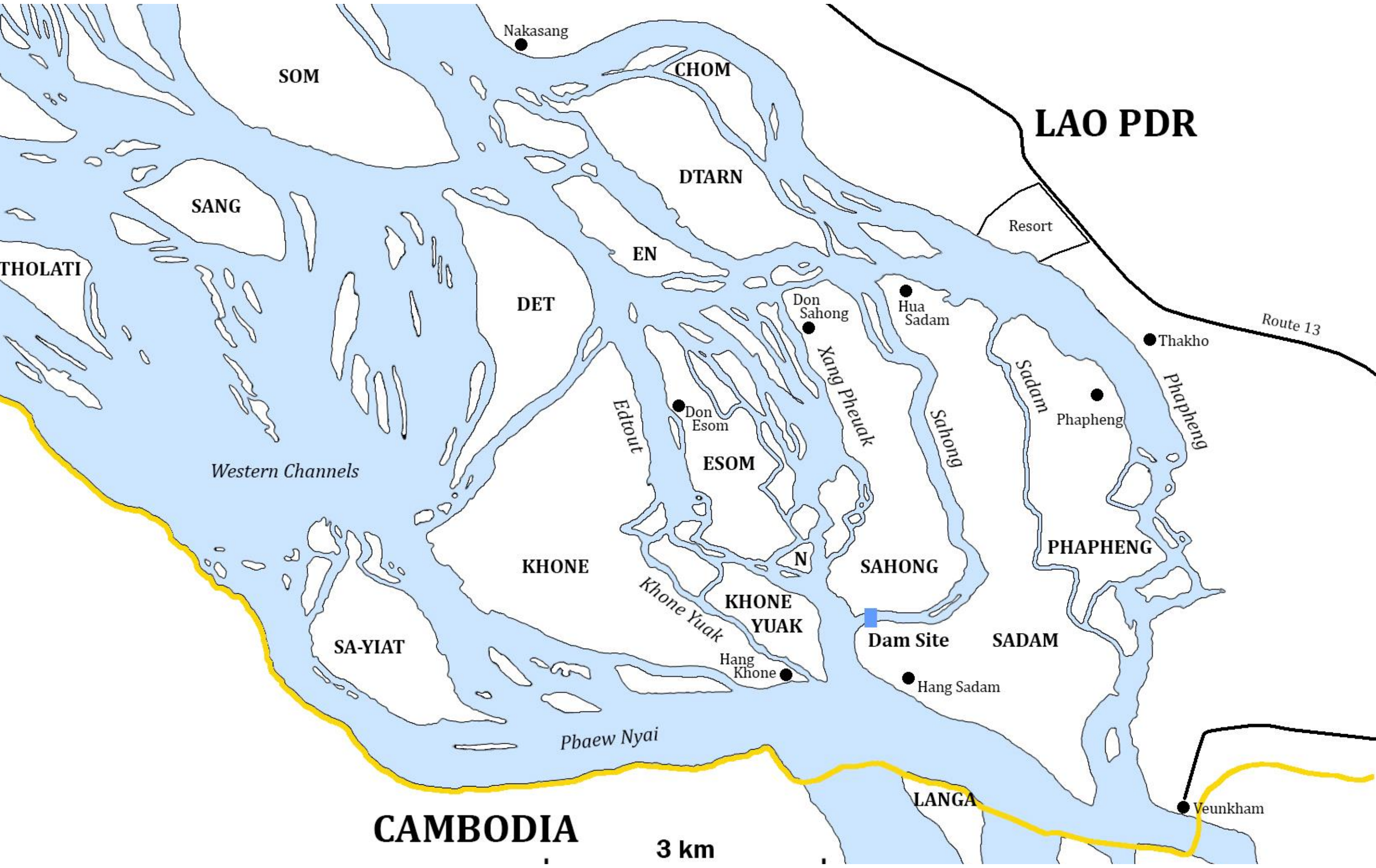
Hydrology of the Khone Falls

Don Sahong Hydropower Project

19 September 2016



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EXECUTIVE SUMMARY

This report summarises data collection, analyses and the understanding gained of the surface-water hydrology of the Khone Falls by the developers of the Don Sahong Hydropower Project (DSHPP).

The Khone Falls, in the Champassak province of Southern Lao PDR, is an area where the Mekong River splits into multiple channels across a width of some 10 km.

A long-term flow record exists for the Mekong River at Pakse, some 160 km upstream of the Khone Falls, but including 98.5% of the Khone Falls catchment area. The lengthy record, observed daily since 1924, provides a good indication of patterns and variability of river flow rates. The study of the Khone Falls surface-water hydrology combines the long-term monitoring of the Mekong River at Pakse with flow and stage measurements collected in various channels of the Khone Falls between 2008 and 2015.

The Mekong River exhibits a distinct and remarkably consistent seasonal pattern, with a dry-season from December through to April during which time flows gradually reduce before rising rapidly around May-June, with the wet season generally peaking in August-September before receding. Long-term fluctuations in discharge (on an interdecadal scale) are apparent, but no long-term trends in mean discharge or annual flood peaks can be identified. There is, however, a clear trend that annual minimum flows and average dry season flows have increased in recent years.

Measurement of flows in various channels at the Khone Falls has been made over the range of river conditions during DSHPP project studies from 2008-2015 using acoustic Doppler current profiler (ADCP) instruments. The flow measurements have been compared with concurrent records of Mekong at Pakse discharge, with equations developed herein to describe the correlation between Pakse flow and flow in each of nine channels studied in the Khone Falls.

Water surface levels have been recorded daily at staff gauges installed in eight locations in the project area since 2011. The observations confirm that levels (and thus flow rates) in each of these monitored channels respond consistently to variations in Mekong flow conditions at Pakse. Rating curves have been developed for flow at the staff gauges in Hou Sahong, Hou Sadam, Hou Phapheng and Hou Xang Pheuak which with ongoing observation will provide more accurate flow estimates than correlation with the Pakse gauge.

Establishment of the correlations between flow at the Khone Falls and Pakse allows the production of long-term synthetic flow series for the Khone Falls channels, and the investigation of seasonal flow patterns within each channel and across the Khone Falls. In the dry season, the majority of flow is in Hou Phapheng, with the remainder split between the 'Eastern Channels', principally Hou Sahong, Hou Xang Pheuak and Hou Somphamit, and the 'Western Channels' to the west of Don Det. As the river rises through the transition season and into the wet season, flow in the Hou Phapheng rises relatively modestly; the proportion of flow in the other Eastern Channels increases to around 20% of the total Mekong flow, and the proportion of flow in the Western Channels rises significantly, to make up some 70% of the wet season total.

The Mekong River Commission (MRC) has commissioned studies on likely future hydrology in the Mekong Basin, considering climate change and future basin development, which produced modelled synthetic flows at Pakse for various development scenarios. The MRC 'Definite Future' scenario, modelling the operation of planned storage reservoirs within the catchment, and other expected developments to 2015, predicted an increased dry season flow rate of some 30% at Pakse over historical rates.

Recent observations of flow at Pakse (2011-2014) corroborate these findings, with median monthly flows for November-April increased by 28% over the 1986-2000 period. This equates to increases across the dry season of some 60% for Hou Sahong, 110% for Hou Xang Pheuak, 65% for Hou Sadam and 15% for Hou Phapheng.

MRC climate change modelling predicted an additional increase to dry-season flows at Pakse of around 20% by 2050.

DSHPP will change the flow distribution at the Khone Falls, essentially diverting flow from the Hou Phapheng into Hou Sahong, which will be controlled by turbines at a powerhouse barrage across the Hou Sahong.

Recent site observations of water levels are presented and compared with observations of previous years, investigating the change in water levels in 2016 with the DSHPP cofferdams in place. Flow that would have passed down Hou Sahong is diverted mainly through Hou Phapheng and Hou Sadam, with increased water levels observed in these channels (for a given Pakse flow condition).

ABBREVIATIONS AND ACRONYMS

Abbreviation/ Acronym	Description
ADCP	Acoustic Doppler Current Profiler
DMH	MONRE Department of Meteorology and Hydrology
DSHPP	Don Sahong Hydropower Project
DSPC	Don Sahong Power Company
IBFM	MRC Integrated Basin Flow Management Programme
IKMP	MRC Information and Knowledge Management Programme
masl	Metres above sea level (Hon Dau 1992)
MONRE	Lao Ministry of Natural Resources and Environment
MRC	Mekong River Commission

1. INTRODUCTION

1.1. Background

Don Sahong Power Company (DSPC) is a project company set up to develop the Don Sahong Hydropower Project (DSHPP) in Southern Lao PDR. DSPC has engaged SMEC to provide engineering services to support project development, including advice on the collection of hydrological data and analysis of these data.

The DSHPP scheme includes a barrage structure across the Hou Sahong, one of the many channels the Mekong divides into as it crosses the Great Fault Line in the Khone Falls area.

Hou Sahong is one of the main channels for upstream fish migration through the Khone Falls. There is considerable interest in understanding the present and historical flow rates in the Hou Sahong and adjacent channels, to appreciate and mitigate the environmental effects of DSHPP development. Of particular interest are the dry season flow rates, as it is been conjectured that low flow rates have historically made some channels impassable to fish in the driest period of the annual hydrograph.

This report summarises the hydrological data collection and analyses carried out through the project development phase, and the understanding gained of the surface-water hydrology of the Khone Falls.

1.2. Description of Study Area

The Khone Falls, in the Champassak province of Southern Lao PDR, is an area where the Mekong River splits into multiple channels across a width of some 10 km. The river crosses a geological feature known as the 'Great Fault Line' with an elevation drop of some 15-20 m, with the channels characterised by rapids and waterfalls.

Figure 1-1: the Khone Falls area, Landsat imagery

The Khone Falls are some 160 km downstream of Pakse, the provincial capital, and are immediately upstream of the Cambodian border.

The catchment area of the Mekong at the Khone Falls is some 553,000 km², extending from the Tibetan Plateau through China's Yunnan province, draining parts of Myanmar, Thailand, and most of Laos. Recently, development within the Mekong basin, particularly hydropower storage dams in China and Laos have noticeably altered the flows in the river, as further discussed in Section 5 of this report.

Figures 3.0 to 5.0 illustrate typical characteristics of the channels in the area.

At the Khone Falls, and throughout the wider *Si phan don* ('four-thousand islands') area, the Mekong cuts through an exposure of Mesozoic basalt. The river channels in the area appear to follow weaknesses in the underlying rock mass and are therefore morphologically stable. The many islands are underlain by rock, capped with alluvial sediments.

The large seasonal difference in flow of the Mekong leads to a large water level range below the Khone Falls, with levels varying by some 8-10m over a year. Above the falls the river's discharge is spread over a much larger cumulative width of the various channels, resulting in a smaller water level range of around 3m. Seasonally-submerged vegetation is common in shallower parts of the main channel.

The drop in elevation of 15-20m across the Great Fault Line is manifested in swift currents, rapids and waterfalls.

Figure 1-2: Main channel above Hou Sahong, with seasonally submerged vegetation, swift and turbulent current.

Figure 1-3: Low lying islands with alluvial sediment banks, upstream of Hou Sahong.

Figure 1-4: Rapids and exposed bedrock within Hou Xang Pheuak

1.3. Report Outline

An outline of the methodologies used to investigate flow in the various channels of the Khone Falls is given in Section 2 of this report.

Section 3 describes and summarises the hydrological data collected, including the Mekong River at Pakse discharge series, site flow measurements, and site water level records.

The findings of the study, in terms of the understanding of flow distributions and variability in the various channels in the area are presented in Section 4.

Section 5 reports the investigation into changes in surface-water hydrology as a result of water resource development within the Mekong basin, and summarises the effects of DSHPP operation on flow in the key channels of the Khone Falls.

2. STUDY METHODOLOGY

This study of the Khone Falls surface-water hydrology combines the long-term monitoring of the Mekong River at the Pakse hydrometric station with flow and stage measurements collected in various channels of the Khone Falls.

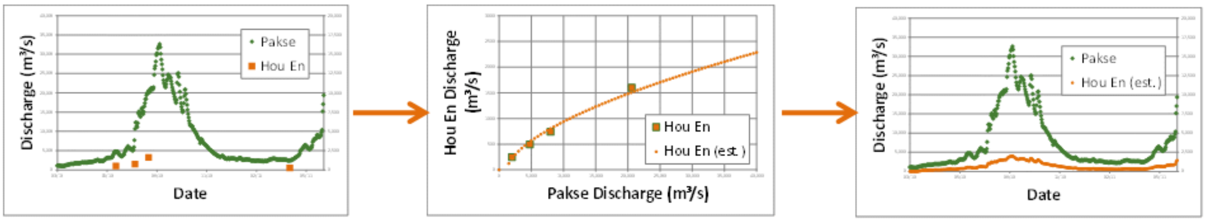
This study builds upon the data collection and analysis described in a previous DSHPP hydrology report by AECOM (2011).

2.1. Correlation between Pakse and Site Discharge Conditions

Flow rates in the Mekong River at Pakse (MRC station 013901) have been recorded daily since 1924, based on river stage measurement. The catchment area at Pakse is 545,000 km², in practical terms the same as the 553,000 km² catchment area for the Mekong at the Khone Falls. Variations in flow at the Khone Falls can therefore reasonably be expected to closely follow variations in flow at Pakse, and the long-term Pakse record can be used to assess the statistical variability of flows at the Khone Falls.

Channelisation at the Khone Falls appears to follow weaknesses in the underlying rock mass and is therefore morphologically stable. Changes due to sedimentation or vegetation growth may have minor effects on flow distribution in the various channels, but generally a consistent relationship between overall river conditions and flow rates in each of the channels can be assumed.

Measurement of flows in various channels at the Khone Falls has been made over the range of river conditions during DSHPP project studies from 2008-2015. From these measurements and the concurrent flows reported for the Pakse gauge, mathematical relationships have been developed to estimate flow rates in given channels at the Khone Falls based on the reported Pakse flow. Using these relationships, long-term synthetic flow series for these channels have been produced from the Pakse record. This process is shown schematically in Figure 2-1.



*Discharge measurements from just one year are shown.

Figure 2-1: Example of methodology - correlating discharge measurements from Hou En at the Khone Falls to Pakse discharge record, to produce a synthetic flow series for Hou En.

The long-term synthetic flow series allow investigation of the hydrological variability of the various channels, including quantification of changes to the flow regime due to changes in the Mekong basin.

2.2. Direct Estimates from Stage Observation

Estimation of flows in the various channels at the Khone Falls based on Pakse discharge neglects the effects of any changes in flow between the two locations, including intermediate inflows and the attenuating effects of in-channel storage. To allow more direct estimates of flow in key channels in the Khone Falls region, staff gauge boards have been installed. Estimates of discharge can be made from direct observation of water surface levels ('stage') within the channel of interest.

Relationships between river stage and discharge at the staff gauge locations in the Khone Falls channels are developed in this study based on *in situ* flow measurements. Stage observations have been supplemented with stage heights predicted from Pakse flows for the period before staff gauges were installed.

3. DATA COLLECTION

3.1. Mekong River at Pakse Discharge Series

The record of daily flow in the Mekong River at Pakse, covering the period 1/1/1924 to 31/7/2016 has been collected from the sources listed in Table 3.1.

River stage is monitored at a water-level recorder, and converted to a discharge value using a rating curve derived from concurrent flow and water level measurements. It is understood that flows are periodically measured, and the rating curve updated as necessary.

Figure 3-1: Mekong at Pakse water level recording station.

Table 3.1: Sources for Mekong at Pakse daily flow data

Period	Source
1/1/24 to 31/12/06	Mekong River Commission, Information and Knowledge Management Programme (MRC, IKMP), Database record: "013901 Pakse, Edition E03"
1/1/07 to 31/3/10	Lao Ministry of Natural Resources and Environment, Department of Meteorology and Hydrology (MONRE, DMH)
1/4/10 to 31/12/14	MRC website: http://ffw.mrcmekong.org/tabulardata.htm
1/1/15 to 31/7/16	Lao Ministry of Natural Resources and Environment, Department of Meteorology and Hydrology (MONRE, DMH)

Basic flow statistics for the 91 complete years (1924-2015) are shown in Table 3.2. Tables of monthly mean, median, minimum and maximum discharges for the whole record period are included in Appendix A.

Table 3.2: Flow statistics for Mekong at Pakse daily flow series (1924-2014)

Statistic	Discharge (m^3/s)
Mean flow	10,070
Median daily flow	5,050
Mean annual minimum daily flow	1,600
Mean annual maximum daily flow	37,280
Mean March-April flow	1,860
Mean August-September flow	27,080

3.1.1. Seasonal Flow Distribution

A distinct and remarkably consistent seasonal pattern is apparent in the flow series, with a dry-season from December through to April during which time flows gradually reduce before rising rapidly around May-June, with the wet season generally peaking in August-September before receding. Mean monthly discharges and their variability are illustrated in the box-and-whisker plot of Figure 3-2.

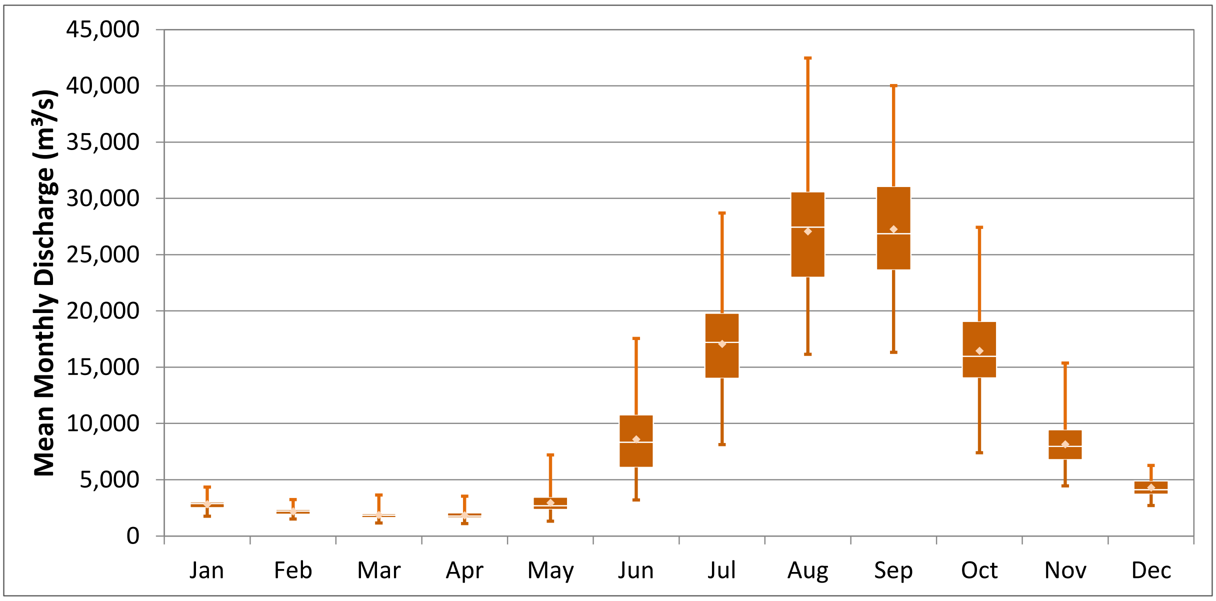


Figure 3-2: Monthly mean discharge for Mekong at Pakse, showing mean, max, min and quartiles.

The MRC Integrated Basin Flow Management (IBFM) programme defines four bio-hydrological seasons in the annual hydrological cycle of the Mekong (MRC, 2009), as illustrated in Figure 3-3. Demarcation of the seasons include:

- End of the dry season: the first time the flow increases to twice the minimum discharge of the preceding dry season
- Beginning of flood season: the first time the flow exceeds the long-term mean annual discharge
- End of flood season: the last time the flow drops below the long-term mean annual discharge
- Beginning of dry season: the first day of the first 15-day period where the recession of the flow averages less than 1%. This is interpreted as an average daily flow reduction of less than 1% of the long-term mean annual discharge.

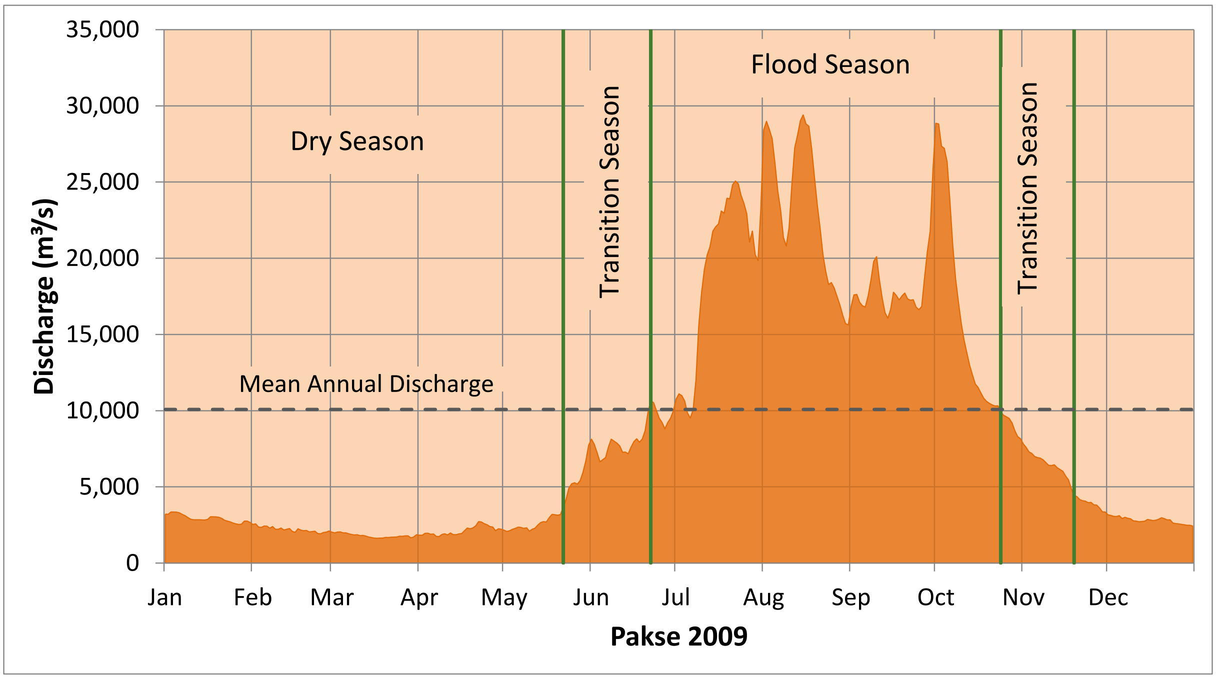


Figure 3-3: Annual hydrograph for Pakse (2009), with four bio-hydrological seasons illustrated

3.1.2. Historical Changes and Future Climate Change

The Mekong experiences long-term fluctuation in discharge on an interdecadal scale, as can be seen in the plots of annual mean discharge (Figure 3-4) and annual maximum discharge (Figure 3-5). Because of the long-period fluctuations, the record is not of sufficient length to confidently identify any long-term trends in the flow series with respect to annual mean discharge or annual flood peaks.

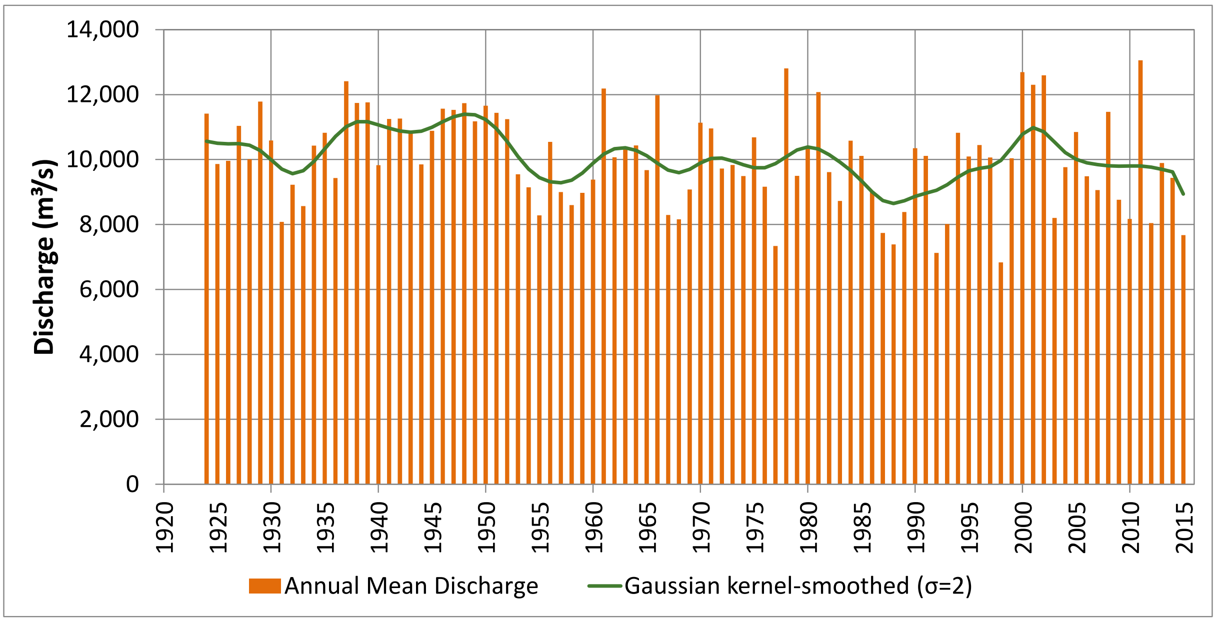


Figure 3-4: Observed annual mean discharge of Mekong at Pakse (1924-2015)

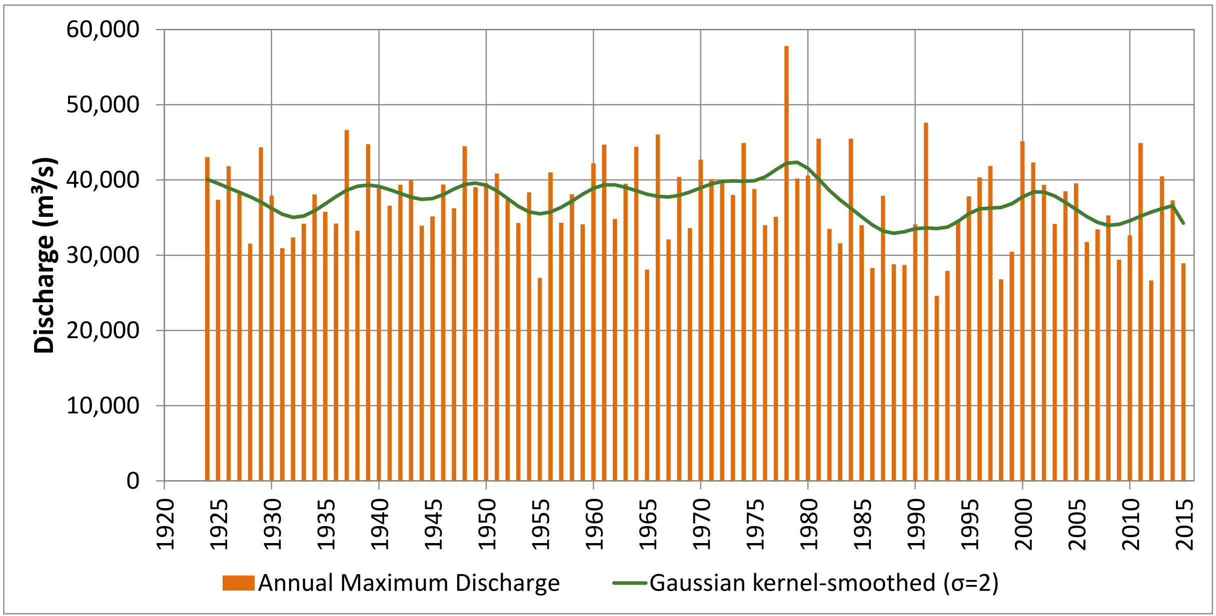


Figure 3-5: Observed annual maximum discharge of Mekong at Pakse (1924-2015)

There is, however, a clear trend that annual minimum flows and average dry season flows have increased in recent years. It can be seen in Figure 3-6 that the past six years (2011-2016) have seen the six highest average February to April flows on record, and five of the six highest annual minimum flows. This is due to the storage and release of flows by hydropower storage schemes constructed within the Mekong basin upstream of Pakse in recent years. This is further discussed in Section 5 of this report.

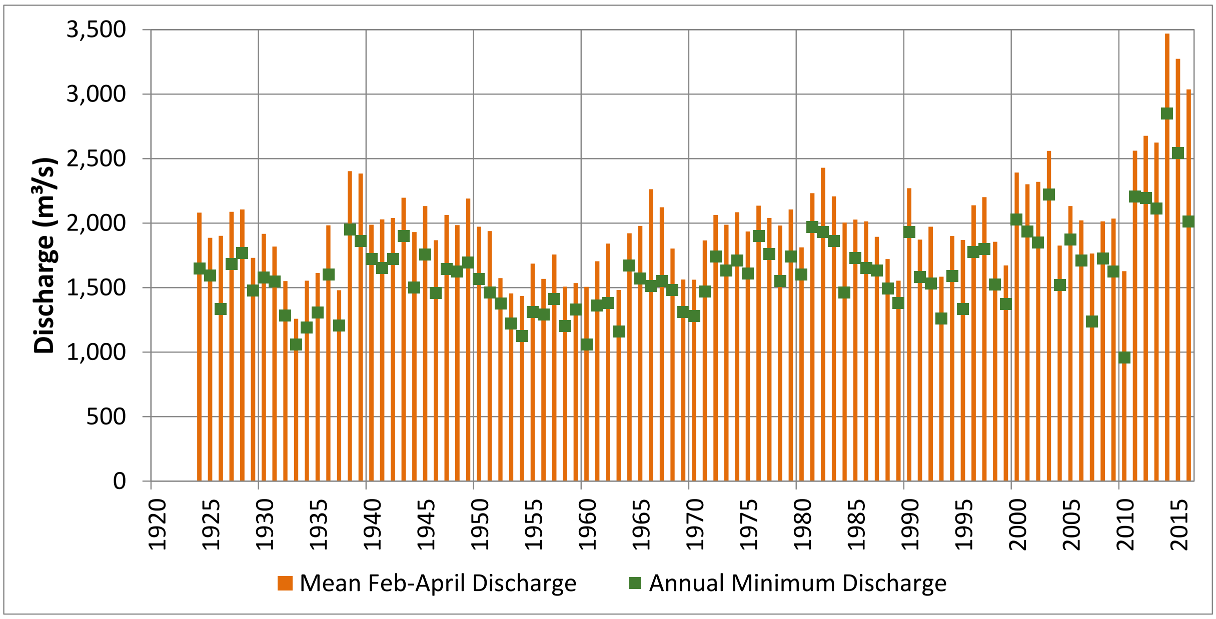


Figure 3-6: Observed mean Feb-April discharge and annual minimum discharge, Mekong at Pakse (1924-2016)

The effect of flow regulation in the catchment may also be apparent in examination of the annual variation of median absolute deviation of daily flows (about the annual median discharge) in Figure 3-7. Median absolute deviation provides a robust statistical measure of variability or spread of flows during the year. In recent years it is seen to be trending lower, consistent with the regulation of flows within the catchment.

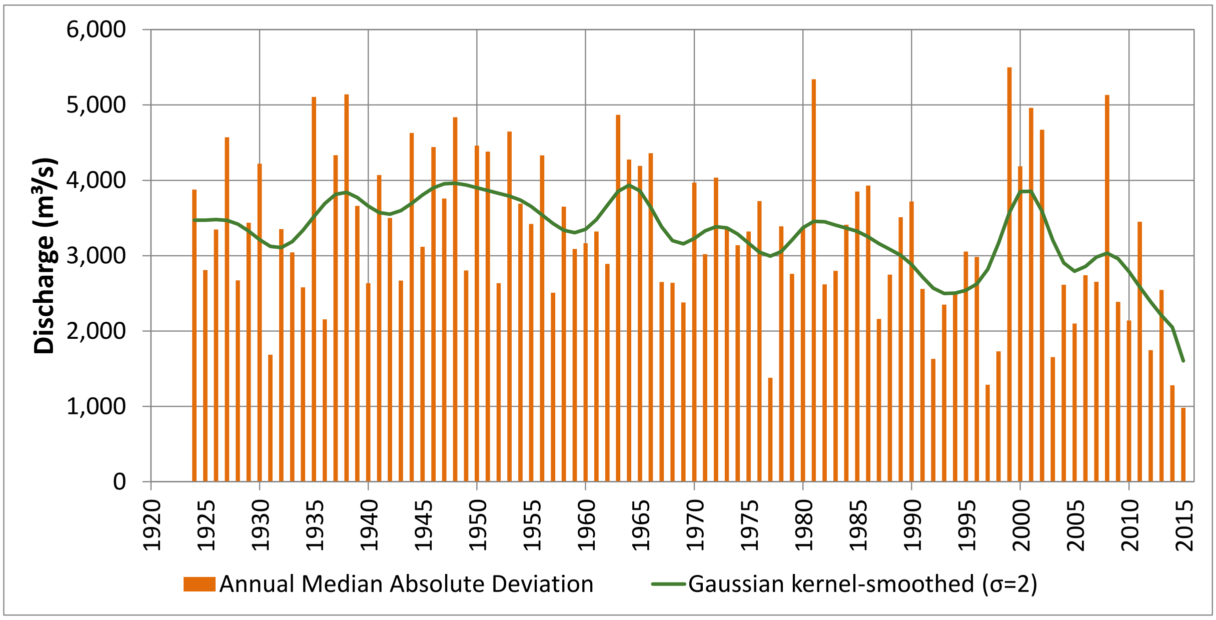


Figure 3-7: Historical annual median absolute deviation of discharge of Mekong at Pakse

The effect of future climate change on Mekong River hydrology has been analysed in a series of models by the MRC (Hoanh *et al.*, 2010). The projected climate from 2010 to 2050 shows an increase in wet-season precipitation throughout the Mekong basin except in the delta, and an increase in dry-season precipitation in the Upper Mekong Basin.

In the wet season, climate change is projected to increase discharge at Pakse by 5-11%, though development, including storage, irrigation and other consumptive uses is projected to decrease flows at Pakse by around 8%. The combined effect is that by 2050, wet season flows at Pakse are expected to have changed between -3.5% and +2%.

In the dry season both development and climate change projections see increases in Mekong flow at Pakse. Climate change is projected to increase dry-season flows at Pakse by 20-22% by 2050. Development, particularly hydropower storage is expected to increase dry-season flows at Pakse by 26-28%. The combined effect is a projected increase in dry season flows of around 54%.

3.1.3. Reliability and Accuracy of Data

There is a level of uncertainty associated with the Pakse discharge series, given its assembly from several sources, and importantly given the multiple differing datasets that have been sighted. Various datasets provided by MRC and DMH which ostensibly cover the same period generally differ by up to 5-10%, and sometimes more during the rapidly changing transition seasons. The differences appear to be related to water level observations used (some datasets contain both AM and PM readings, some just AM, some an average of the two) and also different rating curves used. DMH have provided alternative rating curves adopted for different periods, suggesting that flow gauging at Pakse and periodic updating of the rating curve does occur.

The 1924-2006 MRC dataset was adopted as it is the 'official' dataset included in the MRC database. For the period 2007-2010, discharge data obtained from DMH were adopted as these were consistent with the concurrent water level records and rating curves provided. The subsequent records acquired from the MRC website appear consistent with the DMH series, and were adopted as they provided up-to-date information allowing immediate analysis of site data collected.

A rating curve derived from the MRC website discharge and stage data is shown in Figure 3-8. Close observation reveals that it is made up of linear segments, reducing the precision of flow estimates in this series.

