Annex E: Hydrology and Hydraulics

1.0 INTRODUCTION

This initial review of the available documents relating to the evaluation of the hydrology and hydraulic studies for the design and operation of the Don Sahong Hydropower takes into account design and modelling documents which were available for review as of December 2014. They are listed in the reference section.

2.0 HYDROLOGY

With regard to the hydrological assessment, the DSHPP Hydrology, Hydraulics and Sediment Studies Engineering Status Report (AECOM 2011b) is clear, concise and has a logical structure. All of the pertinent variables relevant to the evaluation of the scheme, its design and operation are considered, and the "at site" estimation methodologies that have been implemented are described in quite adequate detail. The fundamental hydrological estimates required are the reliability of the flows available for power generation and the distribution of flood risk, which is essential for the protection of the permanent works. Other hydrological issues that are covered include the provision of an adequate environmental flow release and the estimation of the likely division of flows amongst the numerous distributary channels within this complex reach of the Mekong mainstream.

An impressive feature of the work undertaken to evaluate the feasibility of the Project is the attention that has been given to "at site" flow gauging and water level observations. This has been undertaken since mid 2006, initially during the low flow season only, while post 2008 discharge measurements and water level observations were also carried out during the flood season as conditions allowed. These data have been collected at sixteen sites within the Project areas, both upstream and downstream of the proposed dam sites. Automatic water level recorders were installed at three key sites in September 2010 and 15 minute data continuously assembled since then. These "at site" hydrological measurements have been correlated with the contemporaneous daily discharges recorded at Pakse which enabled a "synthetic" daily discharge time-series to be estimated for the scheme. These estimates were then used to prepare daily flow duration curves at ten sites within the various distributary channels associated with the Project.

The selection of the flow data observed at Pakse, with an upstream drainage area of 545,000 km^2 as the basis for the hydrological evaluation of the Project, is sound, since the combined Mekong catchment area amongst the multiple channels local to the scheme is less than two percent greater, at 553,000 km^2. A subset of the historical Pakse daily time-series, which is available since 1924, was selected to provide a 28 year "Baseline" covering the years from 1982 to 2009.

This subset is then used for scheme optimization and energy modeling. Table 2-1 on page 4 of the Report provides some summary statistics of the observed mainstream hydrology at Pakse. There are, however, some questions that arise with respect to some of the figures quoted:

- The long term mean annual discharge is given as 10,100 m^3/s (it would be an improvement if the data in such tables were rounded to the nearest ten m^3/s), which is correct. However, the median annual discharge is given as 5,100 m^3/s. The median cannot possibly be half of the mean (!). In fact the correct median figure is also 10,100 m^3/s. For all of the gauged Mekong mainstream sites from Chiang Saen to Kratie, the median annual discharge is insignificantly different to the mean. The annual data are asymptotically normally distributed.
- In the second paragraph beneath Table 2-1, the mean annual flow at Pakse in volumetric terms is quoted as 800 km^3. This is a gross error (!). The correct figure is calculated as :-

$$10{,}100*0.0864*365*10^{-3} = \underline{\mathbf{318\ km^3.}}$$

which is equivalent to a mean annual depth of runoff of 1,065mm.

The objective in this part of the Report is to establish that the seasonal and annual hydrological regime at Pakse during the Baseline period is not significantly different to those over the long term. Rather than simply compare means and contend that the summary statistics are comparable, more statistical rigour would be introduced by estimating the confidence intervals about the estimated statistics and evaluating whether any differences are statistically significant or not. The table overleaf provides the relevant figures.

The results presented in Table 1 indicate that at the 95% level the margin of any statistically significant differences is small and probably well within the scope of gauging error. In terms of the mean flows the Baseline period statistics could therefore be concluded to be indicative of the longer term average hydrology.

The 28-year Baseline series adopted is considered to be of sufficient length to represent the *natural variability in Mekong flows*. This point does, however, require verification. The Report focuses upon the comparison of the long term mean flows at Pakse with those obtained for the Baseline. The inter-annual and seasonal variance of the hydrological data should be evaluated using an appropriate statistical measure such as the standard deviation or, better still, a non-parametric measure of "data spread" such as the median absolute deviation about the mean. This point is raised since average discharge values in themselves do not provide a sufficient indication of flow reliability and the potential incidence and severity of deficient flows for power generation.

