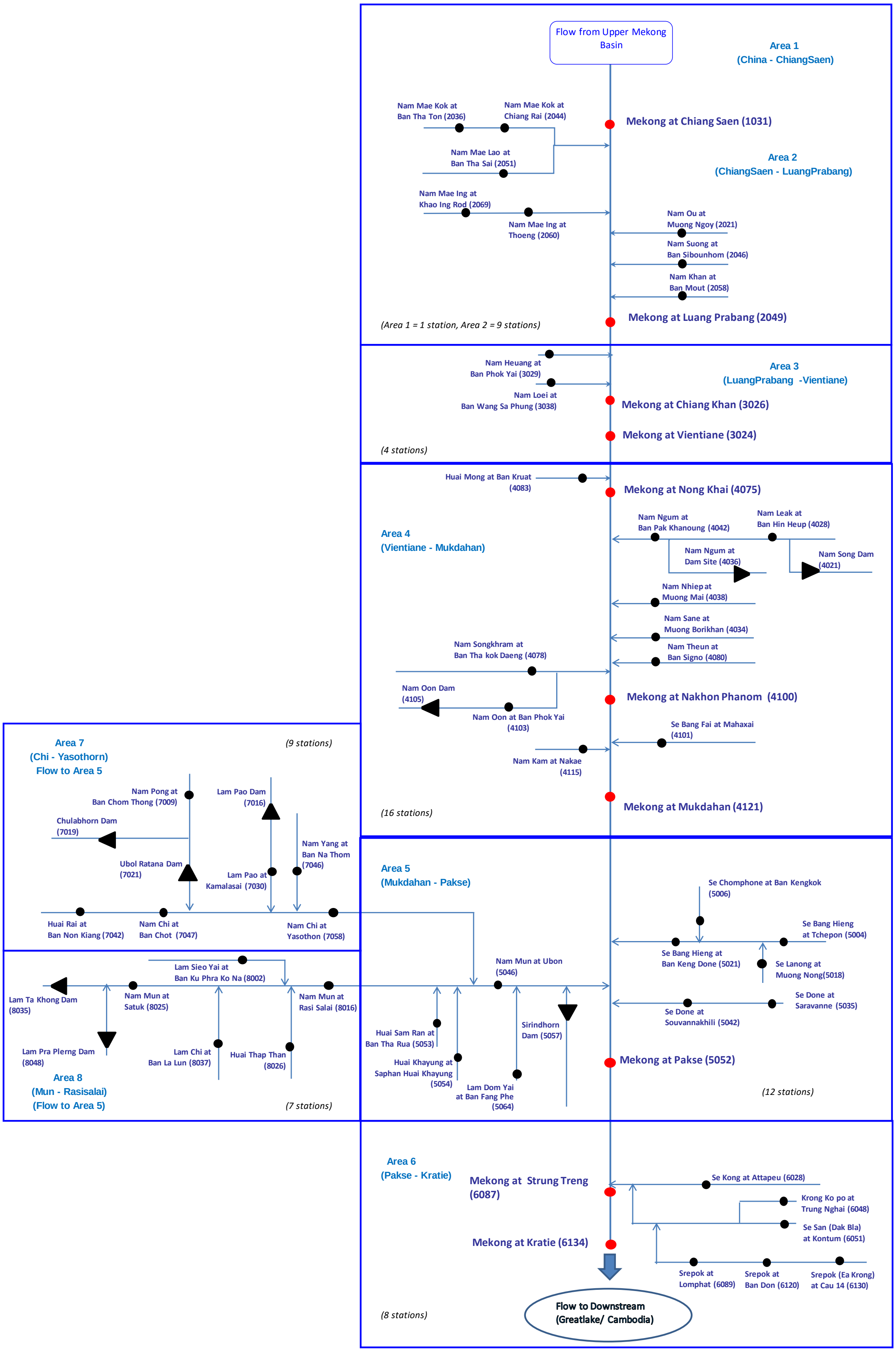

Figure 4.2-1 : Schematization for Flow Calibration Point from Chiang Saen-Kratie

Station Available for Sediment calibration

SWAT Area	Mainstream	Tributary
A0	0	0
A1	1	0
A2	1	5
A3	0	1
A4	3	6
A5	2	5
A6	2	4
A7	0	4
A8	0	1
A9	0	2
Total	9	28

Note
Grey Character = No Sediment data for calibration

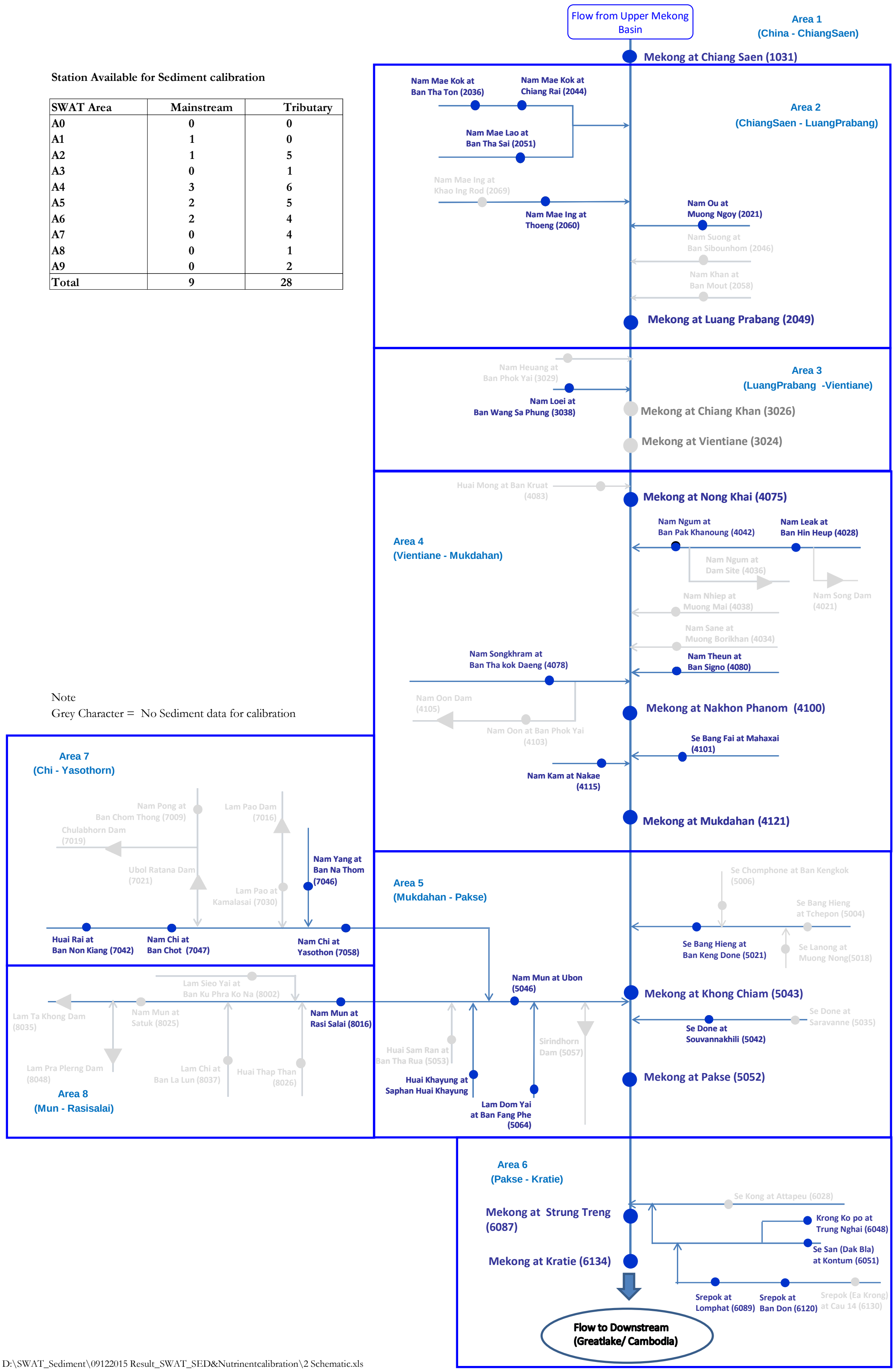

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Figure 4.2-2 : Schematisation for Sediment Calibration Point from Chiang Saen-Kratie

Station Available for Total Nitrogen calibration

SWAT Area	Mainstream	Tributary
A0	0	0
A1	1	0
A2	1	1
A3	0	0
A4	2	3
A5	2	3
A6	2	3
A7	0	2
A8	0	1
A9	0	0
Total	8	13