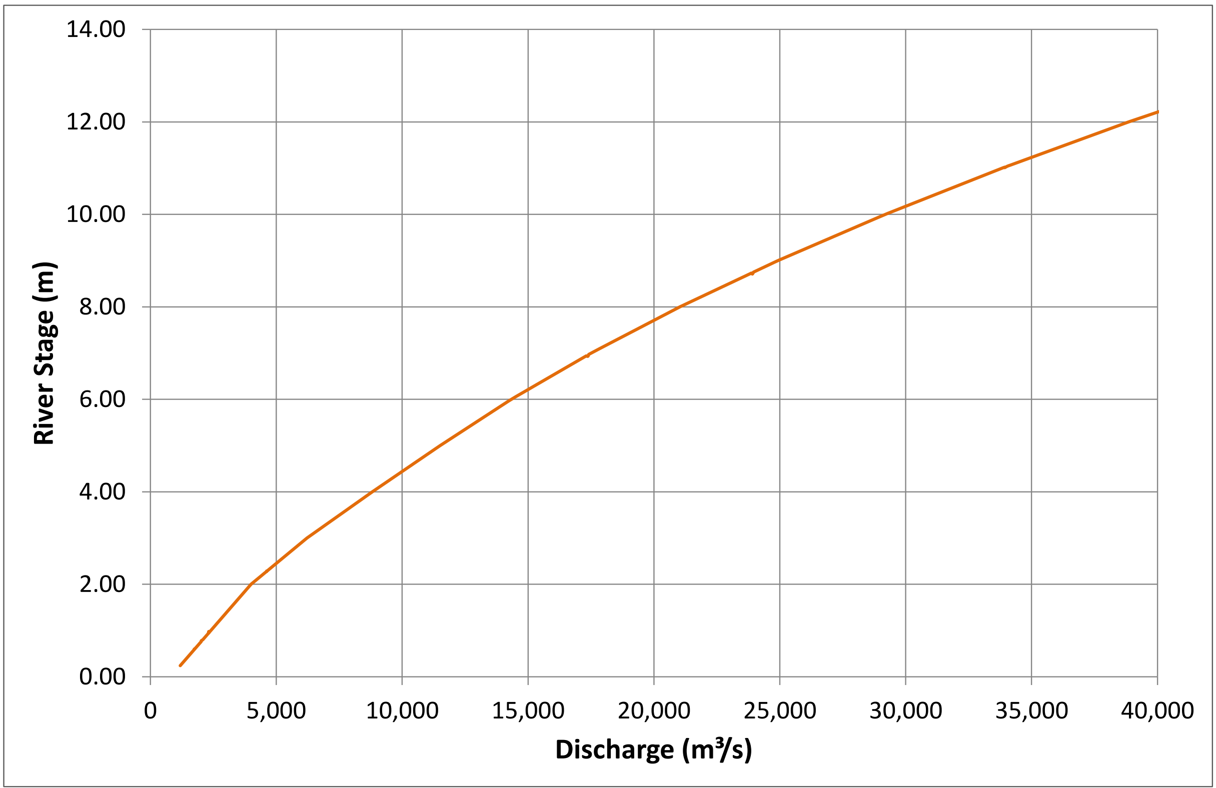


Figure 3-8: Rating curve for the Mekong at Pakse based on stage and discharge data published on the MRC website (2010-present), made up of linear segments.

The stability of the rating at Pakse, related to the stability of channel morphology is relevant to the accuracy of discharge records. The Mekong River from Vientiane to Pakse is described by Carling (2009) as "*alluvial.. but is increasingly bedrock confined towards the south*," and "*bedrock-confined*" from Pakse to Kratie. Carling presents a cross-section of the Mekong channel at the Pakse gauging station (Figure 3-9) with historical water levels superimposed, suggesting a relatively stable channel section at which the rating will not change significantly over time.

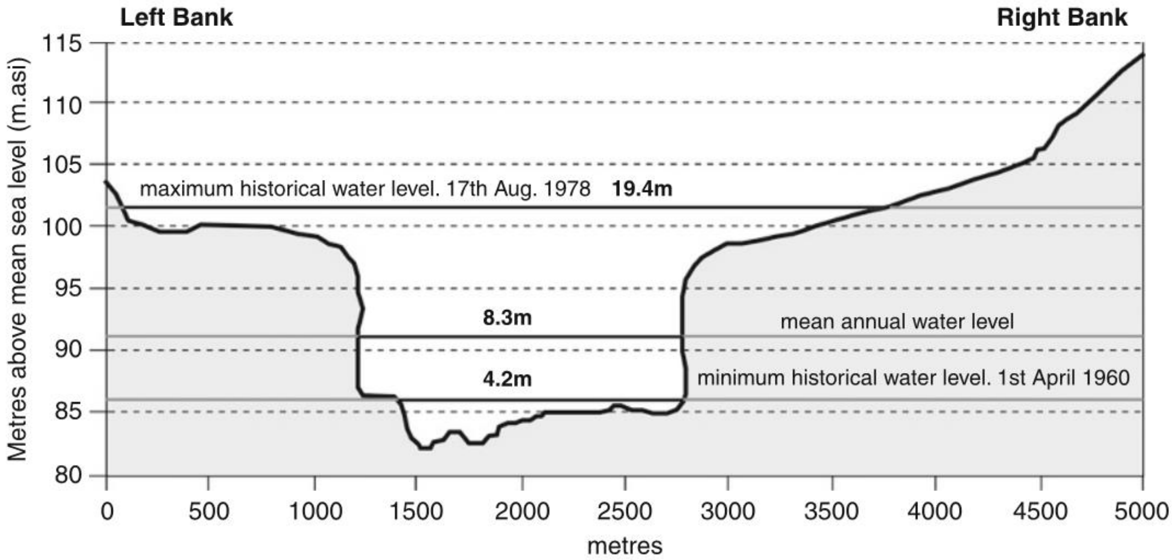


Figure 3-9: Channel cross section at Pakse gauging station, from Carling (2009)

The MRC *Lower Mekong Basin Historical Hydro Meteorology database* contains daily Pakse discharge records from 1923-2006 as well as daily Pakse water levels from 1960-2006. Comparing concurrent records allows the ratings used to be interrogated. It is apparent that a number of rating curves have been used, updated as often as annually, as shown in Figure 3-10. The differences between ratings is generally within +/-5%. The rating curves are not monotonically changing, meaning that there isn't a tendency of aggregation or degradation of the channel control. The differences in ratings between different periods may be realistic, due to morphological changes, or may be artificial due to uncertainties or limitation in their derivation. It is assumed the obvious outliers apparent in Figure 3-10 are due to typographical errors or erroneous application of the ratings.

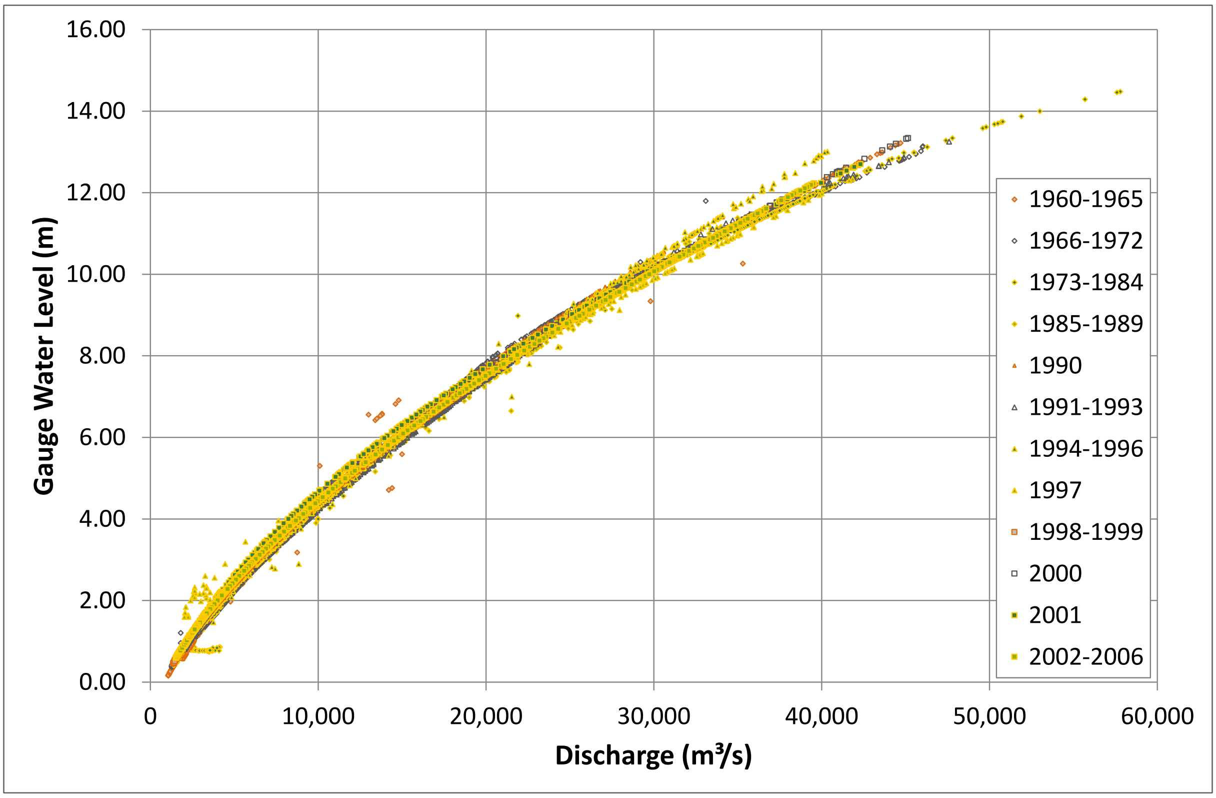


Figure 3-10: Comparison of daily Pakse discharge and gauge water level records, 1960-2006, with multiple distinct rating curves identified.

Even without the uncertainties discussed above, there are inherent uncertainties in river stage and discharge measurements, and such data would typically be considered at best to be within +/- 5% accuracy. This said, the actual values of discharge at Pakse are not of primary importance. Rather, it is important that the series of discharge values is internally consistent such that a given Pakse discharge estimate describes a given flow condition that is experienced at the Khone Falls.

3.2. ADCP Flow Measurements at Site

Flow rates in channels at the Khone Falls have been measured using acoustic Doppler current profiler (ADCP) instruments under the range of annual flow conditions by contractor AAM-VGS. The equipment used included a boat-mounted 600 kHz 'Rio Grande' ADCP, used principally for the larger channels, and a 2 MHz 'StreamPro' ADCP attached to a pulley system to measure flows in the shallower channels.

Figure 3-11: Teledyne RDI Rio Grande 600 ADCP mounted on 4.6m polyethylene Plaka boat

Figure 3-12: Teledyne RDI 'StreamPro' ADCP

The locations of flow measurement cross-sections are shown in Figure 3-13. The discharge results are summarised in Tables 3.3, 3.4 and 3.5. Each result is based on multiple transects made at the cross-section, with valid measurements averaged.

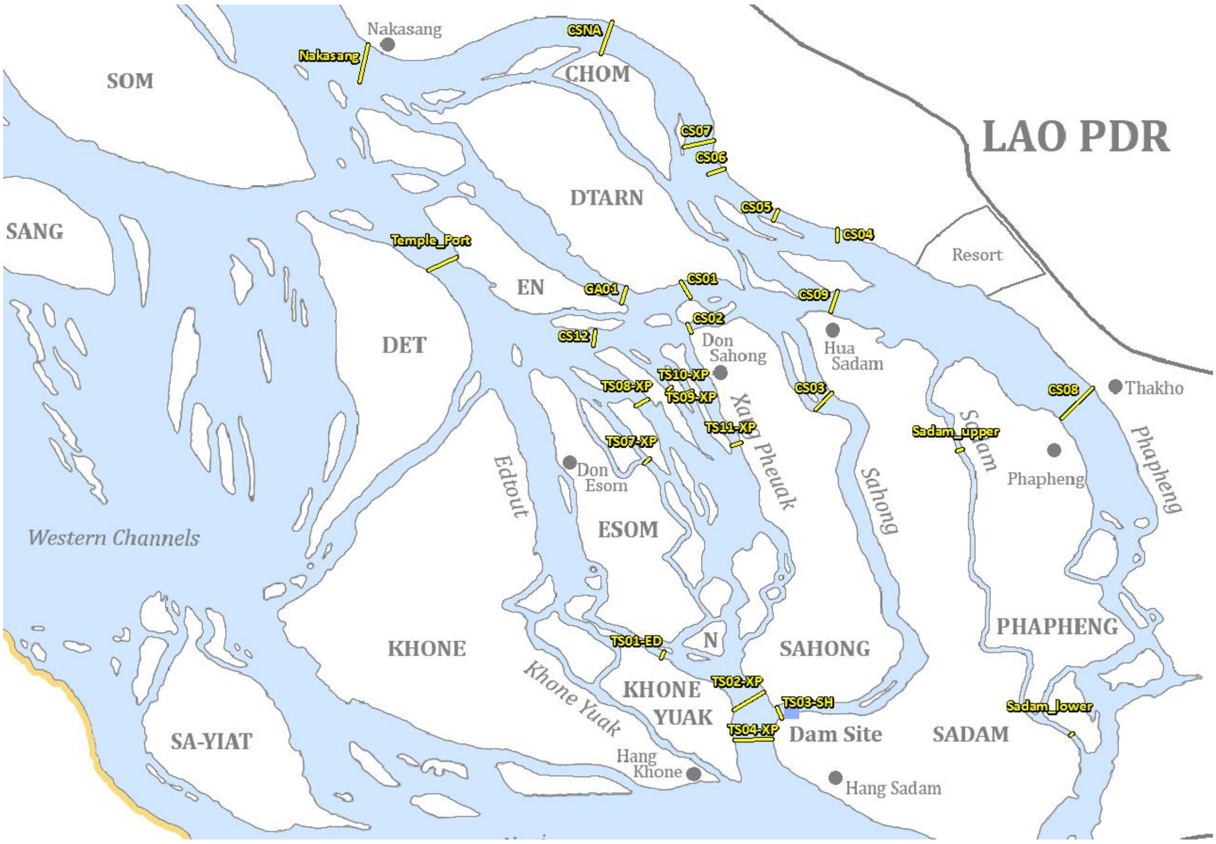


Figure 3-13: ADCP flow measurement locations

Flow measurement campaigns were initially focussed on water availability for scheme conceptualisation, optimisation and design. As such, measurements were focussed on the Hou Sahong and the main channels upstream, as well as flows in the adjacent Hou Phapheng.

Table 3.3: ADCP discharge measurement results (m^3/s), 2008-2012

Date	Pakse	CS01	CS02	Hou Fang	CS08	CS09	TS03-SH	TS04-XP	GA01	CS12	Temple_ port	Sadam_ lower
29/9/08	21,600	1,814	1,009	1,875	3,996		1,033					
25/5/09	4,900	1,101	797	700	2,214		296					
4/7/09	11,000	1,520	912	1,159	3,125	2,274	630	1,876				
20/2/10	1,460	654	743		1,594	1,295						
15/6/10	4,800	1,132	846	769	2,352	1,838	275		494		2,077	
28/8/10	27,000	2,345	1,248	3,336	5,005	3,563	1,385	4,734				
9/9/10	27,400	2,199	1,198	3,132	4,721	3,211	1,315	4,383				262
1/5/11	2,500	820	746		1,975	1,579	114	273	246		1,433	
19/8/11	40,300	2,560	1,483			4,039	1,721	5,992	2,304		6,913	
25/9/11	40,200	2,505	1,275		5,904	3,845	1,716	6,002	2,244	3,004	6,974	
4/11/12	6,000	1,138	865	785		1,890			546	2,427	2,162	

Notes

1. Date: For a given set of discharge results, not all sections were measured on the same day. A representative date is tabulated on which the majority of sections were measured, while some sections may have been measured on preceding or following days.
2. Pakse discharge: The previous day's discharge is tabulated. There is expected to be a lag of 1-2 days between Pakse and the Khone Falls.

3. Hou Fang: Measurements include CS07 (2008-09), CSNA (2012) and Nakasang (2010) cross-sections. In 2008-measurements were also taken at downstream locations CS06. CS05 and CS04 on this same channel, but are not reported herein.
4. TS03-SH: The 2008 measurement was taken on the same channel (Hou Sahong) at upstream location CS03

More recent flow measurement campaigns in 2014 and 2015 had an expanded and altered scope to concentrate on flows in the channels parallel to Hou Sahong, particularly Hou Xang Pheuak and Hou Sadam, to aid environmental impact mitigation studies.

Table 3.4: ADCP discharge measurement results (m^3/s), transition season 2014

Date	Pakse	CS01	CS02	CSNA	CS08	CS09	TS03-SH	TS04-XP	GA01	Temple_ port	Sadam_ lower	TS02-XP	TS01-ED
18/6/14	7,700	1,295	963	1,005	2,686	2,002	464	1,377	672	2,503	55	1,033	189
30/6/14	14,800	1,719	1,130	1,716	3,663	2,609	948	3,145	1,216	3,898	186	2,434	482

Table 3.5: ADCP discharge measurement results (m^3/s), dry season 2014-2015

Date	Pakse	TS01-ED	TS02-XP	TS03-SH	TS04-XP	TS07-XP	TS08-XP	TS09-XP	TS10-XP	TS11-XP	Sadam_ upper
11/12/14	4,670	81	412	246	641	15	107	86	28	119	24
24/1/15	3,600	50	229				57	57		71	16
12/3/15	2,600	17	115	100			28	35		38	9

3.3. Supplementary Flow Measurements

3.3.1. Hou Sadam (DSPC)

Supplementary flow measurements in the Hou Sadam channel have been made by DSPC staff in 2013 and 2014. Measurements were taken at the same cross-section as ADCP measurements (Sadam_upper), adjacent to gauge board GB04 (see Section 3.4).

Flow rates were determined using a velocity-area method, with velocities measured using a mechanical flow meter (General Oceanics model 2030R), or optical flow meter (Swoffer 3000).

The method and equipment used are expected to provide less accurate results than the StreamPro ADCP, but provide useful indications of flow rate to supplement ADCP measurements.

Figure 3-14: Swoffer 3000 current meter used for supplementary flow measurements

3.3.2. Hou Phapheng and Others (CNR)

The understanding of flows in Hou Phapheng and some other channels upstream of Hou Sahong has been supplemented by flow measurements published in reports on feasibility of the nearby Thakho Hydropower Project (CNR, 2011). These flows are understood to have been measured using ADCP equipment, as described above.

3.3.1. Dry Season 2007 Flow Measurements

During early feasibility studies of the DSHPP, flow measurements were successfully carried out in the 2007 dry season between January and April (PEC and APW, 2007). Measurements were limited to the three channels considered most important for demonstrating water availability for the project, Hou Sahong, Hou Phapheng and Hou Sadam. The measurements were performed by contractor ASA Power Engineering Co Ltd of Vientiane using a Rickly Hydrological Type AA (Price-type) current meter, with the supervision of international consultants APW. Results of the stream gauging are summarised in Table 3.6.

Table 3.6: Results of stream gauging, 2007 dry season (PEC and APW, 2007). Flow rates in m^3/s.

Date	Hou Phapheng	Hou Sahong	Hou Sadam
6-7/1/07	1,860		
30/1/07			6
31/1/07		79	
1/2/07	1,580		
17/2/07		42	
6/3/07		60	
22/3/07			3
23/3/07	1,444		
24/3/07		40	
23/4/07	1,790		

3.4. Daily Stage Observations

Water surface levels are recorded daily at staff gauges installed in eight locations in the Khone Falls area. The staff gauge locations are shown in Figure 3-15, with details provided in Table 3.7.

The gauge boards are maintained by local staff, with damaged boards replaced as necessary. Survey was carried out in May 2015 to confirm the elevations of gauges AR02, GB04 and GB05. The upper boards at GB05 (2m, 3m and 4m) were found to be overlapping due to incorrect installation, and the boards were reinstated. Corrections have been made to the recorded levels at GB05 as necessary. The levels of boards at AR02 and GB04 were found to be consistent.

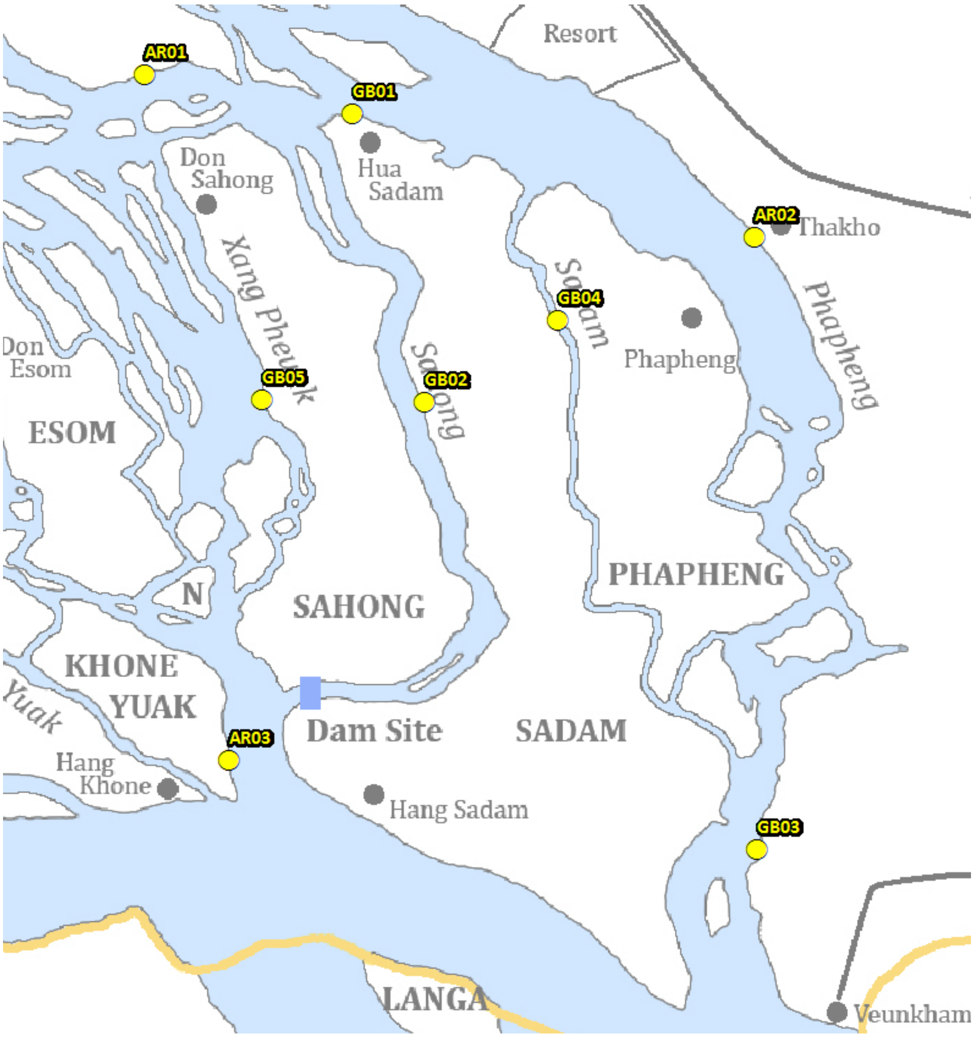


Figure 3-15: Staff gauge locations

Figure 3-16: Staff gauge boards at AR01

Table 3.7: Staff gauge locations and elevations

ID	Location	UTM Easting	UTM Northing	Gauge zero elevation (masl)	Observation period
AR01	Upstream of Hou Sahong – Don Dtarn	602275	1545765	72.72	4/2011 - present
AR02	Hou Phapheng at Ban Thakho	606235	1544705	68.42	4/2011 – present
AR03	Downstream of Hou Sahong - Don the Khone Yuak	602820	1541310	48.66	4/2011 – present
GB01	Ban Hua Sadam	603620	1545510	71.16	4/2011 – present
GB02	Hou Sahong	604090	1543640	65.29	4/2011 – 1/2016
GB03	Hou Phapheng near bridge site	606250	1540730	49.07	4/2011 – present
GB04	Hou Sadam	604960	1544170	66.58	11/2013 - present
GB05	Hou Xang Pheuak	603040	1543655	68.05	7/2014 - present

The recorded water levels are plotted in Figure 3-17.

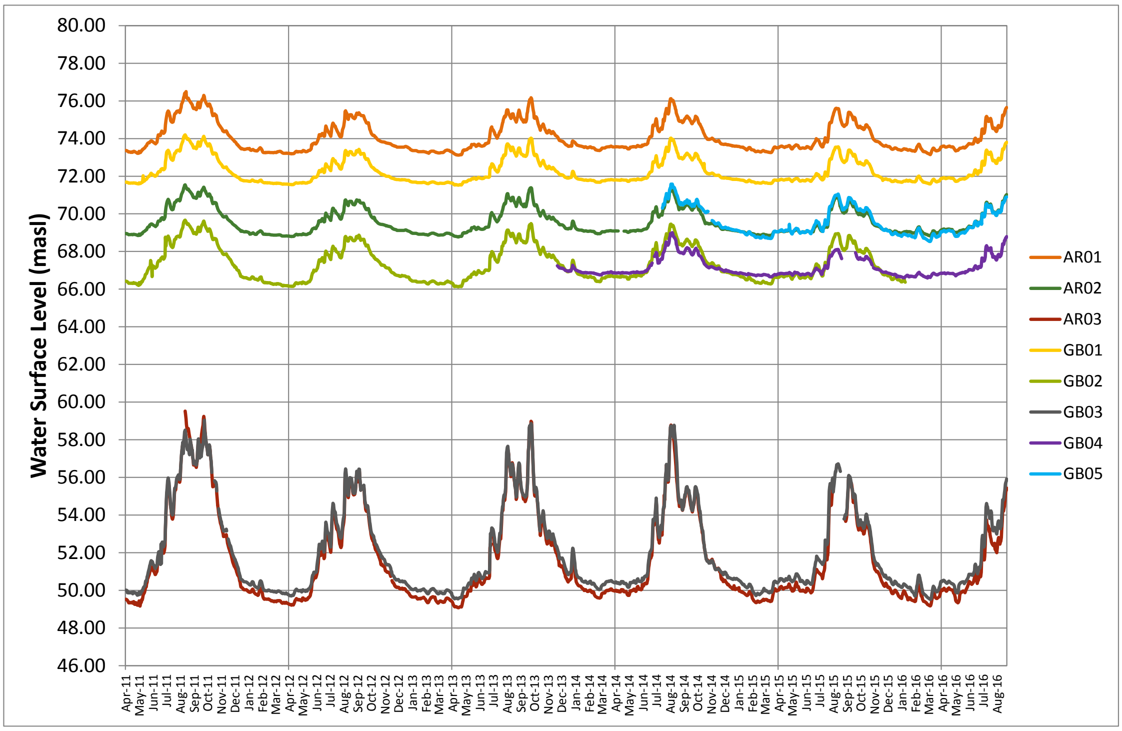


Figure 3-17: Observed water surface levels from site gauge boards (2011-present)

A larger seasonal range in water levels is apparent at downstream locations (AR03 and GB03). This is because downstream of the Khone Falls water levels are controlled by the Mekong in Cambodia, where the full flow of the river is constricted into a relatively narrow 1 km width. At the Khone Falls in the wet season, the Mekong flow is split across channels with a combined width of some 8 km.

The observations confirm that levels (and thus flow rates) in each of these monitored channels respond to variations in Mekong flow conditions. As an example, spikes are apparent in the water levels of all channels for the dry season 'freshes' of January 2012, December 2013 and February 2016.

3.4.1. Historical Gauge Board Installations

The hydropower potential of the Khone Falls region has been identified for some time, and gauge boards were installed in the area from 1998 at Hou Phapheng, Hou Sahong (x2), Veunkham, Ban Hang Sadam, and Khonetai. These gauge boards were inspected during the first DSHP Feasibility Study (PEC and APW, 2007), and found to generally be in poor condition. The recorded observations from 1998 to 2006 are poorly correlated with Pakse flows (see Figure 3-18). These gauge boards are no longer present, and the recorded data have not been used in the current study.

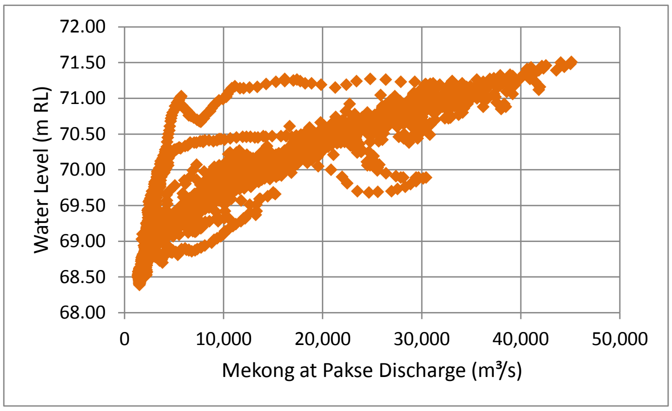


Figure 3-18: Observed Water Levels at Hou Phapheng (WG01), 1998-2006

4. THE KHONE FALLS CHANNEL FLOWS

This section presents the findings of analyses of the flow and river-level data collected, including

- regression fits to quantify the correlation between Mekong at Pakse flows and flows in the various channels at the Khone Falls
- development of rating curves correlating river stage at the gauge boards with discharge in the channels
- a summary of general seasonal flow distributions at the Khone Falls

4.1. Correlations of Flow in the Khone Falls Channels with Mekong at Pakse

As outlined in Section 2.1, mathematical relationships have been developed to correlate flow rates in given channels at the Khone Falls and at Pakse, based on the collated stream gauging results. These relationships have been developed for the nine channels identified in Figure 4-1, and are described in the sections below. Flow is generally from north to south, top to bottom in the figure below.

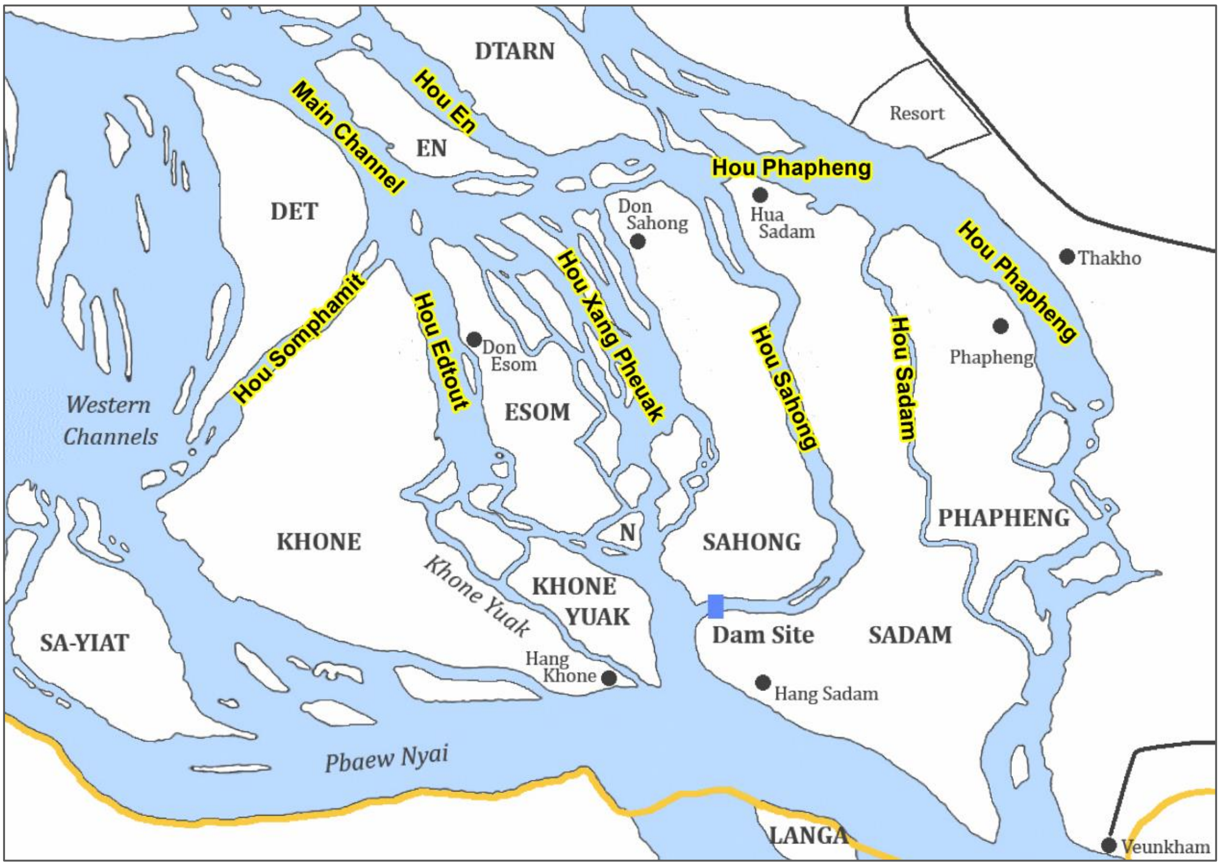


Figure 4-1: Schematic map of the Khone Falls, with studied channels highlighted

4.1.1. Main Channel at Don Det Port

The 'main channel' between Don Det and Don En is so named because it carries the majority of the Mekong flow in the dry season, and retains the highest discharge of all channels on the eastern side of the Khone Falls through the wet season. Where flows were gauged adjacent to the old French port on Don Det, the channel is approximately 250 m wide and 25-30m deep, as shown in Figure 4-2.

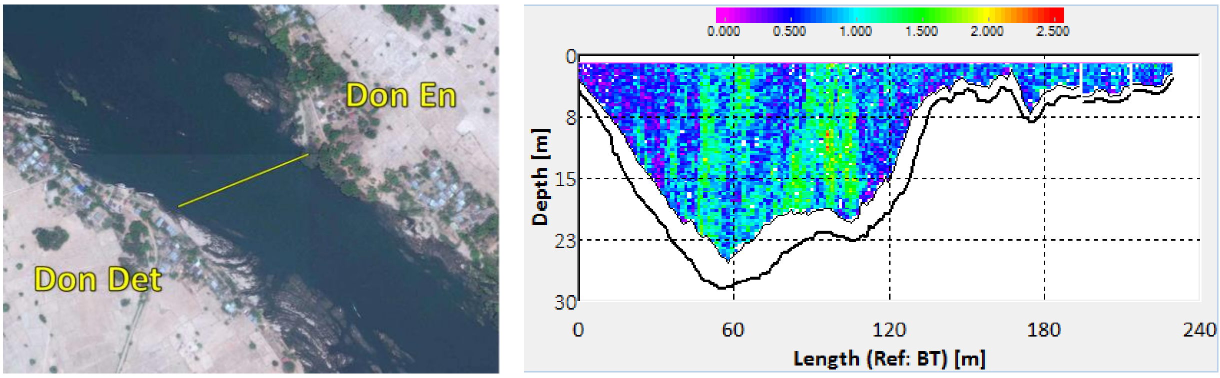


Figure 4-2: Cross-section location and example ADCP discharge measurement, Main Channel at Don Det Port ('Temple port')

Discharge measurements commissioned by DSPC, together with measurements reported by the Thakho Hydropower Project (CNR, 2011) are plotted in Figure 4-3. The channel is seen to convey over half of the Mekong flow in the dry season, with this proportion reducing to some 15-20% in the wet season.

