Mekong River Commission

Technical Support Division
Information and Knowledge Management Program

Component 4: Modelling

DRAFT: Technical Reference Report

eWater Source Model (Baseline 2007):

Application in the Upper Mekong River Basin

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CONTENTS AMENDMENT RECORD

This report has been issued and amended as follows:

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CONTENTS

1 Introduction

1.1 Introduction

The MRC Council Study aims to assess past, ongoing and planned water resources development in the Mekong River Basin to further understanding of socio-economic and hydrological impacts (both positive and negative) across the basin. The Council Study Hydrologic Assessment Discipline Team led by the Information and Knowledge Management Programme (IKMP) is responsible for carrying out the hydrologic, hydraulic, sediment transport, and water quality modelling required to support the assessment of environmental and socioeconomic impacts associated with water resources developments in six thematic areas. The six thematic areas include hydropower, irrigation, agriculture and land use change, domestic and industrial water use, navigation, and flood protection. The water resources development impacts are also to be studied in relation to climate change.

The core of the Basin Simulation Package for the Decision Support Framework (DSF) is the hydrological model (SWAT), the basin simulation model (IQQM) and the hydraulic model (iSIS). Because of limitations in the sediment and water quality modelling capabilities of IQQM, eWater Source has been identified to augment the functionality of IQQM. The IQQM whole of Mekong Basin model has previously been converted to Source, including the transfer of network structure, configuration, input data and parameters. The converted Source model has been shown to reproduce the IQQM model results.

This interim report focusses on the application of the Source to model sediment and nutrients for the Baseline 2007 study. The report is intended to demonstrate the Source model capability and workflow. It presents preliminary results of the eWater Source application in the region upstream of Chiang Saen. The Source model is used in conjunction with, and relies on, inputs from other components of the project, such as the SWAT model, that are still being finalised. The final results, and application to the remainder of the Mekong Basin, will be described in the final report due in early 2016.

1.2 Objectives

The general objective of using eWater Source to support the Council Study is to integrate the results of other tools and to:

1. Incorporate empirically-based sediment and nutrient trapping algorithms in reservoirs so that the impact of storages can be assessed.
2. Transport/translate sediment and nutrient loads from upstream sources (land use, in-stream processes) through the network of river links.

1.3 Significant of the study

Ultimately, it is hoped that this study will improve understanding of the impacts of sediment and nutrient trapping and release from dams. In particular, the benefits of this study are as follows:

1. Improve understanding of the eWater Source model capabilities for sediment and nutrient routing and trapping
2. Provide an overview of the impacts of trapping of sediment, phosphorus and nitrogen in reservoirs in the Manwan and Dachaoshan Dam
3. Sediment routing on tributary links will allow sediment loads to be transferred to the ISIS model to investigate sediment routing on mainstream
4. The Source model will form the basis for the various scenarios envisaged for the second phase of the Council Study
5. Enhancements to the Decision Support Framework (DSF) together with its Knowledge Base (KB) through updated functions and model outputs, particularly for sediment and nutrients.

2 Background

2.1 The Upper Mekong River Basin

The Mekong River is the 12th longest river in the world with a length of 4,800 km, a basin area of 795,000 km^2 and average annual runoff of 475,000 million m^3 (Dai and Trenberth, 2002). It rises in the Tibetan Plateau and flows southward through China, Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam where it discharges into the South China Sea. The river basin is functionally divided into the

- Upper Basin which flows southwards through China where it is called the Lancang River, and the
- Lower Basin which includes Lao PDR, Thailand, Cambodia and Viet Nam (Figure 2-1).

The upper Mekong Basin makes up 24% of the total Basin area and contributes 15-20% of the water that flows into the Mekong River (MRC, 2005).

The rainfall pattern in the Upper Basin in China is determined by global monsoon systems, although in Yunnan province there is a much wider variation from year-to-year in the date of the onset of the southwest monsoon. The seasonal distribution of rainfall is the same as for the Lower Basin, although annual amounts decrease towards the north to as little as 600 mm. Snow is rare in the valleys, but significant at higher altitudes and is the major source of water for the dry season and spring flows (April, May) in the upper mainstream part. The runoff from China dominates the dry season flow throughout much of the overall Mekong system. Although the average yearly runoff from Yunnan is only 16% of the total runoff, it is over 35% for April and May. The basin area of Lancang River forms a narrow and rectangular topography and in general, tributaries flowing into both riverbanks are rather small and short. The final outlet of this river is the Chiang Saen station.

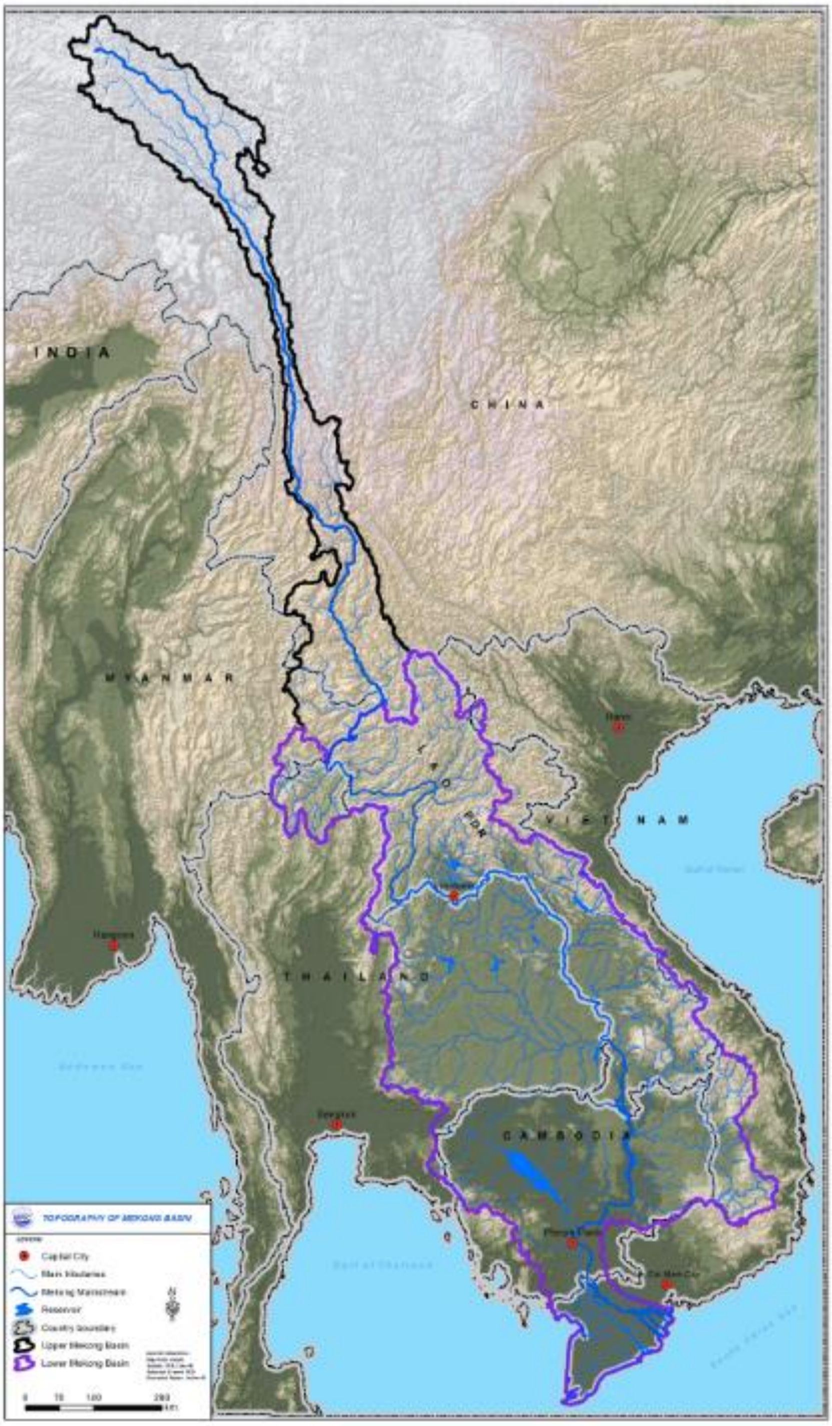

Figure 2-1. Mekong River Basin (Upper Mekong and Lower Mekong).