	Mean discharge 1923 - 2013	95% CI	Baseline: mean discharge 1982 - 2009	Significantly different at the 95% level ?
Jan	2,810	2,720 – 2,900	2,760	No
Feb	2,180	2,110 – 2,240	2,190	No
Mar	1,840	1 780 – 1,900	1,930	Yes
Apr	1,820	1,750 – 1,890	1,940	Yes
May	2,940	2,750 – 3,130	3,150	Yes
Jun	8,680	8,020 – 9,340	8,380	No
Jul	17,040	16,110 – 17,960	16,720	No
Aug	27,150	26,030 – 28,270	26,140	No
Sep	27,300	26,220 – 28,380	25,480	Yes
Oct	16,430	15,630 – 17,230	15,180	Yes
Nov	8,130	7,720 – 8,540	7,570	Yes
Dec	4,290	4,120 – 4,450	4,020	Yes
Annual	10,100	9,800 – 10,380	9,660	Yes

Table 1: A comparison of the mean seasonal and annual long term hydrology at Pakse (1923 – 2013) with the Baseline years (1982 – 2009) with reference to the 95% confidence interval (CI) about the former.

River conditions at Pakse during the “at site” flow measurements are expressed in Figure 2-4 on page 6. Those on the dates of the gauging during 2010 and 2011 are indicated on the Pakse daily flow duration curve. The range of hydrological conditions that would have been observed at the Project site during the gauging program clearly covers the full spectrum, which is most encouraging.

The relationship between the flows observed at Pakse and the flows and water levels monitored “at site” is estimated on the basis of regression analyses. It is noted that there is an appreciable time lag between changes at the two locations which is dependent on flow conditions, with shorter lags at high-flow and longer lags at low-flow conditions. During periods of higher flow the mean time of travel is reported to be 15 hours and during low flow conditions as long as 3.5 days. The time offsets adopted were related to flow classes at Pakse. These data are presented in Table 2-9. The non-linear correlation models were highly satisfactory, with coefficients of determination as high as 0.99. Using these models it was possible to construct synthetic daily time series for the various channels contiguous to the Scheme, from which flow duration curves (FDCs) were prepared.

Table 2 below summarizes the FDC’s in terms of the 50% exceedance level in order to assess more readily the distribution of the Mekong flows amongst the various channels. From this summary result the proportion of flow entering the Don Sahong channel and therefore available to the Scheme is a modest proportion of the total.

In this context, it should be noted that the fluvial morphology of the distributary channels adjacent to the Project is transient. Engineering works and channel deepening will in time affect the distribution of flows such that ongoing flow monitoring will be required.

Channel	Daily flow exceeded 50% of the time (m^3/s)
En	545
C501	1,120
C502	860
North 1	230
North 2	660
Sahong	300
Sadam	60
Thakho	2,510
Mainstream	1,930
Xang Peuk	490

Table 2: Daily flows equaled or exceeded 50% of the time in the various channels.

The design flood risk studies are quite straightforward and are based on the 87 year historical record of annual maxima at Pakse between 1924 and 2010. A number of extreme value models were evaluated but each one was constrained by the presence of a large outlier in the time series in the form of the peak discharge in 1978. A "conservative' model was adopted that approximated best the risk of the outlier event. By extrapolation this gave a 1:1,000 design flood peak discharge of 66,000 m^3/s. Under natural conditions this would be distributed amongst the various channels adjacent to the Scheme.

3.0 COMPUTATIONAL HYDRAULIC MODELLING.

Computational hydraulic modeling has been undertaken to gain an understanding of the natural water levels and flows in the project area, and to determine the effects of channel excavation and station operation on water levels, velocities and flow rates. The evaluation is based upon the 15 discrete points on the flow duration curves that were estimated for each of the "at site" channels. The hydraulic study comprises two principal components:

- The Hou Sahong headwater model, and
- The Hou Sahong – Hou Xang Peuk tailrace model.

The headwaters were modelled by two diffeent models: Mike21 (AECOM 2011b) and Telemac 3D and 2D (SMEC 2014a, SMEC 2014b).