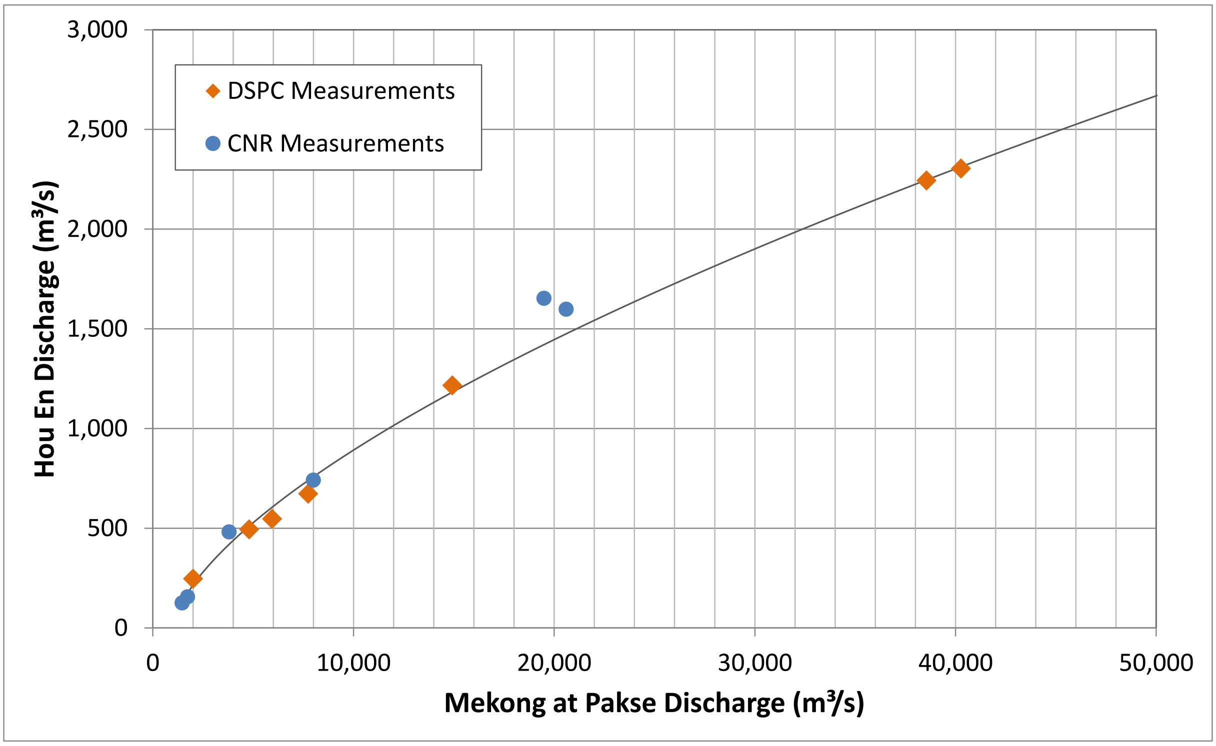


Figure 4-3: Regression fit between discharge at Pakse and Main Channel at Don Det Port

The discharge is estimated as:

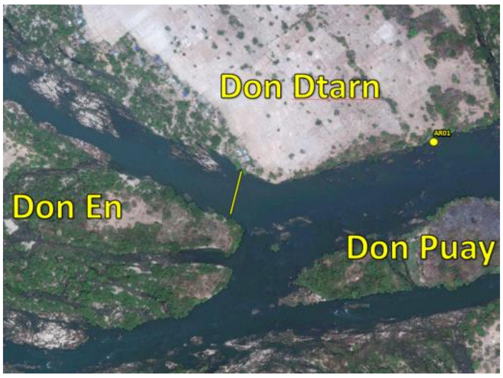
$Q_{Port} = 204.8 \times Q_{Pakse}$^0.240 for $Q_{Pakse} < 1540$ m³/s

$Q_{Port} = 33.17 \times Q_{Pakse}$^0.488 for $1540 < Q_{Pakse} < 4700$ m³/s

$Q_{Port} = 16.87 \times Q_{Pakse}$^0.568 for $Q_{Pakse} > 4700$ m³/s

4.1.2. Hou En

The Hou En flow is parallel and to the east of the aforementioned main channel, re-joining the northern branch of the main channel ('Hou Don Dtarn') as it splits around the island of Don Puay. Flows were gauged at a suitable site near the channel outlet, as shown in Figure 4-4.



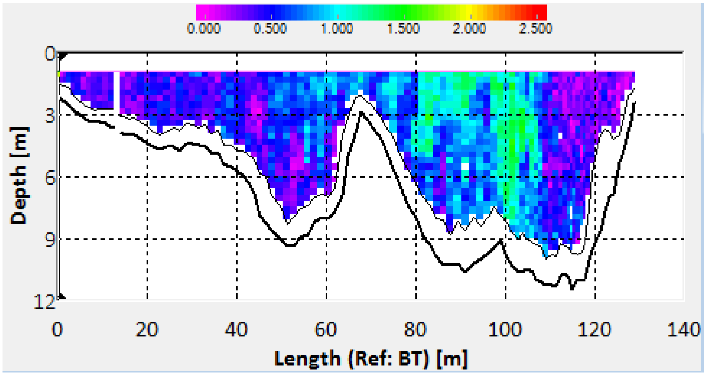


Figure 4-4: Cross-section location and example measurement, Hou En ('GA01')

Discharge measurements commissioned by DSPC, together with measurements reported by the Thakho Hydropower Project (CNR, 2011) are plotted in Figure 4-5.

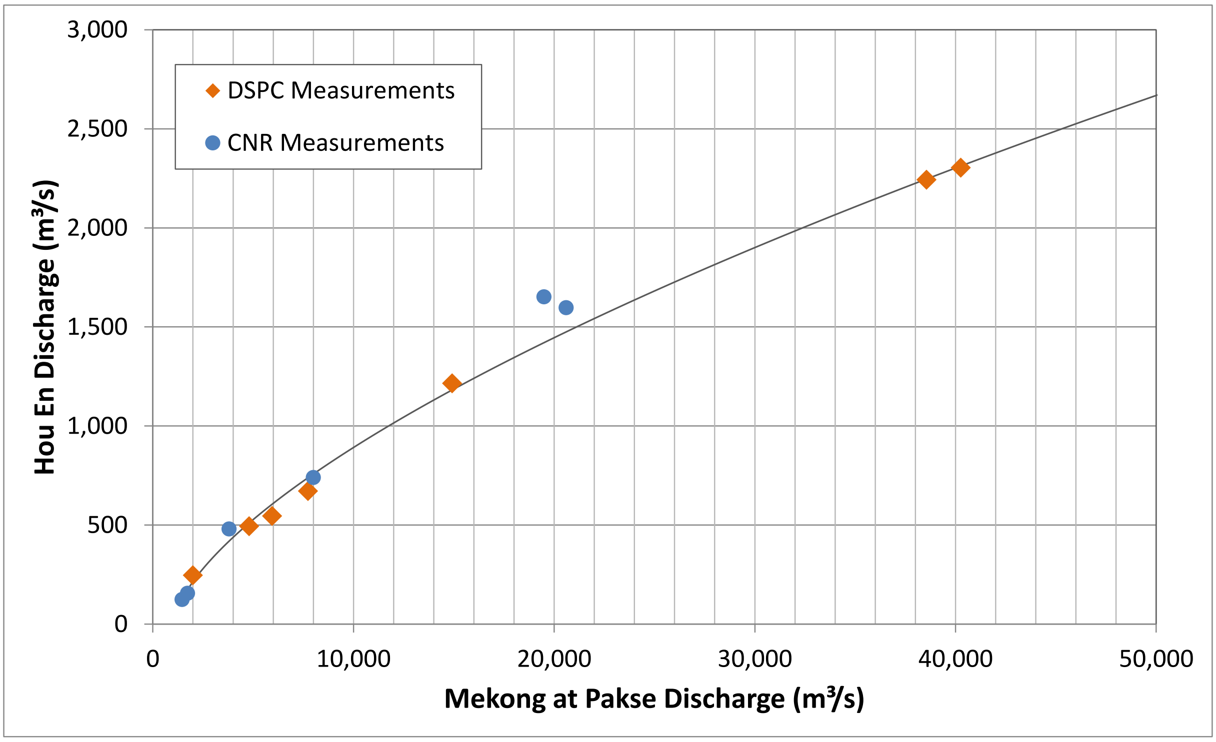


Figure 4-5: Regression fit between discharge at Pakse and Hou En

The discharge is estimated as:

$$Q_{En} = 2.465 \times (Q_{Pakse} - 1000)\text{^}0.647$$

with zero flow assumed if the Mekong at Pakse discharge is below 1000 m³/s.

4.1.3. Hou Somphamit

Hou Somphamit, between Don Det and Don Khone and flowing south-west to Somphamit Falls, has not been gauged as part of the DSHPP project. Nevertheless, flow rates are of interest in checking the sum of flows in the other studied channels.

Based on discharge measurements reported by the Thakho Hydropower Project (CNR, 2011), a regression fit is shown in Figure 4-6.

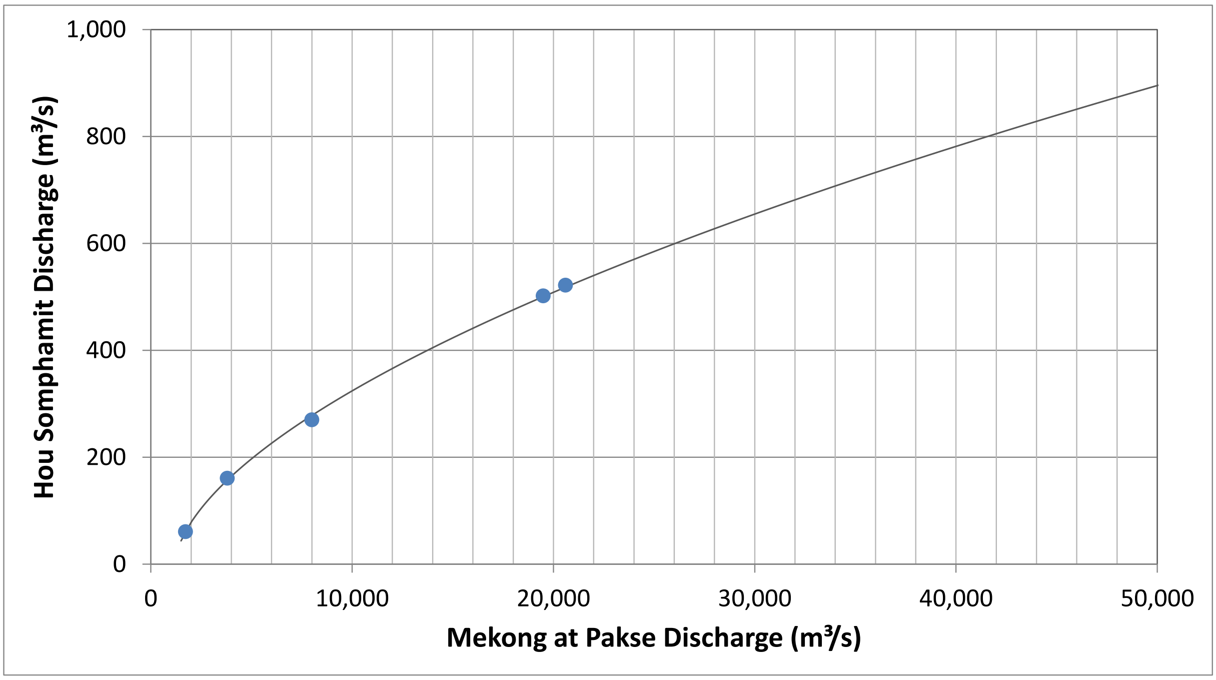


Figure 4-6: Regression fit between discharge at Pakse and Hou Somphamit. All measurements from Thakho Hydropower Project reports published by CNR.

The discharge is estimated as:

$$Q_{Somphamit} = 1.485 \times (Q_{Pakse} - 1200)\text{^}0.593$$

with zero flow assumed if the Mekong at Pakse discharge is below 1200 m³/s.

Figure 4-7: Hou Somphamit looking upstream from French bridge, Q_{Pakse} approximately 6,000 m³/s

4.1.4. Hou Sahong

The Hou Sahong has been gauged at a section near its outlet, close to the proposed DSHPP dam location, as shown in Figure 4-8.

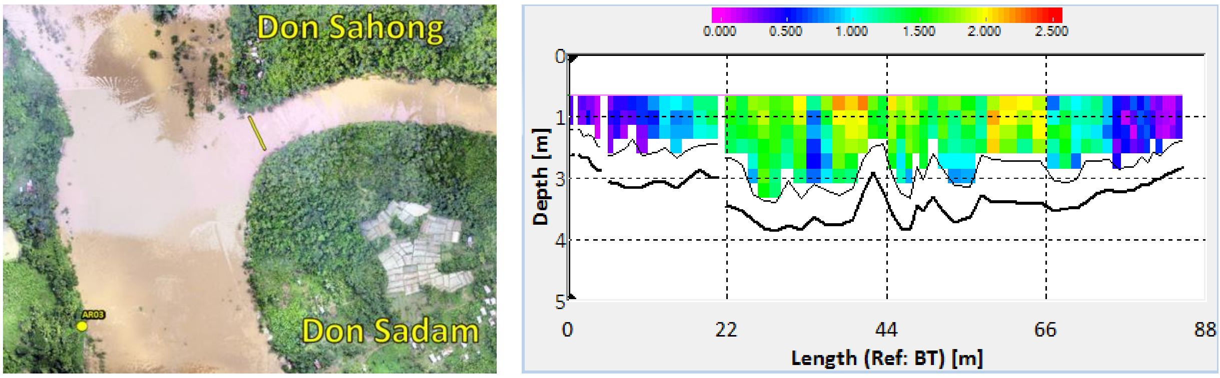


Figure 4-8: Cross-section location and example measurement, Hou Sahong ('LHS')

Discharge measurements are plotted in Figure 4-9.

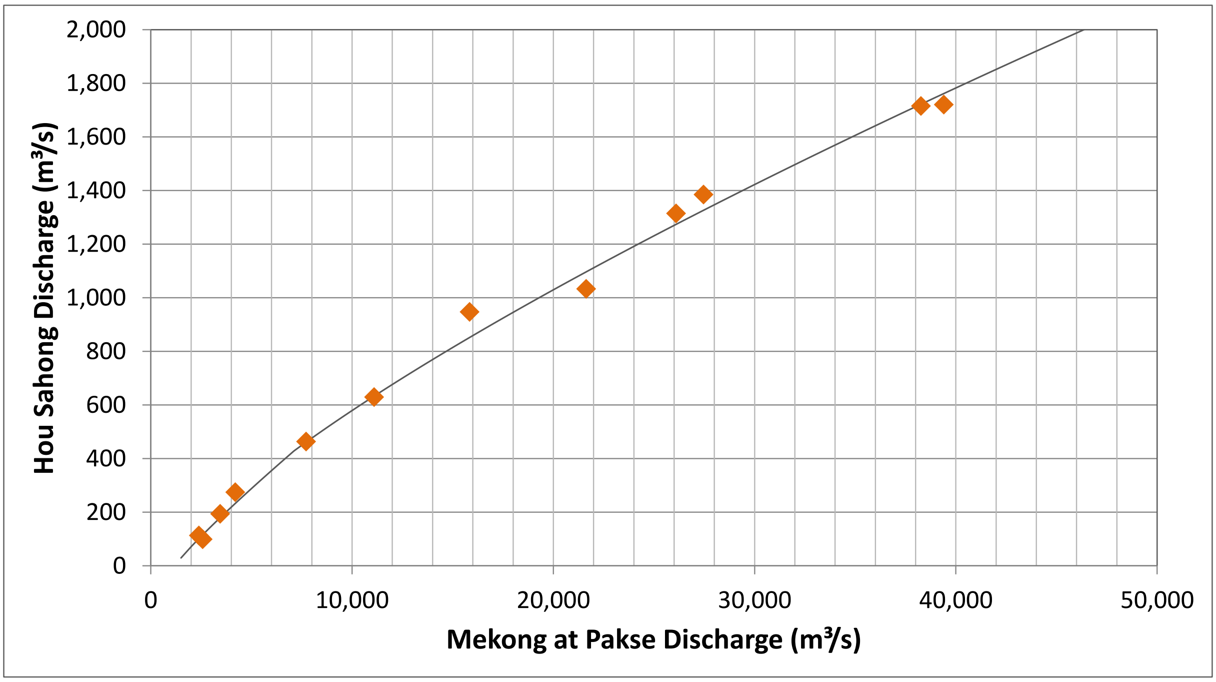


Figure 4-9: Regression fit between discharge at Pakse and Hou Sahong

The discharge is estimated as:

$Q_{Sahong} = 0.1758 \times (Q_{Pakse} - 1200)^{\wedge}0.898$ for $Q_{Pakse} < 7100$ m³/s

$Q_{Sahong} = 0.5951 \times (Q_{Pakse} - 1200)^{\wedge}0.758$ for $Q_{Pakse} > 7100$ m³/s

4.1.5. Hou Phapheng at Ban Hua Sadam

After Hou Somphamit, Hou Edtout, Hou Xang Pheuak and Hou Sahong branch off the right bank, the main channel is known as Hou Phapheng, the eastern-most channel of the Khone Falls region, leading to the renowned Phapheng Falls. Measured adjacent to the village of Ban Hua Sadam, the Hou Phapheng comprises two distinct channels below the water surface with depths up to 20m, as shown in Figure 4-10. The measured section is downstream of where multiple small channels join from the left bank, but upstream of the confluence with Hou Fang.

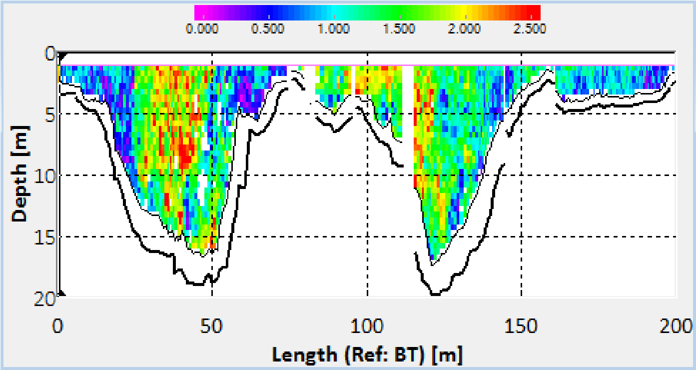


Figure 4-10: Cross-section location and example measurement, Hou Phapheng at Ban Hua Sadam ('CS09')

Discharge measurements commissioned by DSPC, together with measurements reported by the Thakho Hydropower Project (CNR, 2011) are plotted in Figure 4-11.

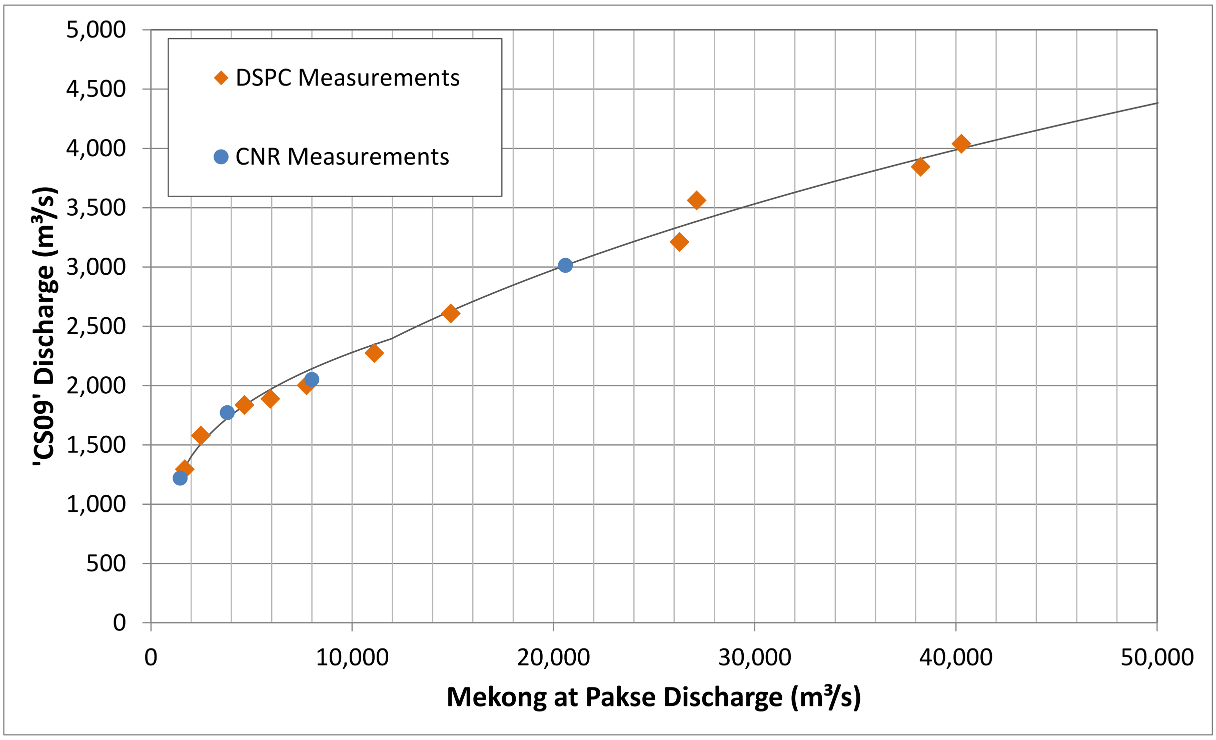


Figure 4-11: Regression fit between discharge at Pakse and Hou Phapheng at 'CS09'

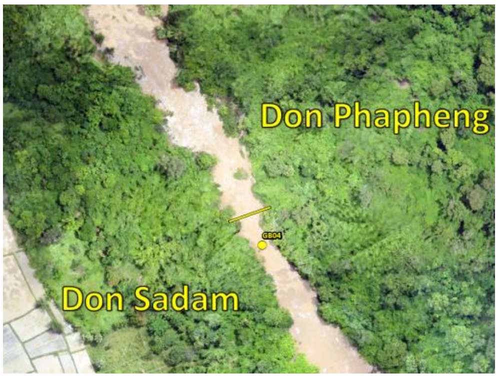
The discharge is estimated as:

$Q_{Phapheng(Hua\ Sadam)} = 203.7 \times (Q_{Pakse} - 500)^{\wedge}0.264$ for $Q_{Pakse} < 12000$ m³/s

$Q_{Phapheng(Hua\ Sadam)} = 45.57 \times Q_{Pakse}{}^{\wedge}0.422$ for $Q_{Pakse} > 12000$ m³/s

4.1.6. Hou Sadam

Hou Sadam has been gauged at a suitable location approximately 1 km downstream of its inlet, with the channel section shown in Figure 4-12.



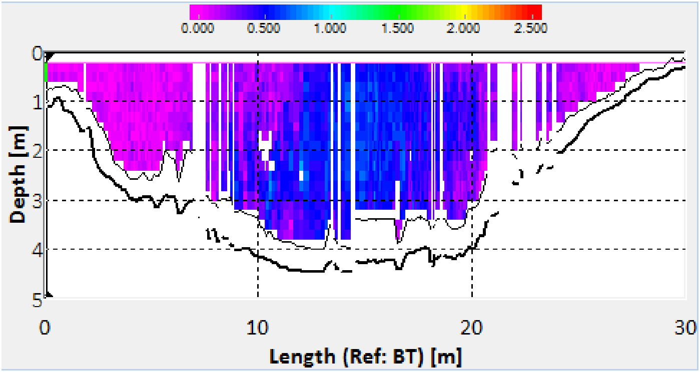


Figure 4-12: Cross-section location and example measurement, Hou Sadam

Discharge measurements commissioned by DSPC using the *StreamPro* ADCP are plotted in Figure 4-13, together with selected measurements by DSPC staff using a current meter.

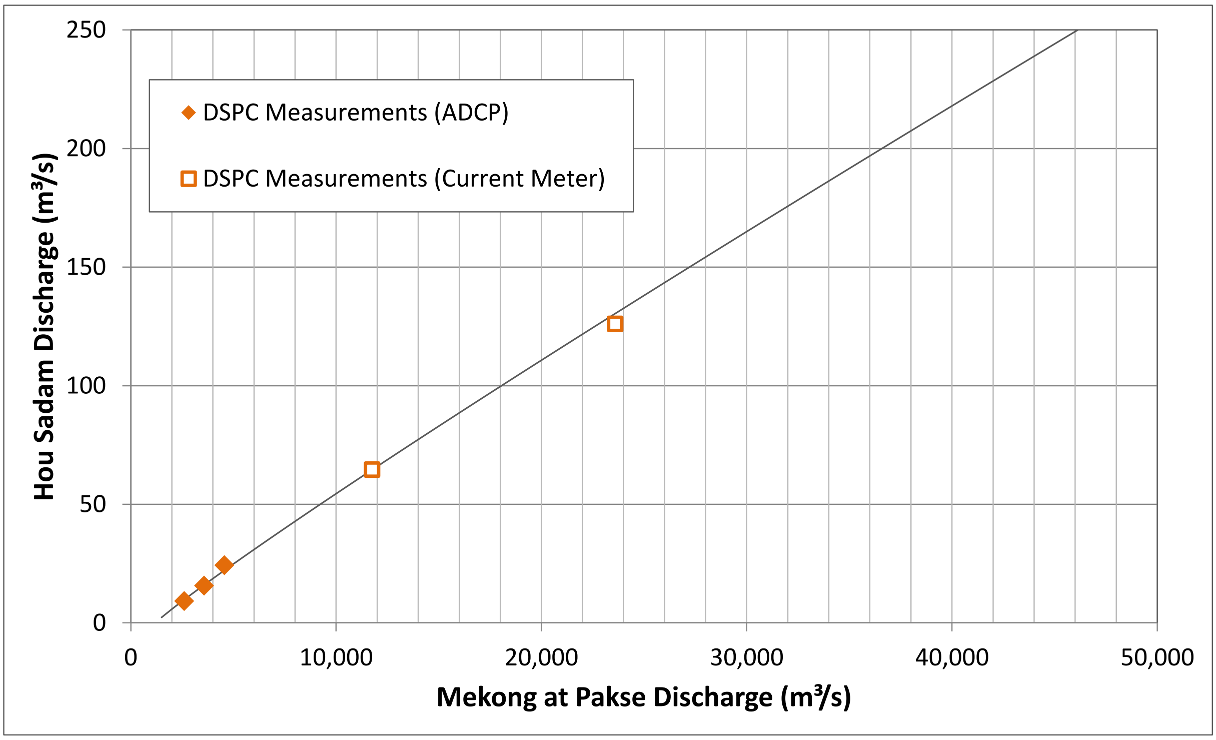


Figure 4-13: Regression fit between discharge at Pakse and Hou Sadam. Hollow markers represent current-meter measurements taken by DSPC staff

The discharge is estimated as:

$Q_{Sadam} = 0.0112 \times (Q_{Pakse} - 1200)^{\wedge}0.935$ for $Q_{Pakse} < 1200$ m³/s

4.1.7. Hou Phapheng at Ban Thakho

Hou Phapheng was measured adjacent to Ban Thakho, approximately 1 km upstream of Phapheng Falls. The flow rate measured here is identical to the flow rate over the falls. The channel is around 450 m wide and relatively shallow, as shown in Figure 4-14.

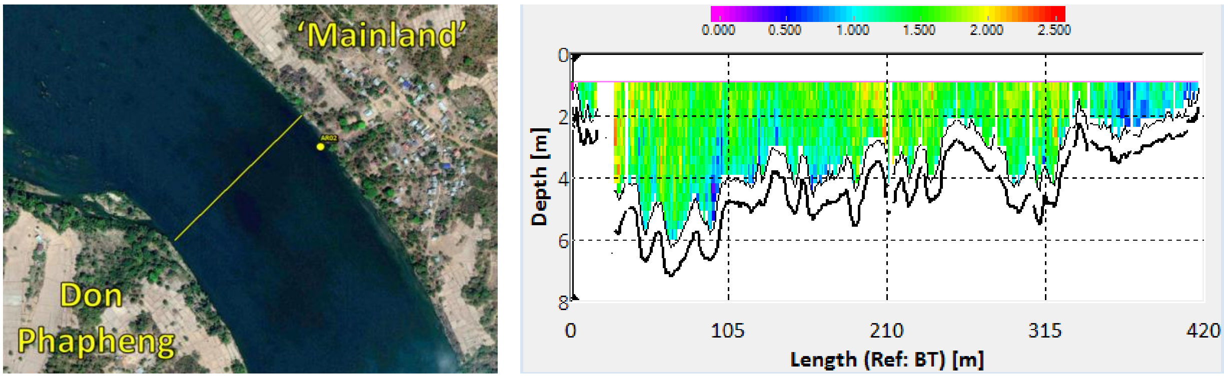


Figure 4-14: Cross-section location and example measurement, Hou Phapheng at Ban Thakho ('CS08')

Discharge measurements commissioned by DSPC, together with measurements reported by the Thakho Hydropower Project (CNR, 2011) are plotted in Figure 4-15.

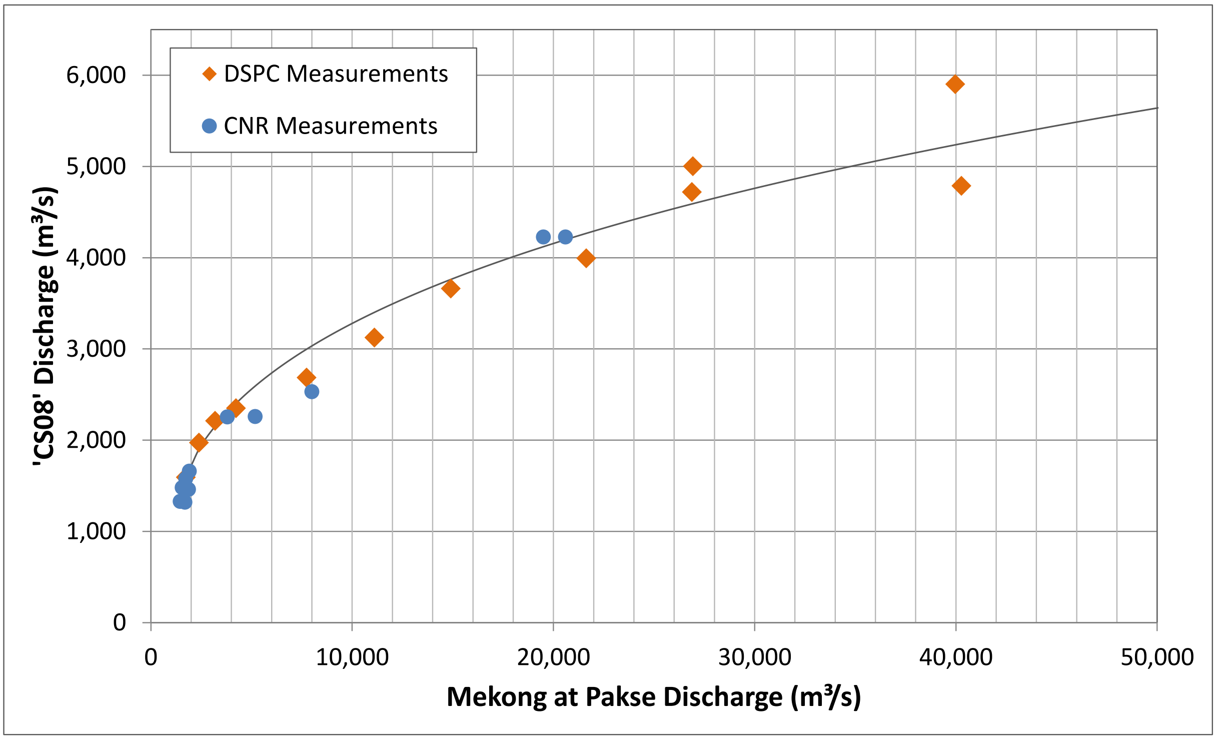


Figure 4-15: Regression fit between discharge at Pakse and Hou Phapheng at 'CS08'

The discharge is estimated as:

$Q_{Phapheng(Thakho)} = 77.36 \times (Q_{Pakse} - 600)\text{^}0.428$ for $Q_{Pakse} > 2400$ m³/s

$Q_{Phapheng(Thakho)} = 165.0 \times (Q_{Pakse} - 600)\text{^}0.327$ for $Q_{Pakse} < 2400$ m³/s

4.1.8. Hou Xang Pheuak

The Hou Xang Pheuak consists of multiple small channels between Don Esom and Don Sahong that combine above and below the Khone Larn falls. The most practical location to measure the total flow rate is near the channel outlet, although here it is also combined with Hou Edtout. Depending on flow conditions, either the combined Hou Xang Pheuak and Hou Edtout discharge was measured at section TS02-XP, or the channel was measured further downstream at TS04-XP which also included discharge from Hou Sahong, then Hou Sahong discharge was measured separately and subtracted from the result.

For the dry season 2014-15 measurements, the main branches within Hou Xang Pheuak upstream of the Khone Larn were also measured, and the summed flow rate was in good agreement with the downstream measurement (with Hou Edtout discharge measured and subtracted from the result).

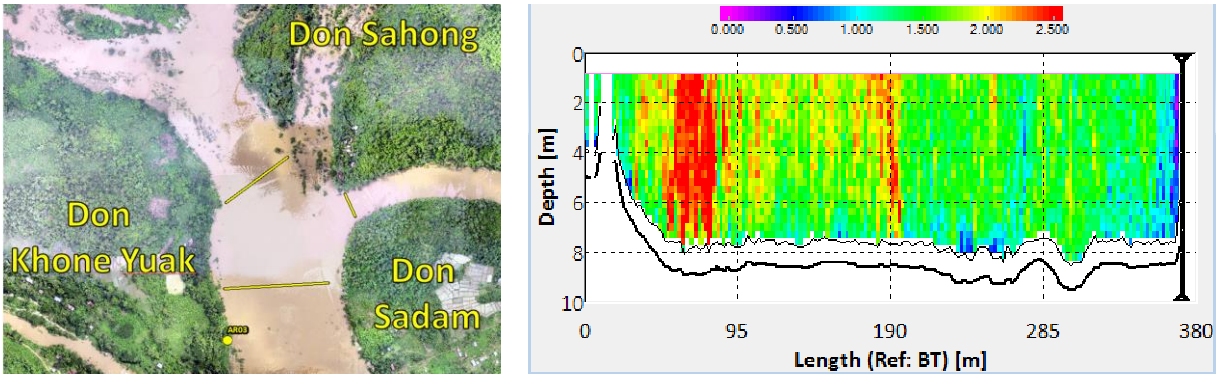


Figure 4-16: Cross-section locations for Hou Xang Pheuak, and example measurement at combined downstream channel 'TS04-XP'

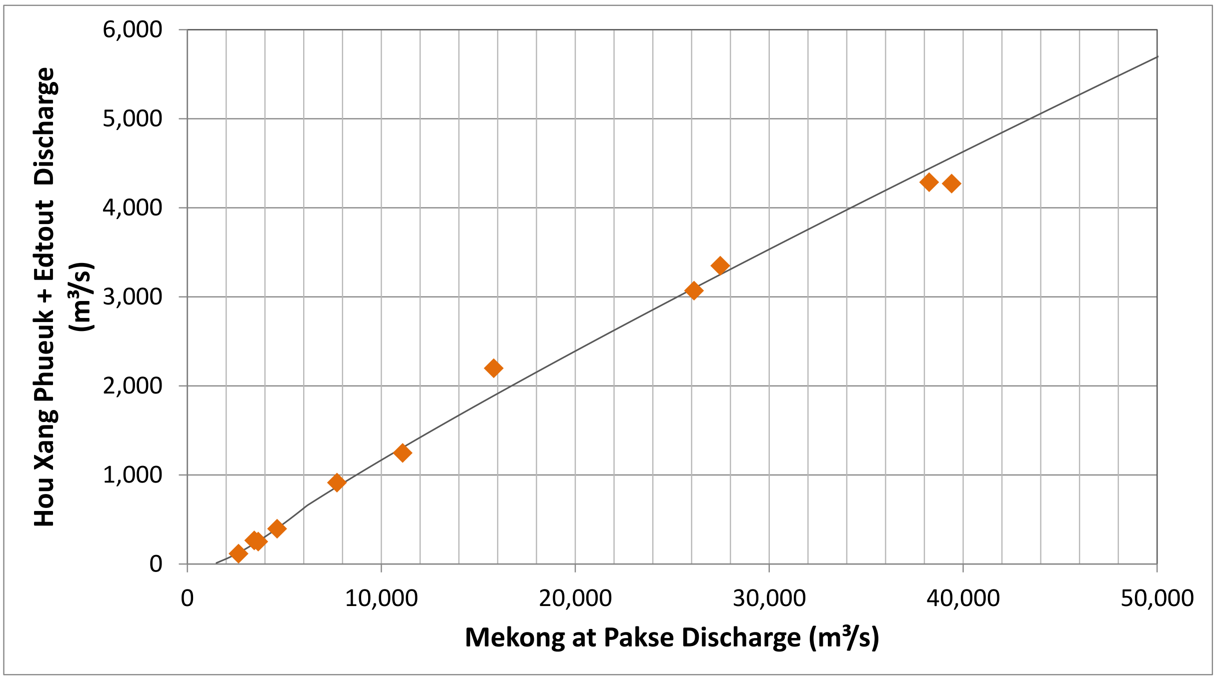


Figure 4-17: Regression fit between discharge at Pakse and Hou Xang Pheuak (including Hou Edtout)

The discharge is estimated as:

$Q_{Xang\ Pheuak} + Q_{Edtout} = 1.011 \times 10^{-8} \times (Q_{Pakse} - 800)\text{^}3.18$ for $Q_{Pakse} < 1930$ m³/s

$Q_{Xang\ Pheuak} + Q_{Edtout} = 0.00762 \times (Q_{Pakse} - 1200)\text{^}1.335$ for $1930 < Q_{Pakse} < 6165$ m³/s

$Q_{Xang\ Pheuak} + Q_{Edtout} = 0.4105 \times (Q_{Pakse} - 2000)\text{^}0.885$ for $Q_{Pakse} > 6165$ m³/s

4.1.9. Hou Edtout

Flow rate in Hou Edtout was gauged at a section some 140 m upstream of its confluence with one of the channels of Hou Xang Pheuak, shown in Figure 4-18.