Note
Grey Character = No Total Nitrogen data for calibration

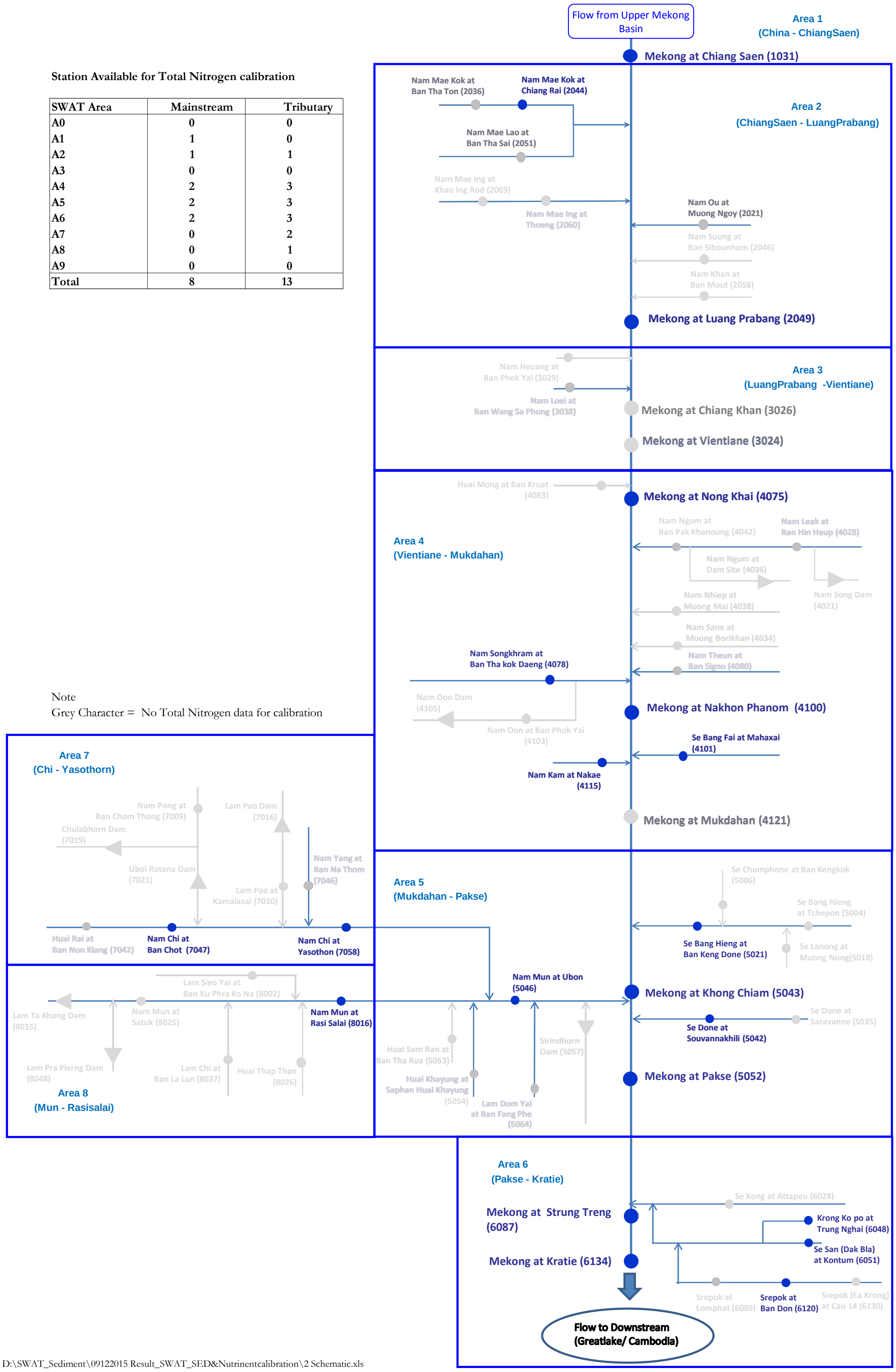

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Figure 4.2-3 : Schematisation for Total Nitrogen Calibration Point from Chiang Saen-Kratie

Station Available for Total Phosphorus calibration

SWAT Area	Mainstream	Tributary
A0	0	0
A1	1	0
A2	1	1
A3	0	0
A4	2	3
A5	2	3
A6	1	3
A7	0	2
A8	0	1
A9	0	2
Total	7	15

Note
Grey Character = No Total Phosphorus data for calibration

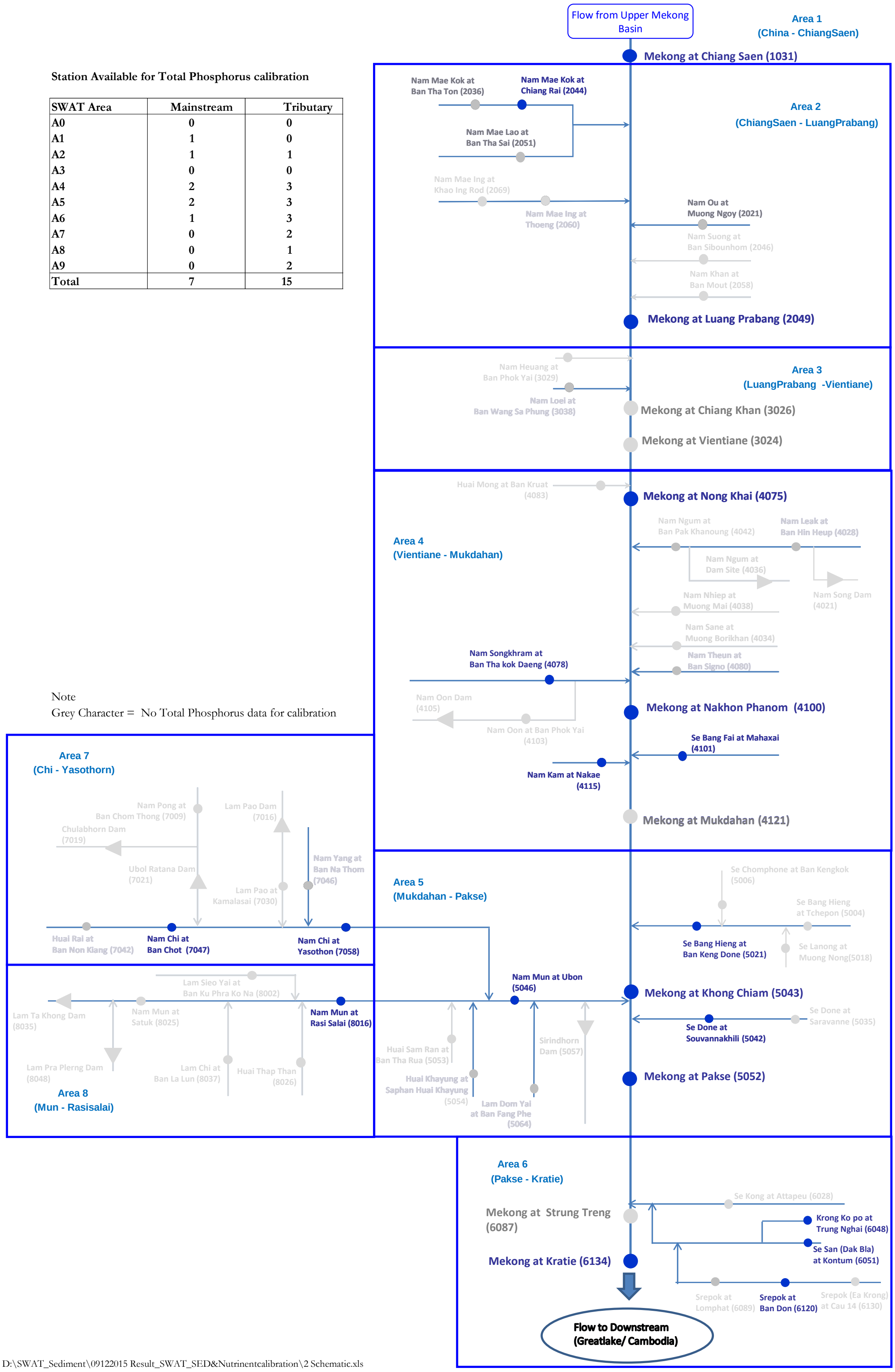

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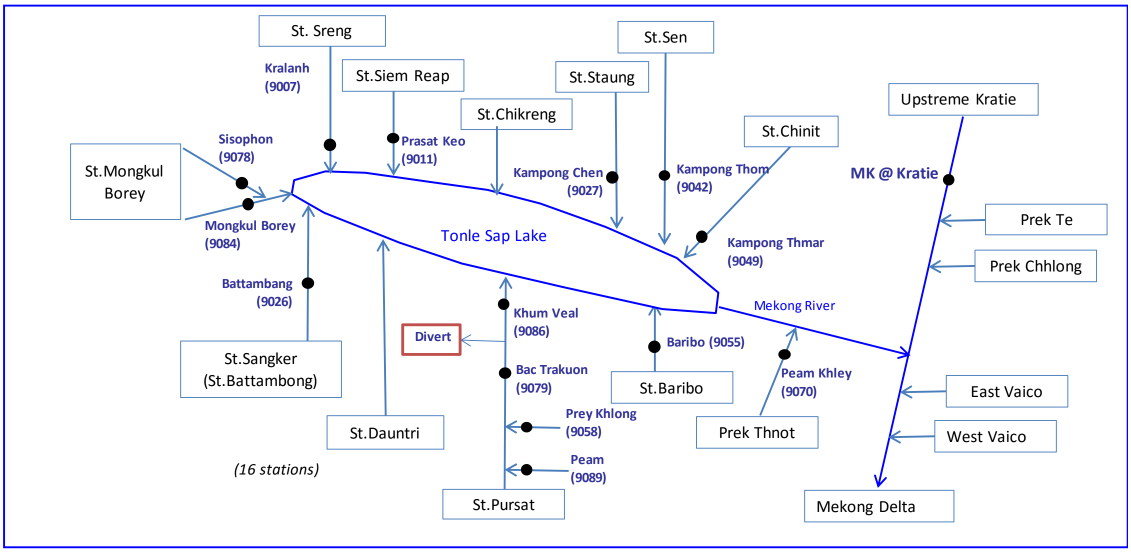
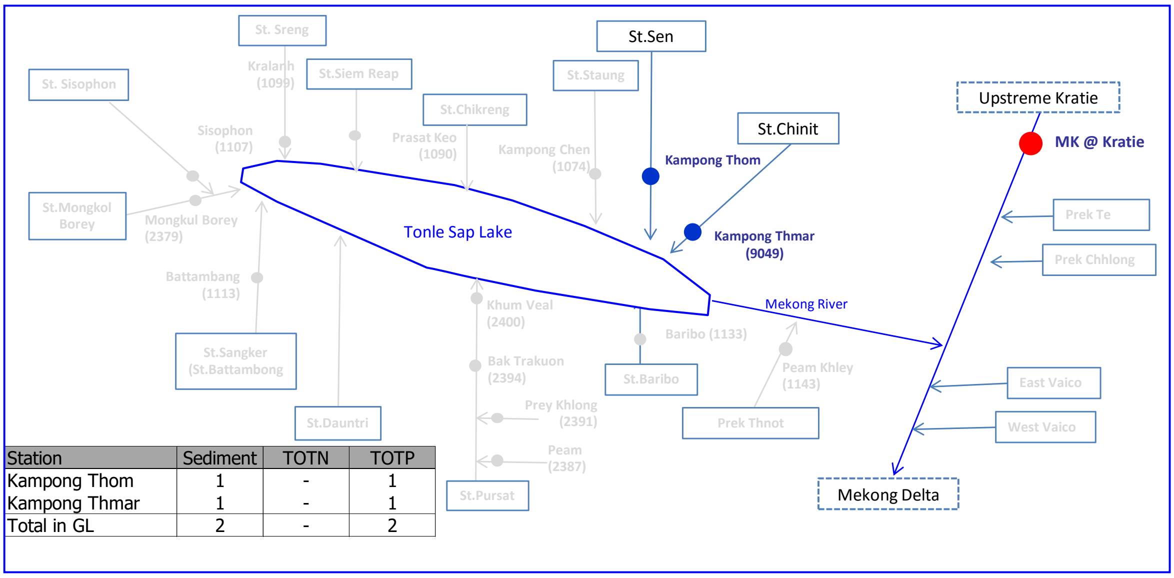
Figure 4.2-4 : Schematisation for Total Phosphorus Calibration Point from Chiang Saen-Kratie