2.2 Hydropower Dam and Reservoir Development in the Upper Mekong

The effects of a hydropower dams and reservoirs on the sediment and nutrient balance in the Mekong river system can have significant environmental, agricultural as well as other impacts, depending on the design and operation of the dam. Theoretically, sediment trapping efficiency in reservoirs is high, half of the reservoirs showing a local sediment trapping efficiency of 80% or more (Vörösmarty *et al.*, 2003). The trapping efficiency of large reservoirs (volume > 107 m^3) is commonly greater than 99%, depending on the characteristics of the sediment, inflow, and the reservoir (Graf, 2005). Trapping efficiency for smaller dams ranges between 10 and 90% (Brune, 1953).

As of 2007, two dams had been built on the on the mainstream of Langcang River of Upper Mekong Basin (Figure 2-2). The first dam is called Manwan which was completed in 1993. It started generating power three years later in 1996 (Plinston and He, 1999). The second dam was completed in October 2003 in Dachaoshan (Dore and Yu, 2004). The total storage of the Manwan and Dachaoshan dams are 0.92 km^3 and 0.89 km^3 respectively (Plinston and He, 1999). Since 2007, six other dams have either been completed or are under construction and planning (Table 2-1).

An estimated fifty percent of the Mekong's annual sediment load is derived from the Chinese section of the Mekong Basin; the construction of the Chinese cascade dams therefore poses a disproportionately large threat to the supply of nutrients downstream. The reduction in the wet season flood pulse caused by dams also limits the annual natural distribution of nutrients by floodwaters (Goh, 2004).

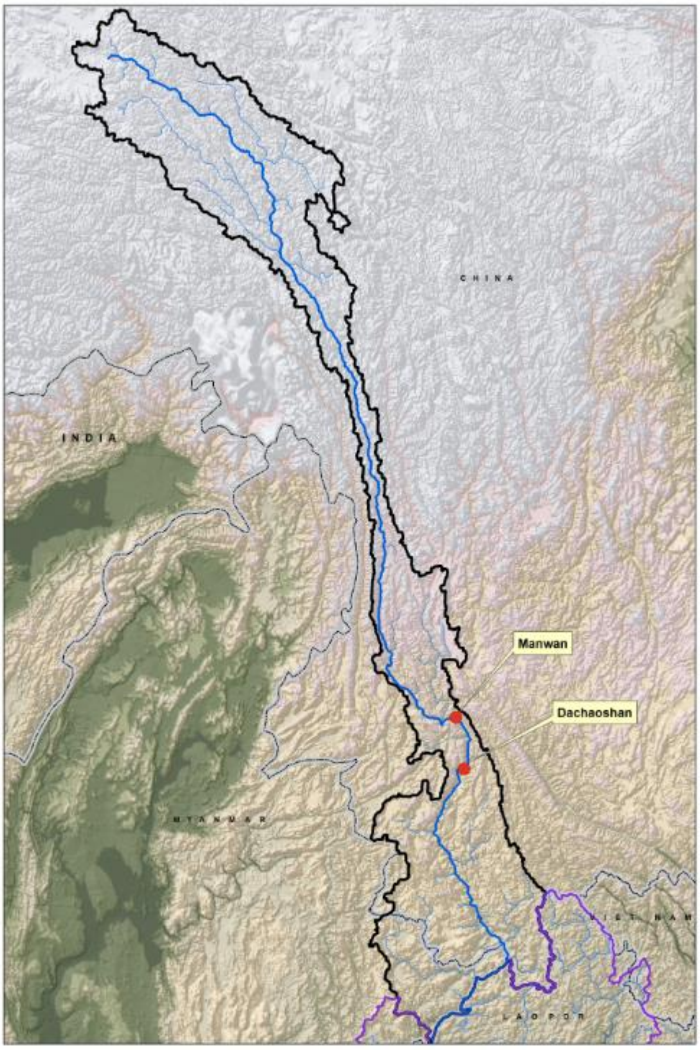

Figure 2-2. The upper Mekong River Basin, highlighting the locations of the Manwan and Dachaoshan Dams.

Table 2-1. List of dam located within Upper of Mekong Basin, including both planned and completed dams.

No	Name	Catchment (km2)	Average inflow (million m3)	Installed Capacity (MW)	Annual Energy (GWh)	Total Storage (Million m3)	Active Storage (Million m3)	Dam Height (m)	Commission Year
1	Gongguoqiao	97,200	31,060	750	3,940	510	120	130	2008
2	Xiaowan	113,300	38,470	4,200	18,890	15,043	10,382	292	2010
3	Manwan	114,500	38,790	1,500	7,600	920	257	132	1996
4	Dachaoshan	121,000	42,260	1,350	6,710	940	467	111	2003
5	Nuazhadu	144,700	54,600	5,850	23,900	23,703	21,749	261.5	2016
6	Jinghong	149,100	58,030	1,750	7,620	1,233	249	108	2010
7	Ganlanba	151,800	59,290	150	780	N/A	N/A	N/A	Designed
8	Mengsong	160,000	63,700	600	2,890	N/A	N/A	N/A	Cancelled

3 eWater Source Workflow & Conceptual Approach

3.1 Introduction

eWater Source (Carr *et al.*, 2012; Welsh *et al.*, 2012) is an integrated water resource management modelling tool, developed by eWater Ltd. It is used to create hydrological models for integrated planning, management and operations for catchment and river systems, including demands for water from urban areas, agriculture and the environment. To support the Council Study, the existing IKMP IQQM model has been converted to eWater Source using eWater's IQQM Network Converter plugin. The converted Source model has been extended to incorporate sediment and nutrient trapping in reservoirs. Sediment and nutrient loads generated from the SWAT land-phase and channel-phase are imported into the Source model at input nodes and routing links, as appropriate.

The application of the integrated models such as SWAT and IQQM and their linkage with Source is shown in Figure 2.1. The top half of the figure represents the workflow based on the conversion of an existing IQQM model to eWater Source. This provides the underlying infrastructure that was created in the IQQM model and also transfers the SWAT generated flows previously loaded into IQQM. Carr and Redpath (2015) confirmed the accuracy of these transferred flows. The bottom half of Figure 3-1 represents the workflow extended to transfer modelled sediments and nutrients from SWAT to the converted eWater Source model.

eWater Source can run as a multi-core processor, meaning that model runs can occur simultaneously with each run using a separate core. A comparison of run times is given in the Model Run Time section below.

All data transfers between models are facilitated by the Data Transfer Tool (DTT) which passes data between models via a central database called the Knowledge Base (KB). Several changes have been made to the DTT to enable the transfer and storage of data to and from eWater Source.

The IQQM model conversion, DTT and sediment and nutrient modelling approach are described in more detail below.