The aerial image of Figure 4-18 shows a secondary channel branching off the left bank of Hou Edtout not covered by the measurement section. This image is from the 2014 wet season, and during the measurements (taken dry season to mid-season conditions, see Figure 4-19) it was noted that no flow or an insignificant flow rate was passing down this left-bank channel.

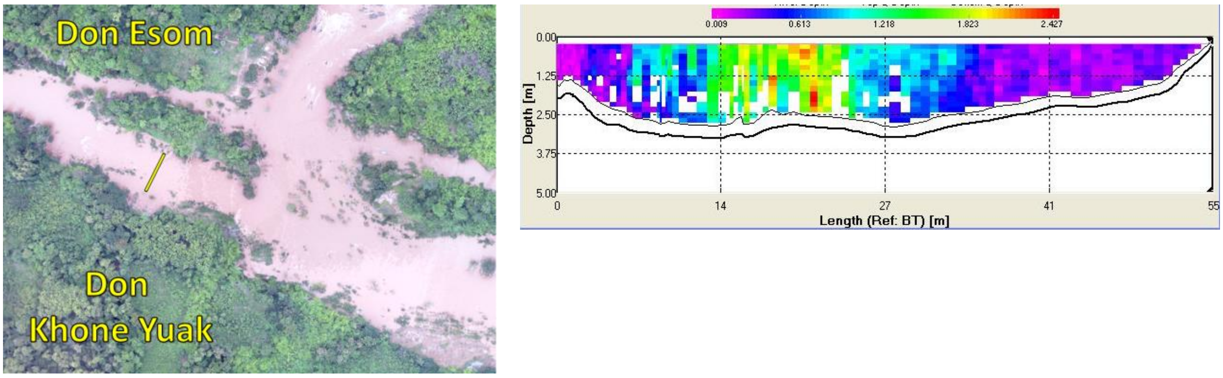


Figure 4-18: Cross-section location and example measurement, Hou Edtout

Discharge measurements are plotted in Figure 4-19.

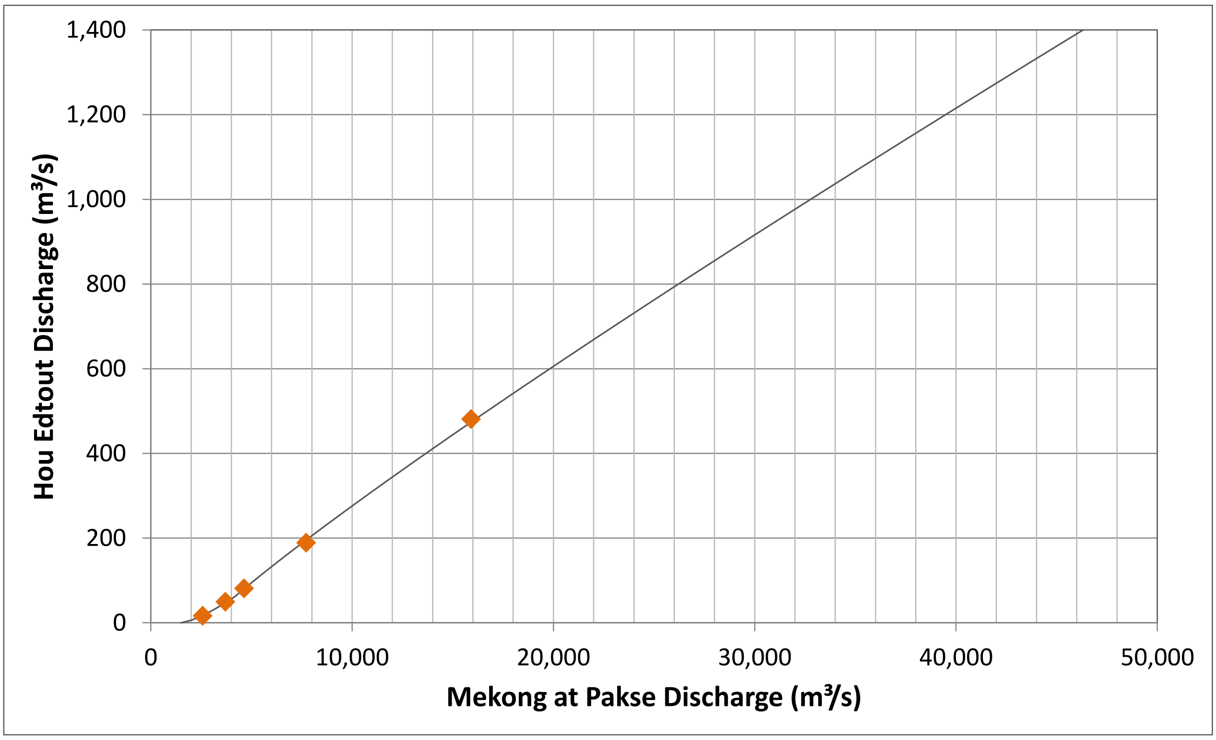


Figure 4-19: Regression fit between discharge at Pakse and Hou Edtout

The discharge is estimated as:

$Q_{Edtout} = 0.00109 \times (Q_{Pakse} - 1500)$^1.387 for Q_{Pakse} < 4200 m³/s

$Q_{Edtout} = 0.0908 \times (Q_{Pakse} - 2800)$^0.903 for Q_{Pakse} > 4200 m³/s

with zero flow assumed if the Mekong at Pakse discharge is below 1500 m³/s.

4.2. Correlations of Flow in the Khone Falls Channels with Gauge Board Levels

Flow estimates based on direct observation of water levels in the channels of interest will be more accurate than estimates based on water levels some 160 km upstream at Pakse. Mathematical relationships developed to correlate measured flow rates with river levels (i.e. rating curves) are described in the sections below.

The staff gauges downstream of the Great Fault Line (AR03 and GB03) are not suitable for rating purposes, as they are affected by backwater from the recombined Mekong downstream. Similarly, AR01 and GB01 are not suitable, as the water level at these locations is not only dependant on the flow rate passing, but also on flows from other channels joining and separating downstream.

4.2.1. Hou Sahong (GB02)

Flow rates in Hou Sahong have been measured on multiple occasions since 2007, with many of these measurements made before daily observations of the staff gauge at GB02 in began April 2011. To make use of the earlier flow measurements, a regression fit between observed GB02 levels and concurrent Pakse flow has been made (Figure 4-20), allowing the level at GB02 for earlier years to be estimated based on the Pakse flow record.

The derived GB02 level estimates will not be as accurate as direct measurements, but provide a useful secondary dataset. Obvious outliers (noted with open symbols in the figure below), presumably due to observation/recording error, were ignored when deriving the regression fit.

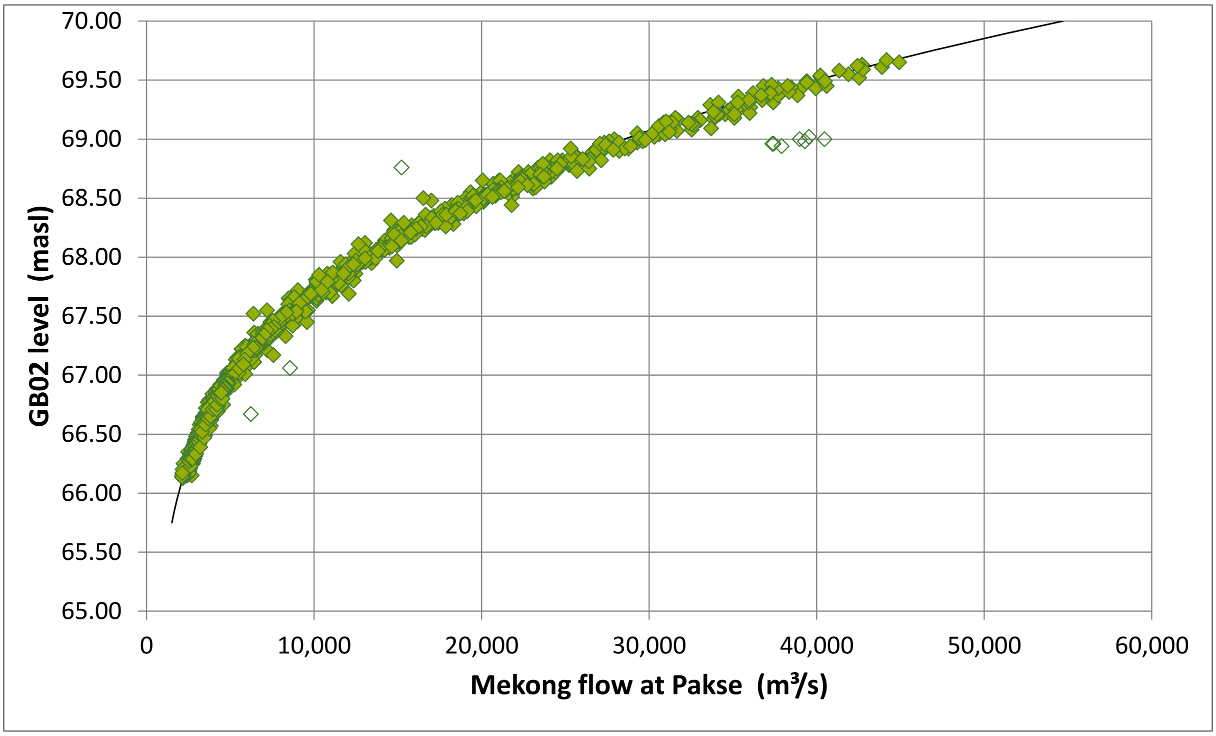


Figure 4-20: Regression fit between Mekong discharge at Pakse and GB02 level. Outliers which were not included in the regression are represented with open symbols.

The derived rating curve for Hou Sahong at GB02 is shown in Figure 4-21, with the rating equation:

$$Q_{Sahong} = 79.95 \times (WL_{GB02} - 65.15)^{2.112}$$

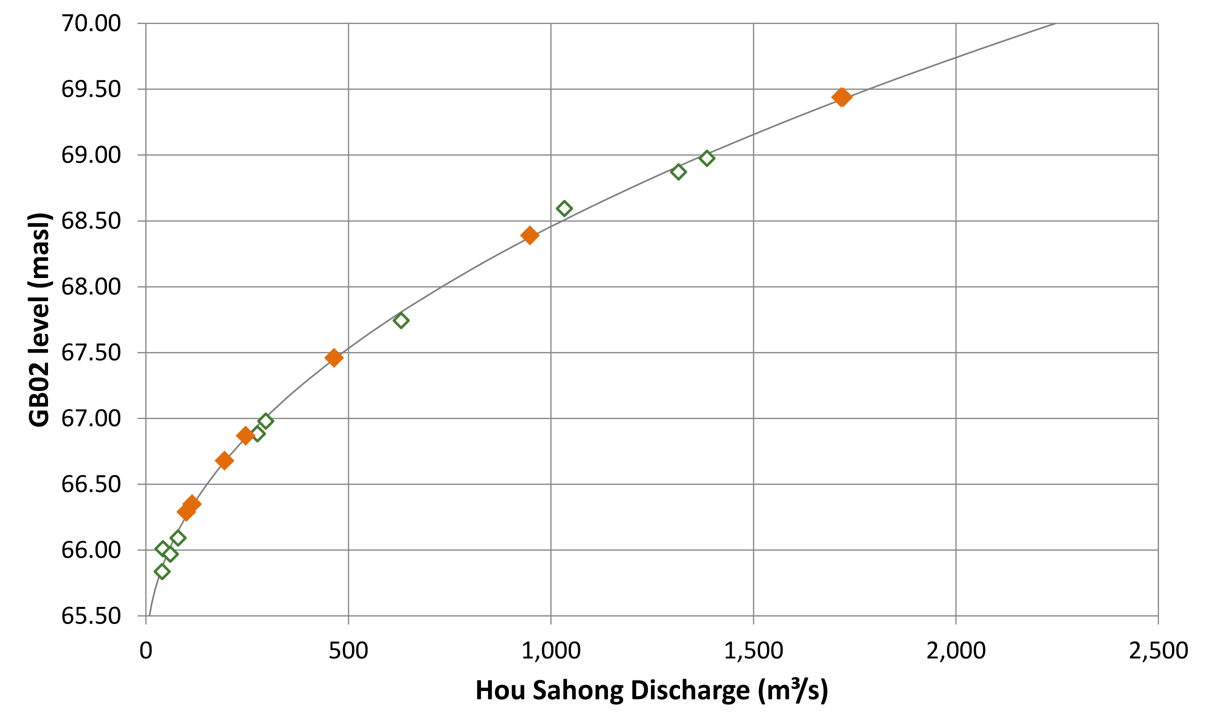


Figure 4-21: Regression fit between GB02 level and measured Hou Sahong discharge. Open markers represent GB02 water levels estimated based on reported Mekong at Pakse discharge (i.e. pre April 2011).

Using this rating curve with the daily observations, a reasonably accurate daily discharge series for the Hou Sahong can be derived. Figure 4-22 shows the daily Hou Sahong discharge series for 2014, with bio-hydrological season defined as per MRC (2009).

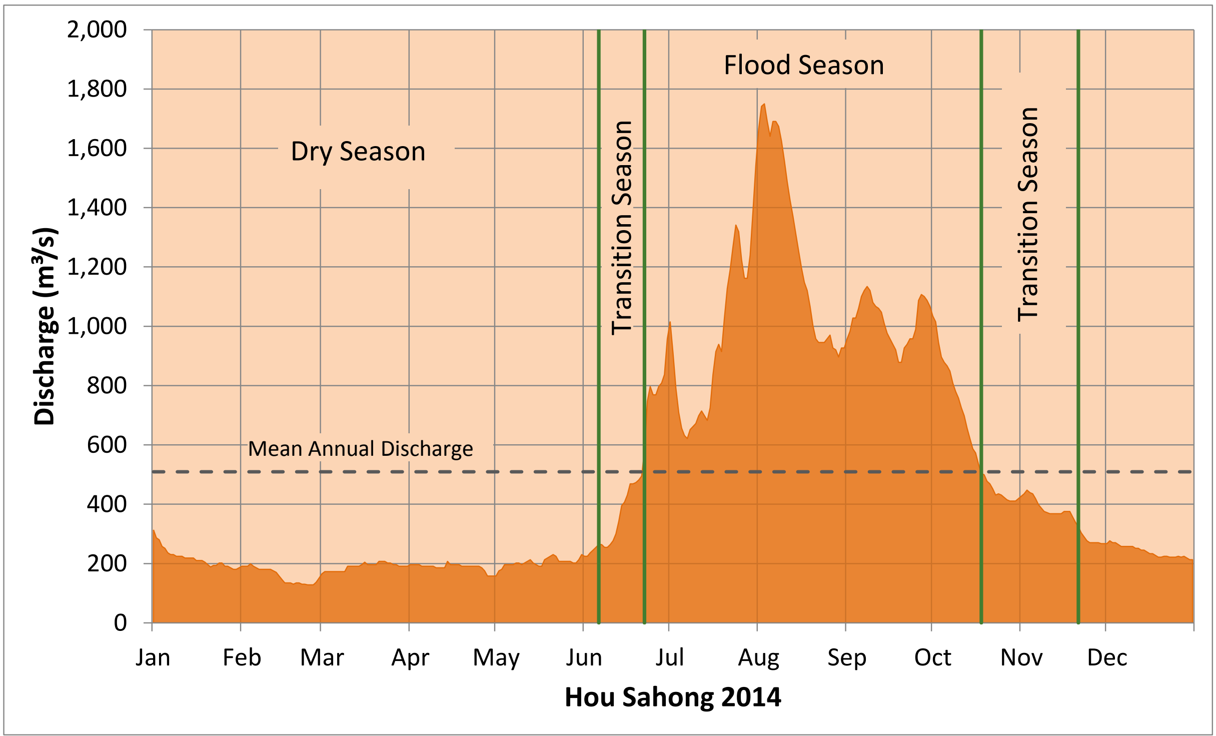


Figure 4-22: Annual hydrograph for Hou Sahong, 2014, based on gauge board observations, with bio-hydrological seasons identified as defined by MRC, 2009.

4.2.2. Hou Sadam (GB04)

A rating curve for the Hou Sadam at GB04 was developed using recent flow measurements (2014-2015), including both those made with the *StreamPro* ADCP and supplementary measurements made with a current meter.

The derived rating curve is shown in Figure 4-23, with the rating equation:

$$Q_{Sadam} = 45.49 \times (WL_{GB04} - 66.30)^{1.529}$$

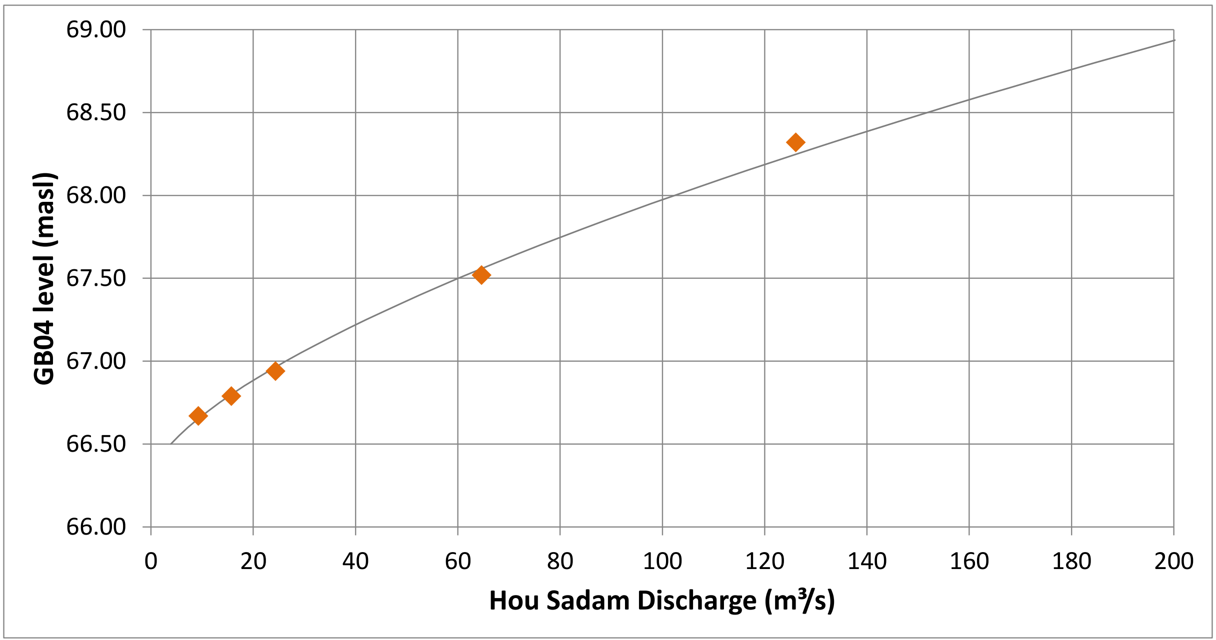


Figure 4-23: Regression fit between GB04 level and measured Hou Sadam discharge

Using this rating curve, Figure 4-24 shows the daily Hou Sadam discharge series for 2014, with bio-hydrological season defined as per MRC (2009).

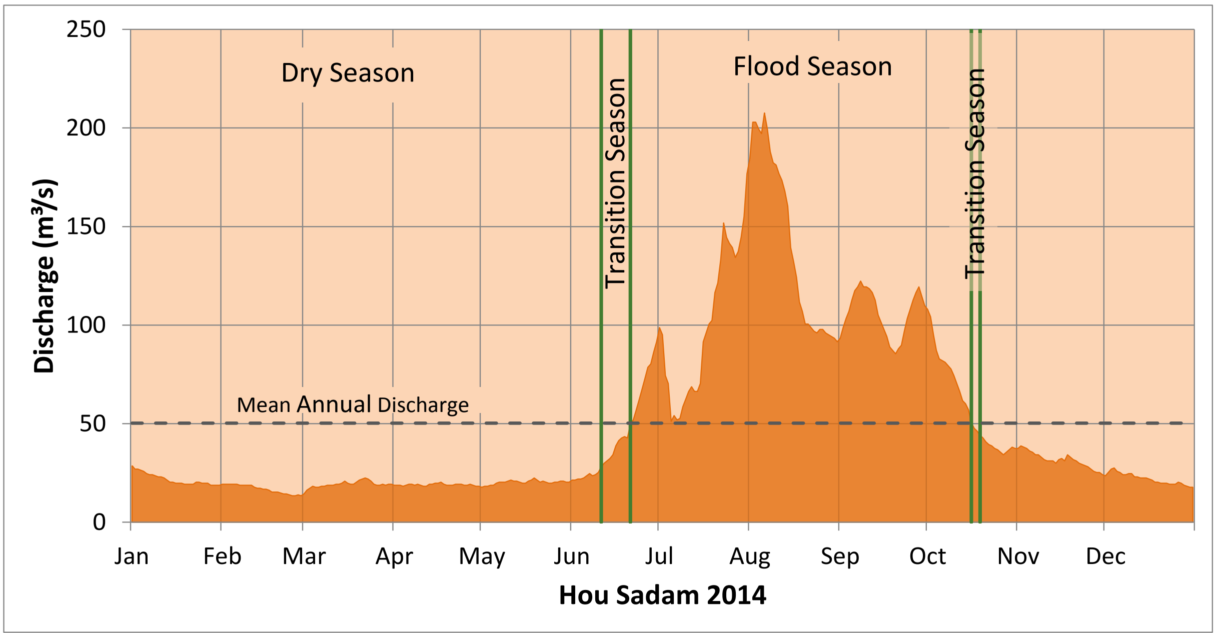


Figure 4-24: Annual hydrograph for Hou Sadam, 2014, based on gauge board observations, with bio-hydrological seasons identified as defined by MRC, 2009.

It is noted that during development of the proposed DSHPP, excavation works are planned for the Hou Sadam inlet to ensure that flow rates in the channel are maintained despite the projected decrease in Hou Phapheng water levels. The rating curve for GB04 will remain valid so long as the gauging station is downstream of the influence of these works.

4.2.3. Hou Phapheng at Ban Thakho (AR02)

Flow rates in Hou Phapheng at Ban Thakho have been measured on multiple occasions since 2007, with many of these measurements made before daily observations of the staff gauge at AR02 in began April 2011. To make use of the earlier flow measurements, a regression fit between observed AR02 levels and concurrent Pakse flow has been made (Figure 4-25), allowing the level at AR02 for earlier years to be estimated based on the Pakse flow record.

The derived AR02 level estimates will not be as accurate as direct measurements, but provide a useful secondary dataset. The obvious outliers (noted with open symbols in the figure below), presumably due to observation/recording error, were ignored when deriving the regression fit.

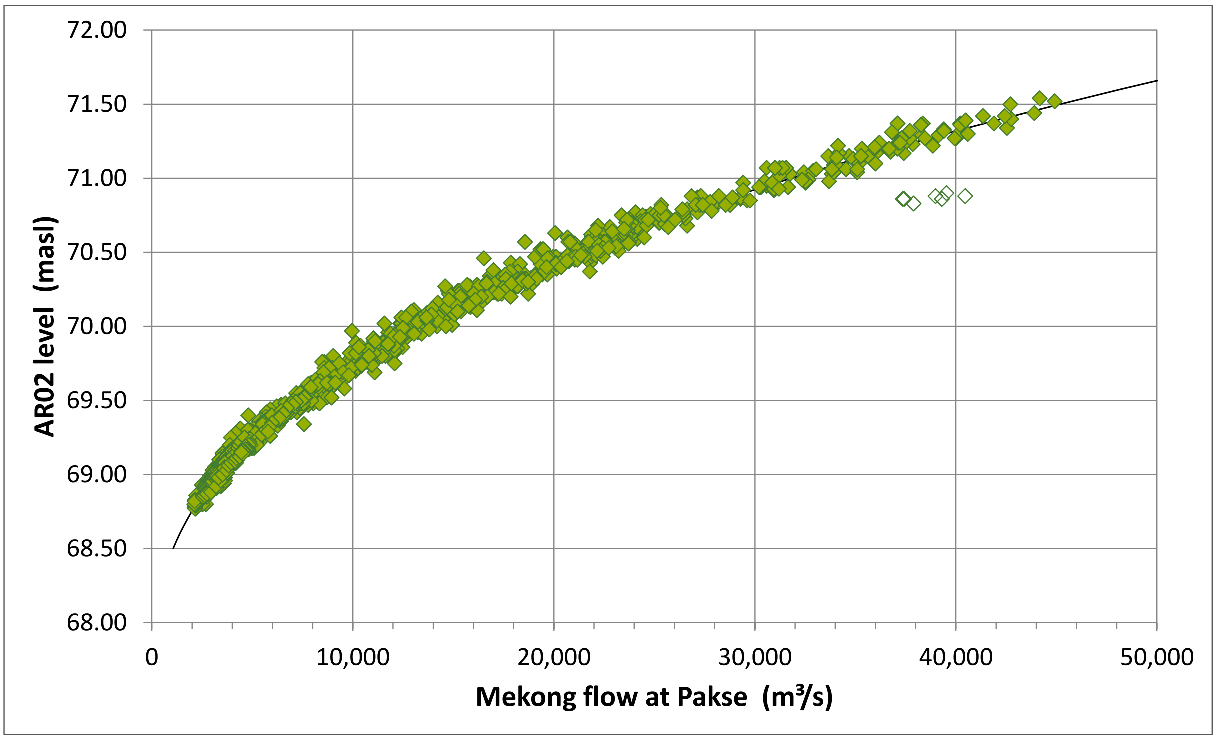


Figure 4-25: Regression fit between Mekong discharge at Pakse and AR02 level. Outliers which were not included in the regression are represented with open symbols.

The derived rating curve for Hou Phapheng at AR02 is shown in Figure 4-26, with the rating equation:

$$Q_{Phapheng} = 482.1 \times (WL_{AR02} - 66.50)^{1.568}$$

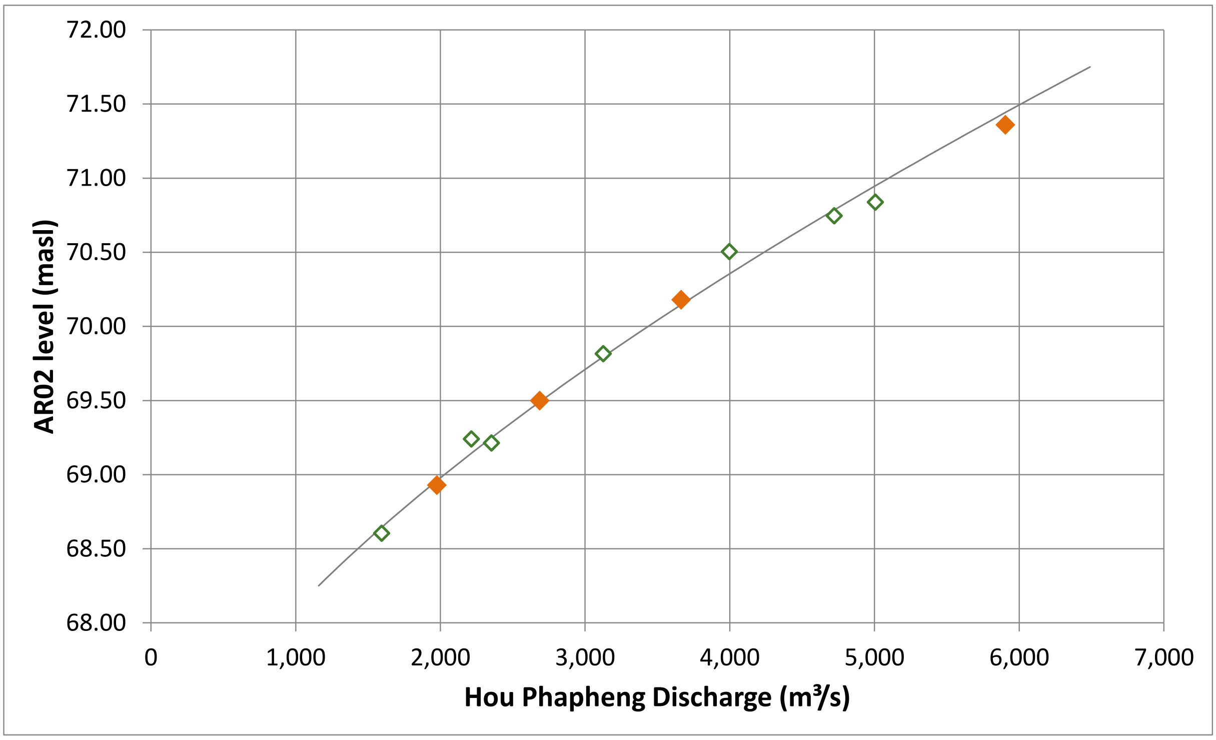


Figure 4-26: Regression fit between AR02 level and measured Hou Phapheng discharge. Open markers represent AR02 water levels estimated based on reported Mekong at Pakse discharge (i.e. pre April 2011).

Using this rating curve with the daily observations, Figure 4-27 shows the daily Hou Phapheng discharge series for 2014, with bio-hydrological season defined as per MRC (2009). It is noted that no transition seasons as defined by MRC occur either side of the flood season, because of the high dry-season flow rate relative to the annual mean.

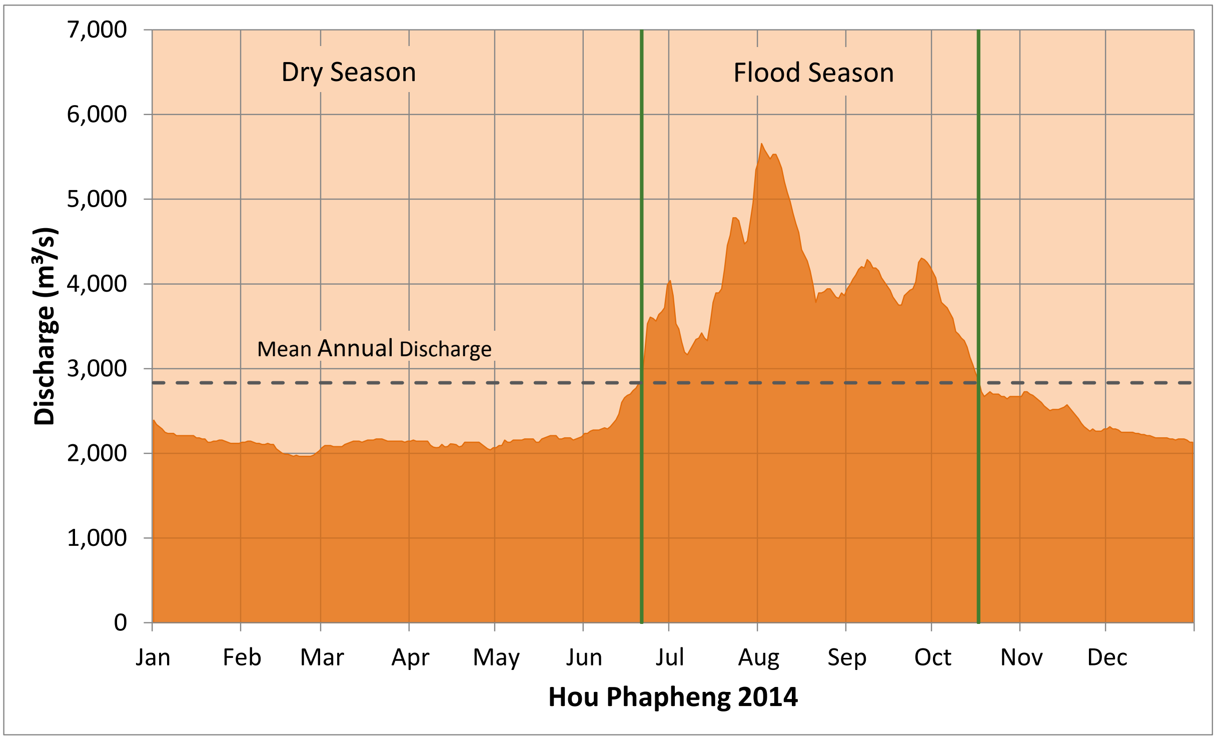


Figure 4-27: Annual hydrograph for Hou Phapheng, 2014, based on gauge board observations, with bio-hydrological seasons identified as defined by MRC, 2009.

4.2.4. Hou Xang Pheuak (GB05)

The staff gauge GB05 on Hou Xang Pheuak has only been in place and observed since July 2014. Flow measurements during the intervening period have been limited, and the derived rating curve should be considered preliminary only, to be improved with continuing observation over the coming transition seasons and wet season of 2015.

To make use of flow measurements taken prior to July 2014, a regression fit between observed GB05 levels and concurrent Pakse flow has been made (Figure 4-28). Problems with observations in October 2014 means there are no valid records for a significant part of the range, and it is expected that the relationship between Pakse discharge and GB05 will be improved with further data collection.

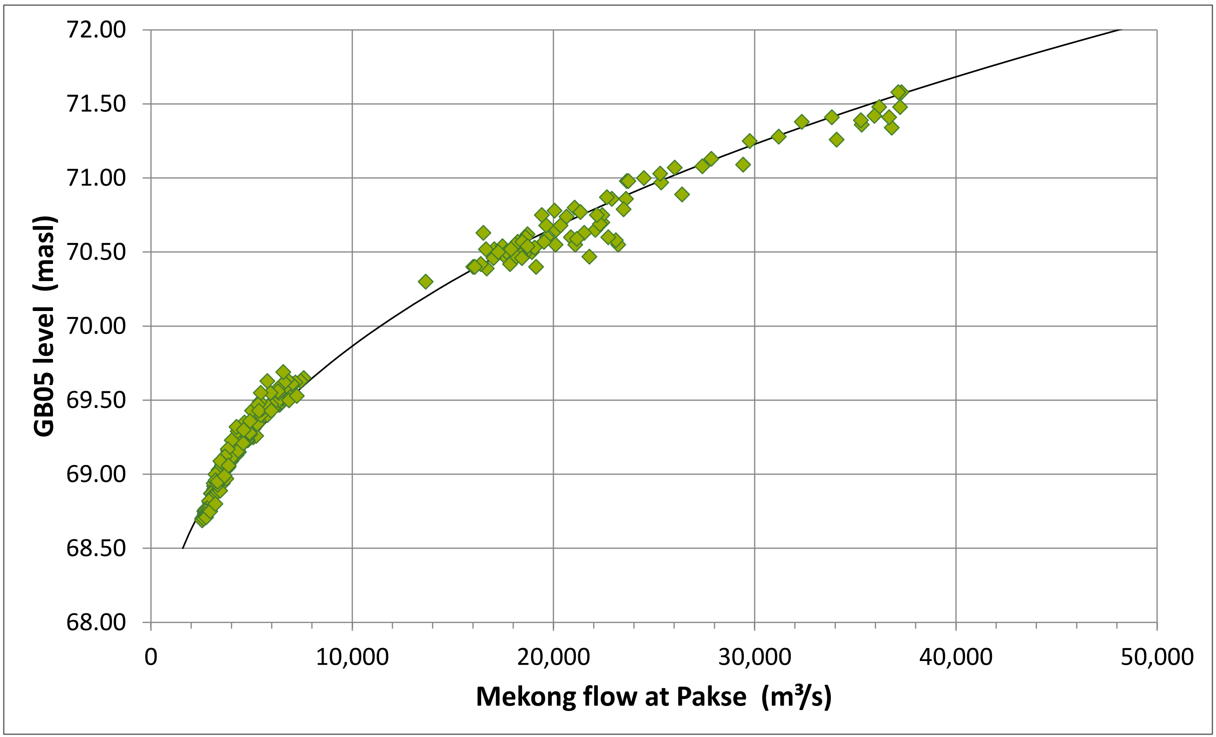


Figure 4-28: Regression fit between Mekong discharge at Pakse and GB05 level

The rating curve derived from flow measurements is shown in Figure 4-29. All available flow measurements were used, including those based on estimates of water levels at GB05, and as such it contains considerable uncertainty and must be considered preliminary. The flow rate was generally measured in the combined Hou Xang Pheuak and Hou Edtout outlet, with Hou Edtout discharge estimated according to the relationship developed in Section 4.1.9 and subtracted from the measurement.

The preliminary rating equation is:

$$Q_{Xang\ Pheuak} = 522.0 \times (WL_{GB05} - 68.40)^{1.533}$$

This rating estimates the total Hou Xang Pheuak discharge, although not all of the discharge directly affects water level at the staff gauge, as the main channel is some 400 m wide at this location, with additional smaller side channels and is splitting into two distinct channels downstream. The rating relationship relies on consistent flow distribution within the upper Hou Xang Pheuak.