Schematic map for Calibration Point around Great Lake

Figure 4.2-5 : Schematisation for Flow Calibration Point around Great Lake



Station	Sediment	TOTN	TOTP
Kampong Thom	1	-	1
Kampong Thmar	1	-	1
Total in GL	2	-	2

Figure 4.2-6 : Schematisation for Sediment, Total Nitrogen and Total Phosphorus Calibration Point around Great Lake

4.3 Calibration Criteria

Calibration Criteria used the same method as flow calibration that evaluate model result in term of Assessment of preservation of mass (Volume Ratio) and Assessment of preservation of monthly flow peaks (Coefficient of Efficiency, Nash-Sutcliffe).

The purpose for SWAT Sediment and Nutrient simulation is to estimate sediment load and nutrient load from tributary then provide result to IQQM/Source model for basin simulation (include HP dam operation and irrigation), then the result will be for ISIS model simulation on Mekong Mainstream from Chiang Saen – Kratie.

Assessment of preservation of mass (Volume Ratio)

To ensure that the model is robust through the calibration and during wet and dry season the mass preservation criteria then the Volume criteria that use for Mainstream and Tributary is within 20%

$$V_r = \left(1 - \frac{\sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} O_i}\right) * 100\%$$

$O_i = Observed\ flow\ at\ \text{month}\ i$
$S_i = Simulated\ flow\ at\ \text{month}\ i$
$i = month\ no.\ i$
$n = Number\ of\ \text{month}$
$\overline{O} = Mean\ of\ observed\ flows$

Assessment of preservation monthly load peaks (Coefficient of Efficiency, Nash-Sutcliffe)

The Nash-Sutcliffe coefficient is used on a monthly basis for both high and low flows to assess the model calibration. Given that the low flows are serially correlated and the Nash-Sutcliffe coefficient is not valid if the data is correlated it is statistically incorrect to apply this statistic for low flows. Unfortunately in many of the SWAT sub-basins the rainfall is poorly correlated with flow. In many of the mountainous catchments there are no rainfall stations in the sub basins. Consequently it is difficult to meet daily Nash-Sutcliffe criteria for the high flows and then will effect to sediment and nutrient.

$$CE = 1 - \frac{\sum_{i=1}^{n} (O_i - S_i)^2}{\sum_{i=1}^{n} (O_i - \overline{O})^2}$$

$O_i = Observed\ flow\ at\ \text{month}\ i$
$S_i = Simulated\ flow\ at\ \text{month}\ i$
$i = month\ no.\ i$
$n = Number\ of\ \text{month}$
$\overline{O} = Mean\ of\ observed\ flows$

It is important to preserve the time series of flow and to have a measure that assesses how well the model performs over time. Consequently it is recommended that the daily and monthly Nash-Sutcliffe criteria over the entire record be used to assess the model performance with respect to representing flow peaks. For this study will set up the target for tributary is 0.40 and mainstream 0.80 in monthly basis.

5. Calibration Result:

5.1 Sediment Calibration Result

5.1.1 Sediment Trapping in Dam

Based on SWAT model use a simple mass balance model to semulate the transport of sediment into and out of reservoir, however based on further investigate the equation is suitable only for Small reservoir.

Therefore in SWAT model calibration will check only Trapping efficiency in overall, the detail will simulate in IQQM/Source model.

Manwan (1993) : Sediment trapping during 1993-2008 = 72.24 %

Dachaoshan (2003) : Sediment trapping during 2003-2008 = 65.69 %

Jing Hong (2008) : Sediment trapping on year 2008 = 67.99 %

Summary of Sediment Trapping Efficiency in Existing Dam form SWAT model was shown in Table 5.1-1

Table 5.1-1 : Summary of Sediment Trapping Efficiency in Existing Dam form SWAT model

SWAT Area	Reservoir No.	Sub SWAT at Dam	Name	Year	Trapping Efficiency (%)	Remark
A0	9	25	Manwan	1993	72.24	
	10	26	Dachoshan	2003	65.69	
	13	29	Jinghong	2008	67.99	
A4	20	102	Huay Luang	1985	58.17	
	22	105	Nam Oon	1985	81.65	
	23	116	Nam Pung	1985	99.56	
	34	36	Nam Ngum	1995	74.65	
	31	59	Nam Theun-Hiboun	1999	21.72	
A5	7	57	Siridhorn Dam	1980	85.83	
	13	45	PakMun Dam	1995	85.5	
A6	9	21	Huay Ho	1999	87.63	
	28	56	Yali	2000	78.48	
A7	1	19	Chulabhorn	1985	88.08	
	3	16	Lam Pao	1985	64.31	
	4	21	Ubon Ratana Dam	1980	87.54	
A8	1	35	Lam Ta Khong P.S	1980	99.88	
	2	48	Lam Pra Plerng	1980	99.99	
	3	52	Upper Mun	1980	60.44	
	4	58	Lam Nang Rong	1980	99.65	

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5.1.2 *Sediment Calibration result at Tributary*

As discuss in previous section regarding with uncertainty of observed, therefore calibration will do only on monthly to guidance on sediment budget from tributary. However the calibration station is not cover the whole main tributary, therefore the other information such as transfer parameter, verify on sediment production based on area will be apply.

	No of stations
Total Stations for sediment calibration:	28
Station that Pass criteria:	24
Station that need to improve in the future :	4

The stations that should be improve in the future because the calibration is lower than criteria (COE lower than 0.40 than cannot match well in term of time) as listed below. Anyway the volume of simulation and observed load is still within the range +- 20% :

- Nam Mae Kok at Chiang Rai
- Nam Leak at Bah Hin Heup
- Se San at Kontum
- Huai Rai at Ban non Kiang

5.1.3 *Sediment Calibration result at Mekong Mainstream*

The assumption for SWAT Sediment before start calibration on mainstream:

- The calibration result at 28 stations tributary should be achieve good result at least in term of Assessment of preservation of mass (Sediment load Volume Ratio)
- The sediment load from main tributaries (at least 50 tributaries from Chiang Saen - Kratie) should be check the result in Sediment budget.
- The each SWAT model from A2 – A6, will used observed load at inlet location, to ensure the sediment load between monitoring station is reasonable.
- SWAT model for A0 (from Upper Mekong) and A1 will calibrate and provided result at Chiang Saen.
- Then the result from A0 and A1 at Chiang Saen will used to be inlet and connect the model area. This method will provide flexibility for improve each area in the future.