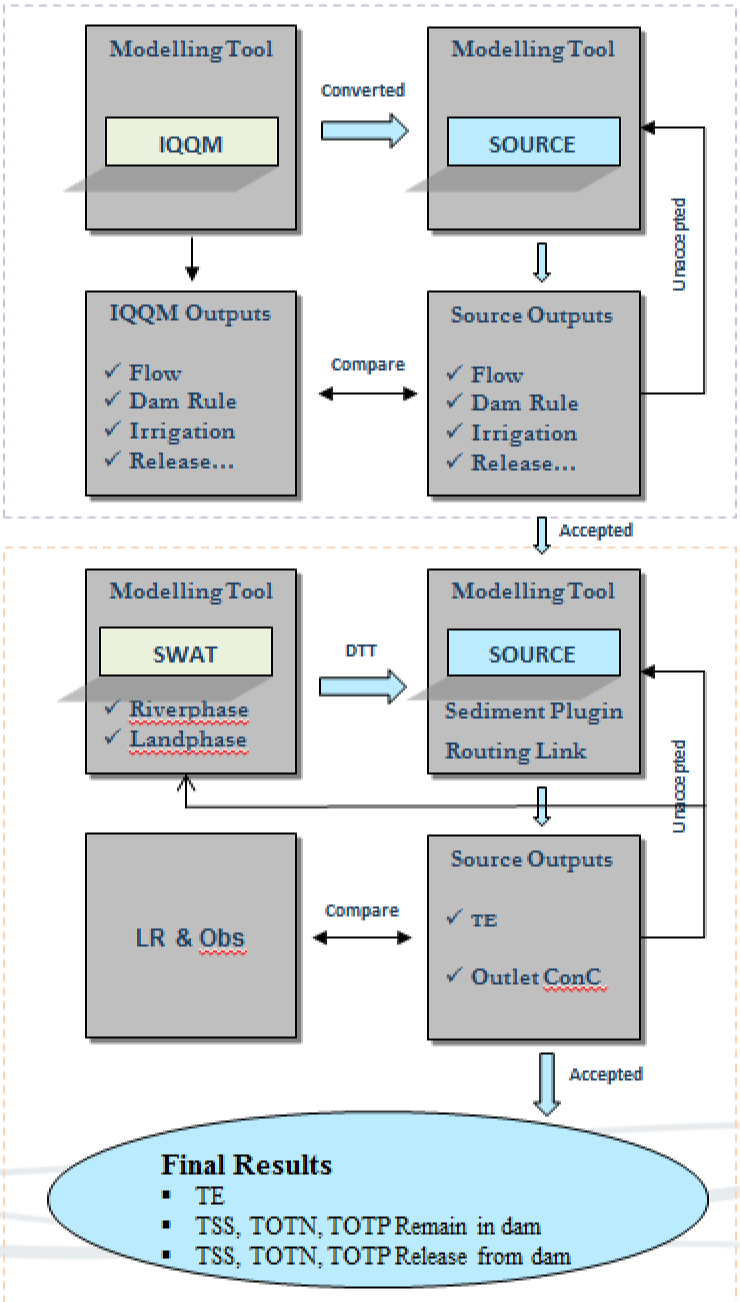

Figure 3-1. Flow chart for the eWater Source model implementation

3.2 IQQM to Source Conversion

The MRC IQQM model is automatically converted into an eWater Source model via a "plugin" program called the IQQM Network Converter. Node and link types found in IQQM are automatically matched to node and link types in Source. The configurations of the IQQM nodes and links are also automatically transferred. Descriptions of how to apply the plugin and the conversion workflow are available in the user guide (Redpath *et al.*, eWater Source, 2015), which includes details of how each IQQM model feature relates to a Source feature. Figure 3-2-A shows the China to Chiang Saen model as it appears in Source Geographic View. Figure 3-2-B shows a similar view of the original model as it appears in IQQM.

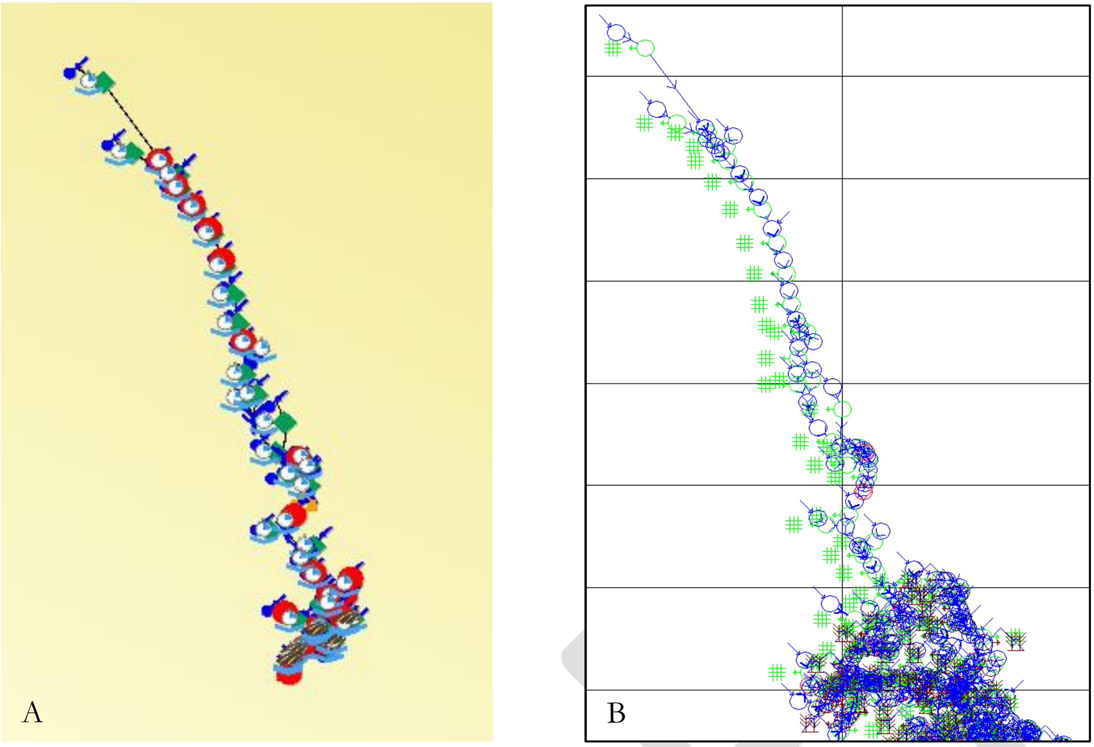

Figure 3-2. The A) eWater Source model of the region upstream of Chiang Saen in Geographic View and B) a view of the IQQM model that has been clipped to a similar region.

A detailed comparison of the IQQM and Source model outputs was completed in July 2015 and is reported in Carr and Redpath (2015). The comparison considers flows in the tributaries and Mekong mainstream, inflow into dams, dam volumes and hydropower energy generation. Figure 3-3 is taken from this report and compares the flows at the gauge at Chiang Saen for two years; 2007 and 2008. Table 3-1 shows comparative statistics for the entire simulation period from 1980 to 2008. The correlation coefficient between the two output series is 0.9998. These comparisons are based on the version of SWAT outputs in use at IKMP in July 2015. The slight differences between the outputs of the IQQM and eWater Source models can be accounted for by an improved implementation of some river network features in Source.

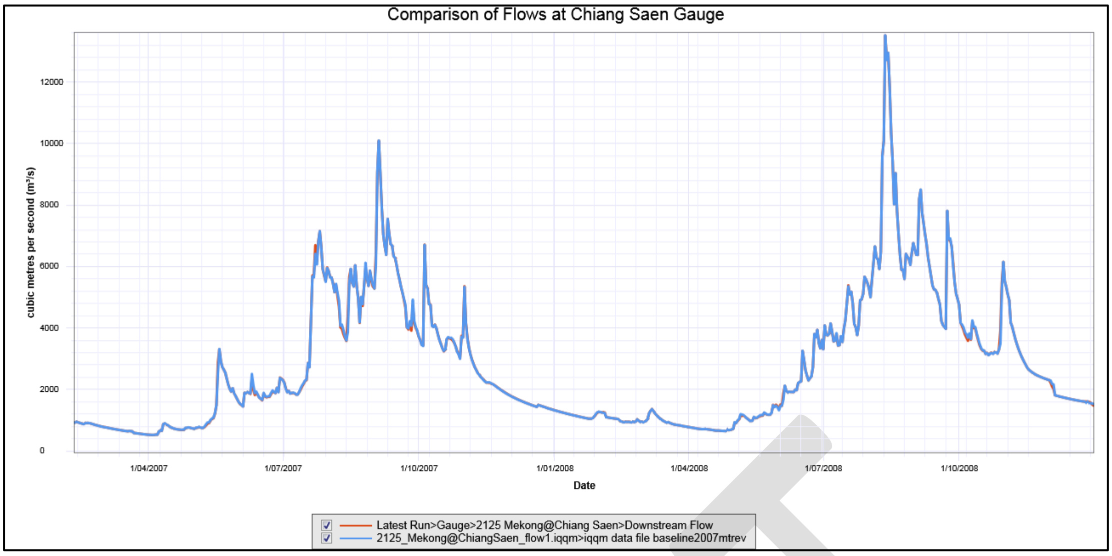

Figure 3-3. Comparison of modelled flows from IQQM and eWater Source at Chiang Saen gauge for the years 2007 and 2008 (from Carr and Redpath, 2015)

Table 3-1. Statistical comparison of flows at Chiang Saen from IQQM and Source for the period 1980 – 2008 (Carr and Redpath, 2015).