Headwaters and Tailrace with Mike21

The first headwater model was created using Mike21, a two dimensional model and uses a structured square grid of 5x5m with the modeled bathymetric surface derived from the DEM studies discretized onto the grid. The design powerhouse discharge is set to 1,600 m^3/s while ensuring that the environmental flow available to the Thakho channel is 800 m^3/s. Flows in each channel are estimated with the scheme in operation.

Initial model runs were undertaken with the existing bathymetry, which is without any excavation or the proposed dam in order to allow model calibration. Hydraulic bed roughness was adjusted in order to find the best agreement between the model results and the observed water level measurements. The bed roughness was varied according to the flow conditions.

Once a satisfactory calibration was achieved, local water levels and flows were investigated with the Scheme in place and operational. It was found that due to increased flows in the Hou Sahong channel, there would be a corresponding reduction in the flows in the other channels, particularly the Hou Sam and Hou Xeng Peuk. It is proposed that excavation works be carried out to ensure that the flow rates in these two channels remain as great as those under natural conditions and improve the situation for fish passage. The bathymetry was adjusted accordingly.

The model was therefore used to investigate the optimal excavation works needed to guarantee the required flow rates into the Hou Sahong channel while at the same time allowing a range of water levels suitable for power generation. The proposed works include a raised sill at the inlet to the Hou Sahong channel, the purpose of which is to exclude any heavier bed material from entering the diversion and protect the turbines. This sill is included in the model.

A "base case" is presented against which the sensitivity of headwater levels to the adopted hydraulic roughness could be assessed. The sensitivity of headwater levels to the depth of excavation was found to be greatest during mid season when river levels are relatively low and the power station is operating at full discharge capacity.

It is indicated that during a 1:1,000 year flood event the peak discharge entering the Hou Sahong channel would be 2,400 m^3/s. Under such conditions the scheme would not be operating, but sluicing through the turbines. With a freeboard allowance of 1.0m, the powerhouse upstream wall and head pond embankment minimum elevation were estimated.

The same computational hydraulic model was used for the assessment of tail race conditions, but with a coarser 10x10m grid. The model was run using the same range of flow conditions as the inlet model. Model calibration was achieved by modelling flows over the existing bathymetry and comparing results to observed water levels. Observations of water level near the downstream end of Hou Sahong are available from historical gauge-board observations. Preliminary modeling showed that channel roughness was insignificant in the wet season, when water levels are high, and so calibration was carried out against dry-season flow. The ability to model high-flow conditions was verified by comparison of results with high-flow level observations.

An optimal tailrace excavation was determined using model results for a range of excavation scenarios. Tail water levels are obviously sensitive to the depth of excavation in the tailrace area – deeper excavation resulting in lower velocities and lower head losses, and vice-versa. Flood levels in the tailrace are controlled by the water level in the downstream Mekong, which rises over 12m between dry-season and flood flows.

The hydraulic assessment of the scheme is considered to be more than adequate and appears to cover all of the key issues, amongst the most important of which are the levels of channel excavation required both upstream and downstream. The presentation of the results is comprehensive and the analysis follows a logical structure.

It would, however, be a considerable help if the key findings were presented in explicit summary tables. One such would be a comparison between pre- and post- scheme channel flows and water levels. Such material would be fundamental to those undertaking the environmental impact assessment as well as those concerned with the potential consequences for fisheries.

It is noted with interest that following construction of DSHPP, significant contractual penalties will be enforceable if insufficient excavation work has been carried out to provide guaranteed water levels at the powerhouse. Contractual arrangements will require the Contractor to carry out his own model studies during detailed design of the civil works to ensure that sufficient excavation works are planned to provide the desired water levels. This will provide further confidence in the required excavation extents before the excavation works are carried out. This presumably implies that the present hydraulic assessment is preliminary or at least to be independently verified.

Headpond and Extended Headwaters with Telemac 3D /2D

Telemac is a well reknown software for solving the Navier-Stokes Equations in three and two dimensions within the user community of hydraulic engineers. The Navier-Stokes Equations are solved by the Finite Element Approach. In the two-dimensional case these elements are triangles, in the three-dimensional case they resemble tetrahedrons.