The key stations (9 stations) along Mekong River that was evaluated for sediment namely:

- Mekong at Chiang Saen
- Mekong at Luang Prabang
- *Mekong at Chiang Khan (Cannot balance Sediment Budget)*
- *Mekong at Vientiane (Cannot generate sediment Rating Curve from DSMP)*
- Mekong at Nong Khai
- Mekong at Nakhon Phanom
- Mekong at Mukdahan
- Mekong at Khong Chiam (added based on data available)
- Mekong at Pakse
- Mekong at Stung Treng
- Mekong at Kratie

Discussion Result at Chiang Saen:

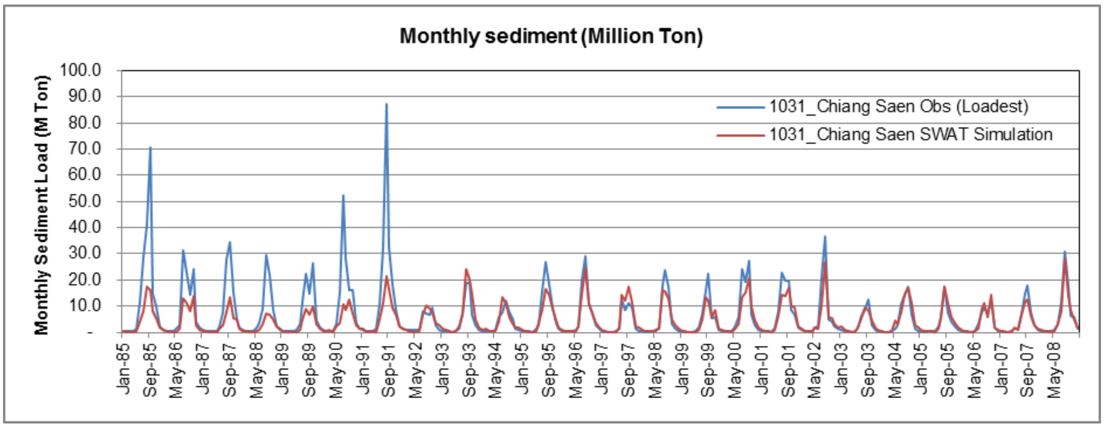
At Chiang Saen station the HM dataset has limitation of data (no data during 1985-2003) therefore EP dataset was used to generate sediment rating curved. However during pre-dam (before 1993) sediment load seems as produce too high compare when compare with sediment balance for entire basin (As discuss in Part of Data preparation) as table below.

Comparing Sediment Load estimated from Sediment Rating Curve at Chiang Saen station.

Year	Dam	Flow-cms	Estimated Sediment Load - M Ton					
			HM	EP	EP (adjust)	DSMP	Walling	Year book
Pre Dam (1985 - 1992)	No dam	2,559	69*	88	116	-	-	-
1993 - 2002	Manwan	2,762	124	53	69	-	102	110
2003 - 2008	Manwan, Dachaoshan, Jinghong	2,461	94	40	52	-	-	48
1993 - 2008	Manwan, Dachaoshan, Jinghong	2,649	113	48	63	-	95	63
1985 - 2008	Manwan, Dachaoshan, Jinghong	2,619	98	61	80	-	-	63
2009 - 2012		2,326	-	11	15	15	-	-

**Estimate from year 1968-1975*

The simulation from 1985-2008 with Manwan dam operation (1993) and Dachaoshan dam operation (2003) shown in figure below, the result can see clear that SWAT model can simulate situation after year 1993 well. However, SWAT model can simulated sediment in small reservoir but not fit well with the large reservoir. Therefore the result for sediment will check only period 1993-2008 (17 years).



Period	Model Calibration		Sediment Load (Million Ton)	
	COE	Vol (%)	Observed from Loadest	SWAT Simulation
1985-1992	0.33	41.97	115.6	48.5
1993-2008	**0.87**	**93.53**	**62.7**	**58.0**
1985-2008	0.52	68.79	80.3	55.2

The result at Chiang Saen station using sediment result from Upper Mekong (A0) and include area from China -Lao border to Chiang Saen (A1) area 1, can get COE 0.87 and Volume Ratio is 94 % and Sediment Load from observed and Simulation is 62.7 and 58.0 Million Ton respectively. The model cannot simulate during period 1985 – 1992 that perform not good, need further investigation.

The table below was present the model evaluation comparing between period 1985-2008 and 1993-2008, the calibration for Key station is based on fit with period 1993-2008

Chiang saen:	COE	0.87,	Vol Ratio	94 %
Luang Prabang	COE	0.84,	Vol Ratio	90 %
Nong Khai	COE	0.87,	Vol Ratio	100 %
Nakhon Phanom	COE	0.89,	Vol Ratio	95 %
Mukdahan	COE	0.89,	Vol Ratio	99 %
Khong Chiam	COE	0.83,	Vol Ratio	101 %
Pakse	COE	0.94,	Vol Ratio	103 %
Stung Treng	COE	0.86,	Vol Ratio	96 %
Kratie	COE	0.92,	Vol Ratio	104 %

The COE is between 0.83 – 0.94 and different of Volume Ratio is between -10 % to 4 %

Sub	Gauge Name	Entired Period (1985 - 2008)					After Manwan Dam (1993 - 2008) *				
		Sediment Calibration			Sediment Load (Million Ton)		Sediment Calibration			Sediment Load (Million Ton)	
		Period	COE	Vol (%)	Obserevd	Simulation	Period	COE	Vol (%)	Obserevd	Simulation
1031	Mekong at Chiang Saen	1985 - 2008	0.52	69	80.3	55.2	1993 - 2008	0.87	94	62.7	58.6
2049	Mekong at Luang Prabang	1985 - 2008	0.65	76	99.4	75.4	1993 - 2008	0.84	90	85.0	76.7
3026	Mekong at Chiang Khan	*No Sediment Data*					*No Sediment Data*				
3024	Mekong at Vientiane	*No Sediment Data*					*No Sediment Data*				
4075	Mekong at Nong Khai	1985 - 2008	0.68	85	101.8	86.7	1993 - 2008	0.87	100	88.3	88.1
4100	Mekong at Nakhon Phanom	1985 - 2008	0.77	86	114.7	98.1	1993 - 2008	0.89	95	108.7	103.1
4121	Mekong at Mukdahan	1985 - 2008	0.75	88	118.0	103.3	1993 - 2008	0.89	99	109.4	108.3
5043	Mekong at Khong Chiam	1985 - 2007	0.67	86	120.6	107.8	1993 - 2007	0.83	101	109.6	111.3
5052	Mekong at Pakse	1985 - 2008	0.77	91	124.2	116.4	1993 - 2008	0.94	103	115.2	119.8
6087	Mekong at Stung Treng	1985 - 2008	0.76	86	148.5	128.4	1993 - 2008	0.86	96	137.7	132.9
6134	Mekong at Kratie	1985 - 2008	0.81	93	150.0	139.0	1993 - 2008	0.92	104	141.2	146.8

Comparison flow between Simulated and Observed data during 1993-2008 (Simulation Period) at Mekong Key Station for 9 stations was shown in Appendix B.

5.2 Total Nitrogen Calibration Result

5.2.1 Total Nitrogen Calibration result at Tributary

As discuss in previous section regarding with uncertainty of observed, therefore calibration will do only on monthly to guidance on sediment budget from tributary. However the calibration station is not cover the whole main tributary, therefore the other information such as transfer parameter, verify on sediment production based on area will be apply.

	No of stations
Total Stations for sediment calibration:	13
Station that Pass criteria:	7
Station that need to improve in the future :	6

The stations that should be improve in the future because the calibration is lower than criteria (COE lower than 0.40 than cannot match well in term of time) as listed below. Anyway the volume of simulation and observed load is still within the range +- 20% :

- Nam Songkhram at Ban Tha kok Daeng
- Se Done at Souvannakhili
- Nam Mun at Ubon
- Krong Ko Po at Trung Nghai
- Se San (Dak Bla) at Kontum
- Nam Chi at Yasothon

5.2.2 Total Nitrogen Calibration result at Mekong Mainstream

Nitrogen Calibration cannot see clear different between pre and after year 1993, therefore entire simulation (1985 – 2008) will be compared for 8 stations in monthly basis. However some station (i.e. Luang Prabang, Vientiane and Pakse donot have the direct calcultion of TOTN then use the equation to combine value from NO2, NO32, NH4 (as detail in report Data preparation, 2015)

Chiang saen:	COE	0.81,	Vol Ratio	77 %	(need further improved)
Luang Prabang	COE	0.79,	Vol Ratio	101 %	
Nong Khai	COE	0.71,	Vol Ratio	116 %	
Nakhon Phanom	COE	0.71,	Vol Ratio	117 %	
Khong Chiam	COE	0.87,	Vol Ratio	106 %	
Pakse	COE	0.87,	Vol Ratio	107 %	
Stung Treng	COE	0.86,	Vol Ratio	114 %	(need further improved)
Kratie	COE	0.84,	Vol Ratio	122 %	(need further improved)

The COE is between 0.71 – 0.86 and different of Volume Ratio is between -23 % to 22 %, 3 stations will be improved namely Chiang Saen, Stung Treng and Kratie that is in Area 0 (Upper Mekong) and A6 (3S area)

Sub	Gauge Name	Total Nitrogen Calibration			Total Nitrogen Load (Ton)	
		Period	COE	Vol (%)	Observed	Simulation
1031	Mekong at Chiang Saen	1985 - 2008	0.81	77	46,790	36,062
2049	Mekong at Luang Prabang	1985 - 2008	0.79	101	73,811	74,912
3026	Mekong at Chiang Khan	*No Observed Data*				
3024	Mekong at Vientiane	*No Observed Data*				
4075	Mekong at Nong Khai	1985 - 2008	0.71	116	80,122	93,056
4100	Mekong at Nakhon Phanom	1985 - 2007	0.71	117	115,567	135,185
4121	Mekong at Mukdahan	*No Observed Data*				
5043	Mekong at Khong Chiam	1985 - 2007	0.87	106	165,941	175,717
5052	Mekong at Pakse	1985 - 2008	0.87	107	171,375	183,751
6087	Mekong at Stung Treng	1985 - 2008	0.86	114	209,781	239,628
6134	Mekong at Kratie	1985 - 2008	0.84	122	197,404	240,502

Comparison flow between Simulated and Observed data during 1985-2008 (Simulation Period) at Mekong Key Station for 8 stations was shown in Appendix B.

5.3 Total Phosphorus Calibration Result

5.3.1 Total Phosphorus Calibration result at Tributary

As discuss in previous section regarding with uncertainty of observed, therefore calibration will do only on monthly to guidance on sediment budget from tributary. However the calibration station is not cover the whole main tributary, therefore the other information such as transfer parameter, verify on sediment production based on area will be apply.