Model Period 1/1/1980 - 31/12/2008	Minimum Flow (m^3/s)	Maximum Flow (m^3/s)	Mean Flow (m^3/s)	Total Volume (MCM)
IQQM	0	13 519.8	2 646.8	2 422 418.2
eWater Source	0	13 516.3	2 646.7	2 422 320.7

As newer, more recently calibrated, versions of the SWAT outputs become available, the IQQM-Source flow comparisons remain consistently good. Another comparison was undertaken in November 2015, based on a newer version of the SWAT calibrated outputs. The comparisons are based on the period 1985-2008, as the period 1980-1984 is the SWAT model warm-up and only results after 1985 are used in final analyses. Table 3-2 lists the comparative statistics. The correlation coefficient remains at 0.9998.

Table 3-2. Statistical comparison of flows at Chiang Saen from IQQM and Source for the period 1985 – 2008, based on SWAT outputs released in November 2015.

Model period 1/1/1985 - 31/12/2008	Minimum Flow (m^3/s)	Maximum Flow (m^3/s)	Mean Flow (m^3/s)	Total Volume (MCM)
IQQM	498.6	13 648.9	2 608.7	1 975 752.7
eWater Source	499.0	13 645.3	2 608.5	1 975 664.6

Based on these comparisons the conclusion is that SWAT flow outputs can be imported directly to eWater Source with confidence that eWater Source will produce equivalent outputs to the IQQM model.

3.3 Model Run Time

The Whole Mekong model is divided into three sections:

- Upper Mekong (including China to Chiang Saen gauge),
- Lower Mekong (Chiang Saen to Kratie gauge) and
- the Delta (downstream of Kratie).

The multi-core processing abilities of Source make it possible to run these models simultaneously without impacting on the run time of the others. All models were run on a 16GB 64bit 4 core PC. Each model was set to only produce flow output at each gauge node in the model, for the time period 1980 - 2008. No constituents were included in the test because only the Upper Mekong model has constituents configured at the time of writing. Table 3-3 presents the respective run times of these three models. Two tests were done: a) the models were run back-to-back, one after the other; b) the models were run simultaneously. No differences were found in model run times between a) and b).

Source can also be run in a batch mode where scripts can be set up to execute the models and scenarios, in this mode the whole system can be executed in less than 25 minutes for the 28 year period.

Future versions of Source are planned to be run in the cloud, which will allow for multiple scenarios to be executed simultaneously.

Table 3-3. eWater Source model run times.

Model section	No. of gauge nodes	Output	Model run time (mins)
Upper Mekong	20	Flow (1980-2008)	2
Lower Mekong	230	Flow (1980-2008)	24
Delta	173	Flow (1980-2008)	11

3.4 Data Transfer Tool

The Data Transfer Tool (DTT) is a software tool that transfers data between the models in the DSF and the KB. The KB stores data and model outputs in a common format and the DTT converts between this format and the varying input and output formats required by the DSF models. The DTT was adapted to transfer SWAT data from the KB to Source and then save Source results back to the KB (for details, see Kelly *et al.* (eWater Source, 2015). Several enhancements to adaptors in the DTT have been made by eWater to facilitate these procedures:

1. Adaptor4Source - new adaptor added to convert time series from the KB to eWater Source and to transfer Source results to the KB.

2. Adaptor4SWAT – enhancements to the existing adaptor to allow export of both SYLD and SLOAD results from SWAT to the KB. This feature was designed to handle unit conversions as well as catchment aggregations.
3. As part of the work on the DTT eWater also reviewed the SWAT to KB transfer process (Adaptor4SWAT), resulting in an improvement to the speed with which data is transferred from SWAT to the KB.

An indication of the performance improvements to the Adaptor4SWAT are given in Table 3-4. Initial performance improvements were made in version 61 of the DTT. While substantial improvements to read and write speeds were implemented for writing new SWAT data to the KB, users reported that they were not experiencing a significant increase in speed. Further investigation revealed that users were most commonly using the "write to KB with replacement feature", which was not considered in the original performance enhancements. As illustrated in Table 3-4, the DTT v79 (released on 11/12/2015) addresses this, and makes the process of writing to the KB with replacement more than 4 times faster than the original DTT for the test case.

Table 3-4. Performance comparison of the original DTT and the eWater releases. The speeds were tested by extracting 4 parameters from 93 catchments from the SWAT *output.sub* file.

DTT Version	Task	SWAT Read	KB Write	Total Time
Original DTT	SWAT to KB: First write to KB	10:00	1:14	**11:14**
	SWAT to KB: Write to KB with replacement	8:00	15:30	**23:30**
DTT v61	SWAT to KB: First write to KB	0:20	1:07	**1:27**
	SWAT to KB: Write to KB with replacement	0:18	17:19	**17:37**
DTT v79	SWAT to KB: First write to KB	0:29	1:20	**1:49**
	SWAT to KB: Write to KB with replacement	0:29	4:33	**5:02**

3.5 Sediment and Nutrient Modelling

3.5.1 Introduction

In Source, the term "constituents" refers to tracers that are generated, transported or transformed within a catchment and are usually associated with water quality characteristics such as nutrients, sediment, salts or dissolved solids. The Source Baseline model for the Council Study currently considers three types of constituents:

- Total suspended sediments (TSS)
- Total nitrogen (TOTN)
- Total phosphorus (TOTP)

The Source model imports time series of sediment and nutrient loads from SWAT (using the DTT to extract the SWAT results from the KB). The SWAT land-phase outputs are imported as concentrations at Source Inflow nodes (in conjunction with the SWAT flows), while the SWAT channel-phase outputs are imported as mass fluxes on Source Storage Routing links.

Constituent routing on links and sediment and nutrient trapping in reservoirs are described in more detail below.

3.5.2 Sediment and Nutrient Routing in Links

The Source Mekong model routes constituents through the river network using a conservative routing model based on kinematic wave theory. Assuming fully-mixed conditions within a river link, the constituent flux and concentration moves from the top of the link to the downstream end of the link at the velocity of the water flow (also known as plug flow), preserving the mass balance. The travel time of the constituent depends on the travel time of the flow within the link.

In addition to transport processes, constituent concentrations in a (Storage Routing) link can be altered in a number of ways, including:

1. the addition of constituents generated from sub-catchments
2. external inflows, such as rainfall, and losses, such as evaporation, within a reach
3. applying instream processing models, such as a decay algorithm
4. applying a time series of constituent losses or gains expressed as mass or concentration

The Source model for the Council Study currently uses the 4th approach to capture constituent losses and gains due to processes such as nutrient cycles and sediment deposition and mobilisation. Sediment and nutrient loads (flow multiplied by concentration) are generated using SWAT. Sediment and nutrient channel-phase loads from SWAT are imported to Source, via the DTT, as a flux of mass on the model links. This flux is positive or negative depending on whether the mass is added to (positive) or removed from (negative) the link.

This approach, rather than using instream processing models, was adopted because the SWAT model has been calibrated using both land use/catchment generation of sediments and an in-stream source/sink processes rather than a deposition/resuspension process using catchment loads. For this reason, it is not possible to use a process model in the Source links and so the source/sink term from SWAT was applied to the Source links via the KB transfer.

For future work, eWater suggests that the SWAT model be recalibrated using land-phase loads only, with deposition/erosion processes incorporated in the Source links.