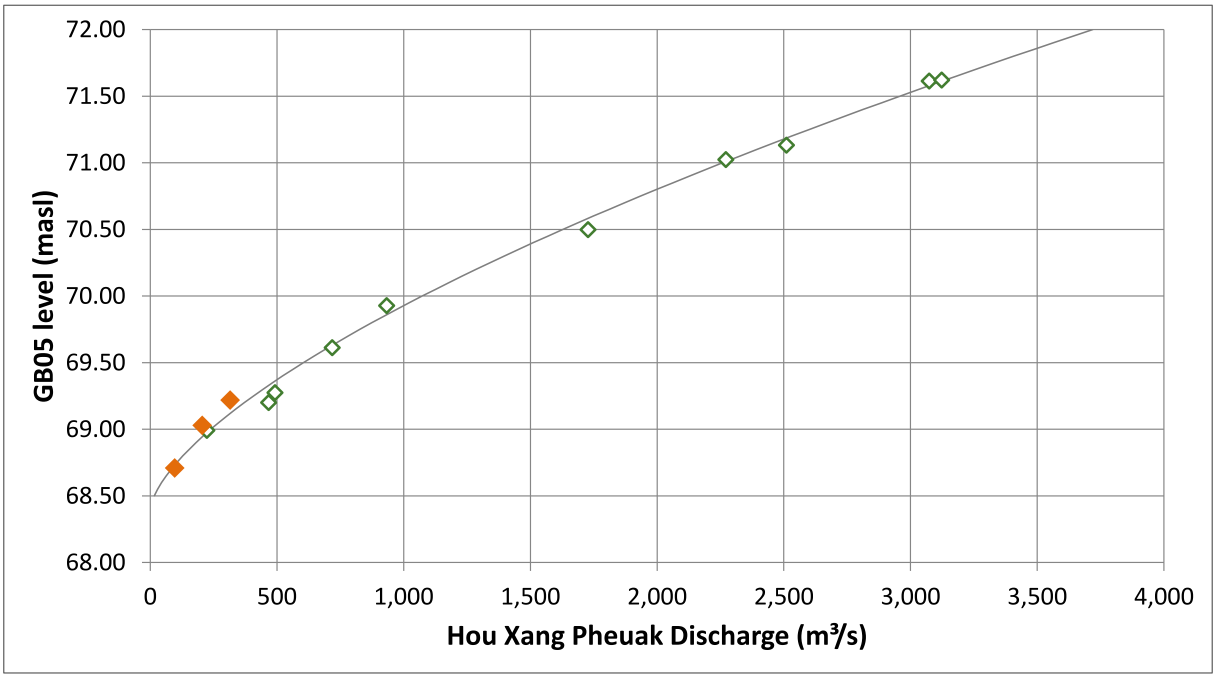


Figure 4-29: Regression fit between GB05 level and measured Hou Xang Pheuak discharge. Open markers represent GB05 water levels estimated based on reported Mekong at Pakse discharge

A derived daily Hou Xang Pheuak discharge series for 2014 is shown in Figure 4-30 with bio-hydrological season defined as per MRC (2009). When staff gauge observations are available they have been used, and at other times GB05 levels have been estimated from the reported Pakse flow using the curve of Figure 4-28.

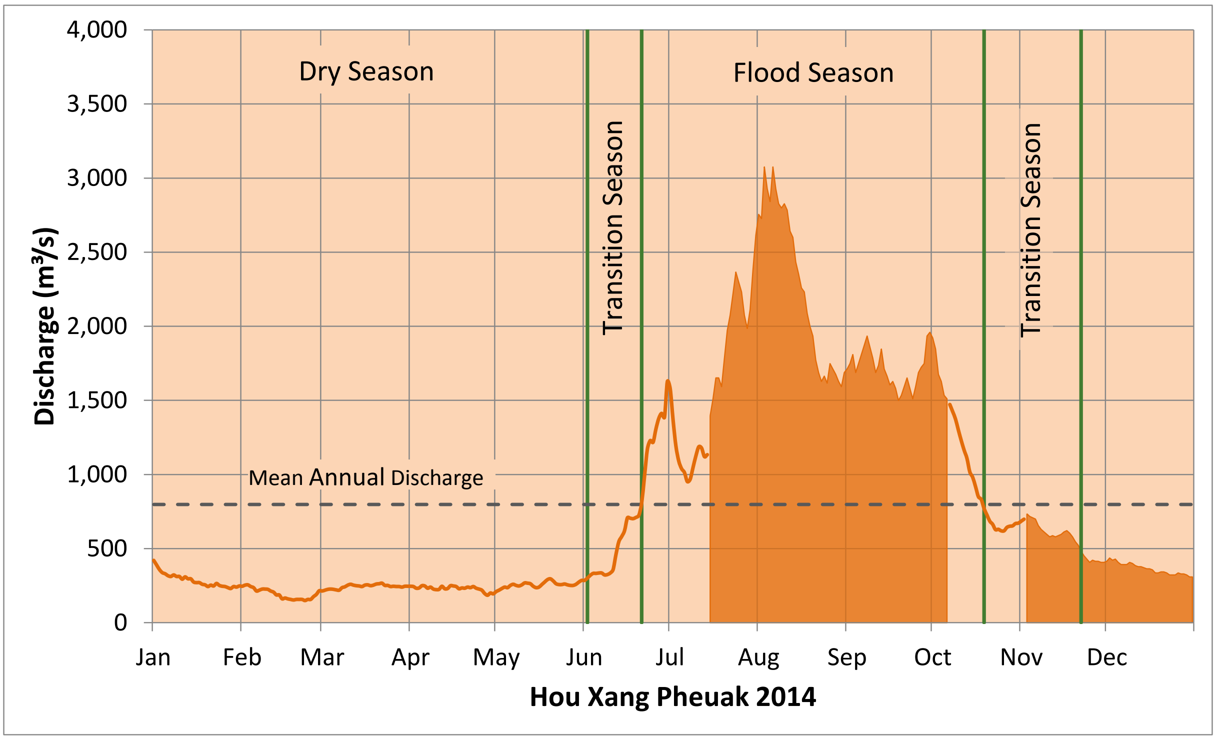


Figure 4-30: Annual hydrograph for Hou Xang Pheuak, 2014, based on gauge board observations, with bio-hydrological seasons identified as defined by MRC, 2009. When gauge board observations are not available (unfilled portions of plot), water levels are estimated based on reported Mekong at Pakse discharge.

4.3. Discussion of Uncertainty

There are myriad sources of potential error in the estimates of flow from rating curves or correlation with other gauges, which makes quantification of the uncertainty impractical.

Sources of error include

- Error in discharge and river stage measurements
- Rating curve uncertainty, including
  - Interpolation and extrapolation error, dependent on choice of curve fit
  - Transient or temporary changes in rating due to sedimentation
  - Seasonal changes in vegetation (i.e. roughness)
  - Hysteresis effects
- Flow changes between Pakse and the Khone Falls, including
  - Uncertainty with lag in flow conditions, especially in rapidly changing mid-season flow conditions
  - Effects of intermediate inflows and flow attenuation

Typically with good practice, discharge measurements are confidently within ± 5-10% (Gordon, 1989). Good accuracy is expected in the discharge measurements taken at the Khone Falls, due to

- the careful selection of suitable measurement sites by an experienced ADCP operator familiar with the area,
- selection of ADCP equipment appropriate to the prevailing flow conditions,
- the practice of measuring multiple transects for each measurement, and
- redundancy in measuring at multiple cross-sections at the same flow conditions.

Uncertainty in the rating curve has been reduced by collecting multiple flow measurements at each section across the range of flow conditions. From measurements taken across multiple years, there is no evidence of temporal changes in the ratings.

Uncertainty due to flow changes between Pakse and the Khone Falls are expected to be small, given the relatively small additional intermediate catchment (1.5%). This uncertainty is removed with the use of local staff gauge observations to estimate flow in Hou Sahong (GB02), Hou Sadam (GB04), Hou Phapheng (AR02) and Hou Xang Pheuak (GB05).

4.4. Summary of General Seasonal Flow Patterns

The geomorphology of the river channels in the Khone Falls area results in a changing proportion of the total Mekong flow in the various channels across the year. The mean monthly flows in each of the channels considered is shown in Table 4.1, based on the Pakse discharge correlations applied to the recent period 2011-2014.

Table 4.1: Monthly average flows in channels across the Khone Falls in m³/s. Based on correlations with Mekong at Pakse flows 2011-2014

Month	Mekong at Pakse	Western Channels [a]	Hou Somphamit	Hou Edtout	Hou Xang Pheuak	Hou Sahong	Hou Sadam	Hou Phapheng
Jan	3,309	593	139	36	173	170	14	2,184
Feb	2,841	372	120	24	126	136	11	2,053
Mar	2,849	376	120	24	126	136	11	2,055
Apr	2,807	356	118	23	122	133	11	2,042
May	3,914	896	161	54	238	213	18	2,333
Jun	8,069	3,310	280	208	705	480	43	3,042
Jul	16,232	9,013	445	484	1,457	869	90	3,873
Aug	28,057	17,954	628	857	2,459	1,349	155	4,656
Sept	25,665	16,108	595	783	2,261	1,257	142	4,519
Oct	14,777	7,955	419	437	1,328	805	82	3,751
Nov	7,668	3,050	270	194	666	459	41	2,988
Dec	4,576	1,244	184	78	313	259	22	2,476

[a] Western Channels are the collection of channels to the west of Don Det (see Figure 4-1)

It can be seen that the majority of Mekong discharge (approximately 70%) passes through Hou Phapheng in the dry season, switching to a majority (60-70%) in the Western Channels in the wet season. This occurs as the rising river spills over the wide but shallow western area.

Each channel has its own response to changes in the overall Mekong flows, based on prevailing upstream water levels and (generally) the elevation and width of the inlet bar which flow has to spill over to enter the channel.

The response of Hou Phapheng, other 'Eastern' channels (sum of Hou Sadam, Sahong, Xang Pheuak, Edtout, Somphamit), and the Western Channels to the total Mekong discharge is shown in Figure 4-31.

Hou Phapheng may be considered the 'main channel', in that it is the deepest channel and at very low flow conditions it passes almost all of the flow. With increasing Mekong discharge, flow quickly increases in the other Eastern channels, to reach a maximum proportion of around 20%. The proportion of flow in the Western Channels continues to increase across the range of Mekong Flows.

This response means that the increase in dry season Mekong flows noted in Section 3.1 (and further discussed in Section 5 below) results in a disproportionate increase in flows in the 'other eastern channels'. As an example, when the Mekong at Pakse discharge is 1,500 m³/s, these channels pass 6% of the flow (some 85 m³/s), while with a Mekong discharge of 3,000 m³/s, these channels pass 15% of the flow (some 450 m³/s).

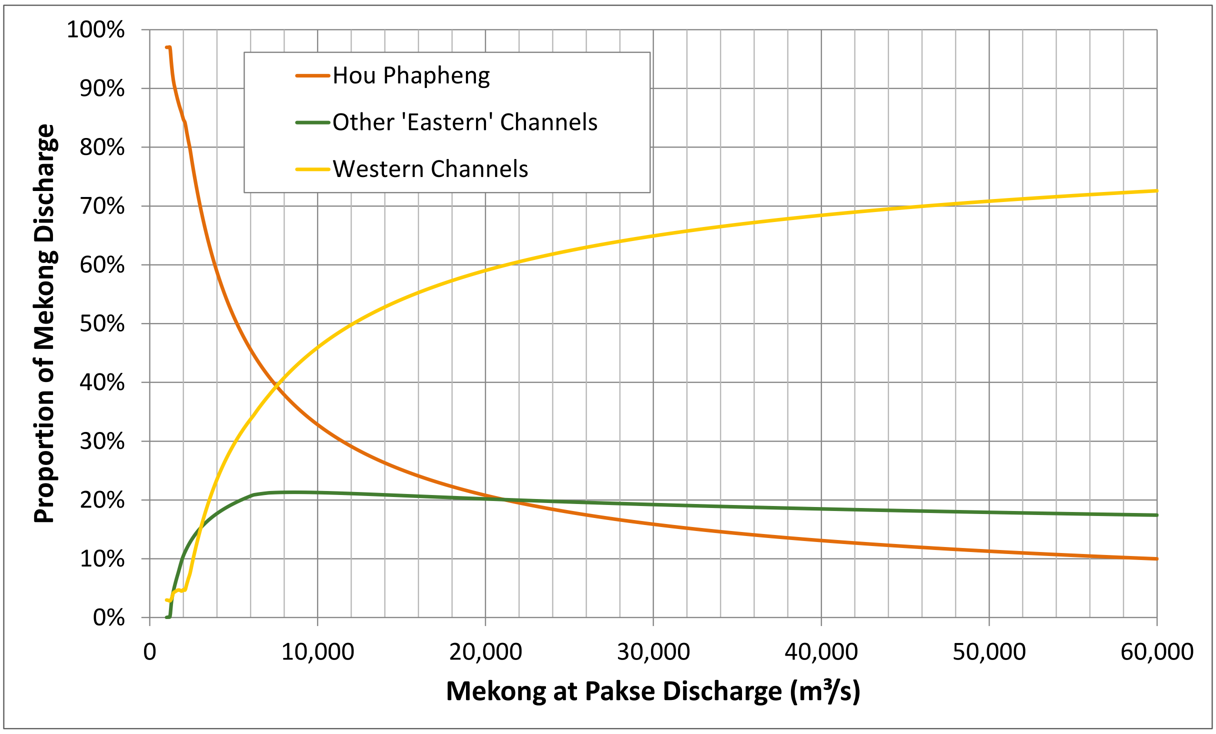


Figure 4-31: Proportion of total Mekong discharge in different channels at the Khone Falls across the range of possible flow conditions

5. CHANGES IN SURFACE HYDROLOGY DUE TO BASIN DEVELOPMENT

It is apparent that dry season flows since 2010 have been higher than those historically observed (e.g. Figure 3-6). This is attributable to water resource development in the basin, specifically the construction of hydropower dams and the creation of 'active storage' which is managed seasonally to maximise energy output from these facilities.

5.1. MRC Development Scenarios

To support the Basin Development Plan (BDP), the MRC Basin Development Programme (MRC, 2011) studied basin-wide development scenarios, investigating the cumulative impacts of the riparian countries' water resources development plans, including hydropower storage dams. Computational modelling of different hydrological scenarios was undertaken by the Information and Knowledge Management Programme (IKMP).

The scenarios studied included:

- **Baseline**. This is based on the observed climate from the period 1985-2000, with dams and irrigation developments as existing in 2000.
- **Definite Future**. A scenario modelling the impacts of developments that were expected to occur by 2015, including mainstream dams on the Lancang (Upper Mekong) and 26 significant tributary dams in the Lower Mekong Basin.
- **Foreseeable Future**. Scenarios modelling water resource development plans to 2030, including irrigation and water-supply development, 11 proposed mainstream dams, and an additional 30 tributary dams. Modelled with and without climate change influences.
- **Long-term Future**. Scenarios looking at 50-year development plans, with and without climate change effects.

The modelled scenarios are based on the observed climate over the period 1985-2000, with the assumption that this period adequately represents future climatic variability. It is noted that the Baseline scenario is a modelled scenario, so for example the model output of the Baseline discharge series for the Mekong at Pakse is not identical to the observed discharge series from 1985.

The Definite Future scenario included 23,193 Mm^3 of active storage in the Upper Mekong Basin (China), 17,166 Mm^3 in Lao PDR and 2,566 Mm^3 in Thailand. This storage is modelled to retain wet season flows and release them through the following dry season to maximise hydropower output. The changes in flows and water levels in the Definite Future scenario can mainly be attributed to the operations of the two largest storage dams (Xiaowan and Nuozhadu) in the Upper Mekong Basin, which have a combined active storage of some 22,000 Mm^3 (Piman *et al*., 2013).

Comparison of the model results for the Definite Future and Baseline scenarios shows the following key changes in the Mekong at Pakse annual discharge hydrograph (see also Figure 5-1):

- Increased flows in the receding transition season and dry season (Oct-Apr) on average 30%
- A corresponding reduction in the rising transition and wet season (May-Sept) by average of 10%

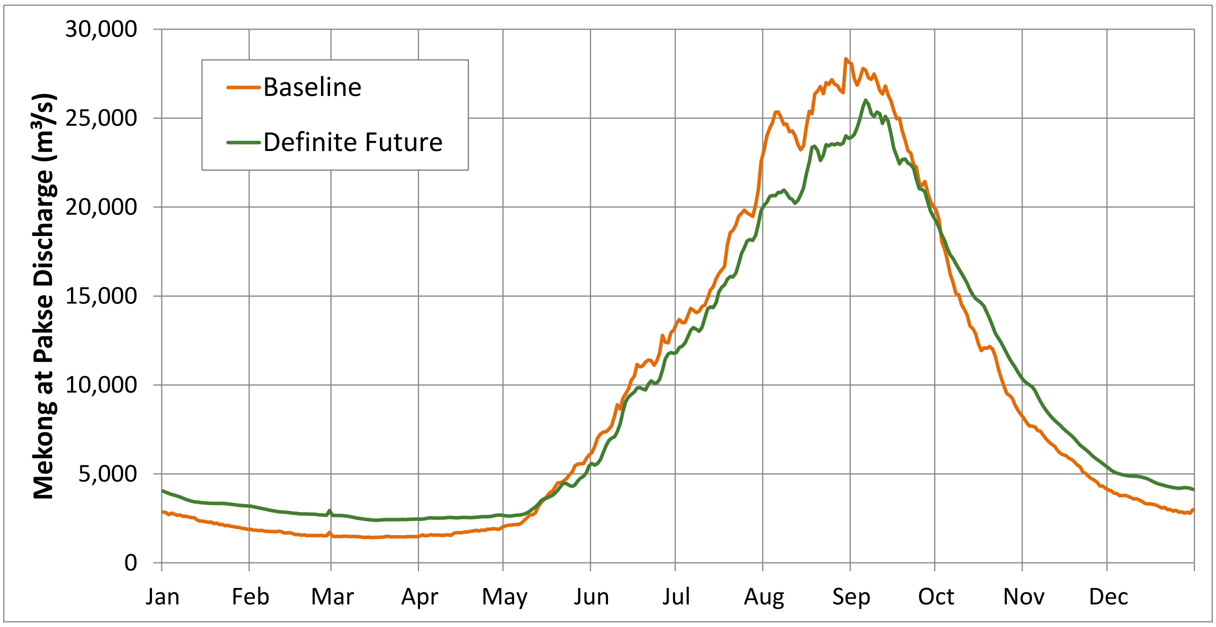


Figure 5-1: Average annual hydrograph for Mekong River at Pakse from MRC basin development scenarios Baseline and Definite Future.

All significant storage included in the Definite Future scenario has now been constructed. Xiaowan Reservoir reportedly began impounding in November 2007 and the dam was completed with all generating units commissioned by August 2010. Nuozhadu Dam was completed with units progressively commissioned from 2012 to June 2014, though it is believed that Nuozhadu Reservoir has not yet been completely filled as of mid-2015.

5.2. Changes in Historical Series

The effects of the new storage are apparent in the flow statistics for the Mekong at Pakse. Table 5.1 shows the monthly median, 5% exceeded and 95% exceeded discharges for two periods of observed discharge, before (1986-2007) and after (2011-2014) the storage was constructed.

Table 5.1 Monthly flow statistics (in m³/s) for observed Mekong at Pakse discharge series, comparing the period 1986-2007 with 2011-2014

	1986-2007			2011-2014		
Month	**5 %ile**	**50 %ile**	**95 %ile**	**5 %ile**	**50 %ile**	**95 %ile**
Jan	3,565	2,612	1,980	4,256	3,089	2,847
Feb	2,792	2,150	1,650	3,501	2,799	2,410
Mar	2,456	1,880	1,490	3,725	2,663	2,288
Apr	2,514	1,900	1,381	3,646	2,719	2,144
May	6,569	2,510	1,720	5,855	3,757	2,751
Jun	15,810	7,183	2,682	13,940	7,997	4,285
Jul	30,809	15,291	7,542	25,344	15,124	8,572
Aug	38,607	26,097	14,740	40,258	25,862	18,351
Sept	38,501	25,164	15,329	40,225	22,276	16,640
Oct	24,648	14,180	7,631	31,544	12,936	6,921
Nov	12,203	6,762	4,080	12,076	6,881	3,947
Dec	5,776	3,746	2,571	6,700	4,269	3,358

There is seen to be a significant increase in low, median and high flows throughout the dry season in the more recent period. The pattern is not as clear in the wet season, due to the more variable nature of wet season flows and the short recent period investigated (see also Figure 5-2).

The clear and consistent pattern of increased dry season flows from 2011-2014 (and seen again in 2015), corroborates the MRC modelling, and signals a new hydrological paradigm for the Lower Mekong Basin.

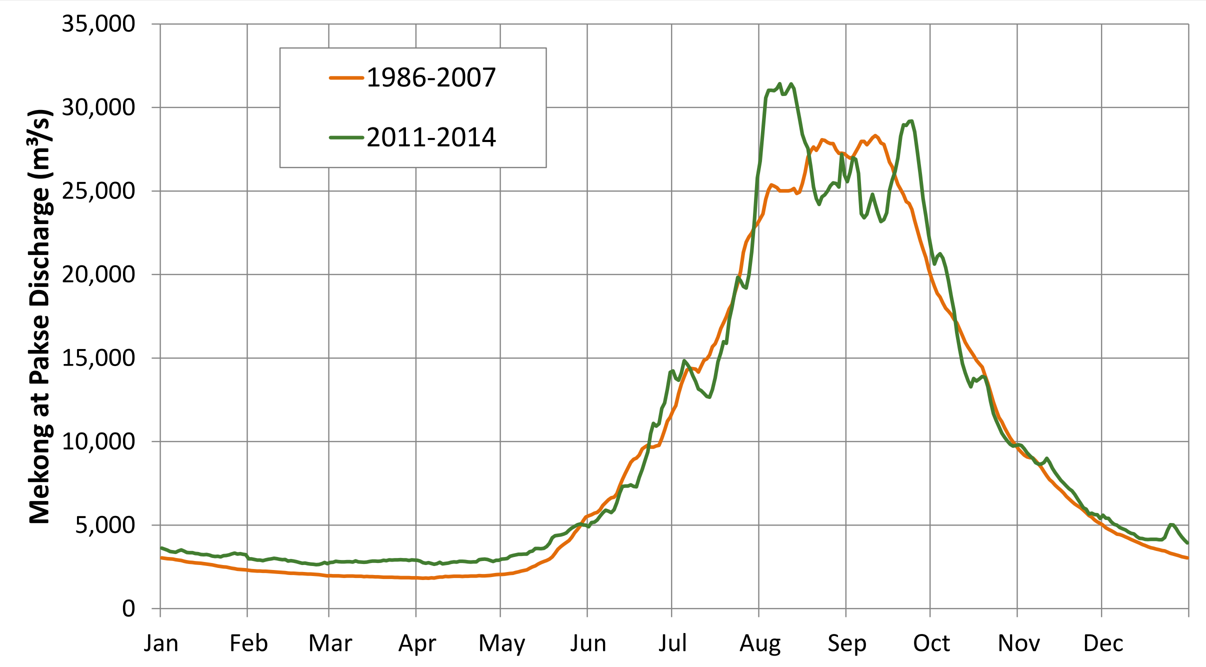


Figure 5-2: Average annual hydrograph of observed discharge for Mekong River at Pakse (1986-2007 and 2011-2014)

5.3. Interannual Variability in Dry Seasons

Flow rates in the dry season are an important indicator of limitations to fish passage at the Khone Falls, both the absolute minimum flow reached and the overall flow volume through the season. The scatter plot of Figure 5-3 presents the interannual variability of dry season flows, with the minimum daily discharge and the total flow volume through the dry season plotted. Three data series are represented; the observed dry season series from 1987 to 2000 and the modelled MRC Definite Future scenario series based on the same hydrological period, plus the observed data from the dry season series from 2011 to 2015.

Dry seasons are defined by the same flow thresholds used by MRC IBFM (MRC, 2009), namely:

- Beginning of dry season: the first day of the first 15-day period where the recession of the flow averages less than 1%. This is interpreted as an average daily flow reduction of less than 1% of the long-term mean annual discharge.
- End of the dry season: the first time the flow increases to twice the minimum discharge of the preceding dry season

In adopting these “bio-hydrological” definitions of the season, the dry season has a variable length dependant on hydrological triggers that migrating fish may experience. The dry season discharge volume therefor takes on a wider meaning than simply the average flow rate over certain months.

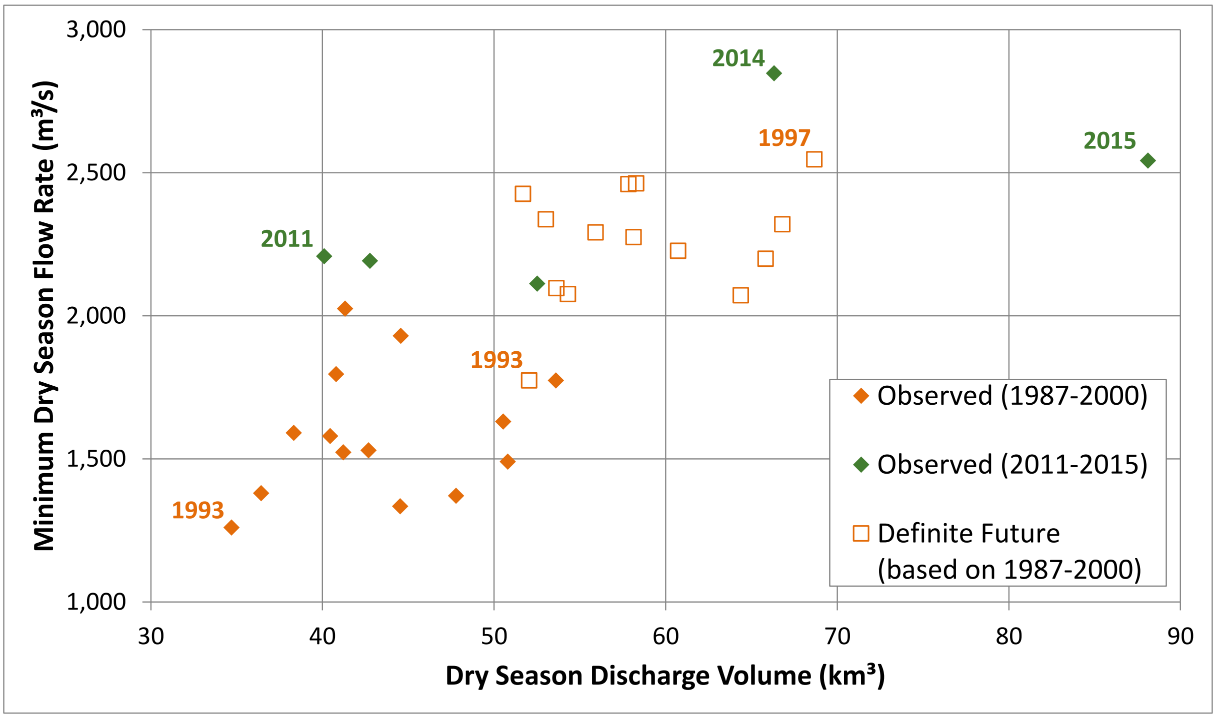


Figure 5-3: Scatter plot of dry season flow parameters for Mekong at Pakse

The plot shows interannual scatter, in both minimum flow rates and dry season flow volumes. It also clearly shows differences between the observed 1987 to 2000 dry season flows and the MRC Definite Future dry season flows, modelled based on the same underlying hydrology.

The recent historical data (2011 to 2015) shows significant scatter in dry season volumes, mainly caused by the variability in dry season duration which ranges from 160 days to 244 days over these five years. This variability may be natural or caused by storage regulation, either typical of future operations or not (e.g. related to initial filling of storage reservoirs). The longest (2015) and shortest (2011) dry seasons of this period are shown in Figure 5-4.

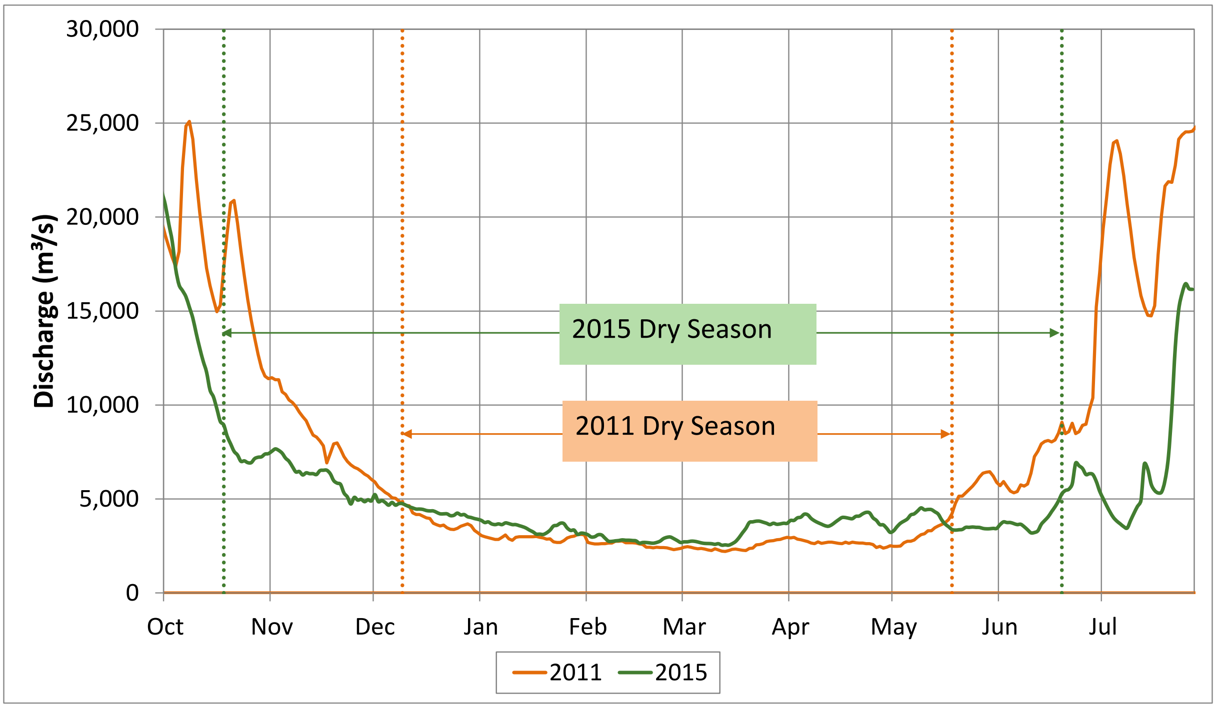


Figure 5-4: Comparison of 2011 and 2015 dry season length

It can be seen in Figure 5-3 that the minimum observed dry season flow rates in recent years is as great as (2015) or greater than (2014) the highest annual minima in the MRC Definite Future model. This suggests that the effects of upstream regulation in increasing dry season discharge may be greater than predicted by the MRC model, though this effect may be related to transitional operating patterns as the storage is being commissioned.

5.4. Changes at the Khone Falls

The increased Mekong dry season flow rates apparent in recent observations and in the projected Definite Future model means that since 2011 channels at the Khone Falls have experienced, and will continue to experience, higher dry season flows than they have historically.

In the sections below, the median monthly flows for key channels – Hou Sahong, Hou Xang Pheuak and Hou Sadam are tabulated for the historical period 1986-2000, the recent period 2011-2014, and for the MRC Definite Future projections based on 1986-2000 hydrological conditions.

Construction and operation of DSHPP will alter the flow split in the Khone Falls, principally diverting flow into the Hou Sahong headpond that would have continued down Hou Phapheng (SMEC, 2014). To mitigate the effects on flow in the Sadam channel and Hou Xang Pheuak respectively of reduced water levels in Hou Phapheng and the main channel above Hou Sahong that would result, excavation is proposed around the Hou Sadam and Hou Xang Pheuak inlets. Median monthly flow rates in these three key channels with DSHPP in operation under the MRC Definite Future river conditions are also tabulated in the sections below.

5.4.1. Hou Sahong

With the increased dry season flow rates in the Mekong, Hou Sahong will experience flow rates of around twice historical rates through March and April. Table 5.2 shows observed and modelled future median monthly flow rates in Hou Sahong based on the correlation with Pakse discharge given in Section 4.1.4.

Table 5.2: Median monthly flows (in m³/s) in Hou Sahong based on correlations to Mekong at Pakse discharge series, comparing the period 1986-2000 with 2011-2014 and Definite Future model results

Month	1986-2000	2011-2014		Definite Future	
Jan	119	154	+29%	177	+49%
Feb	78	132	+69%	138	+76%
Mar	57	122	+116%	108	+91%
Apr	53	126	+138%	111	+109%
May	106	202	+90%	160	+51%
Jun	435	476	+9%	434	-0%
Jul	826	820	-1%	743	-10%
Aug	1,237	1,265	+2%	1,058	-14%
Sept	1,165	1,123	-4%	1,129	-3%
Oct	751	721	-4%	762	+1%
Nov	390	413	+6%	430	+10%
Dec	201	238	+18%	253	+26%

The years exhibiting the driest and wettest dry seasons in the 24 complete years of Definite Future model results have been identified in Figure 5-3, and are based on the 1993 (driest) and 1997 (wettest) hydrology. Derived annual hydrographs for Hou Sahong for these years, and for the averaged historical period 1986-2000 are shown in Figure 5-5. It can be seen that even for the driest dry season in the Definite Future projections flows are greater than historical averages for most of the season.

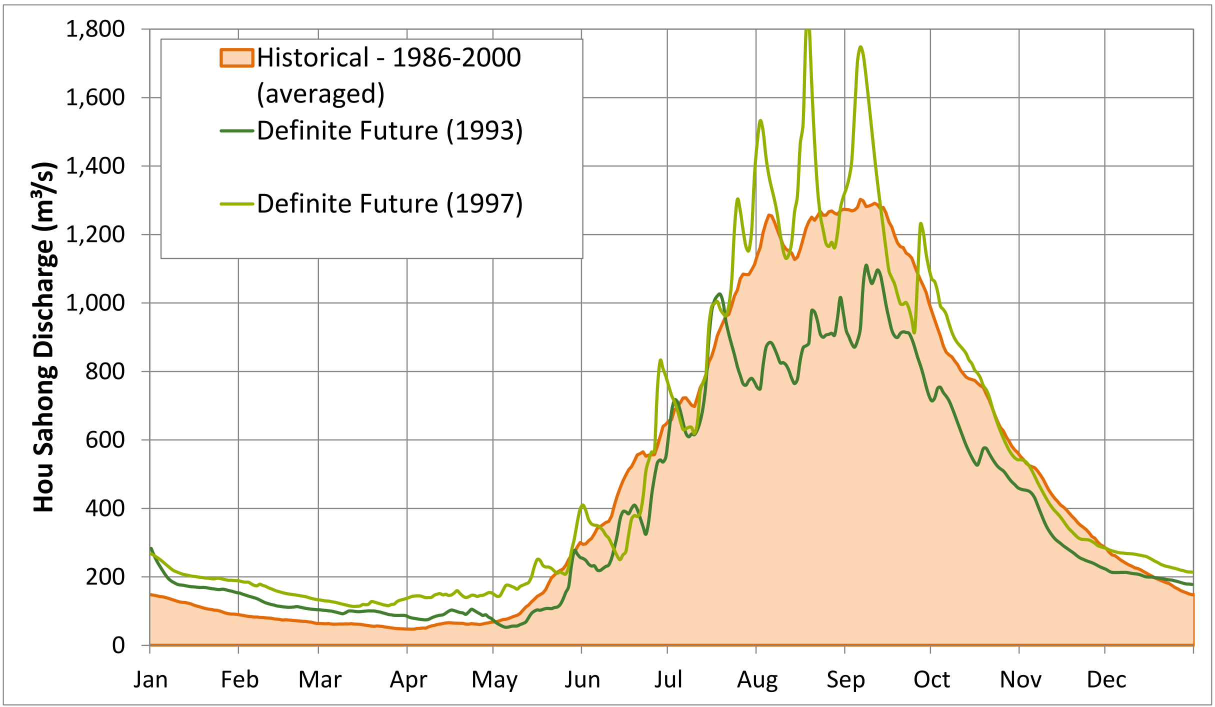


Figure 5-5: Annual hydrograph for Hou Sahong derived from Definite Future projections, compared with average historical hydrograph from 1986-2000

Flow duration curves for the Hou Sahong, derived from Pakse observations over the wider pre-hydropower period 1986-2007 and the recent period 2011-2014 are shown in Figure 5-6. Tabulated percentiles are presented in Appendix B.