	No of stations
Total Stations for sediment calibration:	15
Station that Pass criteria:	7
Station that need to improve in the future :	8

The stations that should be improve in the future because the calibration is lower than criteria (COE lower than 0.40 than cannot match well in term of time) as listed below. Anyway the volume of simulation and observed load is still within the range +- 20% :

- Nam Mae Kok at Chiang Rai
- Se Done at Souvannakhili
- Nam Mun at Ubon
- Krong Ko Po at Trung Nghai
- Se San (Dak Bla) at Kontum
- Sre Pok at Ban Don
- Nam Chi at Yasothon
- Kampong Thmar

5.3.2 Total Phosphorus Calibration result at Mekong Mainstream

Phosphorus Calibration cannot see clear different between pre and after year 1993, therefore entire simulation (1985 – 2008) will be compared for 7 stations in monthly basis. However some station found the abnormal value during year 2002-2004, then the observe data will not be include to create TOTP rating curve (as detail in report Data preparation, 2015)

Chiang saen:	COE	0.78,	Vol Ratio	99 %	
Luang Prabang	COE	0.59,	Vol Ratio	102 %	(need further improved)
Nong Khai	COE	0.70,	Vol Ratio	89 %	
Nakhon Phanom	COE	0.80,	Vol Ratio	97 %	
Khong Chiam	COE	0.71,	Vol Ratio	119 %	
Pakse	COE	0.81,	Vol Ratio	102 %	
Kratie	COE	0.86,	Vol Ratio	105 %	

The COE is between 0.59 – 0.86 and different of Volume Ratio is between -11 % to 19 %, 1 station will be improved namely Luang Prabang.

Sub	Gauge Name	Total Phosphorus Calibration			Total Phosphorus Load (Ton)	
		Period	COE	Vol (%)	Obserevd	Simulation
1031	Mekong at Chiang Saen	1985 - 2008	0.78	99	5,018	4,972
2049	Mekong at Luang Prabang	1985 - 2008	0.59	102	7,566	7,748
3026	Mekong at Chiang Khan	*No Observed Data*				
3024	Mekong at Vientiane	*No Observed Data*				
4075	Mekong at Nong Khai	1985 - 2008	0.70	89	12,824	11,394
4100	Mekong at Nakhon Phanom	1985 - 2008	0.80	97	15,792	15,266
4121	Mekong at Mukdahan	*No Observed Data*				
5043	Mekong at Khong Chiam	1985 - 2007	0.71	119	16,733	19,844
5052	Mekong at Pakse	1985 - 2008	0.81	102	21,025	21,519
6087	Mekong at Stung Treng	*No Observed Data*				
6134	Mekong at Kratie	1985 - 2008	0.86	105	37,042	38,822

Comparison flow between Simulated and Observed data during 1985-2008 (Simulation Period) at Mekong Key Station for 8 stations was shown in Appendix B.

Table 5.1-2: Sediment and Nutrient Calibration Result in Tributary:

Area 2 : Chiang Saen to Luang Prabang

Sub	Gauge Name	Sediment Calibration			Nutrient (TOTN) Calibration			Nutrient (TOTP) Calibration		
		Period	COE	Vol	Period	COE	Vol	Period	COE	Vol
2021	Nam Ou at Muong Ngoy	1986-2008	0.52	102	No Nitrogen Data			No Phosphorus Data		
2036	Nam Mae Kok at Ban Tha Ton	1985-2005	0.60	91	No Nitrogen Data			No Phosphorus Data		
2044	Nam Mae Kok at Chiang Rai	1985-2005	0.32	87	1985-2005	0.65	92	1985-2005	0.39	66
2046	Nam Suong at Ban Sibounhom	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
2051	Nam Mae Lao at Ban Tha Sai	1985-2003	0.72	84	No Nitrogen Data			No Phosphorus Data		
2058	Nam Khan at Ban Mout	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
2060	Nam Mae Ing at Thoeng	1985-2008	0.73	88	No Nitrogen Data			No Phosphorus Data		
2069	Nam Mae Ing at Khao Ing Rod	No Sediment Data			No Nitrogen Data			No Phosphorus Data		

Area 3 : Luang Prabang to Vientiane

Sub	Gauge Name	Sediment Calibration			Nutrient (TOTN) Calibration			Nutrient (TOTP) Calibration		
		Period	COE	Vol	Period	COE	Vol	Period	COE	Vol
3029	Nam Heuang at Ban Pak Huai	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
3038	Nam Loei at Ban Wang Saphung	1985-2007	0.58	115	No Nitrogen Data			No Phosphorus Data		

Area 4: Vientiane to Mukdahan

Sub	Gauge Name	Sediment Calibration			Nutrient (TOTN) Calibration			Nutrient (TOTP) Calibration		
		Period	COE	Vol	Period	COE	Vol	Period	COE	Vol
4028	Nam Leak at Ban Hin Heup	1985-2008	0.39	102	No Nitrogen Data			No Phosphorus Data		
4034	Nam Sane at Muong Borikhan	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
4038	Nam Nhiep at Muong Mai	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
4042	Nam Ngum at Ban Pak Khanoung	1997-2006	0.41	112	No Nitrogen Data			No Phosphorus Data		
4078	Nam Songkhram at Ban Tha kok Daeng	1990-2008	0.84	105	1990-2008	0.33	106	1990-2008	0.74	100
4080	Nam Theun at Ban Signo	1986-2005	0.41	114	No Nitrogen Data			No Phosphorus Data		
4083	Huai Mong at Ban Kruat	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
4101	Se Bang Fai at Mahaxai	1990-2008	0.71	110	1985-2007	0.79	100	1985-2007	0.73	104
4103	Nam Oon at Ban Phok Yai	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
4115	Nam Kam at Na Kae	1985-1999	0.50	91	1985-1999	0.67	95	1985-1999	0.76	105

Table 5.1-2: Sediment and Nutrient Calibration Result in Tributary (Cont'd):

Area 5: Mukdahan to Pakse

Sub	Gauge Name	Sediment Calibration			Nutrient (TOTN) Calibration			Nutrient (TOTP) Calibration		
		Period	COE	Vol	Period	COE	Vol	Period	COE	Vol
5004	Se Bang Hieng at Tchepon	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
5006	Se Chomphone at Ban Kengkok	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
5018	Se Lanong at Muong Nong	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
5021	Se Bang Hieng at Ban Keng Done	1985-2008	0.63	104	1985-2008	0.75	79	1985-2008	0.76	92
5035	Se Done at Saravanne	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
5042	Se Done at Souvannakhili	1985-2008	0.75	108	1985-2008	0.35	108	1985-2008	0.33	111
5046	Nam Mun at Ubon	1985-2008	0.64	104	1985-2008	0.21	133	1985-2008	0.31	125
5053	Huai Sam Ran at Ban Tha Rua	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
5054	Huai Khayung at SaphanHuai Khayung	1985-2005	0.55	101	No Nitrogen Data			No Phosphorus Data		
5064	Lam Dom Yai at Ban Fang Phe	1985-1999	0.62	96	No Nitrogen Data			No Phosphorus Data		

Area 6: Pakse to Kratie

Sub	Gauge Name	Sediment Calibration			Nutrient (TOTN) Calibration			Nutrient (TOTP) Calibration		
		Period	COE	Vol	Period	COE	Vol	Period	COE	Vol
6028	Se Kong at Attapeu	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
6048	Krong Ko Po at Trung Nghai	1985-1997	0.56	98	1985-1997	0.21	106	1985-1997	-1.39	159
6051	Se San (Dak Bla) at Kontum	1985-2006	0.26	93	1985-2006	0.29	97	1985-2006	-0.07	93
6089	Sre Pok at Lomphat	2000-2008	0.45	95	No Nitrogen Data			No Phosphorus Data		
6120	Sre Pok at Ban Don	1985-2008	0.60	96	1985-2008	0.41	94	1985-2008	0.38	97
6130	Sre Pok (Ea Krong) at Cau 14	No Sediment Data			No Nitrogen Data			No Phosphorus Data		

Area 7: Chi to Yasothon

Sub	Gauge Name	Sediment Calibration			Nutrient (TOTN) Calibration			Nutrient (TOTP) Calibration		
		Period	COE	Vol	Period	COE	Vol	Period	COE	Vol
7009	Nam Pong at Ban Chom Thong	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
7030	Lam Pao at Kamalasai	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
7042	Huai Rai at Ban Non Kiang	1985-2003	0.36	104	No Nitrogen Data			No Phosphorus Data		
7046	Nam Yang at Ban Na Thom	1985-2005	0.60	98	No Nitrogen Data			No Phosphorus Data		
7047	Nam Chi at Ban Chot	1985-2008	0.53	86	1985-2008	0.50	84	1985-2008	0.45	99
7058	Nam Chi at Yasothon	1985-2008	0.73	97	1985-2008	0.35	117	1985-2008	0.39	120

Table 5.1-2: Sediment and Nutrient Calibration Result in Tributary (Cont'd):

Area 8: Mun to RasiSalai

Sub	Gauge Name	Sediment Calibration			Nutrient (TOTN) Calibration			Nutrient (TOTP) Calibration		
		Period	COE	Vol	Period	COE	Vol	Period	COE	Vol
8002	Lam Sieo Yai at Ban Ku Phra Ko Na	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
8018	Nam Mun at Satuk	No Sediment Data			No Nitrogen Data			No Phosphorus Data		
8016	Nam Mun at Rasi Salai	1985-2008	0.40	120	1985-2008	0.70	95	1985-2008	0.53	109