3.5.3 Reservoir Trapping: Constituent Processing Plugin

Constituent trapping in reservoirs is handled using a tool called the Constituent Processing Plugin. Details of the plugin are given in Blakers and Moolman (eWater Source, 2015). This report summarises the:

1. Brune Reservoir Sediment Trapping Model (Brune, 1953)

2. Reservoir Nutrient Trapping Model (which is linked to the Brune model)

Brune Reservoir Sediment Trapping Model
Reservoir sediment trap-efficiency (TE) is the proportion of incoming sediment that is deposited in the reservoir. The Constituent Processing Plugin implements the Brune (1953) reservoir sediment trap model, which is a widely used and well-established method. The Brune model derives a relationship between the reservoir capacity – inflow (CI) ratio and sediment TE using annual data. The plugin uses the following equation, which is derived from the Brune (1953) data, to estimate TE:

$$T_{Brune} = \max(0, -0.01491 + 0.9825^{0.1528^{\log 10(CI)}}) \quad (1)$$

where

$$CI = \frac{Reservoir\ Capacity\ (volume)}{Average\ Total\ Annual\ Inflow\ (total\ volume\ per\ annum)} \quad (2)$$

Nutrient Settling in Reservoirs
Sedimentation of nutrients, which can occur by the settling of particulate nutrients or by the association of dissolved substances with settling biotic and abiotic particles, can result in a loss of nutrients from the water column. In Source, nutrient settling is linked to the Brune sediment trapping model, the mass of nutrients settling out being represented as a proportion of the Brune TE, which in turn is a function of the reservoir capacity-inflow ratio. The proportion of nutrient flowing into the reservoir that is lost to sediments is calculated as:

$$T_{Nut} = \alpha T_{Brune}$$

where α is the fraction of total nutrient represented by settleable particulates. The value of α may be different for different nutrients and reservoirs.

4 eWater Source Baseline Model - Preliminary Results

4.1 Introduction

The eWater Source Baseline model for China to Chiang Saen includes two storages; Manwan Dam and Dachaoshan Dam. The preliminary results were generated using flow, sediment and nutrient outputs from SWAT version 3. As discussed in detail below, the SWAT model calibration is being refined and the current results are used solely to demonstrate the capacity of Source to model sediments and nutrients for the Council Study. The Source model will be updated as new SWAT model results become available.

Two sets of results from eWater Source are presented:

1. Without sediment or nutrient trapping in the reservoirs
2. With sediment and nutrient trapping in the reservoirs

Results are shown at the Chiang Saen gauge, which is the outlet of the China to Chiang Saen model. The time period of the results is 01/01/1985 – 31/12/2008, chosen to exclude the 1980-1985 SWAT model warm-up period.

The Source model results without reservoir trapping are compared with the corresponding SWAT model outputs. In the Source model, these results have been achieved by disabling sediment and nutrient trapping in the Manwan and Dachaoshan Dams. In the SWAT model, the results been achieved by removing the dams entirely. Despite the difference in the configuration of the two models, the outputs are very similar.

The Source baseline results with reservoir trapping are compared to sediment and nutrient load estimates produced by the Loadest model. Observed water quality variables are mostly measured at a monthly intervals. Loadest produces a regression equation between flows and observed sediment or nutrients, which is used to generate a flow-dependent daily time series of sediment or nutrient loads. Loadest was used to produce the calibration data for the SWAT baseline model.

4.2 Flow

Modelled flow is generated using the SWAT model and then transferred to eWater Source at Inflow nodes. Flow output from eWater Source versus observed flow per month at Chiang Saen is shown in Figure 4-1. The agreement between the two time series is generally good, with the exception of the peak flows in the years 1992 and 1997.

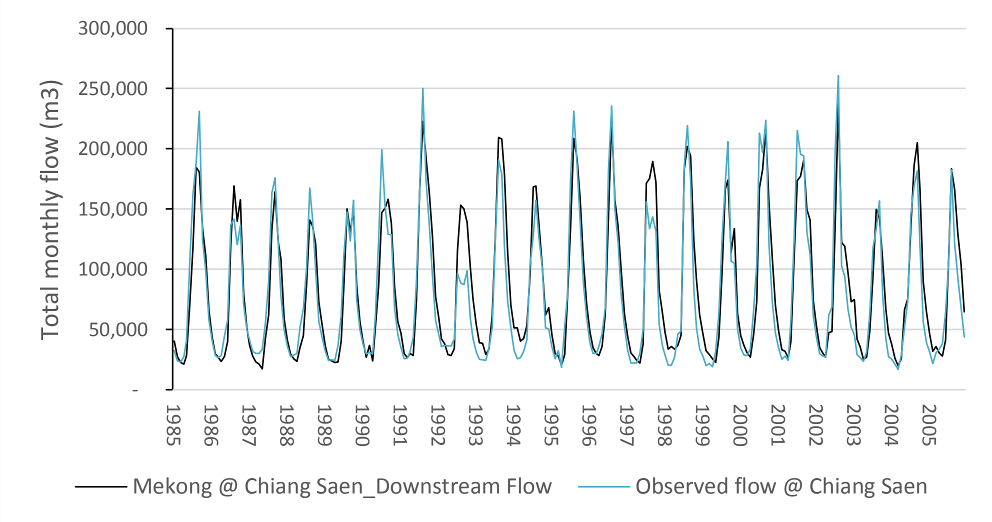

Figure 4-1. Total monthly modelled and observed flow @ Chiang Saen.

4.3 Sediment

Land-phase and channel-phase sediments produced from the SWAT model are transferred to eWater Source at Inflow nodes and Storage Routing links, respectively. eWater Source then models the transport of this sediment through links and the trapping in reservoirs.

Table 4-1 compares sediment TE estimates at Manwan Dam and Dachaoshan Dam from the Source model with other estimates quoted in the literature. Fu *et al.* (2007) applied the Brune and Siyam algorithms while Kummu *et al.* (2010) applied the Brune algorithm. The implementation of the Brune TE methodology in eWater Source produces results comparable to those obtained by Fu *et al.* (2008) using the Brune methodology.

Table 4-1. Percent Sediment Trapping Efficiency at Manwan and Dachaoshan dams

	Fu *et al.* (2008)		Kummu *et al.* (2010)	eWater Source
	Brune TE (%)	Siyam TE (%)	Brune TE (%)	Brune TE (%)
Manwan	60.03	60.03	47	67.2
Dachaoshan	63.97	66.05	50	63.5

4.3.1 Sediment Loads Without Trapping

Total monthly eWater Source sediment output and the original SWAT sediment output at Chiang Saen gauge are shown in Figure 4-2. The time series of sediment loads have a correlation coefficient of 0.999.

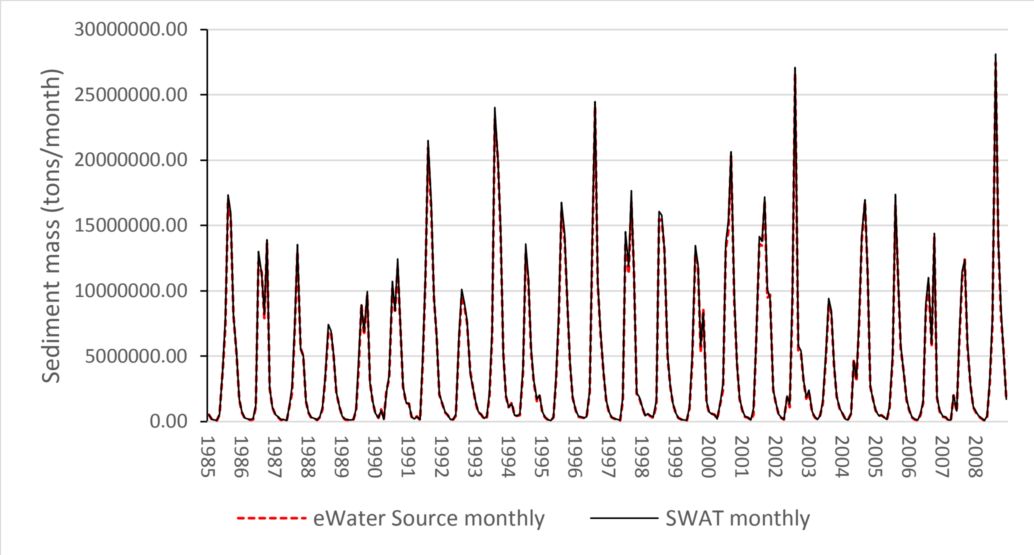

Figure 4-2. Total monthly sediment output, without reservoir sediment trapping, from eWater Source and SWAT @ Chiang Saen.