The Telemac computational hydraulic model was extending upstream by about 3 km, to include Hou Fang, Hou En, and the main channel up to the old French port on Don Det as a 2D model. Figure 1 depicts the two model domains. The baseline geometry was adopted from AECOM (2011b). Both model developments follow the same approach, first the models were calibrated according to the present state of flow. Based hereapon the derived models were used to determine flows for future states.

The Headpond model was modelled with Telemac 3D. The model uses an unstructured two-dimensional triangular mesh, which is duplicated along the vertical direction to define the 3D finite element computational domain. The mesh density was varied spatially, to give more accurate modelling at the Sahong channel inlet, whilst aiming at reasonable model run-times. The mesh at the inlet, and for approximately 1,000m downstream, was generated with a maximum side-length of 5m. Further downstream this was increased to a maximum side-length of 15m. Six vertical layers were used in order to provide a good definition of the vertical differences in the flow field against achieving reasonable model run-times. Trial runs with different numbers of vertical layers showed that six vertical layers were optimal with respect to accuracy and computation time.

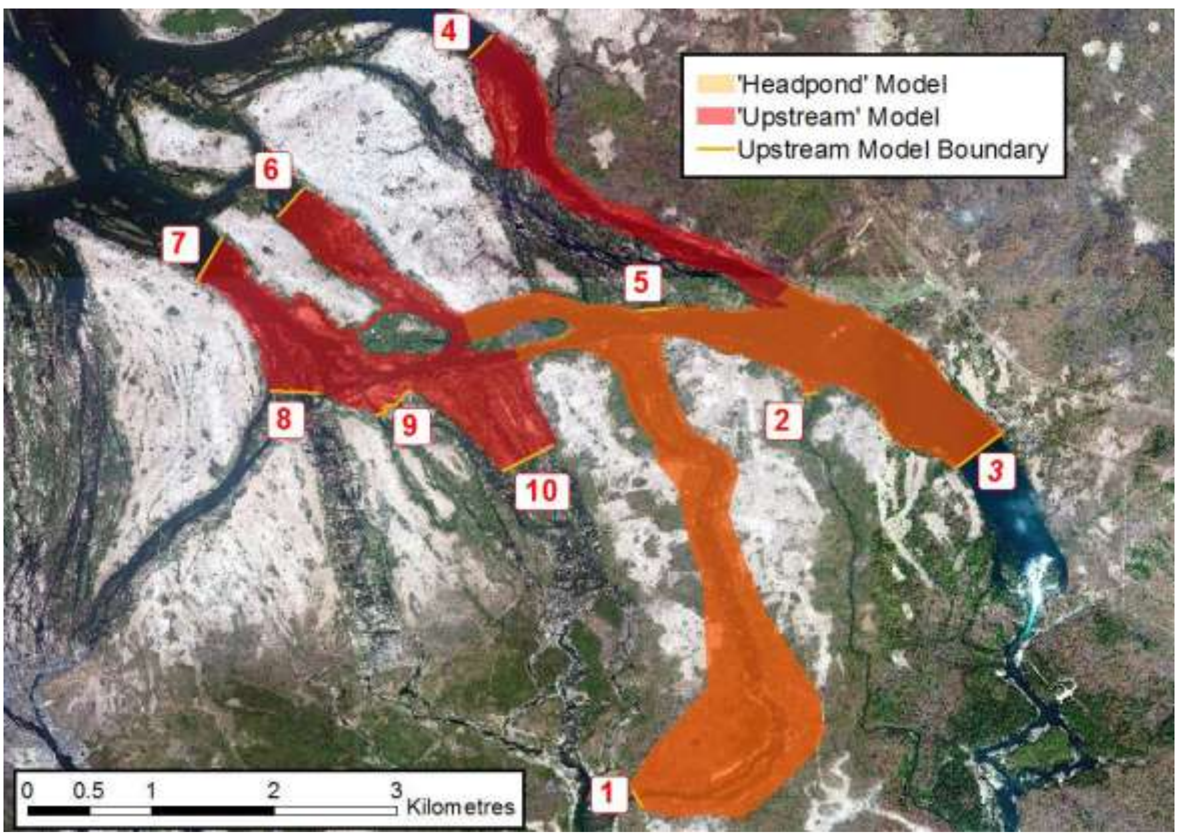

Figure 1: Domains of the Headpond Model and Upstream Model, noting that the Upstream Model includes the entire area covered by the Headpond Model. Upstream Model boundaries are numbered (SMEC 2014b).