Area 9: Around GreatLake

Sub	Gauge Name	Sediment Calibration			Nutrient (TOTN) Calibration			Nutrient (TOTP) Calibration		
		Period	COE	Vol	Period	COE	Vol	Period	COE	Vol
9049	Kampong Thmar	1995-2008	0.50	91	No Nitrogen Data			1995-2008	0.13	41
9042	Kampong Thom	1995-2008	0.62	100	No Nitrogen Data			1997-2008	0.67	101

Summary	Sediment Calibration		Nutrient (TOTN) Calibration			Nutrient (TOTP) Calibration	
Total - station	28	stations	Total	13	stations	15	stations
COE Higher than 0.40	24	stations		7	stations	7	stations
COE less than 0.40	4	stations		6	stations	8	stations

Table 5.1-3: Sediment and Nutrient Calibration Result on Mekong Mainstream:

Sub	Gauge Name	Flow Calibration			Sediment Calibration*			Total Nitrogen Calibration			Total Phosphorus Calibration		
		Period	COE	Vol.	Period	COE	Vol (%)	Period	COE	Vol (%)	Period	COE	Vol (%)
1031	Mekong at Chiang Saen	1985-2008	0.80	103	1993 - 2008	0.87	94	1985 - 2008	0.81	77	1985 - 2008	0.78	99
2049	Mekong at Luang Prabang	1985-2008	0.84	107	1993 - 2008	0.84	90	1985 - 2008	0.79	101	1985 - 2008	0.59	102
3026	Mekong at Chiang Khan	1985-2008	0.84	105		No Observed Data			No Observed Data			No Observed Data	
3024	Mekong at Vientiane	1985-2008	0.83	105		No Observed Data			No Observed Data			No Observed Data	
4075	Mekong at Nong Khai	1985-2008	0.83	102	1993 - 2008	0.87	100	1985 - 2008	0.71	116	1985 - 2008	0.70	89
4100	Mekong at Nakhon Phanom	1985-2008	0.88	102	1993 - 2008	0.89	95	1985 - 2007	0.71	117	1985 - 2008	0.80	97
4121	Mekong at Mukdahan	1985-2008	0.90	105	1993 - 2008	0.89	99		No Observed Data			No Observed Data	
5043	Mekong at Khong Chiam	1985-2007	0.86	116	1993 - 2007	0.83	101	1985 - 2007	0.87	106	1985 - 2007	0.71	119
5052	Mekong at Pakse	1985-2008	0.90	107	1993 - 2008	0.94	103	1985 - 2008	0.87	107	1985 - 2008	0.81	102
6087	Mekong at Stung Treng	1985-2008	0.90	105	1993 - 2008	0.86	96	1985 - 2008	0.86	114		No Observed Data	
6134	Mekong at Kratie	1985-2008	0.91	103	1993 - 2008	0.92	104	1985 - 2008	0.84	122	1985 - 2008	0.86	105

* Period for Sediment calibration is 1993- 2008

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Table 5.1-4: Compare Sediment and Nutrient Load between observed and simulation on Mekong Mainstream

a) Sediment (Million ton) - year 1993 - 2008

Station Name	ChiangSaen		Luangprabang		Nongkhai		NakhonPhnom		Mukdahan		Khong Chiam		Pakse		Strung Treng		Kratie	
Year	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation
Average	62.7	58.6	85.0	76.7	88.3	88.1	108.7	103.1	109.4	108.3	109.6	111.3	115.2	119.8	137.7	132.9	141.2	146.8
Maximum	90.3	78.5	117.8	100.0	127.0	114.9	155.8	130.9	155.5	134.3	160.7	131.4	161.0	140.8	215.2	160.3	212.0	182.2
Minimum	35.7	36.2	41.5	50.8	46.9	65.7	58.8	72.6	59.5	78.4	67.5	86.0	75.2	89.9	76.7	95.3	77.9	92.4
Contribute from Local Area			CSN - LPB		LPB - NKI		NKI - NKP		NKP - MDH		MDH - KCM		KCM-PKS		PKS-STT		STT- KRE	
			22.33	18.12	3.32	11.41	20.42	14.94	0.68	5.21	0.23	3.00	5.52	8.53	22.59	13.11	3.41	13.92

b) Total Nitrogen (Ton) - year 1985 - 2008

Station Name	ChiangSaen		Luangprabang		Nongkhai		NakhonPhnom		Khong Chiam		Pakse		Strung Treng		Kratie	
Year	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation
Average	46,790	36,062	73,811	74,912	80,122	93,056	110,752	129,552	159,027	168,396	171,375	183,751	209,781	239,628	197,404	240,502
Maximum	59,888	41,001	109,917	92,744	117,246	115,665	141,713	160,291	212,334	216,437	235,118	225,296	308,044	281,537	293,137	282,723
Minimum	32,875	28,065	42,628	56,741	47,929	73,268	-	-	-	-	111,973	143,345	117,857	188,171	103,255	188,125
Contribute from Local Area			CSN - LPB		LPB - NKI		NKI - NKP		NKP - KCM		KCM-PKS		PKS-STT		STT- KRE	
			27,021	38,849	6,311	18,145	30,630	36,495	48,275	38,844	12,347	15,356	38,407	55,877	(12,378)	874

C) Total Phosphorus (Ton) - year 1985 - 2008

Station Name	ChiangSaen		Luangprabang		Nongkhai		NakhonPhnom		Khong Chiam		Pakse		Kratie	
Year	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation	Obs (Loadest)	SWAT Simulation
Average	5,018	4,972	7,566	7,748	12,824	11,394	15,792	15,266	16,036	19,017	21,025	21,519	37,042	38,822
Maximum	6,363	5,644	11,887	15,520	20,566	18,277	22,143	24,080	21,288	26,020	29,932	28,888	55,459	51,467
Minimum	3,604	4,049	3,845	6,271	6,488	8,296	8,722	10,861	-	-	12,702	15,129	20,458	26,179
Contribute from Local Area			CSN - LPB				NKI - NKP		NKP - KCM		KCM-PKS		PKS - KRE	
			2,548	2,776	5,258	3,646	2,968	3,872	244	3,751	4,989	2,502	16,017	17,303

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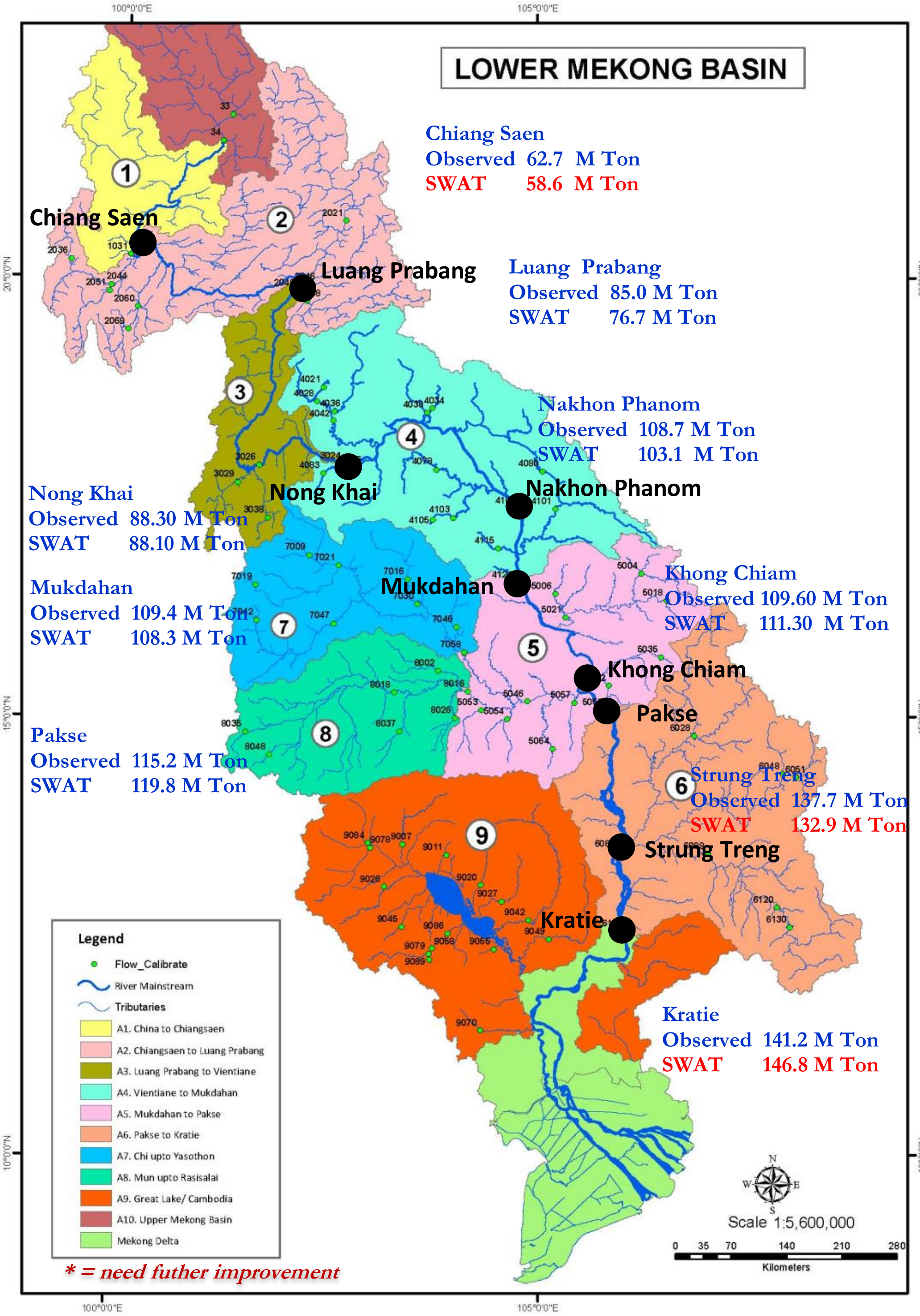