4.3.2 Sediment Loads With Trapping

Figure 4-3 shows total monthly eWater Source sediment mass at Chiang Saen, with reservoir sediment trapping enabled, against Loadest values. It has a correlation coefficient of 0.81.

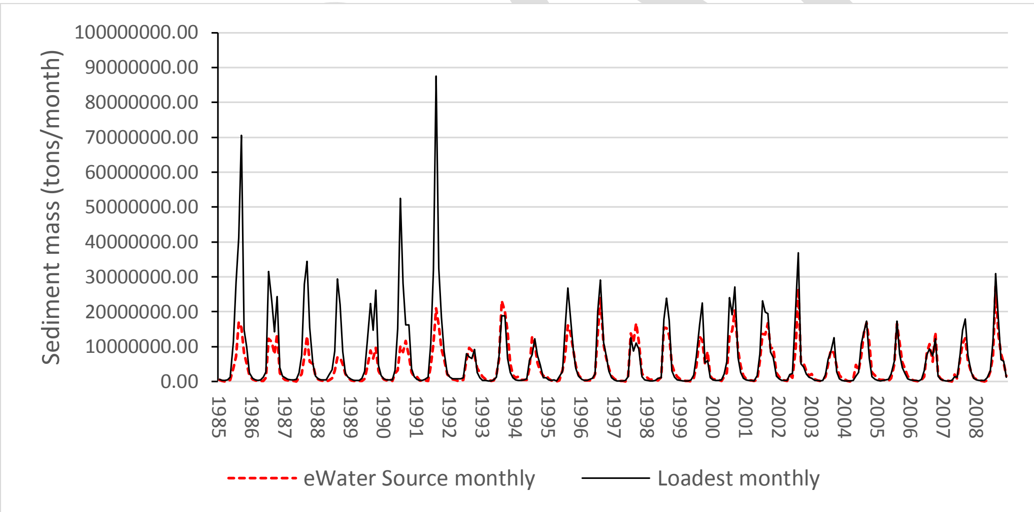

Figure 4-3. Total monthly sediment output, with reservoir sediment trapping, from eWater Source and Loadest @ Chiang Saen.

Figure 4-4 compares the Source model estimates of total monthly sediment mass at Chiang Saen gauge a) without sediment trapping and b) with sediment trapping at Manwan and Dachaoshan dams. Despite the TE values of the dams being acceptable, the actual amount of trapped sediment makes very little difference in the final amount of sediment leaving the catchment at Chiang Saen. This is because the total mass of sediment contributed upstream of Manwan and Dachaoshan dams is very small in comparison to the mass contributed downstream between the dams and Chiang Saen gauge. The spatial distribution of sediment inputs to eWater Source is determined by the SWAT model. Figure 4-5 illustrates the spatial distribution and magnitude of sediment loads from the SWAT model (version 3), using total annual values for 1985 as an example.

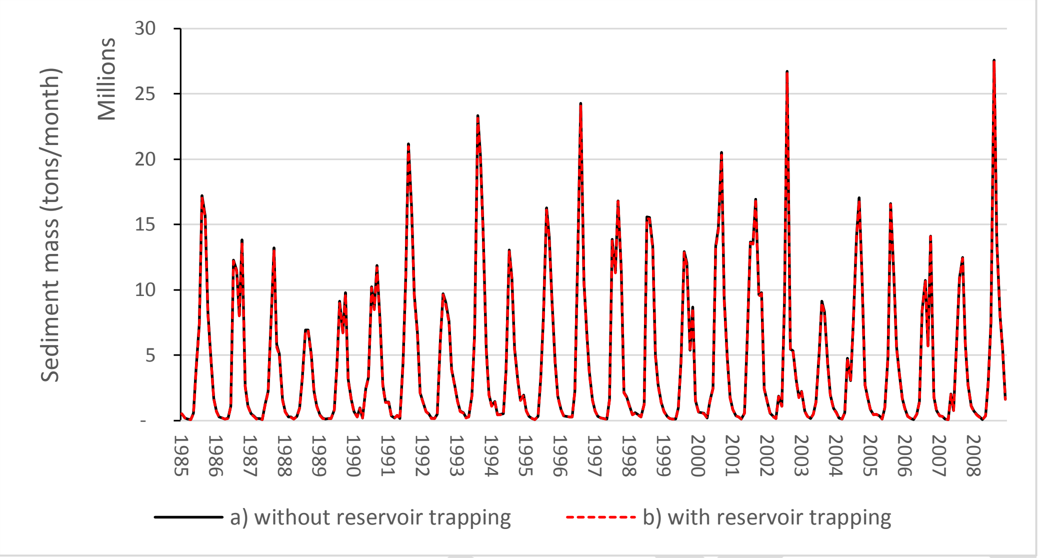

Figure 4-4. Total monthly sediment load @ Chiang Saen from the Source model a) without and b) with reservoir trapping.

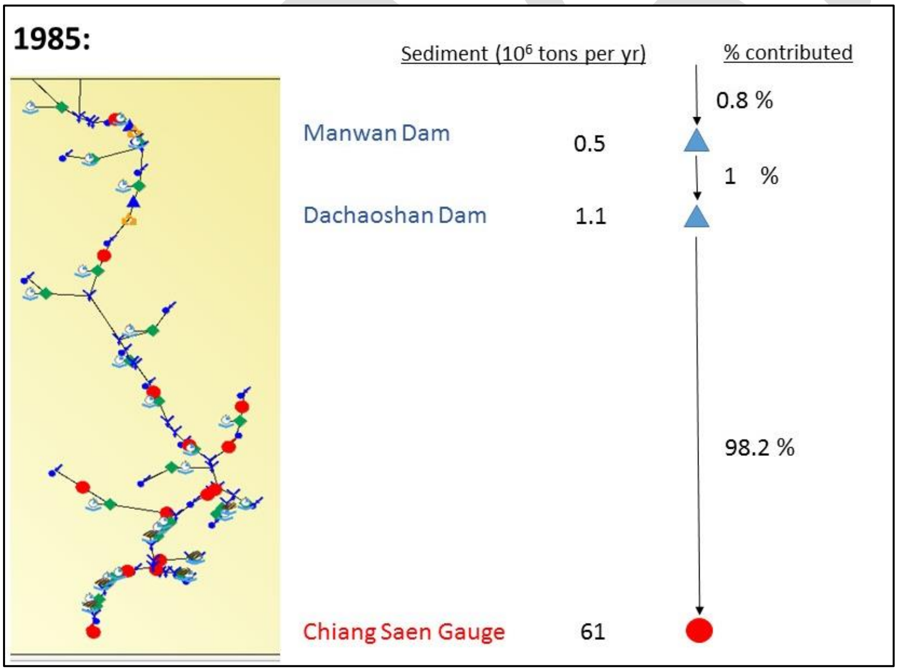

Figure 4-5. Relative sediment contribution in the regions upstream of Chiang Saen gauge, Manwan Dam and Dachaoshan Dam as produced by SWAT v3.

4.3.3 *Adjusted Sediment Loads with Trapping at Manwan, Dachaoshan, Xiaowan and Nuozhadu Dams*

The small change in the sediment loads at Chiang Saen is due to the magnitude and spatial distribution of the input sediment loads from the SWAT model (version 3). An update of the SWAT model is already available (version 3.1) and further refinements of the SWAT model are in progress (to be released as version 4). In the interim, to demonstrate the *capability* of the Source model to represent sediment trapping in the dams, the SWAT sediment inputs to the Source model were re-distributed spatially. Specifically, large sediment loads entering below the Nuozhadu dam were applied to the river reach above the Xiaowan dam location. This change increases the sediment masses entering the Xiaowan Dam from an average of 0.7 Mt per annum to 39.2 Mt per annum, which is more representative of the real system (Thorne *et al.*, 2011, Table B.4). In addition, to enable comparison with results in the Thorne *et al.* (2011) report, the Xiaowan and Nuozhadu dams were added to the model. These, dams are not included in the standard Source Baseline model.