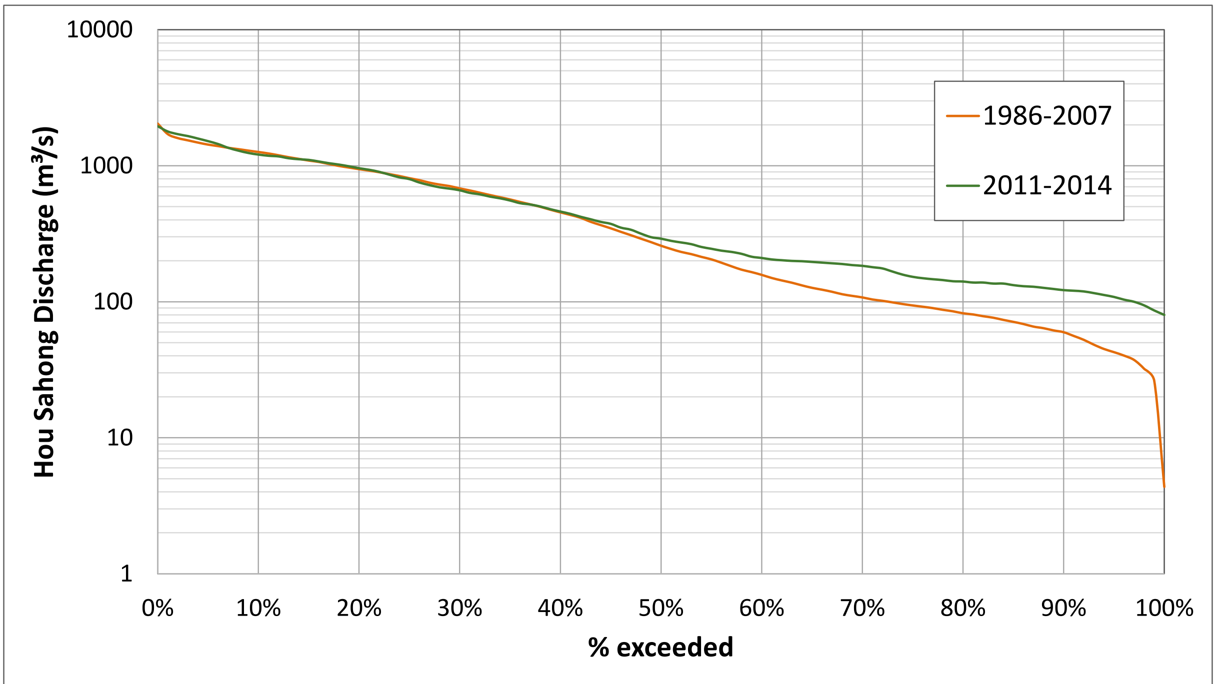


Figure 5-6: Flow duration curves for Hou Sahong derived from observed Pakse flows in the pre-hydropower period 1986-2007 and the recent period 2011-2014

The proposed DSHPP project involves excavation of the Hou Sahong inlet to allow greater flow rates into the channel, with the flow being controlled by turbines to ensure sufficient flow remains in other channels. Table 5.3 shows the projected median monthly flows in Hou Sahong with and without DSHPP, based on Definite Future river conditions and proposed station operation.

Table 5.3: Median monthly flows (in m³/s) in Hou Sahong with and without DSHPP, based on Definite Future projections

Month	Without DSHPP	With DSHPP
Jan	177	1,593
Feb	138	1,402
Mar	108	1,242
Apr	111	1,258
May	160	1,509
Jun	434	1,600
Jul	743	1,600
Aug	1,058	1,600
Sept	1,129	1,600
Oct	762	1,600
Nov	430	1,600
Dec	253	1,600

5.4.2. Hou Xang Pheuak

With increased Mekong dry season flows, the Hou Xang Pheuak channels will experience flow rates of around twice historical rates in February, up to around three times historical rates through March and April. Table 5.4 shows historical and projected median monthly flow rates in Hou Xang Pheuak based on the correlations with Pakse discharge given in Section 4.1.8 and 4.1.9.

Development of the proposed DSHPP will include targeted excavation in the Hou Xang Pheuak to maintain existing flow rates for given Mekong River conditions, even though locally the water surface levels at the inlet may be slightly reduced by diversion of flow into Hou Sahong headpond.

Table 5.4: Median monthly flows (in m³/s) in Hou Xang Pheuak based on correlations to Mekong at Pakse discharge series, comparing the period 1986-2000 with 2011-2014 and Definite Future model results

Month	1986-2000	2011-2014		Definite Future	
Jan	104	150	+44%	184	+76%
Feb	58	121	+108%	129	+120%
Mar	33	109	+226%	91	+173%
Apr	29	114	+289%	94	+223%
May	89	221	+149%	158	+78%
Jun	623	698	+12%	621	-0%
Jul	1,370	1,359	-1%	1,207	-12%
Aug	2,218	2,278	+3%	1,842	-17%

Sept	2,067	1,978	-4%	1,990	-4%
Oct	1,222	1,162	-5%	1,243	+2%
Nov	552	588	+6%	613	+11%
Dec	220	279	+27%	304	+38%

Derived annual hydrographs for Hou Xang Pheuak for the years exhibiting the driest and wettest dry seasons in the Definite Future model results, and for the averaged historical period 1986-2000 are shown in Figure 5-7.

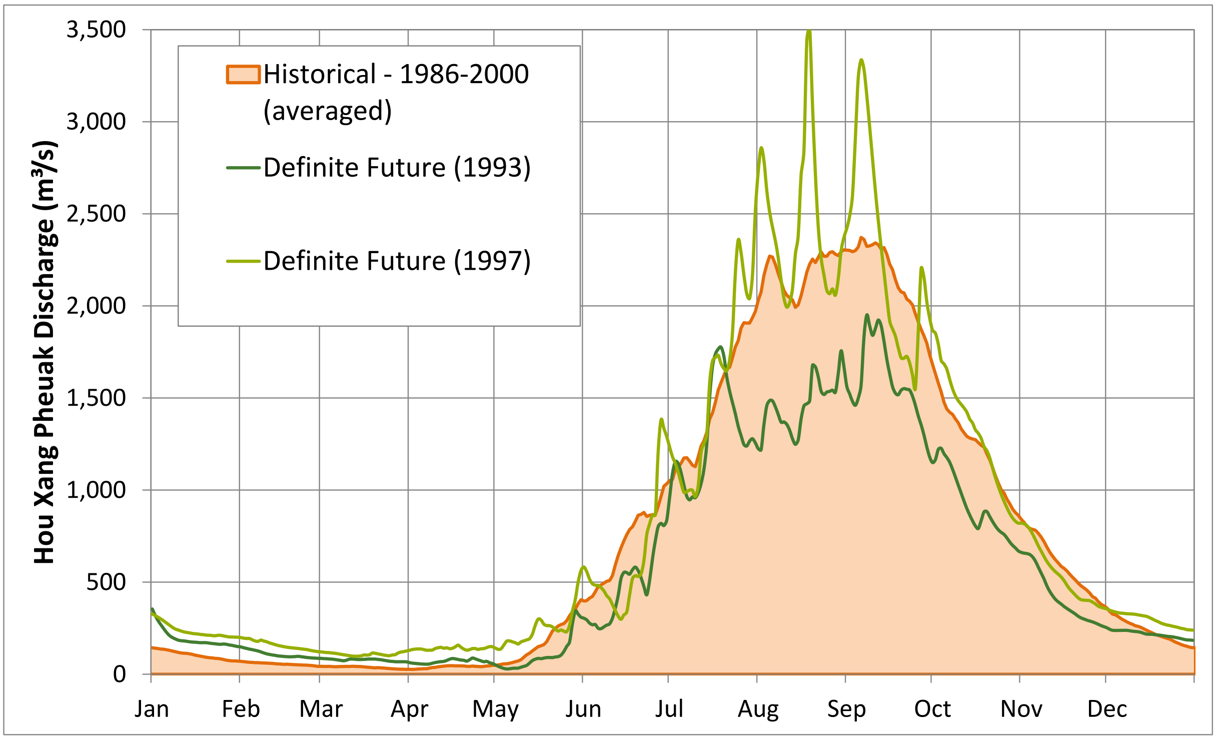


Figure 5-7: Annual hydrograph for Hou Xang Pheuak derived from Definite Future projections, compared with average historical hydrograph from 1986-2000

Flow duration curves for the Hou Xang Pheuak, derived from Pakse observations over the wider pre-hydropower period 1986-2007 and the recent period 2011-2014 are shown in Figure 5-8. Tabulated percentiles are presented in Appendix B.

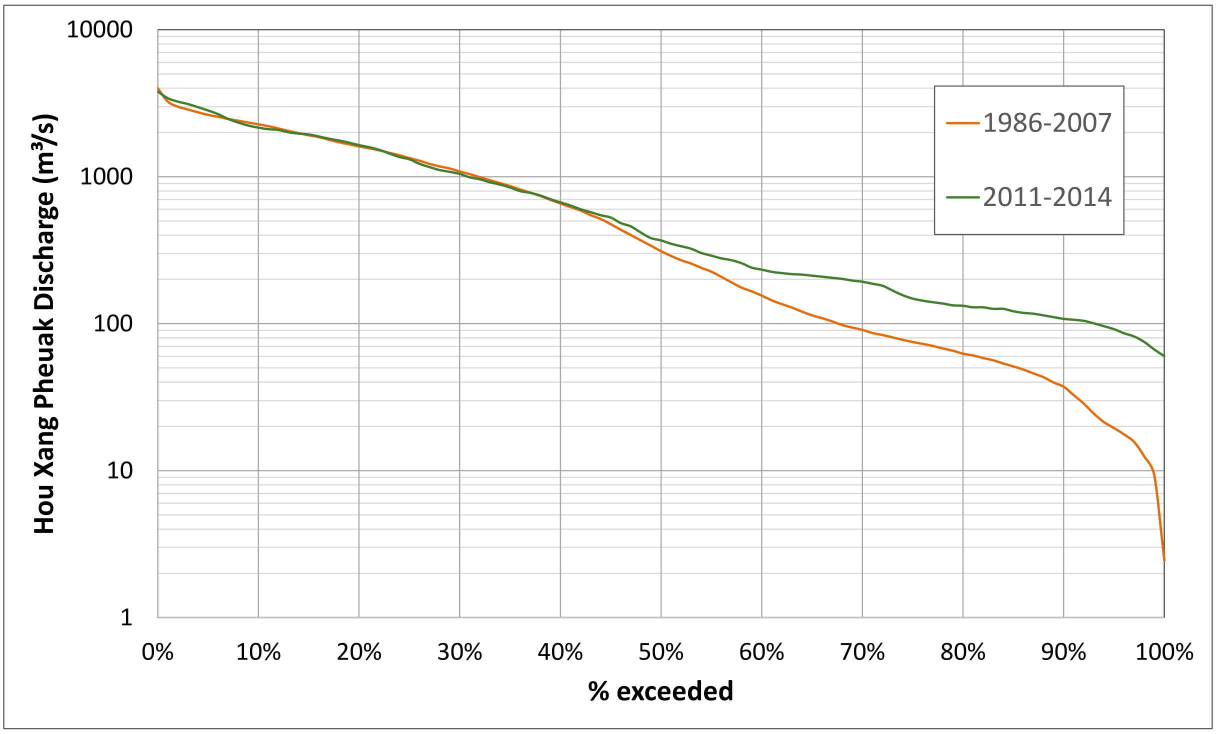


Figure 5-8: Flow duration curves for Hou Xang Pheuak derived from observed Pakse flows in the pre-hydropower period 1986-2007 and the recent period 2011-2014

5.4.3. Hou Sadam

Table 5.5 shows that Hou Sadam is experiencing, and will continue to experience dry season flows of around twice historical rates, based on the correlation with Pakse discharge given in Section 4.1.6.

The correlation is based on flow measurements within Hou Sadam taken in 2014 and 2015. In April 2013, clearing and excavation works were undertaken at the Hou Sadam inlet and within the Hou Sadam, to remove obstructions to fish passage and increase dry season flow rates. Applying the correlation of Section 4.1.6 based on current conditions will then likely overestimate pre-2013 flow rates. This said, the two 2007 dry season flow rates measured and reported by APW (see Section 3.3.1) are very close to the estimates from the current Pakse-Sadam correlation equation.

Table 5.5 Median monthly flows (in m^3/s) in Hou Sadam based on correlations to Mekong at Pakse discharge series, comparing the period 1986-2000 with 2011-2014 and Definite Future model results

Month	1986-2000	2011-2014		Definite Future	
Jan	10	13	+31%	15	+51%
Feb	6	11	+73%	12	+80%
Mar	5	10	+123%	9	+96%
Apr	4	11	+147%	9	+115%
May	9	17	+96%	13	+53%
Jun	38	43	+12%	38	0%
Jul	84	84	-1%	74	-12%
Aug	139	143	+3%	114	-18%
Sept	129	123	-4%	124	-4%

Oct	75	71	-5%	76	+2%
Nov	34	36	+6%	38	+11%
Dec	17	20	+19%	22	+27%

Derived annual hydrographs for Hou Sadam for the years exhibiting the driest and wettest dry seasons in the Definite Future projections, and for the averaged historical period 1986-2000 are shown in Figure 5-9.

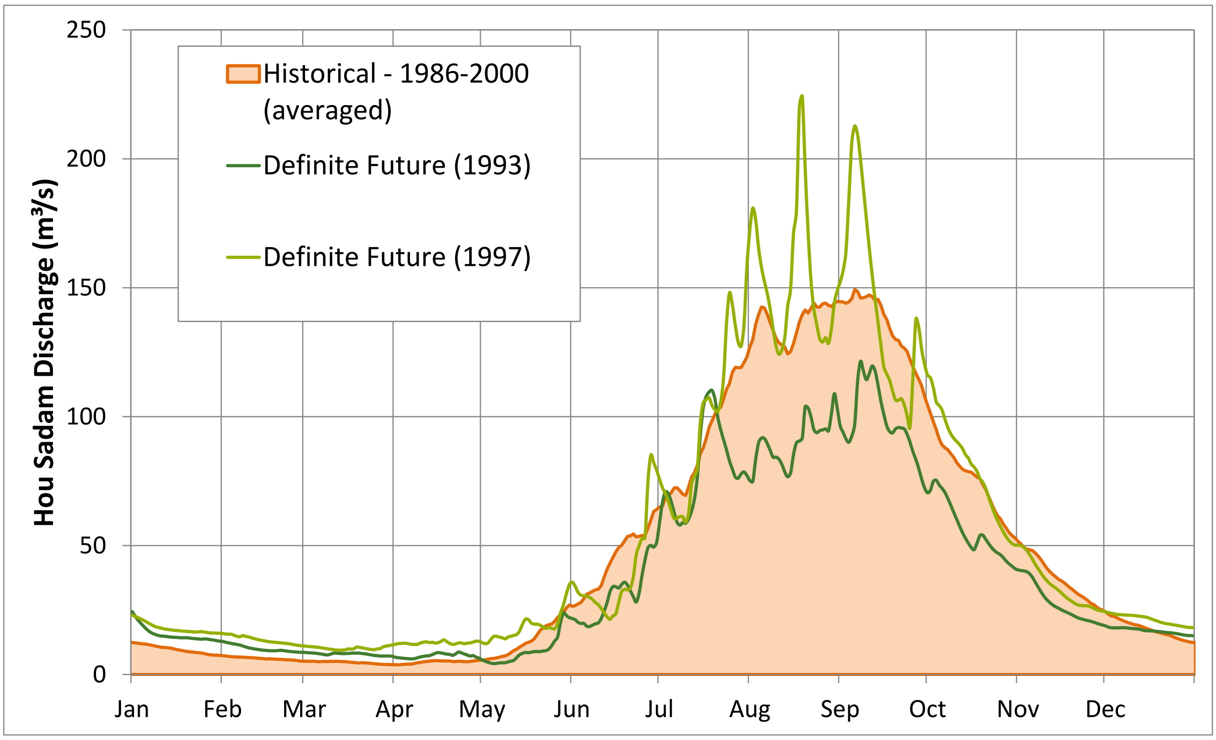


Figure 5-9: Annual hydrograph for Hou Sadam derived from Definite Future projections, compared with average historical hydrograph from 1986-2000

With the proposed DSHPP project in operation, water levels in the Hou Phapheng, which drive the flow rate in the Hou Sadam, will be held essentially constant throughout the dry season at a level significantly lower than existing levels. This will lead to an essentially constant dry season discharge through Hou Sadam, with the rate dependent on excavation of the Hou Sadam inlet. DSPC propose that the inlet be excavated to ensure a minimum discharge of 10 m^3/s. This excavation will lead to significantly increased wet season flows in Hou Sadam. Table 5.6 shows the projected median monthly flows in Hou Sadam with and without DSHPP, based on Definite Future river conditions and hydraulic modelling of proposed station operation.

Table 5.6: Median monthly flows (in m^3/s) in Hou Sadam with and without DSHPP, based on Definite Future projections

Month	Without DSHPP	With DSHPP
Jan	15	10
Feb	12	10
Mar	9	10

Apr	9	10
May	13	10
Jun	38	35
Jul	74	122
Aug	114	216
Sept	124	242
Oct	76	126
Nov	38	35
Dec	22	14

5.4.4. Hou Phapheng

Table 5.7, based on the correlation with Pakse discharge given in Section 4.1.7, shows that the median Hou Phapheng dry season flows have increased with increasing Pakse discharge, but the proportional increase is not as great as in other channels. This is due to morphology of the Khone Falls channels – where the deeper Hou Phapheng carries the majority of the Mekong discharge at low river conditions, and as discharge and water levels increase, proportionally more flow passes over the relatively shallow inlets to the other channels.

Table 5.7 Median monthly flows (in m³/s) in Hou Phapheng based on correlations to Mekong at Pakse discharge series, comparing the period 1986-2000 with 2011-2014 and Definite Future projections

Month	1986-2000	2011-2014		Definite Future	
Jan	1,984	2,124	+7%	2,211	+11%
Feb	1,763	2,040	+16%	2,063	+17%
Mar	1,617	1,998	+24%	1,935	+20%
Apr	1,593	2,016	+27%	1,948	+22%
May	1,927	2,296	+19%	2,146	+11%
Jun	2,927	3,033	+4%	2,923	-0%
Jul	3,792	3,781	-0%	3,631	-4%
Aug	4,488	4,531	+1%	4,203	-6%
Sept	4,377	4,309	-2%	4,319	-1%
Oct	3,646	3,584	-2%	3,668	+1%
Nov	2,821	2,875	+2%	2,912	+3%
Dec	2,294	2,412	+5%	2,459	+7%

Derived annual hydrographs for Hou Phapheng for the years exhibiting the driest and wettest dry seasons in the Definite Future projections, and for the averaged historical period 1986-2000 are shown in Figure 5-10.

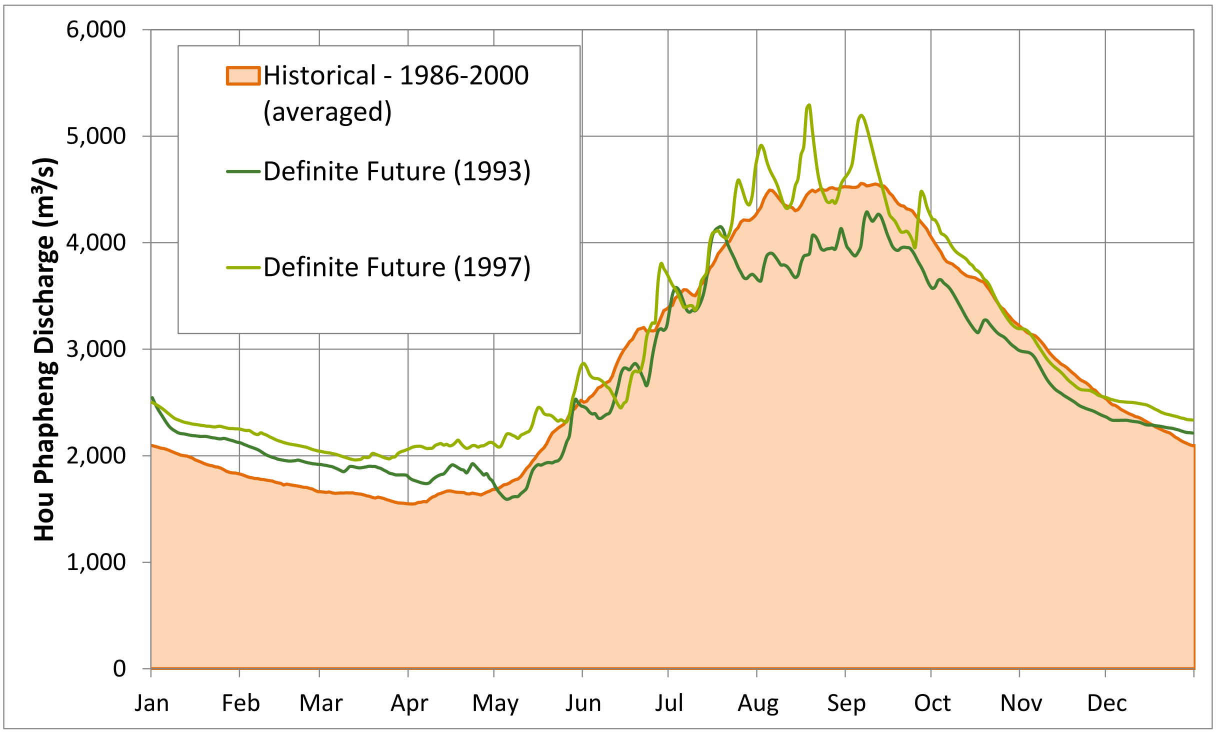


Figure 5-10: Annual hydrograph for Hou Phapheng derived from Definite Future projections, compared with average historical hydrograph from 1986-2000

Operation of the proposed DSHPP project involves diversion of up to 1,600 m^3/s into the Hou Sahong headpond, whilst maintaining at least a minimum of 800 m^3/s in Hou Phapheng. Table 5.8 shows the projected median monthly flows in Hou Phapheng with and without DSHPP, based on Definite Future river conditions and proposed station operation.

Table 5.8: Median monthly flows (in m^3/s) in Hou Phapheng with and without DSHPP, based on Definite Future projections

Month	Without DSHPP	With DSHPP
Jan	2,211	800
Feb	2,063	800
Mar	1,935	800
Apr	1,948	800
May	2,146	800
Jun	2,923	1,760
Jul	3,631	2,727
Aug	4,203	3,559
Sept	4,319	3,730
Oct	3,668	2,780
Nov	2,912	1,745
Dec	2,459	1,120

5.4.5. Proportional Flow Splits

The observed increase in dry season flows leads to a change in the proportional split of flow between the channels at the Khone Falls. The proportion of total Mekong flow in the eastern channels throughout the year, based on correlations to observed Pakse flows over the historical period 1986-2007 is shown in Figure 5-11. A similar plot based on correlations to observed Pakse flows over the more recent period 2011-2014 is shown in Figure 5-12.

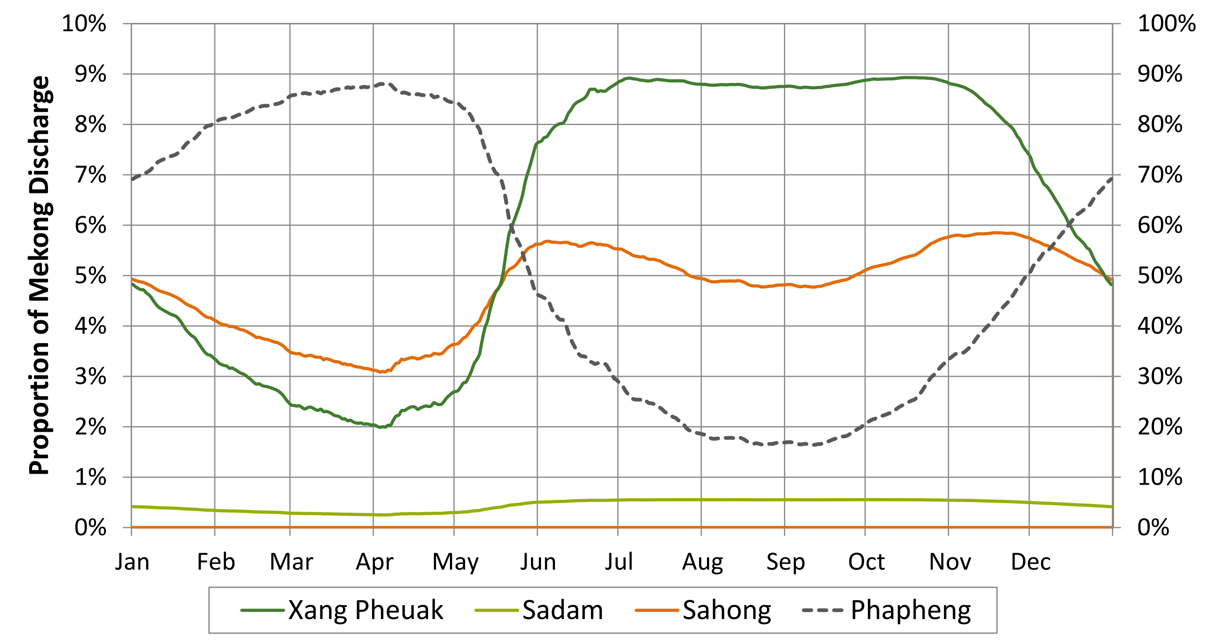


Figure 5-11: Seasonal change in proportions of Mekong flow in easternmost channels of the Khone Falls averaged over historical period 1986-2007. Note the 'main channel' Hou Phapheng is on the secondary scale (0-100%)

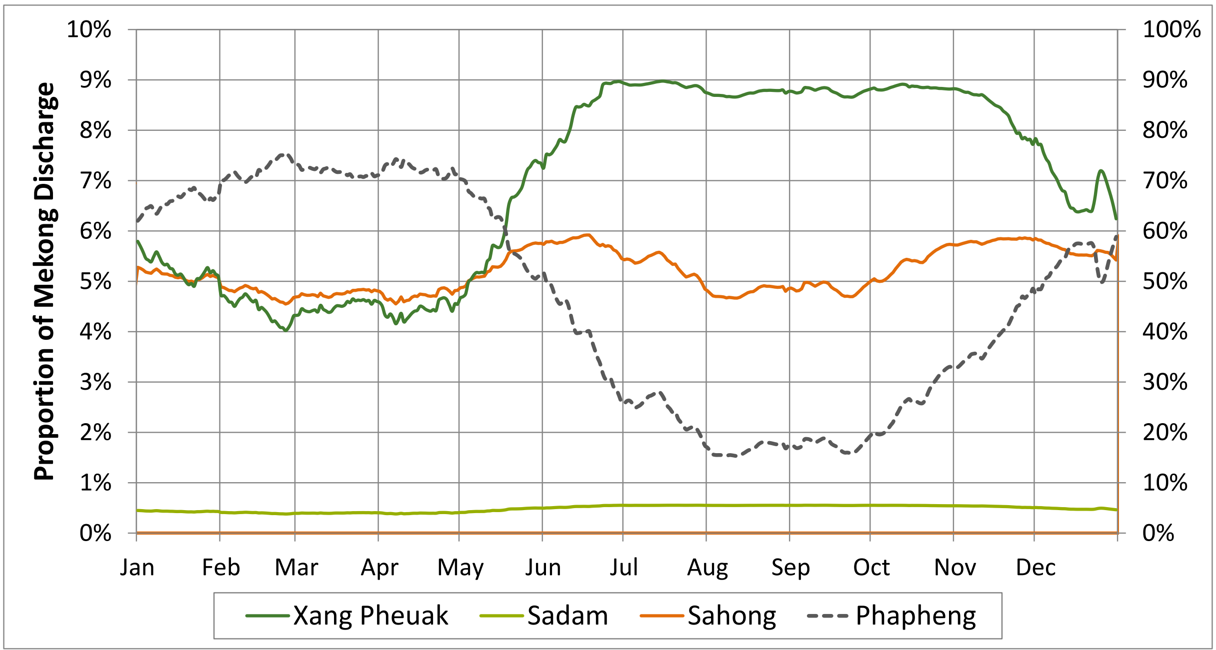


Figure 5-12: Seasonal change in proportions of Mekong flow in easternmost channels of the Khone Falls averaged over historical period 2011-2014. Note the 'main channel' Hou Phapheng is on the secondary scale (0-100%)

In the earlier pre-development period, the proportion of flow carried by Hou Sahong reduced to an average of 3% in the driest time of year, whilst the proportion carried by Hou Xang Pheuak reduced to an average of 2%. In the more recent period since 2011, the Hou Sahong and Hou Xang Pheuak carry a minimum of 4.5% and 4% of the Mekong flow respectively, of an increased total dry season flow.

The changing flow rates in these two channels between these two observed periods is shown in more detail in the flow duration curves of Figures 18.00 and 19.00. These two channels are known to be important for fish migration, given that the Phapheng Falls, carrying a majority of the dry season flow, poses a barrier to upstream passage. The significantly increased dry season flows in Hou Sahong and Hou Xang Pheuak will have important implications for the passability of the channels during the dry season.

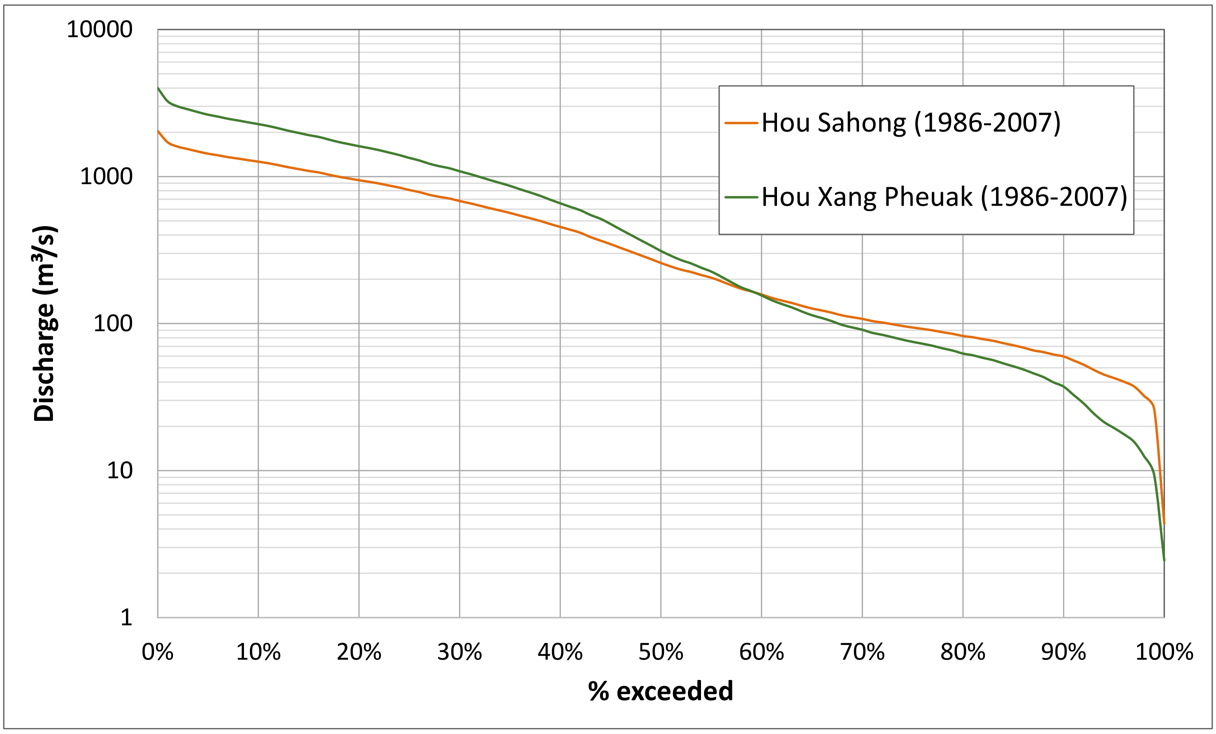


Figure 5-13: Flow duration curves for Hou Sahong and Hou Xang Pheuak derived from observed Pakse flows in the pre-hydropower period 1986-2007

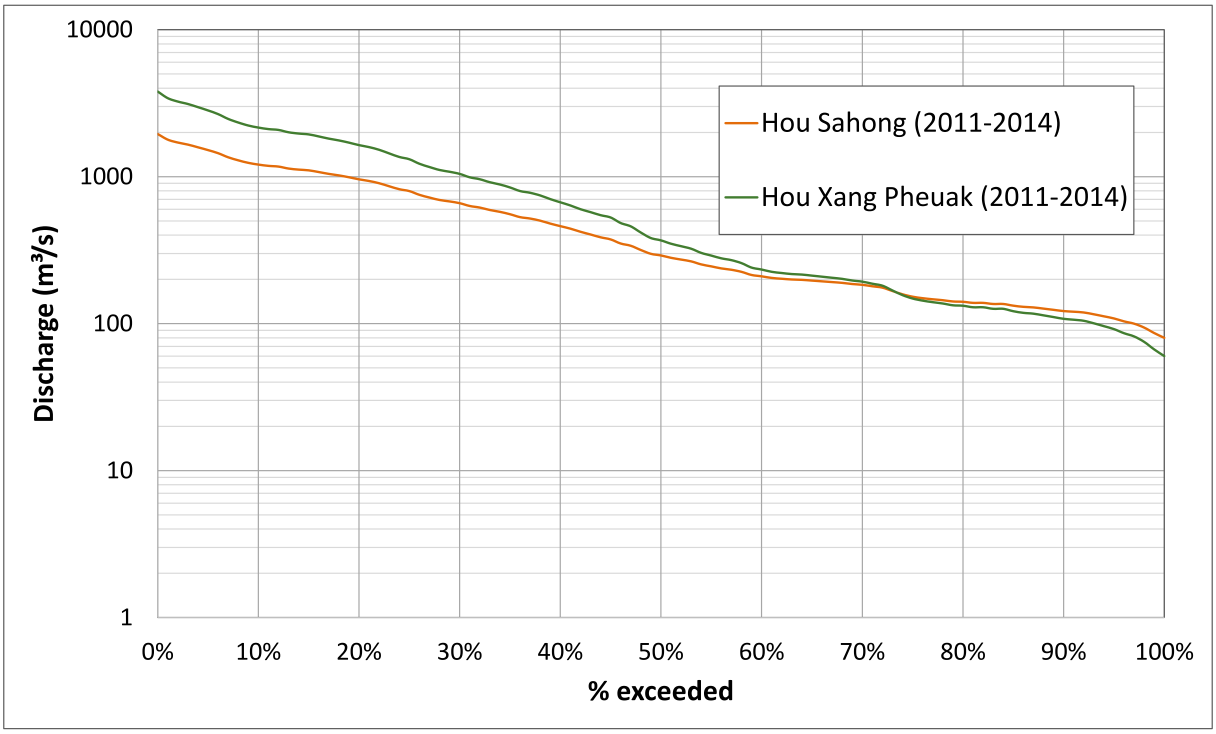


Figure 5-14: Flow duration curves for Hou Sahong and Hou Xang Pheuak derived from observed Pakse flows in the recent period 2011-2014

5.5. Changes During DSHPP Construction

During construction of the DSHPP scheme the Hou Sahong will be isolated by cofferdams, and flows that would have entered Hou Sahong will be diverted elsewhere. Computational hydraulic modelling (SMEC, 2014) shows that the majority of the flow that would have entered Hou Sahong will continue past the inlet and discharge through the Hou Phapheng and Hou Sadam channels. At higher flow conditions, the increased discharge past the Hou Sahong inlet will mean raised water levels, with the 'backwater' effect diverting some of this flow into the Hou Xang Pheuak inlet, upstream of the Hou Sahong inlet.

The Hou Sahong cofferdams were placed in January 2016. Comparison of observed water levels at staff gauges around the project site before and after cofferdam placement are shown below. The locations of the staff gauges are shown in Figure 3-15.

At GB01 (Ban Hua Sadam) on the main channel immediately downstream of the Hou Sahong inlet cofferdam, water levels during the 2016 dry season were similar to those for previous years (for the same Pakse flow condition). At higher flow conditions, water levels are increased over those of previous years, due to the increased discharge in the Hou Phapheng channel. The same pattern is seen at AR02 (Ban Thakho), although the rise in water level is of lower magnitude due to the increased width of the channel in this location. Similarly, increased water levels are observed in the Hou Sadam at GB04.

At AR03, in the channel downstream of DSHPP, water levels during the 2016 dry season were again seen to be similar to those for previous years (for the same Pakse flow condition). At higher flow conditions, water levels are slightly reduced over those of previous years, due to the decreased discharge in this channel.