Figure 5.1-1: Comparing Sediment Load (million Ton/year) at MK Key Monitoring Station

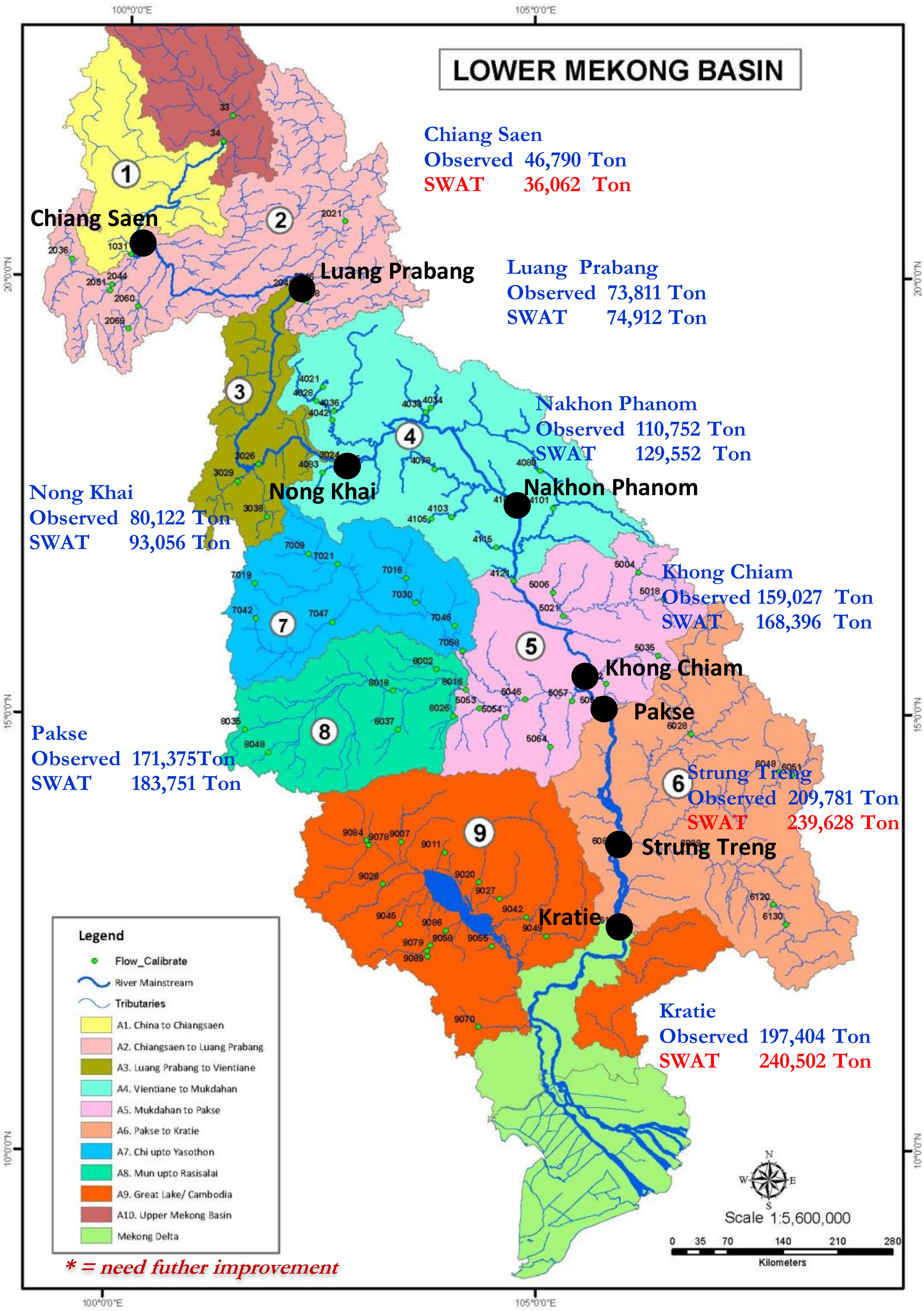


Figure 5.1-2: Comparing Nitrogen Load (ton/year) at MK Key Monitoring Station

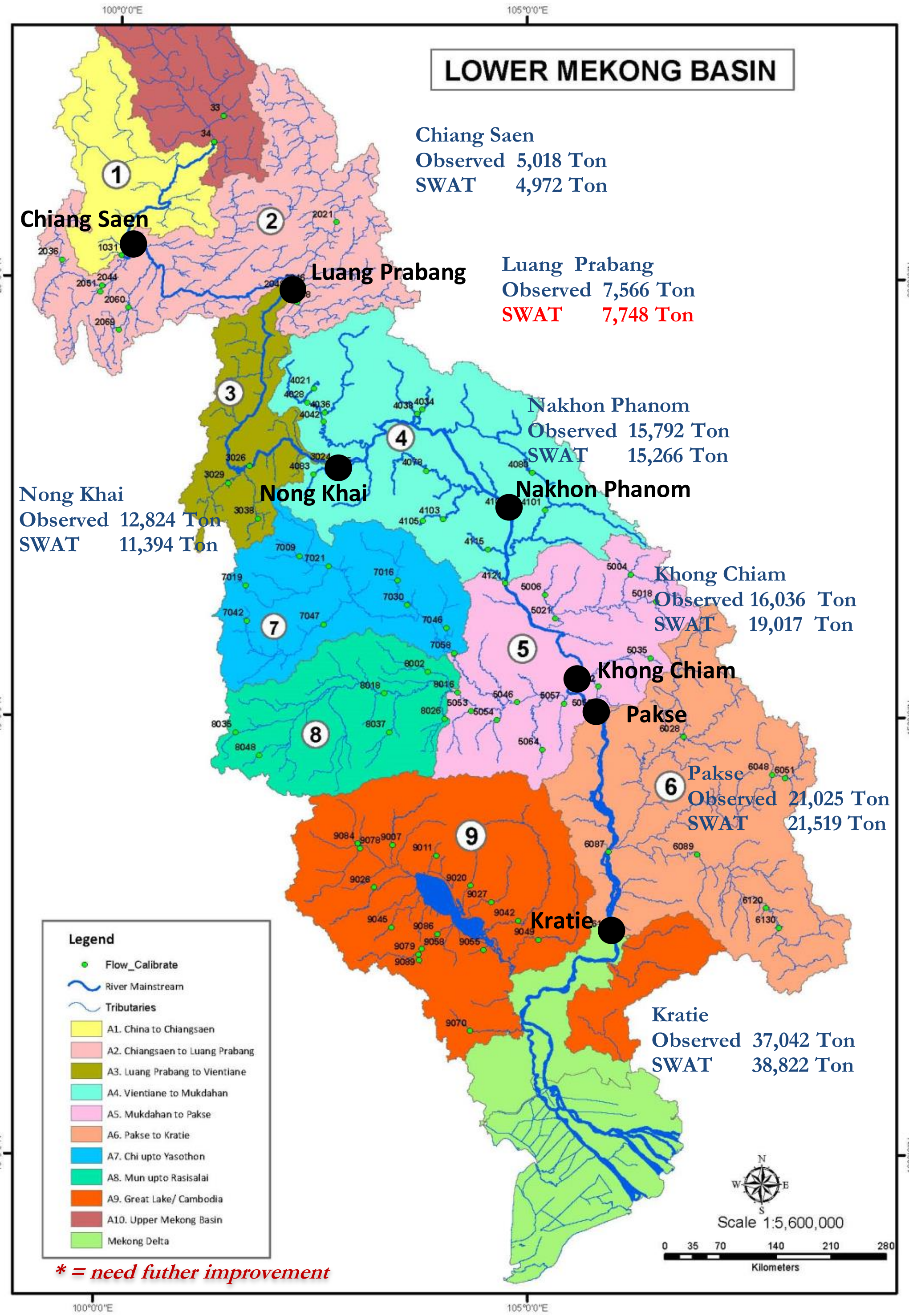


Figure 5.1-3: Comparing Phosphorus Load (ton/year) MK Key Monitoring Station

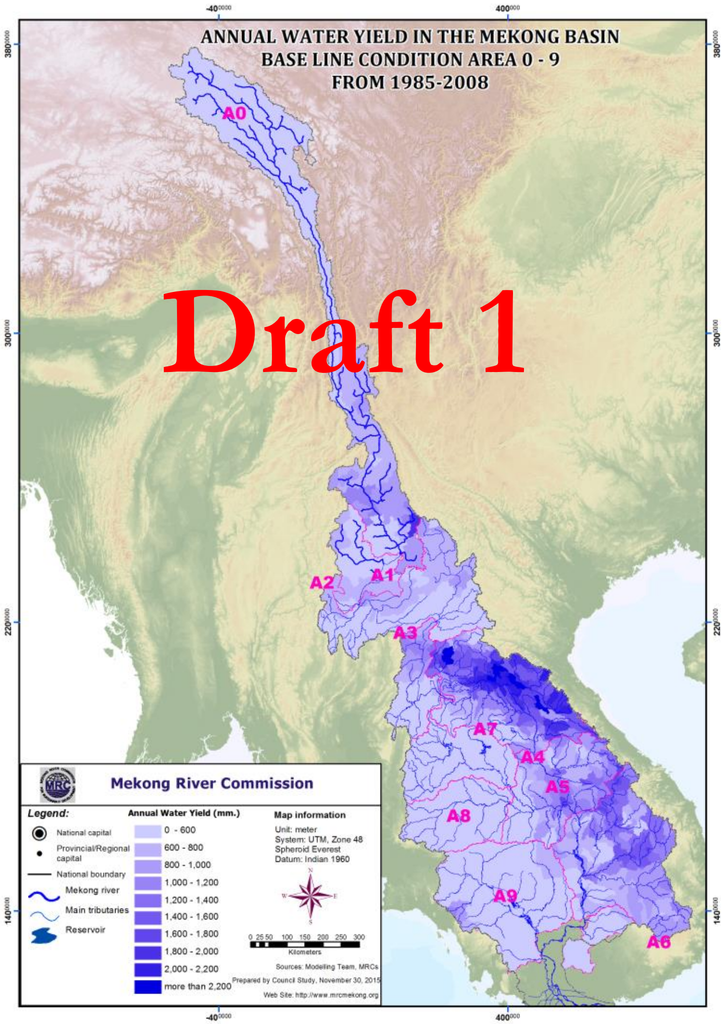
6. The SWAT Model Output

The SWAT model result will output flow time-series at scale of sub-basin to the Basin Simulation Model (IQQM model) that including hydropower, irrigation, diversions and abstractions in the system and will output sediment and nutrient Load (or concentration) at the same scale to Source model for routing sediment and nutrient through the system including trapping in reservoir. SWAT also provides output at strategic locations for use in hydrodynamic model (iSIS). Within SWAT model can simulate the hydrological response due to changes in land use, climate which may occur in the future.

Moreover SWAT will provide sediment and nutrient load into Tonle Sap Lake that can use for 3D-EIA model to simulate load and production in Lake.

The SWAT model can produce more output such as:

- Provide the spatial output such as rainfall, runoff, evapotranspiration, sediment yield (ton/ha), nutrient yield (kg/ha) during simulation period.
- Provide flow and load output at outlet point of main key tributary before flow to Mekong in term of natural situation (no dam in tributary) or SWAT-Source in term of including Dam operation.



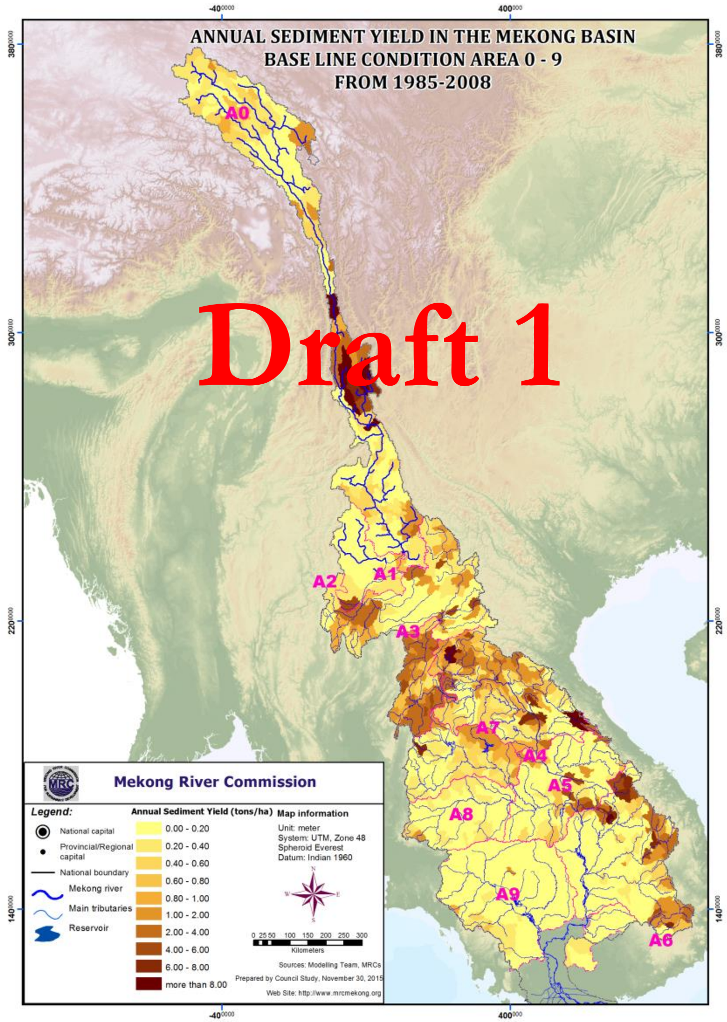


Figure 6.1 – 1: Average Water Yield (mm) from SWAT Model result in Mekong Basin during year 1985-2008	Figure 6.1 – 2: Average Sediment Yield (Ton/Ha) from SWAT Model result in Mekong Basin during year 1985-2008

Figure 6.1 – 3: Average Nitrogen Yield (kg/Ha) from SWAT Model result in Mekong Basin during year 1985-2008

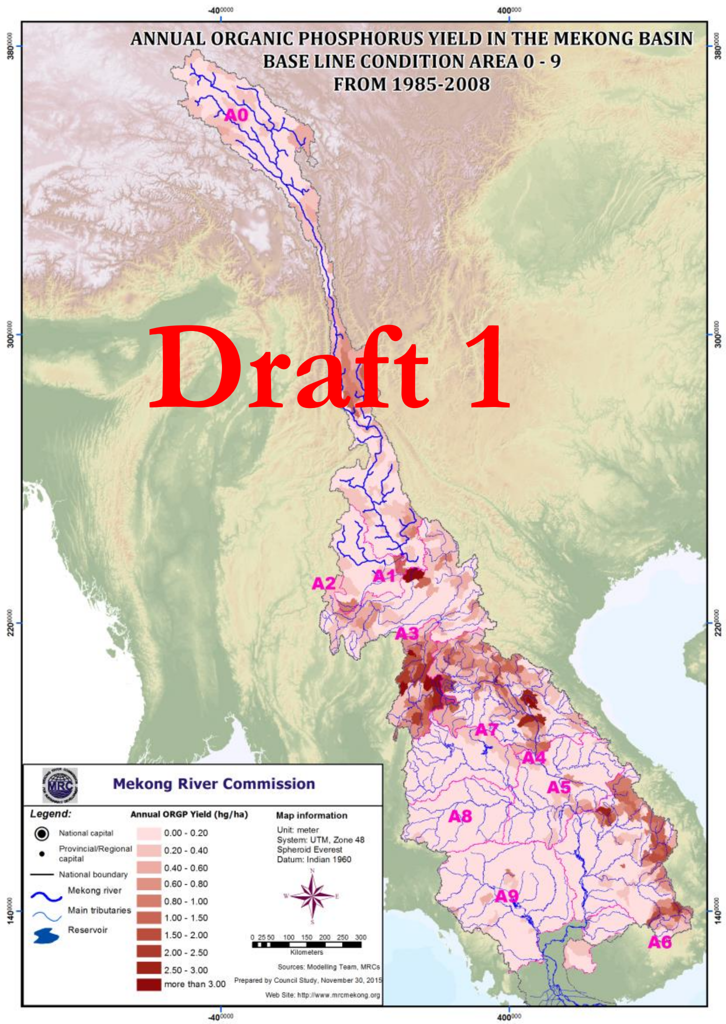


Figure 6.1 – 4: Average Phosphorus Yield (kg/Ha) from SWAT Model result in Mekong Basin during year 1985-2008

7. Conclusion and Area for Improvement