The results of simulating the Source model with the re-distributed sediment loads are show in Table 4-2. These results are comparable to those of Thorne *et al.* (2011) (see Table 4-3). There are some differences, which are likely to be resolved by the improvements to the SWAT model that are in progress. The purpose of these results to demonstrate that the Source model is capable of representing sediment trapping in the dams, given upstream sediment loads that are of the right magnitude. They should not be used in any other context. These results will be replaced when the new SWAT model is available.

Table 4-2. Modelled total annual sediment loads, trap efficiency and trapped masses at the four dams considered in the analysis. Manwan and Dachoashan Dam trap efficiencies are the same as in Table 4-1, but are included for ease of comparison. Also shown is the sediment load at Chiang Saen. Annual sediment masses are averaged over the period 1985 to 2008, inclusive.

Location	Sediment Load (Mt/yr.)	Trap Efficiency (%)	Trap (Mt/yr.)
Xiaowan Dam	39.2	95	37.1
Manwan Dam	1.7	67	1.1
Dachaoshan Dam	1.1	63	0.7
Nuozhadu Dam	7.6	95	7.2
Chiang Saen Gauge	13.8	NA	NA

Table 4-3. Estimated amounts of trapped sediment for mainstream dams in China, reproduced from Thorne *et al.* (2011), Table B.4.

Location	Sediment Load (Mt/yr.)	Trap Efficiency (%)	Trap (Mt/yr.)
Xiaowan Dam	57.5	91	52.4
Manwan Dam	5.1	60	3.1
Dachaoshan Dam	2.0	57	1.2
Nuozhadu Dam	0.9	90	0.8

4.4 *Nutrients*

The Source model includes two types of nutrients, total phosphorus (TOTP) and total nitrogen (TOTN). Similarly to sediments, SWAT generated land-phase and channel-phase nutrients are input at eWater Source Inflow nodes and Storage Routing links.

Reservoir nutrient trapping in eWater Source is associated with sediment trapping. Table 4-4 provides the Source model estimates of TOTN and TOTP particulate proportions and trapping at Manwan and Dachaoshan dams. The estimates of the nutrient proportions associated with sediments were derived from Thorne *et al.* (2011). The Thorne *et al.* (2011) report quotes several different values, and those most relevant to the Upper Mekong were used in this study. The report states that:

- Data from the MRC database show that, at Luang Prabang in 2004-2005, soluble phosphate (P) on average made up 70% of total P, suggesting that 30% was associated with sediments.
- Data for nitrogen (N) for the hydrometric station at Chiang Sean indicate that an average of approximately 50% of nitrogen occurs as particulate.

Table 4-4. Estimates of particulate nutrient proportions and nutrient trap-efficiency (TE) at Manwan and Dachaoshan dams.

Dam	Nutrient	Particulate %	Nutrient TE %
Manwan	TOTN	50	33.6
	TOTP	30	20.2
Dachaoshan	TOTN	50	31.7
	TOTP	30	19.0

4.4.1 *Nutrient Loads at Chiang Saen without Trapping*

Figure 4-6 shows the eWater Source TOTN output at Chiang Saen gauge against the original SWAT output. It has a correlation coefficient of 0.99. Figure 4-7 shows the eWater Source TOTP output at Chiang Saen gauge against the original SWAT output. It has a correlation coefficient of 0.97. Both models have been run without nutrient trapping in reservoirs.

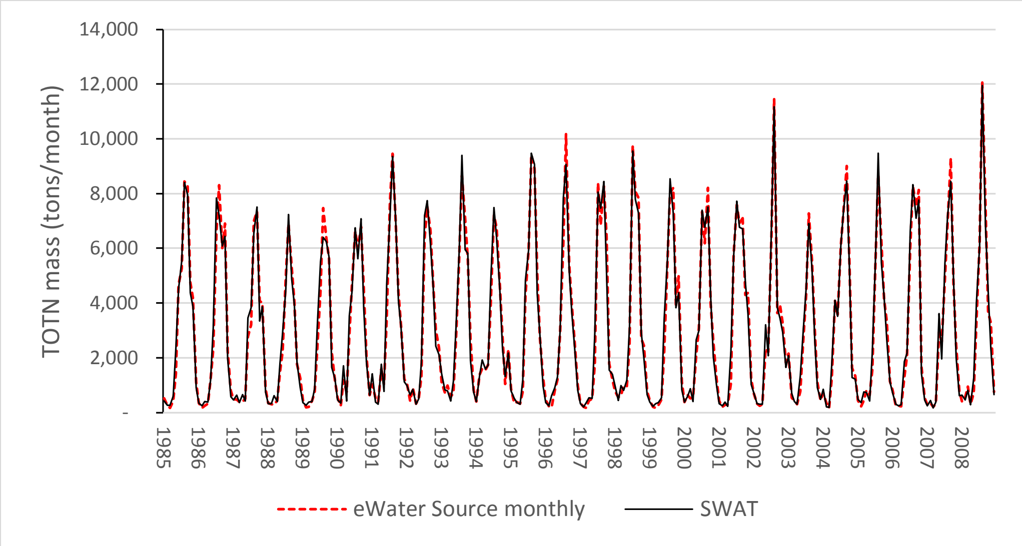

Figure 4-6. Total monthly TOTN output from eWater Source and SWAT @ Chiang Saen

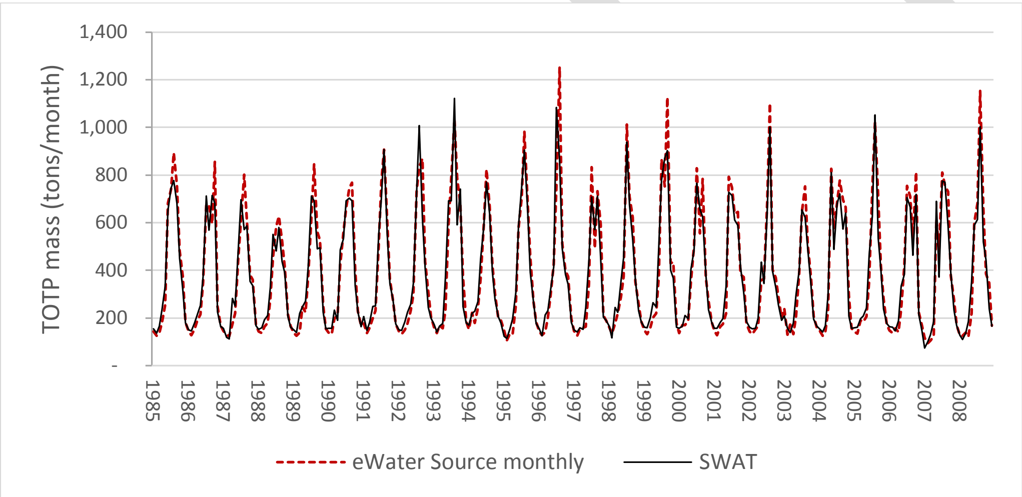

Figure 4-7. Total monthly TOTP output from eWater Source and SWAT @ Chiang Saen.

4.4.2 Nutrient Loads at Chiang Saen with Reservoir Trapping

Figure 4-8 and Figure 4-9 show total monthly eWater Source TOTN and TOTP mass at Chiang Saen against Loadest TOTN and TOTP values. The comparison includes nutrient settling in the eWater Source model. Total monthly TOTN versus Loadest values has a correlation coefficient of 0.94. Total monthly TOTP versus Loadest values has a correlation coefficient of 0.89.