The Existing Geometry model was calibrated to reproduce observed flow splits and water levels. A significant parameter to establish during calibration is the bed roughness. A mixing length vertical turbulence model (Nezu and Nakagawa) and Smagorinsky's horizontal turbulence model were adopted.

Calibration is most critical for low flows in the main channel downstream of Hou Sahong inlet, as it is the water levels in this channel with reduced flow that will determine inlet water levels for station operation. The computational mesh density for the finite element mesh was varied to give accurate results in critical areas. Maximum edge lengths of 5m were adopted for the Hou Sahong inlet and existing Hou Sahong channel, 7.5m for the Phapheng Channel, 10m for the headpond area outside of the existing channel, and 1m for the area around the station intake and training walls.

Excavations were modelled in the area at the northern bank, to create a flatter gradient bypassing the rapids to accommodate upstream fish movement. The second area is a refinement to the Reference Design excavation planned in the river to the East of Don Puay. The excavation would be gradually transitioned in the upstream direction, to avoid a sharp drop and formation of a two meter high waterfall.

A strong current still exists in the headpond which follows the existing channel. The Power Station inlet training walls are suboptimally aligned to the existing channel, resulting in a non-uniform flow across the turbines. Velocities are greater on the southern side of the inlet, and the flow separating from the southern training wall, which causes additional undesirable turbulence.

The primary objective of the Upstream Model was to explore backwater effects of DSHPP. Another aim for the modelling was to investigate on the effects on river hydraulics of blocking the Hou Sahong channel during scheme construction. The Upstream Model was modelled with Telemac 2D. Existing bathymetric data were mapped onto an automatically generated mesh, which resulted in a typical mesh density (approximate edge length of triangular elements) of 7.5m.

Both models were coupled to analyze flow affects on the whole system.

Basic modelling parameters like modelling time step and closely related to that determined Courant numbers at critical locations are missing. The latter provide important information on the quality in terms of spatial resolution of the finite element mesh.

Comparison of Results

The flow conditions in the headpond are clearly three-dimensional. The results derived with the 3D model therefore appear to be more reliable than those derived on a two-dimensional basis. Important results of the comparison of the two modelling approaches include:

- Upstream excavations need to be extended for hydraulic optimization of the headpond inflow (to mitigate the formation of rapids);
- Turbulences exist close to the southern training wall of the power house (loss of head for power generation) which calls for a design refinement;
- Overall annual energy production will decrease from 2,059GWh to 2,028GWh (about 1.5%) comparing modelling results from Mike21 and Telemac.

4.0 OUTSTANDING ISSUES AND CLARIFICATIONS.

This brief review has concentrated on the hydrological and hydraulic material available in the Hydrology, Hydraulics and Sediment Studies which are listed in the References section. There are other documents to be consulted, for example concerning the potential environmental and trans-boundary impacts, with regard to which the hydrological and hydraulic study results are very important.

One or two errors and miscalculations are evident in the Report and these need to be corrected. A number of issues need to be clarified.

As already indicated, it would be most useful if the major hydrological and hydraulic results were succinctly summarized, specifically with regard to site conditions pre- and post development in order for impact studies by those not specialist in hydrology and hydraulic modeling to be undertaken, given that flow and water level changes will drive any potential environmental, fisheries and trans-boundary consequences that result from scheme development and operation.

References

SMEC. 2013. Don Sahong Transboundary Hydraulic Effects Study.

SMEC. 2014a. Don Sahong Hydropower Project CFD Hydraulic Model Study, Revision C.

SMEC. 2014b. Don Sahong Hydropower Project - Extended Computational Hydraulic Modelling: Modelling of Upstream Channels, Revision A.

AECOM. 2011a. Don Sahong Hydropower Project, Design Studies - Hydrology, Hydraulics and Sedimentation Studies Report.

AECOM. 2011b. Don Sahong Hydropower Project - Engineering Status Report - Completion of Reference Design Volume 1 – Report. 0018 RPPG_E.

AECOM. 2011c. Don Sahong Hydropower Project Engineering Status Report - Completion of Reference Design - Volume 2: Drawings. 0018 RPPG_E.