SWAT model (Sediment and Nutrient) was setup based on flow in term of daily basis and calibrate in monthly basis is considered to be adequate for its intended use, which is to model to provide sediment, nitrogen and phosphorus load from key tributary in Mekong River Basin.

The model result will be used for sediment and nutrient simulation within Source model for area of Upper Kratie and send to EIA -3D model to model simulation inside Tonle Sap Lake.

However there are still some more issue that need more improvement (Plan on Jan – Feb 2016) before further use as baseline to enhance and make the more realistic:

- Improvement of sediment and nutrient yield from land phase in China Part, some parameter need more adjustment to get better result at Chiang Saen Station.
- Improvement of sediment and nutrient yield from land phase in 3S Area (SWAT area 6) because the load contributed from local area (3S) and 4P in Cambodia is still not realistic compare with load production. Once it improved, we can get better result on load providing between area of Pakse, Stung Treng and Kratie Station
- Verify more on channel process and yield from land in SWAT A1-A6.
- Input of Nitrogen and Phosphorus from Urban area (population) should be further investigated.
- Verify and check the input on Fertilizer application inside agricultural area.

There are also needs of calibration improvement in tributary or further investigation in the future for other study such as:

- Improve on sediment calibration in tributary : Nam Mae Kok at Chiang Rai, Nam Leak at Bah Hin Heup, Se San at Kontum, Huai Rai at Ban non Kiang
- Improve on Nitrogen calibration in tributary : Nam Songkhram at Ban Tha kok Daeng, Se Done at Souvannakhili, Nam Mun at Ubon, Krong Ko Po at Trung Nghai, Se San (Dak Bla) at Kontum, Nam Chi at Yasothon
- Improve on Phosphorus calibration in tributary : Nam Mae Kok at Chiang Rai, Se Done at Souvannakhili, Nam Mun at Ubon, Krong Ko Po at Trung Nghai, Se San (Dak Bla) at Kontum, Sre Pok at Ban Don, Nam Chi at Yasothon, Kampong Thmar

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