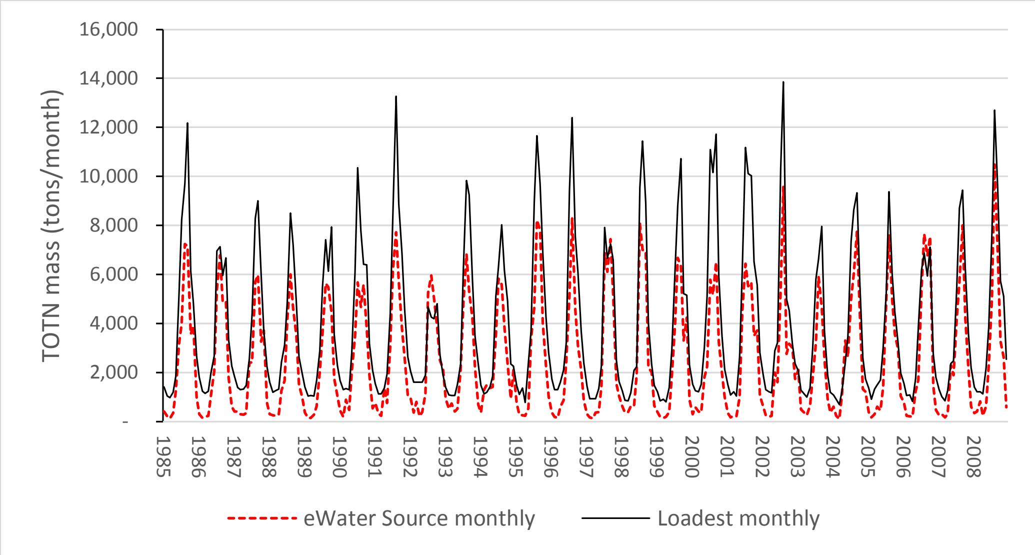

Figure 4-8. Total monthly TOTN output from eWater Source and Loadest @ Chiang Saen.

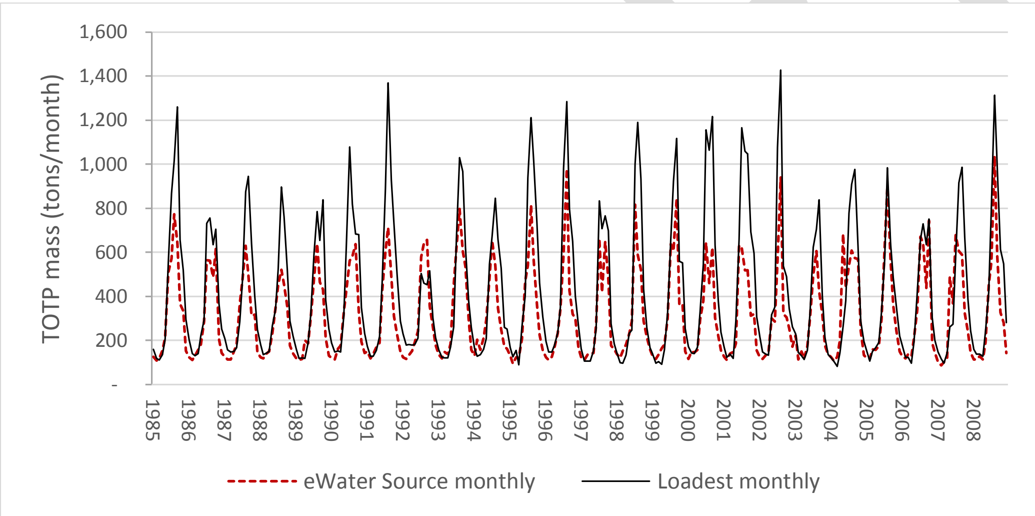

Figure 4-9. Total monthly TOTP output from eWater Source and Loadest @ Chiang Saen.

5 Conclusions

The whole of Mekong Basin IQQM model has been successfully converted to eWater Source and the conversion has shown that Source can faithfully reproduce the IQQM results. The Source model offers additional functionality for sediment and nutrient trapping and routing, and for future studies it has the capability to address trade-off analysis. This report demonstrates the Source model workflow and capability, using the region between China and Chiang Saen as an example. Given appropriate sediment and nutrient inputs at Mekong tributaries, the report demonstrates that Source can route these inputs through the flow network to the Mekong mainstream.

A strength of the eWater Source tool is that it enables the results of other models to be integrated and analysed. In its current configuration, the Source model depends on flow, sediment and nutrient inputs from the SWAT model, which are still being finalised at the time of writing. The eWater Source model will be updated as new SWAT model results become available. eWater Source further has the option of calibrating to inbuilt load generation algorithms as an alternative option to SWAT if required.

6 References

Blakers, R.B., and J. Moolman (eWater Source, 2015) *eWater Source Constituent Processing Plugin Documentation: Technical Report, v1.0*. eWater Ltd, Canberra, Australia, Dec 2015.

Brune, G.M., 1953. Trap efficiency of reservoirs. *Eos, Transactions of American Geophysical Union* 34 (3), 407–418.

Carr, R, Podger, G. (2012) *eWater Source – Australia's Next Generation IWRM Modelling Platform*. 34th Hydrology and Water Resources Symposium (December 2012), ISBN 978-1-922107-62-6

Carr, R and Redpath, K.R (2015) *Source Baseline Model Application for Mekong River Basin - Conversion from IQQM to Source: Technical Report, v1.0*, eWater Ltd, August 2015.

Dai, A., and K.E. Trenberth (2002) Estimates of Freshwater Discharge from Continents: Latitudinal and Seasonal Variations. *Journal of Hydrometeorology* 3(6), 660 –687.

Dore, J., X. Yu (2004) *Yunnan hydropower expansion — update on China's energy industry reforms and the Nu, Lancang and Jinsha hydropower dams*, Chiang Mai University's Unit for Social and Environmental Research and Green Watershed, Kunming, PR of China. 38 pp.

Goh, E. (2004). *China in the Mekong River Basin: The Regional Security Implications of Resource Development on the Lancang Jiang* (Working Paper 69). Singapore: Institute of Defence and Strategic Studies. Retrieved from http://dr.ntu.edu.sg/handle/10220/4469?show=full.

Graf, W.L., (2005) Geomorphology and American dams: the scientific, social, and economic context. *Geomorphology* 71 (1–2), 3–26.

Kelly, M., M. McKerrow, N. Norris (ewater Source, 2015) *Source Adaptor for Data Transfer Tool: User Manual for Mekong River Basin, v1.0*. eWater Ltd, Canberra, Australia, December 2015.

MRC (2005) *Overview of the Hydrology of the Mekong River Basin*, Mekong River Commission, Vientiane. 73p.

Plinston, D., and D. He (1999) *Water Resources and Hydropower*. ADB TA-3139 Policies and Strategies for Sustainable Development of the Lancang River Basin. Asian Development Bank, Manila. 35 pp.

Redpath, K., McKerrow, M., Norris, N. (eWater Source, 2015) *IQQM to Source Model Conversion: User Manual for Mekong River Basin, v1.0*. eWater Ltd, Canberra, Australia, Dec 2015.

Thorne, C., G. Annandale, K. Jensen, E. Jensen, A. Green and J. Koponen (2011) *Review of Sediment Transport, Morphology, and Nutrient Balance*. Report to the Mekong River Commission

Secretariat prepared as part of the Xayaburi MRCS Prior Consultation Project Review Report, Nottingham University, UK, February 2011, 82p.

Vörösmarty, C.J., Meybeck, M., Fekete, B., Sharma, K., Green, P., Syvitski, J.P.M., 2003. Anthropogenic sediment retention: major global impact from registered river impoundments. *Global and Planetary Change* 39 (1–2), 169–190

Welsh WD, Vaze J, Dutta D, Rassam D, Rahman JM, Jolly ID, Wallbrink P, Podger GM, Bethune M, Hardy M, Teng J, Lerat J. (2012) An integrated modelling framework for regulated river systems. *Environmental Modelling and Software*, DOI 10.1016/j.envsoft.2012.02.022