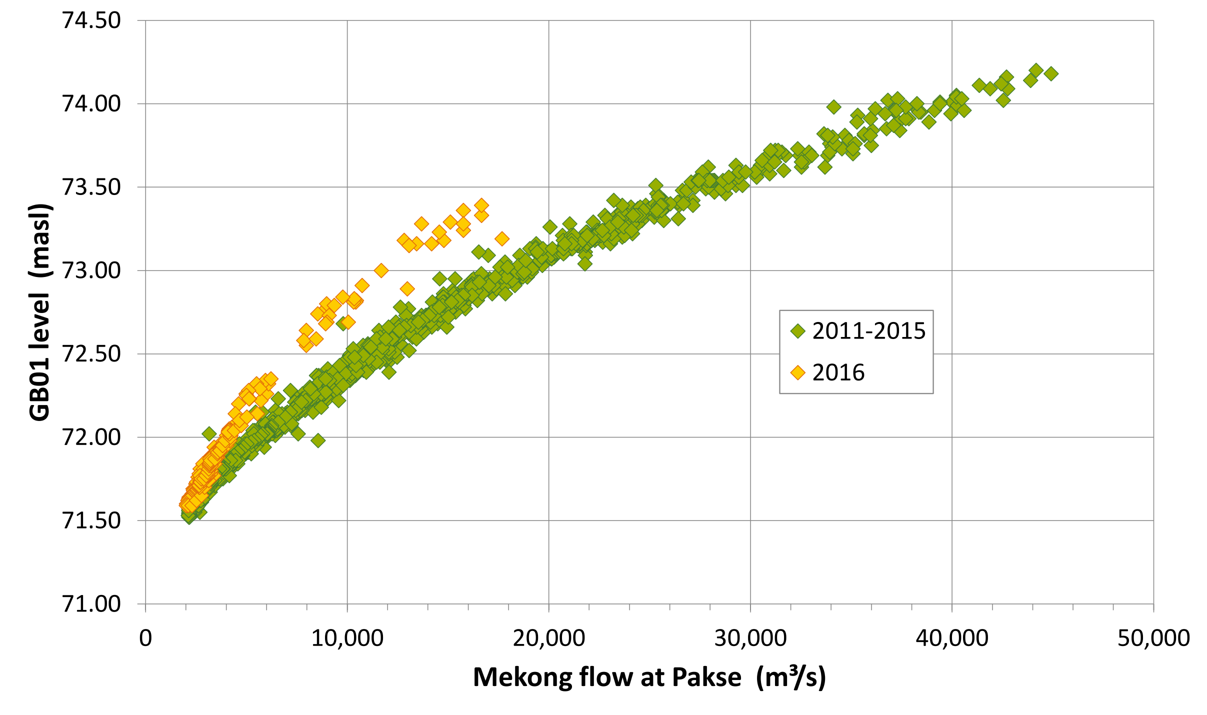


Figure 5-15: Observed Water Levels at GB01 (Ban Hua Sadam), before and after cofferdam closure

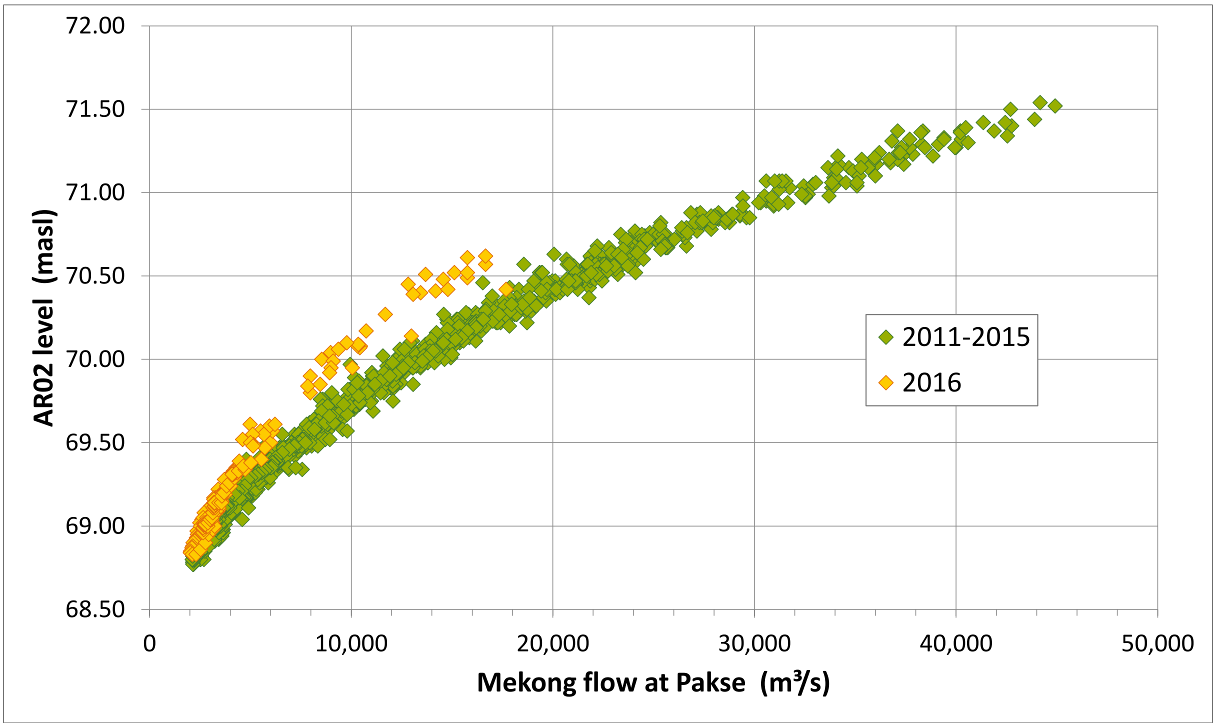


Figure 5-16: Observed Water Levels at AR02 (Ban Thakho), before and after cofferdam closure

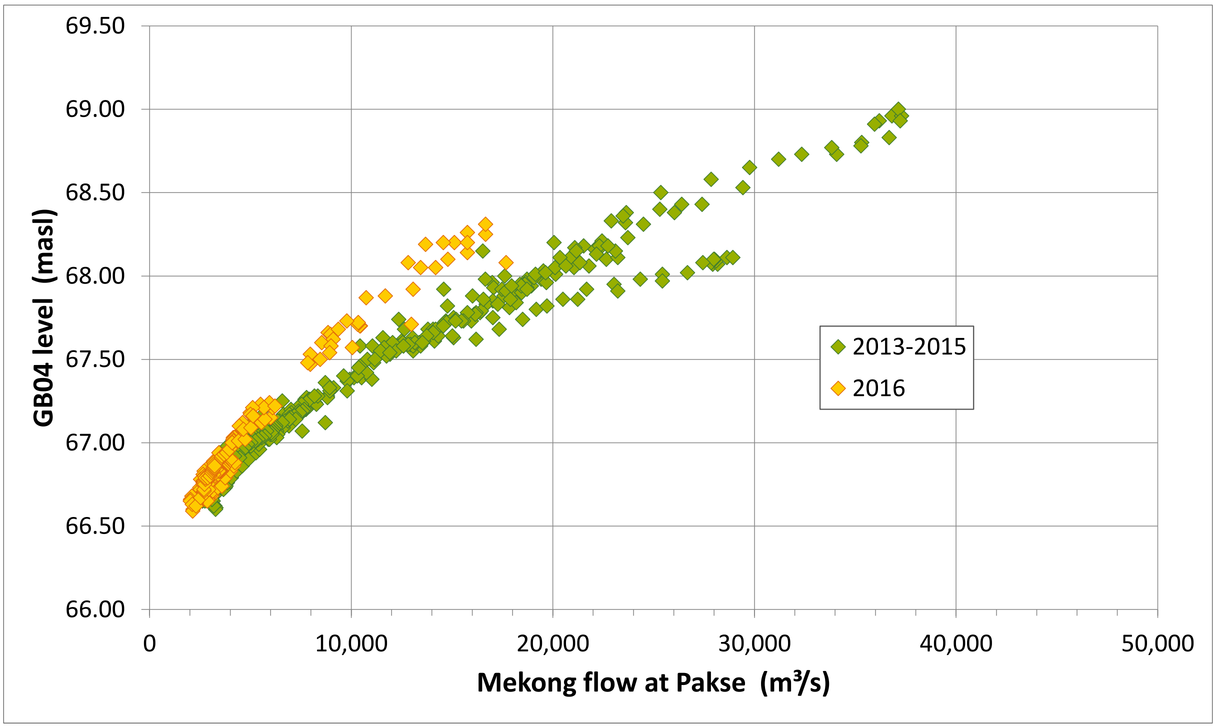


Figure 5-17: Observed Water Levels at GB04 (Hou Sadam), before and after cofferdam closure

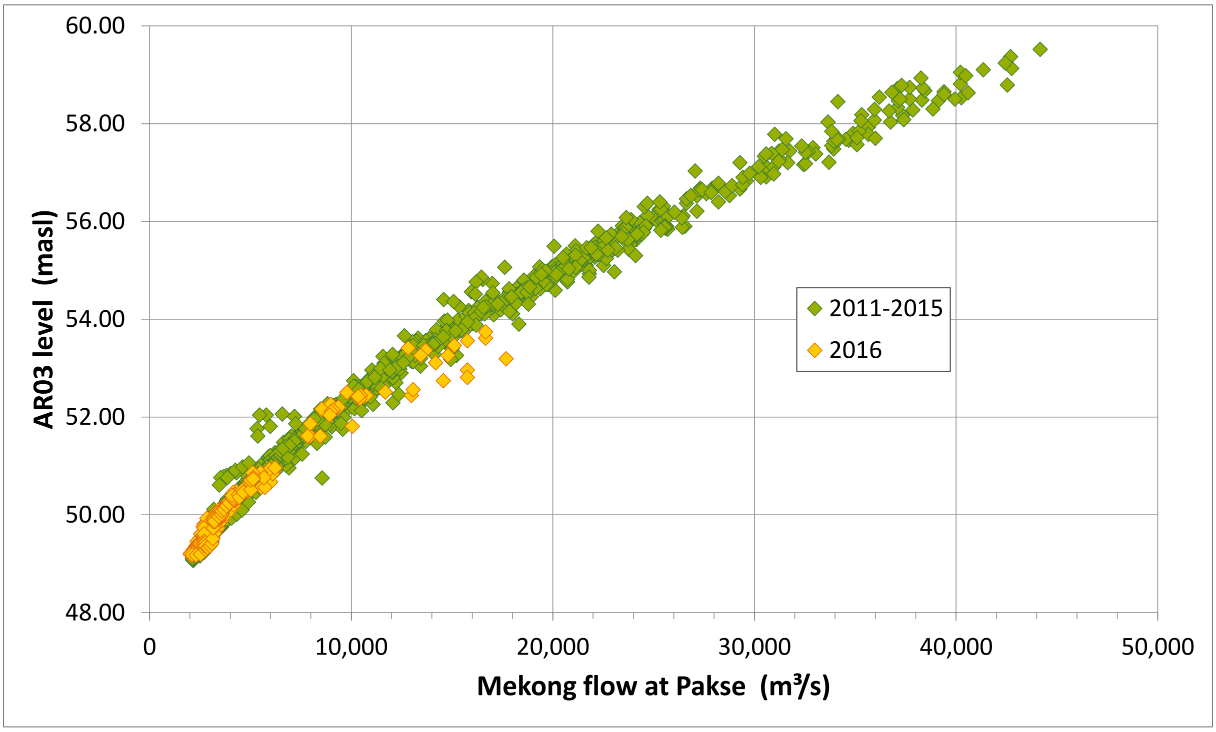


Figure 5-18: Observed Water Levels at AR03 (downstream of DSHPP), before and after cofferdam closure

6. CONCLUSIONS

A long-term daily flow record exists for the Mekong River at Pakse, some 160 km upstream of the Khone Falls, but including 98.5% of the catchment area. This provides a good indication of patterns and variability of flow rates on the river, applicable to the study of surface-water hydrology in the Khone Falls area.

The Mekong stage has been observed daily at Pakse since 1924. Over the years of record there is evidence of different rating curves being used to derive flow estimates, but they are similar and without any trend in rating changes. In addition to the lengthy and robust historical record, the Mekong River Commission (MRC) has commissioned studies on likely future hydrology in the Mekong Basin, considering climate change and future basin development, with modelled resultant flows at Pakse available.

A campaign of flow gauging on multiple channels at the Khone Falls site has been ongoing since 2007, with discharge measured across the range of flow conditions. In addition, staff gauges have been installed in channels of key interest for the DSHPP project, with daily observations ongoing.

The discharge measurements have been compared with concurrent records of Mekong at Pakse discharge, with equations developed herein to describe the correlation between Pakse flow and flow in each of nine channels studied in the Khone Falls. Rating curves have been developed for flow at the staff gauges in Hou Sahong, Hou Sadam, Hou Phapheng and Hou Xang Pheuak, which with ongoing observation will provide more accurate flow estimates than correlation with the Pakse gauge.

Establishment of the correlations with the Pakse record allow investigation of seasonal flow patterns across the Khone Falls. In the dry season, the majority of flow is in Hou Phapheng, with the remainder split between the 'Eastern Channels', principally Hou Sahong, Hou Xang Pheuak and Hou Somphamit, and the 'Western Channels' to the west of Don Det. As the river rises through the transition season and into the wet season, flow in the Hou Phapheng rises relatively modestly; the proportion of flow in the other Eastern Channels increases to around 20% of the total Mekong flow, and flow rates rise in synchrony with the Mekong flow rate; and the proportion of flow in the Western Channels rises significantly, to make up some 70% of the total.

Changes in Mekong flow rates at Pakse have been forecast by MRC models, based on the planned construction and operation of storage reservoirs within the catchment, and other expected development. The MRC 'Definite Future' scenario, modelling the expected level of development in 2015, showed an increased dry season flow of some 30% at Pakse. Recent observations (2011-2014) corroborate these findings, with median monthly flows for November-April increased by 28% over the 1986-2000 period. This equates to increases across the dry season of some 60% for Hou Sahong, 110% for Hou Xang Pheuak, 65% for Hou Sadam and 15% for Hou Phapheng.

The proposed Don Sahong Hydropower Project (DSHPP) will change the flow distribution at the Khone Falls, essentially diverting flow from the Hou Phapheng into Hou Sahong, which will be controlled by turbines at a powerhouse barrage across the Hou Sahong. Of the three flow series considered in this report, the MRC Definite Future scenario is the most suitable flow series for predicting flows in the Khone Falls channels during the operation of the proposed DSHPP.

7. REFERENCES

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APPENDIX A MONTHLY DISCHARGE STATISTICS FOR MEKONG AT PAKSE DISCHARGE SERIES

Table A. 1 Mekong at Pakse, Mean Monthly Discharge (m³/s), 1924-2016

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1924	3,489	2,464	2,059	1,720	2,127	7,855	19,408	41,088	27,246	14,316	9,956	4,703	11,414
1925	2,829	2,136	1,773	1,747	2,446	7,515	19,811	23,370	32,271	13,713	6,392	3,863	9,862
1926	2,690	2,222	1,788	1,693	1,591	4,838	13,879	30,461	24,607	19,380	9,993	5,671	9,960
1927	3,417	2,273	1,997	1,991	3,009	10,507	18,065	32,134	21,303	22,625	9,307	4,940	11,037
1928	3,026	2,206	1,972	2,141	3,354	11,487	21,669	25,190	23,656	14,570	6,725	3,743	10,010
1929	2,515	1,902	1,634	1,657	2,296	8,189	21,404	35,844	33,849	19,556	7,300	4,447	11,785
1930	2,882	2,099	1,783	1,870	3,265	8,359	19,233	29,275	25,478	19,961	7,606	4,450	10,588
1931	2,866	2,015	1,686	1,754	2,224	4,245	9,236	22,209	24,566	16,627	5,888	3,175	8,079
1932	2,206	1,677	1,477	1,496	1,817	5,159	16,196	20,520	25,352	20,629	8,991	4,846	9,227
1933	2,353	1,512	1,163	1,098	1,313	4,566	14,609	26,261	21,302	15,233	8,868	3,872	8,565
1934	2,400	1,876	1,523	1,263	1,894	3,787	16,092	29,303	31,303	21,476	9,005	4,514	10,429
1935	2,807	1,910	1,547	1,381	2,182	7,803	16,949	26,794	23,981	22,233	15,366	6,262	10,826
1936	2,987	2,295	1,836	1,815	2,698	8,502	20,303	25,506	28,178	10,937	4,721	3,101	9,430
1937	2,283	1,660	1,530	1,248	2,930	8,724	21,764	36,278	39,976	18,261	8,290	5,253	12,414
1938	3,431	2,573	2,143	2,492	3,861	13,131	21,088	27,956	27,000	21,962	9,414	5,135	11,742
1939	3,305	2,604	2,267	2,281	3,808	12,705	19,413	32,948	30,456	18,271	7,581	4,820	11,763
1940	2,991	2,225	1,940	1,798	2,654	8,849	18,269	27,481	30,532	11,592	5,633	3,677	9,824
1941	2,916	2,363	1,970	1,754	2,594	10,795	17,394	28,984	28,131	21,130	11,222	5,073	11,247
1942	3,023	2,279	1,935	1,905	3,713	10,742	24,023	32,746	25,972	15,726	8,254	4,042	11,264
1943	2,950	2,195	2,041	2,353	2,565	10,863	18,945	26,966	31,093	18,609	6,902	3,991	10,838
1944	2,972	2,334	1,847	1,609	2,911	7,372	16,039	28,362	22,045	16,439	10,454	5,413	9,851
1945	3,369	2,440	2,037	1,918	3,632	11,723	20,626	25,096	32,268	14,589	7,645	4,803	10,887
1946	3,195	2,186	1,766	1,649	3,450	11,079	17,347	27,393	35,583	20,168	9,505	4,922	11,565
1947	3,267	2,536	1,877	1,776	4,574	8,565	24,362	28,728	33,094	17,328	7,440	4,122	11,532
1948	2,925	2,278	1,830	1,842	3,788	8,861	17,745	29,554	36,438	19,731	10,260	5,283	11,734
1949	3,154	2,546	1,954	2,072	3,471	5,370	12,977	28,646	34,103	23,536	10,773	4,907	11,175
1950	3,109	2,452	1,860	1,606	2,328	8,668	20,213	29,015	26,646	23,587	13,754	5,868	11,655
1951	3,241	2,514	1,710	1,591	2,706	13,134	19,088	30,703	28,406	18,055	10,416	5,107	11,440
1952	2,660	1,707	1,544	1,470	2,314	6,039	16,903	31,763	35,198	21,030	10,339	3,591	11,243
1953	1,756	1,616	1,377	1,370	4,316	11,618	16,958	23,324	24,465	14,123	8,779	4,316	9,544
1954	2,405	1,594	1,276	1,435	2,675	7,658	9,529	19,048	30,981	19,881	8,914	4,027	9,146
1955	2,426	1,805	1,464	1,787	2,150	6,278	15,866	20,701	22,614	11,687	7,703	4,426	8,280
1956	2,557	1,924	1,435	1,342	3,868	10,491	15,661	33,342	31,717	13,451	6,851	3,602	10,544
1957	2,544	1,998	1,612	1,661	2,134	7,762	19,077	18,445	23,573	17,687	7,819	3,160	9,000
1958	2,116	1,786	1,480	1,256	1,627	6,714	14,158	19,652	29,877	13,848	6,753	3,581	8,598
1959	2,003	1,648	1,513	1,446	1,888	5,139	10,391	21,632	30,783	17,929	8,985	3,947	8,973
1960	2,504	1,906	1,505	1,107	1,313	5,004	10,198	30,058	28,203	18,758	7,821	3,835	9,379
1961	2,371	1,850	1,559	1,704	2,607	13,344	17,448	25,845	38,530	27,423	8,908	4,073	12,185
1962	2,908	2,203	1,772	1,549	2,836	10,867	18,239	26,819	25,027	17,442	7,376	3,157	10,067
1963	2,220	1,743	1,418	1,285	1,476	9,065	18,499	31,977	25,310	14,108	11,007	5,150	10,326
1964	2,841	2,154	1,813	1,795	3,287	8,776	17,090	20,861	29,140	22,477	9,748	4,924	10,433
1965	2,950	2,325	1,899	1,710	2,137	15,514	19,790	21,839	21,387	11,309	10,152	4,685	9,674
1966	4,350	3,098	2,038	1,652	4,142	9,873	19,275	30,807	40,031	15,616	7,727	4,671	11,981
1967	3,383	2,567	2,096	1,704	2,505	6,789	10,388	18,365	24,190	17,266	5,835	4,046	8,293
1968	2,565	2,103	1,746	1,557	3,284	6,081	11,634	19,955	26,040	12,185	7,068	3,560	8,159
1969	2,370	1,841	1,488	1,362	1,646	10,062	21,200	28,658	19,680	10,433	6,339	3,198	9,078
1970	2,190	1,723	1,393	1,568	3,035	9,821	22,661	32,635	32,153	14,195	6,522	4,973	11,134
1971	3,138	2,217	1,781	1,600	2,082	8,827	27,645	30,965	26,870	14,345	7,186	4,010	10,957
1972	2,956	2,330	1,870	1,988	2,197	6,875	14,230	34,271	21,223	14,113	8,238	5,864	9,721
1973	3,245	2,288	1,922	1,751	2,879	7,099	15,861	22,055	32,207	15,864	7,570	4,832	9,834
1974	2,950	2,318	1,831	2,105	2,936	8,978	11,249	29,071	28,173	12,621	7,193	4,060	9,492
1975	2,977	2,333	1,777	1,696	2,627	10,464	16,439	27,526	31,023	17,568	9,221	4,051	10,683
1976	2,731	2,370	1,994	2,042	3,280	7,221	12,867	27,690	18,057	16,542	10,122	4,658	9,166
1977	2,645	1,946	1,978	2,196	2,420	3,210	10,427	17,016	23,733	11,683	6,800	3,673	7,336
1978	3,135	2,250	1,901	1,795	3,122	10,600	20,203	42,477	32,340	22,984	7,971	3,919	12,806
1979	2,911	2,385	1,990	1,945	4,066	11,449	17,332	25,330	23,493	13,726	5,365	3,456	9,500

1980	2,479	1,950	1,741	1,745	2,648	7,693	16,042	23,342	34,647	18,026	9,459	4,431	10,363
1981	3,030	2,426	2,145	2,125	3,883	17,551	27,171	32,523	23,507	15,558	8,677	5,489	12,075
1982	3,561	2,765	2,201	2,319	2,645	6,111	12,286	23,284	26,027	21,110	8,125	4,370	9,611
1983	3,020	2,341	2,208	2,071	2,395	5,391	9,611	19,874	23,633	17,219	11,023	5,518	8,724
1984	3,519	2,462	1,877	1,674	3,305	8,158	19,548	32,023	26,960	14,719	8,183	4,082	10,579
1985	2,908	2,245	2,008	1,828	2,666	11,753	15,861	27,445	26,873	13,999	7,964	5,298	10,113
1986	3,023	2,358	1,937	1,747	4,752	11,619	16,037	23,426	21,140	11,206	6,729	3,763	9,018
1987	2,521	2,135	1,859	1,685	1,918	4,414	10,806	21,029	22,263	13,416	6,394	4,046	7,742
1988	2,645	1,890	1,665	1,607	3,444	7,513	9,557	22,813	16,327	12,045	5,722	3,142	7,389
1989	2,061	1,667	1,482	1,513	2,642	8,690	12,358	23,158	19,307	15,971	7,562	3,684	8,386
1990	2,680	2,294	2,425	2,091	2,898	13,719	19,984	24,058	24,637	16,419	8,239	4,211	10,350
1991	2,802	2,039	1,748	1,827	2,159	5,821	16,916	30,206	27,700	16,565	8,809	4,091	10,112
1992	2,887	2,236	1,917	1,762	2,014	5,262	12,002	20,006	17,513	10,544	5,961	3,119	7,123
1993	2,324	1,731	1,575	1,449	2,451	5,822	17,959	21,619	21,793	9,996	5,783	3,147	8,014
1994	2,265	2,046	1,648	2,006	2,441	12,853	23,243	29,991	28,239	14,985	5,472	3,985	10,821
1995	2,819	2,089	1,868	1,651	2,586	7,004	16,014	28,826	29,962	15,751	7,708	4,267	10,094
1996	2,813	2,218	2,041	2,154	3,583	5,730	12,887	27,095	30,453	19,705	10,927	5,459	10,446
1997	2,898	2,282	1,919	2,402	2,677	3,397	20,953	32,941	26,737	14,856	5,541	3,312	10,062
1998	2,556	1,975	1,707	1,881	2,636	4,811	15,019	16,151	20,111	7,400	4,510	2,921	6,835
1999	1,982	1,734	1,502	1,778	4,907	12,556	15,425	23,823	26,175	15,073	10,416	4,646	10,039
2000	2,880	2,399	2,349	2,427	7,202	15,348	28,706	27,451	36,393	15,178	7,561	4,099	12,692
2001	2,784	2,333	2,347	2,224	3,296	12,401	23,647	34,333	32,495	15,278	10,914	4,881	12,301
2002	3,396	2,683	2,232	2,045	3,943	12,540	27,543	34,653	31,565	16,346	8,194	5,145	12,593
2003	3,884	2,863	2,422	2,396	2,643	6,538	11,537	19,896	27,397	11,395	4,458	2,705	8,199
2004	2,191	2,000	1,640	1,840	3,175	8,797	15,060	28,823	32,697	12,324	5,032	3,388	9,764
2005	2,510	2,117	1,984	2,295	2,461	5,920	18,232	34,674	30,623	17,499	7,066	3,996	10,845
2006	2,646	2,219	1,984	1,859	2,776	5,312	17,197	27,915	19,477	21,012	7,321	3,246	9,483
2007	2,289	1,922	1,719	1,654	2,927	4,850	9,991	21,993	23,785	23,748	9,437	3,818	9,059
2008	2,367	2,164	1,809	2,068	4,260	13,993	21,006	31,281	25,087	16,408	11,390	5,407	11,469
2009	2,925	2,201	1,794	2,109	3,457	8,340	19,033	23,283	18,020	14,797	5,492	2,816	8,761
2010	2,085	1,764	1,252	1,868	2,416	3,844	8,118	20,830	24,990	17,815	8,420	4,209	8,169
2011	2,935	2,554	2,467	2,661	4,254	8,106	21,053	36,963	36,174	24,094	10,154	4,414	13,057
2012	3,375	2,821	2,575	2,633	3,661	9,599	12,615	22,515	19,595	8,499	4,934	3,537	8,046
2013	2,919	2,760	2,712	2,400	3,993	6,388	13,546	26,229	26,665	15,229	9,445	5,920	9,894
2014	4,007	3,231	3,642	3,533	3,747	8,182	17,714	26,522	20,227	11,285	6,137	4,434	9,437
2015	3,482	2,811	3,112	3,896	3,719	4,685	9,025	21,208	19,594	11,891	4,964	3,295	7,673
2016	2,876	2,929	2,792	3,387	3,310	5,300	12,125						
1924-2015	2,825	2,190	1,869	1,855	2,942	8,540	16,968	26,991	27,170	16,390	8,110	4,280	10,054

Table A. 2 Mekong at Pakse, Median Monthly Discharge (m³/s), 1924-2016

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1924	3,200	2,424	2,010	1,702	2,084	8,285	19,111	41,798	24,754	14,656	9,417	4,372	5,858
1925	2,769	2,100	1,770	1,716	2,641	7,459	20,868	21,264	34,327	12,326	5,866	3,862	4,583
1926	2,779	2,206	1,787	1,710	1,508	4,109	14,039	27,514	25,561	17,965	9,625	5,251	5,046
1927	3,274	2,271	1,959	1,961	2,791	10,384	14,906	32,158	21,034	21,150	8,699	4,667	6,698
1928	2,919	2,179	2,003	1,836	3,297	12,277	19,602	25,436	23,144	12,534	6,748	3,622	4,568
1929	2,428	1,857	1,616	1,613	2,357	8,536	17,719	34,112	34,935	19,642	6,712	4,420	5,115
1930	2,905	2,063	1,787	1,903	2,492	7,735	19,546	30,009	23,713	17,051	7,461	4,249	6,188
1931	2,819	2,012	1,692	1,720	2,412	4,544	9,709	20,257	24,960	17,235	5,644	3,149	3,317
1932	2,166	1,671	1,470	1,454	1,814	5,674	15,223	22,269	27,002	21,615	8,457	4,706	4,950
1933	2,327	1,461	1,141	1,095	1,222	5,163	13,159	24,584	18,392	15,021	8,803	3,646	4,169
1934	2,373	1,823	1,537	1,221	1,878	3,681	16,710	29,260	31,500	20,461	8,647	4,348	3,910
1935	2,845	1,902	1,562	1,387	2,356	8,160	16,254	28,011	24,431	21,195	15,898	5,628	6,596
1936	2,930	2,290	1,740	1,820	2,350	8,220	20,000	25,588	28,590	9,700	4,550	3,030	3,945
1937	2,310	1,617	1,522	1,230	3,091	9,614	20,376	35,058	40,948	17,824	8,034	5,448	5,771
1938	3,440	2,560	2,140	2,560	2,640	13,100	21,651	29,329	27,115	22,136	8,785	4,820	7,460
1939	3,230	2,580	2,270	2,260	3,610	13,350	18,300	29,565	28,076	17,200	7,220	4,710	5,930
1940	2,990	2,190	1,950	1,770	2,080	7,920	16,699	25,944	31,658	10,600	5,540	3,520	4,490
1941	2,934	2,384	1,974	1,729	2,112	10,800	17,800	31,597	28,289	20,144	10,050	5,140	5,860
1942	3,050	2,300	1,940	1,930	3,920	10,180	23,800	32,539	25,627	15,600	8,185	3,710	5,450
1943	2,760	2,220	2,060	2,215	2,640	11,400	21,200	26,663	28,558	17,000	6,835	3,880	4,730
1944	2,990	2,370	1,830	1,620	2,700	7,160	17,900	28,010	21,524	15,800	10,250	5,600	6,530
1945	3,294	2,463	1,995	1,931	3,766	11,188	20,008	29,657	31,807	13,014	7,764	4,502	5,092
1946	3,166	2,139	1,757	1,710	2,802	12,571	18,060	24,903	35,080	19,587	9,106	4,724	6,161
1947	3,216	2,552	1,871	1,720	4,165	9,073	26,103	27,993	33,358	17,400	7,200	4,050	5,646
1948	2,920	2,251	1,806	1,859	3,273	9,360	16,917	30,211	38,454	20,400	10,300	5,200	6,790
1949	3,102	2,586	1,966	1,983	3,438	4,781	12,200	28,900	34,195	21,700	12,950	4,814	4,836
1950	3,101	2,456	1,850	1,581	1,920	8,025	18,500	29,443	25,200	21,900	13,300	5,679	6,168
1951	3,220	2,575	1,703	1,524	2,765	9,600	18,400	31,526	26,922	18,000	9,550	4,970	6,020
1952	2,533	1,655	1,539	1,460	2,120	5,345	16,100	31,294	35,204	18,700	10,400	3,300	4,145
1953	1,728	1,618	1,395	1,363	4,970	10,195	16,800	19,700	24,819	12,600	9,265	4,200	6,090
1954	2,306	1,547	1,279	1,307	2,614	7,755	9,590	19,804	30,043	19,700	8,180	3,950	5,100
1955	2,440	1,745	1,460	1,805	2,050	6,700	15,000	22,084	22,303	11,300	7,450	4,150	5,100
1956	2,500	1,910	1,390	1,335	4,140	11,950	15,700	34,100	33,450	11,900	6,500	3,500	5,720
1957	2,490	1,980	1,610	1,680	2,010	8,650	19,200	16,500	21,100	17,600	7,800	3,040	4,080
1958	2,050	1,820	1,500	1,250	1,700	7,250	10,800	18,400	29,100	12,500	6,430	3,090	5,140
1959	1,950	1,635	1,450	1,425	1,690	5,115	10,900	21,200	31,000	16,000	9,450	3,820	4,570
1960	2,440	1,860	1,520	1,090	1,190	5,085	9,960	27,900	30,700	18,700	7,430	3,880	4,370
1961	2,290	1,850	1,580	1,765	2,290	13,950	17,400	25,600	38,100	23,700	7,995	3,970	4,900
1962	2,950	2,260	1,770	1,520	2,540	8,670	20,300	25,400	23,750	16,500	7,435	2,990	4,470
1963	2,140	1,750	1,420	1,240	1,360	10,950	17,600	31,000	23,850	13,400	11,450	4,660	6,230
1964	2,850	2,140	1,830	1,780	2,790	9,090	17,200	23,200	28,500	21,800	10,090	4,790	6,125
1965	2,890	2,310	1,860	1,695	1,950	13,400	20,000	22,100	21,150	10,800	9,790	4,510	5,950
1966	4,177	3,031	1,821	1,605	3,495	9,167	19,285	32,550	41,822	16,218	7,054	4,653	6,430
1967	3,289	2,493	2,090	1,680	2,400	6,555	10,100	18,400	24,700	16,100	5,690	3,860	4,740
1968	2,510	1,940	1,740	1,540	3,590	5,280	11,200	19,700	24,450	11,100	6,925	3,460	4,275
1969	2,330	1,830	1,500	1,360	1,550	9,680	23,300	29,000	17,200	9,760	6,995	3,110	3,770
1970	2,180	1,725	1,380	1,490	2,040	9,035	22,600	29,600	31,150	13,600	6,225	5,080	5,470
1971	3,090	2,210	1,690	1,600	1,910	9,760	30,000	30,700	27,400	13,400	6,680	3,970	4,650
1972	2,910	2,330	1,820	2,015	2,240	6,830	13,400	34,300	19,350	14,300	8,060	6,000	6,115
1973	3,110	2,320	1,820	1,760	2,840	7,990	17,700	22,500	32,650	15,100	7,460	4,520	5,290
1974	2,900	2,250	1,810	2,195	2,860	8,495	9,820	34,800	28,500	13,000	7,025	3,860	5,360
1975	2,920	2,310	1,730	1,680	2,140	9,930	15,800	28,900	29,650	17,200	8,870	3,820	5,010
1976	2,630	2,320	1,970	2,040	3,400	7,375	12,500	28,700	17,550	14,800	10,445	4,800	5,795
1977	2,700	1,900	2,000	2,225	2,320	3,020	9,610	16,800	22,650	11,200	6,975	3,680	3,300
1978	3,080	2,315	1,900	1,660	2,590	9,725	19,600	42,700	30,950	22,900	7,535	3,820	5,150
1979	2,940	2,370	2,020	1,890	3,240	7,770	17,800	24,200	21,400	13,300	5,145	3,420	4,800

1980	2,400	1,930	1,690	1,760	2,470	5,930	15,000	23,000	36,400	18,400	9,005	4,230	5,100
1981	3,020	2,440	2,110	2,070	3,180	19,100	28,800	31,000	24,900	15,900	8,650	5,120	7,560
1982	3,470	2,740	2,180	2,225	2,700	6,575	12,400	24,900	25,900	20,200	7,485	4,300	4,870
1983	3,080	2,220	2,220	2,070	2,440	4,570	8,340	19,000	23,200	18,100	10,600	5,100	4,960
1984	3,550	2,470	1,860	1,525	2,900	7,495	18,500	30,800	24,450	14,400	8,520	3,970	5,170
1985	3,000	2,250	1,930	1,790	2,690	6,880	15,700	28,600	26,200	13,900	7,920	4,830	5,780
1986	3,030	2,340	1,930	1,740	4,560	11,900	14,600	24,100	23,200	11,400	5,970	3,870	5,870
1987	2,500	2,130	1,880	1,680	1,880	3,840	10,900	14,700	20,300	13,100	6,210	3,830	3,870
1988	2,560	1,890	1,650	1,610	3,620	7,570	9,450	22,500	16,300	10,900	5,045	3,160	4,400
1989	2,020	1,665	1,450	1,500	2,020	7,775	10,700	22,600	18,950	15,500	6,940	3,640	5,070
1990	2,680	2,285	2,410	2,085	2,620	15,000	20,000	23,200	23,600	17,000	8,380	4,040	5,850
1991	2,770	2,040	1,730	1,725	1,880	5,760	15,700	25,400	23,050	16,300	9,055	3,910	4,280
1992	2,950	2,300	1,970	1,750	2,040	5,100	11,700	18,400	17,500	10,800	5,265	3,140	3,380
1993	2,190	1,720	1,590	1,370	1,900	5,935	15,700	22,000	22,450	9,780	5,785	3,160	3,860
1994	2,195	2,052	1,624	1,973	1,982	14,601	23,658	29,854	27,107	15,064	4,924	4,054	4,226
1995	2,695	2,043	1,929	1,682	2,600	7,261	16,223	28,578	32,629	16,860	6,687	4,183	4,845
1996	2,810	2,212	2,069	2,176	3,695	4,216	9,302	27,433	31,173	18,547	11,178	5,440	5,106
1997	2,856	2,293	1,914	2,497	2,581	3,088	19,033	32,605	29,398	16,204	5,457	3,214	3,307
1998	2,521	1,927	1,690	1,976	2,381	4,653	17,049	17,151	20,468	6,490	4,415	2,940	3,657
1999	1,984	1,668	1,528	1,698	5,074	12,006	13,246	22,856	25,595	13,591	10,079	4,509	7,130
2000	2,857	2,396	2,335	2,442	5,599	12,923	31,632	27,741	37,499	15,803	7,268	4,144	6,521
2001	2,716	2,260	2,304	2,166	2,622	12,731	23,621	35,954	32,733	15,857	10,795	4,671	7,162
2002	3,409	2,536	2,221	2,098	2,650	13,457	27,766	34,471	32,101	16,365	8,347	4,681	6,893
2003	3,803	2,864	2,406	2,381	2,423	5,983	10,237	18,717	27,702	10,698	4,487	2,526	4,027
2004	2,204	1,944	1,637	1,712	2,756	8,029	11,612	29,203	33,830	10,844	4,757	3,274	4,266
2005	2,480	2,205	1,910	2,330	2,300	5,325	15,970	34,190	30,420	16,880	7,115	3,970	4,030
2006	2,690	2,195	1,990	1,830	2,460	5,280	15,700	27,820	17,725	21,870	6,955	3,140	4,750
2007	2,248	1,911	1,681	1,511	2,752	4,831	9,157	23,003	24,628	24,608	9,843	3,596	4,335
2008	2,248	2,168	1,798	2,034	4,397	13,434	22,312	31,638	23,918	16,386	12,117	5,413	7,007
2009	2,866	2,192	1,769	1,965	2,717	8,061	21,065	23,488	17,445	11,515	5,864	2,826	4,171
2010	2,073	1,832	1,165	1,904	2,336	3,741	5,840	20,290	23,971	17,856	8,036	3,996	3,868
2011	2,959	2,607	2,368	2,655	3,741	8,088	21,888	37,428	36,545	23,640	10,270	3,836	5,929
2012	3,405	2,847	2,544	2,743	3,086	9,489	12,976	22,978	20,224	8,400	4,696	3,677	4,340
2013	2,895	2,735	2,655	2,192	3,996	4,874	11,051	26,630	22,394	14,190	9,718	5,507	5,107
2014	3,868	3,182	3,661	3,549	3,757	7,322	16,520	24,492	20,247	9,799	6,347	4,386	4,671
2015	3,564	2,789	2,755	3,947	3,509	4,190	5,780	21,234	20,447	12,553	4,785	3,216	3,976
2016	2,857	2,857	2,755	3,491	3,216	5,013	11,683						
1924-2015	2,800	2,200	1,820	1,770	2,560	7,740	16,412	27,164	26,564	15,623	7,560	4,080	5,018

Table A. 3 Mekong at Pakse, Minimum Monthly Discharge (m³/s), 1924-2015

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1924	2,742	2,281	1,956	1,646	1,787	2,905	8,766	37,253	19,170	10,593	6,768	3,314	1,646
1925	2,472	1,908	1,727	1,593	1,972	3,045	12,199	20,121	23,274	9,762	4,583	2,973	1,593
1926	2,309	1,889	1,745	1,564	1,333	2,062	9,699	23,016	19,544	13,844	6,411	4,274	1,333
1927	2,644	2,089	1,683	1,691	2,448	6,056	9,708	28,151	17,121	16,378	6,654	3,615	1,683
1928	2,562	1,975	1,767	1,773	3,171	4,005	14,557	19,986	16,944	9,797	4,908	2,842	1,767
1929	2,191	1,765	1,552	1,478	1,919	2,481	10,266	32,175	25,230	10,463	5,877	3,364	1,478
1930	2,394	1,961	1,576	1,681	2,068	6,401	13,079	19,125	20,556	9,552	6,188	3,523	1,576
1931	2,385	1,754	1,602	1,556	1,546	2,492	5,232	13,283	18,497	8,289	4,193	2,801	1,546
1932	1,818	1,587	1,290	1,284	1,749	1,878	7,155	11,369	11,723	14,589	6,629	3,623	1,284
1933	2,005	1,398	1,060	1,062	1,169	1,903	8,286	19,925	16,192	9,009	5,368	3,065	1,060
1934	1,870	1,661	1,263	1,190	1,583	2,380	7,339	20,714	24,777	11,850	6,765	3,287	1,190
1935	2,258	1,670	1,434	1,308	1,348	4,077	6,037	18,607	17,559	17,616	11,116	4,153	1,308
1936	2,480	2,180	1,650	1,600	1,740	5,380	11,500	22,690	21,371	6,230	3,800	2,546	1,600
1937	1,907	1,497	1,296	1,204	1,421	3,236	11,933	32,520	30,085	12,096	6,030	3,686	1,204
1938	2,830	2,330	1,950	2,080	2,290	9,930	15,700	23,047	22,072	13,500	7,210	3,870	1,950
1939	2,830	2,460	2,080	1,860	2,700	6,730	12,400	25,305	23,597	10,700	5,700	3,670	1,860
1940	2,520	1,990	1,790	1,720	1,810	5,520	13,683	17,230	18,797	7,430	4,210	3,010	1,720
1941	2,604	2,130	1,784	1,652	1,936	4,530	11,500	18,343	22,650	17,500	6,560	3,690	1,652
1942	2,560	2,040	1,880	1,720	2,290	4,950	16,900	29,672	21,500	10,600	6,320	3,460	1,720
1943	2,460	1,900	1,920	2,060	2,010	3,880	8,960	24,223	23,692	8,620	4,710	3,200	1,900
1944	2,650	2,090	1,700	1,500	1,530	4,750	10,700	24,549	16,901	12,100	7,560	3,900	1,500
1945	2,761	2,171	1,829	1,757	1,903	3,464	17,412	14,024	28,449	8,159	6,242	4,144	1,757
1946	2,515	1,991	1,549	1,457	1,831	5,613	12,499	21,048	31,370	12,455	7,088	3,754	1,457
1947	2,820	2,154	1,660	1,643	2,661	5,920	14,291	26,349	27,654	9,680	5,200	3,347	1,643
1948	2,554	2,125	1,629	1,624	2,089	6,510	10,999	23,018	22,407	14,600	7,000	3,783	1,624
1949	2,740	2,275	1,696	1,692	2,815	4,209	10,000	23,000	27,805	14,900	5,920	3,866	1,692
1950	2,630	2,212	1,610	1,566	1,750	3,592	14,900	24,392	20,300	18,300	8,115	4,257	1,566
1951	2,556	2,092	1,471	1,463	2,007	3,242	16,500	21,398	19,400	17,000	7,160	3,460	1,463
1952	2,056	1,543	1,508	1,377	1,570	3,380	9,220	28,606	32,673	15,800	6,000	2,214	1,377
1953	1,550	1,511	1,223	1,235	1,900	6,090	13,100	14,300	19,673	10,500	6,200	3,200	1,223
1954	1,899	1,434	1,126	1,208	1,881	3,900	7,530	9,730	24,748	14,600	5,500	2,950	1,126
1955	2,060	1,600	1,310	1,380	1,600	3,500	12,100	15,594	18,411	6,900	6,500	3,150	1,310
1956	2,150	1,700	1,360	1,290	1,370	5,810	13,000	18,400	22,400	9,160	4,800	3,015	1,290
1957	2,240	1,780	1,520	1,410	1,890	3,000	10,300	12,000	16,400	11,500	4,500	2,500	1,410
1958	1,860	1,550	1,310	1,200	1,250	1,720	6,800	16,800	25,600	9,670	5,470	2,770	1,200
1959	1,700	1,370	1,330	1,340	1,550	3,280	4,820	14,200	27,500	12,300	5,430	3,030	1,330
1960	1,900	1,580	1,260	1,060	1,060	2,120	6,700	18,400	21,000	11,900	4,680	2,910	1,060
1961	2,030	1,760	1,380	1,360	1,760	4,340	12,400	14,600	32,900	15,100	5,200	3,190	1,360
1962	2,460	2,010	1,550	1,380	2,030	4,400	11,800	21,000	20,400	11,600	4,660	2,560	1,380
1963	1,940	1,490	1,350	1,160	1,190	2,250	9,750	23,800	17,700	8,130	7,880	3,555	1,160
1964	2,380	1,860	1,690	1,670	2,010	6,070	11,200	12,200	21,000	14,200	6,140	3,515	1,670
1965	2,600	2,190	1,720	1,570	1,650	5,360	14,100	17,600	15,100	7,430	5,950	3,900	1,570
1966	3,537	2,813	1,594	1,511	1,863	7,372	15,350	19,285	25,100	11,537	5,686	3,909	1,511
1967	3,103	2,297	1,987	1,550	2,060	2,490	5,570	11,000	15,900	8,600	4,740	3,110	1,550
1968	2,290	1,800	1,560	1,480	1,870	2,910	8,340	11,200	15,100	8,650	4,970	2,770	1,480
1969	2,130	1,630	1,400	1,310	1,440	3,350	13,300	23,400	13,900	8,140	4,100	2,710	1,310
1970	1,910	1,580	1,280	1,320	1,660	5,760	19,200	23,000	23,200	9,440	5,240	4,100	1,280
1971	2,470	2,060	1,630	1,470	1,680	2,950	12,600	24,900	16,900	10,200	4,800	3,500	1,470
1972	2,550	2,170	1,790	1,740	1,820	2,530	6,800	25,400	13,200	11,800	5,810	4,560	1,740
1973	2,620	1,940	1,690	1,630	2,000	3,680	7,060	15,300	25,000	9,500	5,870	3,660	1,630
1974	2,570	2,220	1,710	1,740	2,200	4,960	6,580	15,800	16,800	7,740	5,990	3,170	1,710
1975	2,780	1,920	1,640	1,610	1,810	4,010	11,600	17,500	22,900	14,100	5,700	3,400	1,610
1976	2,420	2,230	1,900	1,900	2,420	3,840	6,310	21,000	15,300	12,100	6,960	3,040	1,900
1977	2,180	1,810	1,760	1,800	2,040	2,590	5,340	14,300	16,400	7,510	4,550	3,080	1,760
1978	2,940	1,780	1,710	1,550	2,130	6,740	15,300	29,400	27,700	13,100	4,920	3,260	1,550
1979	2,590	2,270	1,740	1,800	2,250	5,770	10,200	9,390	19,900	6,810	4,080	2,940	1,740

1980	2,130	1,830	1,640	1,600	1,850	4,410	10,700	17,400	27,000	13,200	6,110	3,595	1,600
1981	2,640	2,290	2,040	1,970	2,340	9,230	17,300	24,000	13,400	10,500	7,060	4,290	1,970
1982	3,120	2,470	1,970	1,930	2,290	2,660	9,230	12,200	21,000	12,800	6,060	3,380	1,930
1983	2,630	2,130	2,040	1,860	1,860	2,780	5,920	13,900	19,400	11,700	8,570	3,865	1,860
1984	2,780	2,220	1,610	1,460	2,440	5,050	14,200	20,600	15,600	12,600	5,220	3,310	1,460
1985	2,550	2,040	1,760	1,730	2,260	2,970	12,700	19,900	19,200	9,970	6,100	3,620	1,730
1986	2,590	2,150	1,790	1,650	1,940	8,150	8,990	17,000	13,300	7,870	4,890	2,760	1,650
1987	2,230	1,960	1,650	1,630	1,720	1,870	6,050	10,400	17,600	7,790	5,800	3,190	1,630
1988	2,130	1,720	1,520	1,490	2,080	5,410	5,890	11,500	10,100	7,840	3,820	2,440	1,490
1989	1,780	1,510	1,380	1,380	1,480	4,890	6,900	19,900	16,100	13,400	4,710	3,000	1,380
1990	2,380	2,230	2,320	1,960	1,930	5,720	16,500	15,700	19,800	11,100	5,850	3,340	1,930
1991	2,300	1,820	1,650	1,580	1,660	2,520	10,900	18,700	20,300	12,300	5,350	3,120	1,580
1992	2,420	1,900	1,530	1,530	1,810	2,300	6,150	16,400	14,600	6,500	3,620	2,500	1,530
1993	1,880	1,610	1,420	1,260	1,610	3,330	8,970	15,800	15,000	7,090	3,970	2,670	1,260
1994	2,034	1,843	1,591	1,724	1,691	4,033	16,764	26,560	22,643	8,133	4,118	3,315	1,591
1995	2,267	1,981	1,624	1,334	1,429	3,184	8,791	26,884	19,808	10,598	5,534	3,264	1,334
1996	2,267	2,123	1,774	1,774	2,105	3,674	7,210	22,642	18,711	11,593	7,822	3,737	1,774
1997	2,481	2,004	1,796	1,884	2,221	2,035	10,807	25,142	16,134	7,780	3,903	2,734	1,796
1998	2,243	1,831	1,568	1,523	2,025	3,597	6,710	11,231	11,973	5,219	3,657	2,192	1,523
1999	1,858	1,528	1,371	1,456	1,781	10,263	11,277	20,193	21,584	9,616	6,274	3,510	1,371
2000	2,427	2,230	2,097	2,025	2,957	9,322	17,962	23,080	23,275	10,197	5,129	3,423	2,025
2001	2,514	2,202	2,101	2,031	1,935	8,178	18,200	25,423	22,229	11,185	7,162	3,901	1,935
2002	2,901	2,441	2,073	1,851	2,188	7,601	14,706	30,546	26,032	10,210	6,186	3,724	1,851
2003	3,104	2,649	2,237	2,220	2,220	4,150	8,952	14,413	19,252	6,137	3,331	2,237	2,220
2004	1,976	1,682	1,519	1,519	2,089	6,401	8,653	24,686	22,417	7,344	3,965	2,756	1,519
2005	2,360	1,880	1,870	1,960	1,960	2,600	9,760	30,350	26,090	7,970	5,210	3,200	1,870
2006	2,300	2,070	1,880	1,710	2,020	4,750	6,670	24,820	12,710	12,190	4,320	2,650	1,710
2007	2,073	1,791	1,539	1,236	2,073	3,732	7,623	11,890	17,072	12,901	6,044	3,036	1,236
2008	1,995	1,858	1,725	1,725	1,995	6,126	12,560	25,525	20,396	10,823	7,597	3,405	1,725
2009	2,529	1,919	1,623	1,739	2,073	6,640	9,515	15,628	16,064	8,153	3,349	2,478	1,623
2010	1,836	1,128	958	1,664	2,022	3,102	3,996	14,490	19,726	11,401	6,040	3,198	958
2011	2,687	2,304	2,208	2,384	2,480	5,329	14,743	25,649	28,762	14,190	6,218	3,453	2,208
2012	3,038	2,671	2,368	2,192	2,687	5,440	8,452	14,965	12,017	6,478	3,868	2,879	2,192
2013	2,847	2,496	2,544	2,112	3,070	4,129	7,517	19,761	19,479	10,431	6,504	4,618	2,112
2014	3,533	2,847	3,390	3,150	3,358	3,996	10,135	17,469	16,690	6,934	4,733	3,918	2,847
2015	3,113	2,620	2,542	3,182	3,271	3,199	3,454	13,900	13,375	6,576	3,801	2,857	2,542
2016	2,557	2,114	2,012	2,686	2,686	4,093	7,838						2,012
1924-2015	1,550	1,128	958	1,060	1,060	1,720	3,454	9,390	10,100	5,219	3,331	2,192	958

Table A. 4 Mekong at Pakse, Maximum Monthly Discharge (m^3/s), 1924-2015

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1924	6,602	2,742	2,250	1,814	2,764	12,516	38,983	43,037	40,453	18,659	15,964	6,556	43,037
1925	3,210	2,451	1,885	1,975	2,957	12,185	24,203	36,917	37,374	22,568	9,811	4,688	37,374
1926	2,970	2,540	1,846	1,746	2,085	9,342	20,000	41,821	29,501	27,071	15,275	7,985	41,821
1927	4,250	2,600	2,387	2,425	5,357	14,010	38,165	36,515	29,009	31,541	15,131	6,801	38,165
1928	3,608	2,538	2,103	3,588	3,799	16,886	31,545	31,429	29,885	21,634	9,426	4,808	31,545
1929	2,951	2,151	1,764	1,922	2,540	13,821	35,149	44,319	42,663	26,404	10,049	5,713	44,319
1930	3,295	2,360	1,968	2,014	5,909	11,684	21,341	37,937	37,209	37,130	9,257	5,996	37,937
1931	3,366	2,355	1,778	1,995	2,787	6,113	12,867	30,935	30,157	24,606	7,973	4,039	30,935
1932	2,639	1,804	1,642	1,877	1,885	8,097	31,889	30,099	32,372	24,080	14,890	6,510	32,372
1933	3,300	1,895	1,415	1,162	1,827	7,101	24,074	34,170	31,710	24,396	13,286	5,201	34,170
1934	2,910	3,306	1,719	1,536	2,333	6,626	20,694	38,087	37,583	32,731	11,988	6,483	38,087
1935	3,313	2,227	1,661	1,437	3,587	9,442	28,800	35,768	32,424	30,383	17,616	10,703	35,768
1936	3,820	2,460	2,460	2,040	5,160	10,900	28,500	27,445	34,203	20,121	6,090	3,780	34,203
1937	2,536	1,966	1,861	1,381	4,311	12,162	33,436	40,684	46,625	28,368	11,577	6,154	46,625
1938	4,250	2,770	2,850	2,930	8,280	15,800	23,278	33,267	32,562	31,152	13,400	6,940	33,267
1939	3,840	2,810	2,440	2,830	5,950	17,600	31,599	44,744	44,711	26,834	10,100	6,320	44,744
1940	3,570	2,500	2,060	1,950	5,400	18,900	25,800	38,891	38,584	17,800	7,210	4,490	38,891
1941	3,134	2,585	2,126	2,032	4,571	20,700	23,400	36,570	32,899	26,626	18,600	6,370	36,570
1942	3,670	2,500	2,030	2,080	4,730	16,000	33,660	39,365	31,342	21,200	10,500	6,090	39,365
1943	3,500	2,480	2,100	2,850	3,460	16,100	30,400	30,400	39,987	33,009	8,570	4,840	39,987
1944	3,140	2,580	2,080	1,700	4,600	10,100	24,655	33,915	27,626	21,600	13,900	6,720	33,915
1945	4,037	2,730	2,291	2,024	5,196	20,078	25,558	32,934	35,153	26,962	8,478	6,224	35,153
1946	3,858	2,486	1,985	1,808	5,658	17,009	20,937	36,866	39,399	30,781	12,543	6,960	39,399
1947	3,724	2,807	2,124	2,365	5,909	13,174	29,957	35,059	36,231	27,381	10,000	5,200	36,231
1948	3,344	2,527	2,094	2,044	5,872	10,780	25,954	37,648	44,499	22,050	14,400	6,900	44,499
1949	3,765	2,716	2,242	2,958	4,051	9,852	21,100	29,599	39,056	34,553	14,800	6,361	39,056
1950	3,823	2,614	2,169	1,743	3,687	20,000	33,300	32,300	39,582	31,600	25,500	7,955	39,582
1951	3,930	2,785	2,057	1,932	3,109	27,600	24,800	36,563	40,840	19,100	16,500	7,040	40,840
1952	3,397	2,033	1,571	1,616	4,120	14,000	29,304	36,311	37,443	31,938	15,300	5,800	37,443
1953	2,178	1,753	1,563	1,687	5,580	18,400	21,800	34,295	27,718	22,500	10,400	6,000	34,295
1954	3,096	1,871	1,427	1,842	3,721	9,480	11,200	26,958	38,350	29,100	14,100	5,400	38,350
1955	2,900	2,050	1,600	2,150	3,300	11,100	19,720	25,789	26,980	18,800	9,900	6,800	26,980
1956	3,100	2,150	1,680	1,410	6,340	13,600	18,100	41,000	36,900	22,000	10,800	4,680	41,000
1957	3,000	2,280	1,760	2,010	2,600	10,900	26,400	28,300	34,300	25,000	11,300	4,360	34,300
1958	2,555	2,040	1,600	1,320	2,000	10,000	25,100	24,400	38,100	25,400	9,460	5,490	38,100
1959	2,620	2,030	1,790	1,650	2,910	6,300	14,100	33,000	34,100	27,500	12,200	5,300	34,100
1960	3,170	2,540	1,670	1,240	2,030	7,730	16,500	42,200	33,700	26,800	11,700	4,600	42,200
1961	2,850	2,010	1,760	2,040	4,170	24,200	24,400	40,400	44,700	43,600	14,500	5,030	44,700
1962	3,310	2,460	1,970	2,160	4,100	19,900	24,000	34,800	31,600	26,200	11,000	4,470	34,800
1963	2,580	1,940	1,520	1,450	2,310	14,400	33,800	39,500	32,100	20,900	14,300	7,680	39,500
1964	3,520	2,380	1,920	1,950	6,000	11,200	23,600	33,600	44,400	34,000	14,100	6,440	44,400
1965	3,440	2,580	2,140	1,920	4,530	28,100	25,700	25,700	26,900	15,500	14,500	6,320	28,100
1966	5,500	3,495	2,751	1,842	7,703	18,405	25,260	37,020	46,035	23,780	10,915	5,665	46,035
1967	3,950	3,020	2,214	2,030	3,110	10,900	19,800	28,000	32,100	30,500	8,060	5,570	32,100
1968	3,050	2,950	1,910	1,860	4,670	9,330	15,100	33,000	40,400	16,100	10,000	4,900	40,400
1969	2,850	2,090	1,610	1,440	2,890	17,600	30,800	33,600	31,800	13,600	7,930	4,050	33,600
1970	2,640	1,890	1,580	1,880	7,800	17,900	26,400	42,000	42,700	23,400	9,760	5,590	42,700
1971	4,250	2,440	2,170	1,710	2,780	12,200	40,100	35,600	33,100	21,500	10,700	4,710	40,100
1972	3,480	2,530	2,130	2,290	2,570	10,800	19,600	39,600	30,600	16,800	11,400	7,800	39,600
1973	4,560	2,580	2,580	1,880	3,510	10,400	21,800	30,500	38,000	24,400	9,770	7,160	38,000
1974	3,550	2,550	2,180	2,400	4,410	13,700	18,800	44,900	36,900	16,400	9,360	5,700	44,900
1975	3,300	3,020	2,000	1,950	3,970	18,500	21,300	38,800	38,800	22,300	13,600	5,460	38,800
1976	3,340	2,630	2,270	2,420	4,150	9,440	19,300	34,000	21,000	23,600	12,700	6,610	34,000
1977	2,900	2,140	2,090	2,610	3,020	5,580	17,700	20,400	35,100	18,900	9,340	4,500	35,100
1978	3,630	2,860	2,140	2,230	6,160	19,700	30,200	57,800	39,100	37,100	12,500	4,890	57,800
1979	3,260	2,570	2,200	2,250	6,880	27,600	25,200	40,200	32,900	24,200	7,560	4,060	40,200

1980	2,920	2,090	1,900	1,860	4,190	16,000	27,700	29,900	40,600	25,800	13,200	5,960	40,600
1981	3,510	2,630	2,340	2,400	9,550	26,800	32,200	45,500	28,100	20,700	11,100	7,560	45,500
1982	4,260	3,100	2,470	2,860	2,920	11,100	16,000	31,800	33,500	31,400	11,900	5,770	33,500
1983	3,360	2,630	2,320	2,310	2,630	13,900	14,700	31,600	31,100	22,000	14,200	9,070	31,600
1984	4,410	2,740	2,180	2,180	5,890	14,000	24,800	45,500	40,300	18,300	12,400	5,100	45,500
1985	3,280	2,530	2,270	2,230	3,080	24,300	19,700	31,100	34,000	18,400	10,300	8,830	34,000
1986	3,580	2,590	2,130	1,930	10,300	16,600	28,300	27,900	28,300	14,600	10,400	4,810	28,300
1987	2,940	2,290	2,010	1,790	2,130	8,460	13,700	37,900	29,300	18,700	7,540	6,170	37,900
1988	3,160	2,130	1,820	2,090	5,390	9,610	12,900	28,800	21,600	17,000	9,920	3,880	28,800
1989	2,390	1,780	1,610	1,620	7,100	15,300	22,600	28,700	23,600	20,900	12,900	4,470	28,700
1990	3,020	2,370	2,600	2,400	5,660	19,500	26,800	34,100	30,600	20,500	10,900	5,870	34,100
1991	3,280	2,280	1,840	2,380	2,770	14,500	25,200	43,400	47,600	21,300	12,000	5,330	47,600
1992	3,350	2,480	2,340	2,190	2,320	11,300	21,200	24,600	21,500	14,900	9,060	4,110	24,600
1993	2,970	1,910	1,750	1,790	5,300	8,460	27,900	25,800	25,600	14,500	7,420	3,860	27,900
1994	2,638	2,195	1,809	2,395	4,054	20,009	30,382	33,955	34,699	21,640	8,845	4,357	34,699
1995	3,550	2,267	2,034	2,158	3,990	10,766	25,220	32,359	37,827	19,507	11,564	5,534	37,827
1996	3,284	2,340	2,212	2,563	4,666	10,068	25,328	30,452	40,342	36,467	13,147	7,693	40,342
1997	3,476	2,531	2,065	2,683	3,903	9,526	34,342	41,847	35,152	19,560	7,417	4,225	41,847
1998	2,902	2,209	1,847	2,192	3,478	6,056	18,732	20,037	26,797	12,033	5,333	3,839	26,797
1999	2,261	2,178	1,571	2,261	10,896	15,523	29,717	29,510	30,467	24,696	15,228	6,131	30,467
2000	3,512	2,646	2,711	2,940	13,415	23,905	37,332	31,189	45,149	22,730	10,989	4,962	45,149
2001	3,260	2,514	2,844	2,669	7,162	16,404	28,365	42,319	41,956	21,682	15,052	6,947	42,319
2002	3,986	2,993	2,423	2,204	8,254	16,297	34,471	39,343	36,428	24,650	10,153	7,422	39,343
2003	4,943	3,085	2,649	2,561	3,884	10,495	17,560	30,838	34,159	18,576	5,690	3,467	34,159
2004	2,287	2,355	1,773	2,321	6,450	13,361	29,744	32,894	38,510	21,293	7,016	4,444	38,510
2005	2,720	2,340	2,410	2,480	3,050	13,870	35,920	39,560	35,160	30,100	8,550	5,030	39,560
2006	3,030	2,410	2,110	2,060	5,510	6,070	25,250	31,760	30,950	26,570	11,620	4,260	31,760
2007	2,631	2,073	1,957	2,395	5,916	6,161	15,146	28,856	28,520	33,442	13,213	5,651	33,442
2008	2,946	2,478	1,919	2,462	5,939	23,236	26,741	35,283	30,944	22,618	14,329	7,394	35,283
2009	3,349	2,571	2,042	2,717	7,738	10,649	25,065	29,405	25,847	28,856	7,815	3,163	29,405
2010	2,370	2,370	1,588	2,128	3,102	4,774	15,156	30,256	32,624	25,095	11,455	5,907	32,624
2011	3,113	2,767	2,959	2,959	6,452	17,059	24,807	44,915	42,758	35,088	13,795	6,478	44,915
2012	3,757	2,975	2,783	2,911	5,374	13,428	16,678	25,606	26,630	11,509	6,296	3,932	26,630
2013	3,070	3,086	2,911	3,054	4,885	12,948	30,952	31,370	40,482	21,888	12,073	8,815	40,482
2014	5,151	3,741	3,836	3,693	4,085	17,574	34,072	37,299	23,220	20,645	7,663	5,234	37,299
2015	3,859	3,096	3,820	4,288	4,526	6,910	21,676	28,923	25,631	15,565	6,256	3,976	28,923
2016	3,290	4,229	3,454	3,655	4,346	8,973	17,674						
1924-2015	6,602	3,741	3,836	4,288	13,415	28,100	40,100	57,800	47,600	43,600	25,500	10,703	57,800

APPENDIX B FLOW DURATION STATISTICS

Table B. 1 Flow Duration of Mekong River at Pakse – MRC Baseline model (1986-2000)

% greater	Discharge (m³/s)									
	0	1	2	3	4	5	6	7	8	9
0	47,028	37,276	34,054	31,218	29,767	28,109	26,759	25,838	24,949	24,432
10	23,794	23,164	22,505	21,789	21,221	20,675	20,057	19,552	18,949	18,482
20	17,927	17,368	16,670	16,001	15,293	14,596	14,040	13,460	13,018	12,537
30	11,976	11,615	11,138	10,597	10,219	9,844	9,201	8,955	8,646	8,347
40	7,963	7,638	7,161	6,777	6,406	6,062	5,748	5,380	5,078	4,824
50	4,565	4,325	4,131	3,930	3,770	3,613	3,464	3,392	3,334	3,256
60	3,192	3,075	2,949	2,854	2,770	2,697	2,621	2,543	2,474	2,412
70	2,341	2,274	2,206	2,144	2,084	2,024	1,959	1,914	1,872	1,835
80	1,795	1,758	1,718	1,672	1,634	1,599	1,572	1,547	1,520	1,499
90	1,474	1,453	1,425	1,403	1,375	1,351	1,309	1,272	1,243	1,174
100	1,016									

Table B. 2 Flow Duration of Mekong River at Pakse – MRC Definite Future model (1986-2000)

% greater	Discharge (m³/s)									
	0	1	2	3	4	5	6	7	8	9
0	44,521	34,401	31,259	29,095	27,573	26,342	24,995	24,099	23,323	22,469
10	21,724	21,164	20,535	19,841	19,289	18,791	18,282	17,879	17,417	17,077
20	16,677	16,356	15,914	15,433	14,928	14,329	13,757	13,218	12,727	12,339
30	11,971	11,579	11,257	10,942	10,632	10,280	9,915	9,498	9,120	8,638
40	8,023	7,596	7,194	6,909	6,571	6,299	6,031	5,787	5,572	5,346
50	5,194	4,951	4,776	4,633	4,510	4,398	4,301	4,189	4,085	3,957
60	3,873	3,783	3,701	3,613	3,524	3,459	3,404	3,358	3,311	3,257
70	3,225	3,179	3,130	3,090	3,052	3,004	2,970	2,930	2,888	2,852
80	2,804	2,768	2,737	2,706	2,668	2,629	2,599	2,565	2,539	2,510
90	2,475	2,444	2,419	2,390	2,356	2,321	2,291	2,240	2,160	2,105
100	1,774									

Table B. 3 Flow Duration of Mekong River at Pakse – Observed (1986-2007)

% greater	Discharge (m³/s)									
	0	1	2	3	4	5	6	7	8	9
0	47,600	37,849	34,724	33,087	31,547	30,208	29,253	28,200	27,412	26,559
10	25,797	25,000	24,063	23,100	22,301	21,500	20,887	20,002	19,200	18,565
20	17,957	17,420	16,848	16,200	15,587	14,894	14,300	13,591	13,074	12,672
30	12,100	11,616	11,100	10,600	10,152	9,720	9,253	8,836	8,421	7,970
40	7,580	7,219	6,892	6,480	6,162	5,869	5,570	5,300	5,039	4,798
50	4,560	4,361	4,190	4,070	3,925	3,800	3,640	3,481	3,340	3,244
60	3,140	3,030	2,946	2,874	2,791	2,720	2,667	2,610	2,547	2,505
70	2,468	2,420	2,390	2,355	2,320	2,290	2,264	2,237	2,204	2,176
80	2,140	2,120	2,090	2,065	2,030	2,000	1,968	1,932	1,910	1,881
90	1,858	1,813	1,770	1,720	1,680	1,652	1,623	1,590	1,530	1,463
100	1,236									

Table B. 4 Flow Duration of Mekong River at Pakse – Observed (2011-2014)

% greater	Discharge (m³/s)									
	0	1	2	3	4	5	6	7	8	9
0	44,915	40,082	37,822	36,289	34,394	32,531	30,581	28,207	26,561	25,265
10	24,418	23,811	23,476	22,589	22,121	21,810	21,095	20,349	19,761	19,063
20	18,314	17,730	16,982	16,027	15,154	14,616	13,620	12,941	12,367	12,034
30	11,650	11,062	10,744	10,275	9,936	9,515	9,031	8,805	8,478	8,052
40	7,699	7,371	7,006	6,738	6,472	6,279	5,929	5,747	5,422	5,151
50	5,040	4,885	4,774	4,663	4,485	4,374	4,263	4,192	4,085	3,932
60	3,868	3,795	3,757	3,725	3,709	3,677	3,645	3,613	3,581	3,533
70	3,501	3,443	3,390	3,265	3,150	3,070	3,022	2,988	2,959	2,921
80	2,911	2,879	2,879	2,847	2,847	2,799	2,767	2,751	2,719	2,687
90	2,655	2,639	2,620	2,576	2,528	2,480	2,416	2,368	2,291	2,192
100	2,112									

Table B. 5 Flow Duration of Hou Sahong based on MRC Baseline model (1986-2000)

%	Discharge (m^3/s)									
greater	0	1	2	3	4	5	6	7	8	9
0	2,022	1,687	1,572	1,468	1,414	1,351	1,299	1,264	1,229	1,209
10	1,184	1,158	1,132	1,103	1,080	1,058	1,032	1,011	986	966
20	942	918	888	859	828	796	771	745	724	702
30	675	658	635	609	590	572	539	526	510	495
40	475	457	431	407	382	360	339	314	293	276
50	258	242	228	214	203	192	181	176	172	166
60	161	153	144	137	130	125	119	113	108	103
70	98	93	87	83	78	73	68	64	61	58
80	55	51	48	44	41	38	36	34	31	29
90	27	25	23	21	18	16	12	8	5	0
100	0									

Table B. 6 Flow Duration of Hou Sahong based on MRC Definite Future model (1986-2000)

%	Discharge (m^3/s)									
greater	0	1	2	3	4	5	6	7	8	9
0	1,938	1,584	1,469	1,388	1,331	1,283	1,231	1,196	1,165	1,131
10	1,100	1,078	1,052	1,023	1,000	979	958	940	921	906
20	889	875	855	834	811	784	758	734	711	693
30	675	657	641	626	611	593	575	554	535	510
40	478	455	433	415	393	375	358	341	327	312
50	301	285	273	263	255	247	240	232	225	216
60	210	204	198	192	185	181	177	173	170	166
70	164	160	157	154	151	148	145	142	139	136
80	133	130	128	125	123	120	117	115	113	111
90	108	106	104	102	99	96	94	90	84	79
100	53									

Table B. 7 Flow Duration of Hou Sahong based on Observed Pakse Discharge (1986-2007)

%	Discharge (m^3/s)									
greater	0	1	2	3	4	5	6	7	8	9
0	2,041	1,707	1,596	1,536	1,480	1,430	1,394	1,355	1,324	1,292
10	1,262	1,231	1,194	1,156	1,124	1,091	1,066	1,030	996	970
20	944	921	896	868	841	810	783	751	727	708
30	681	658	633	609	587	565	542	520	499	475
40	454	434	414	387	366	347	327	309	291	274
50	258	244	232	224	214	205	194	182	172	165
60	158	150	143	138	132	127	123	118	114	110
70	108	104	102	99	96	94	92	90	87	85
80	82	81	78	76	74	71	69	66	64	62
90	60	56	52	48	45	43	40	37	32	26
100	4									

Table B. 8 Flow Duration of Hou Sahong based on Observed Pakse Discharge (2011-2014)

%	Discharge (m^3/s)									
greater	0	1	2	3	4	5	6	7	8	9
0	1,951	1,786	1,706	1,652	1,584	1,516	1,444	1,355	1,292	1,241
10	1,208	1,184	1,171	1,135	1,117	1,104	1,075	1,044	1,020	991
20	959	934	902	860	822	797	752	721	694	678
30	660	632	616	593	576	555	530	519	502	479
40	460	443	422	404	387	374	351	339	317	298
50	291	280	273	265	253	245	237	232	225	214
60	210	205	202	200	199	196	194	192	189	186
70	184	180	176	167	158	152	149	146	144	141
80	141	138	138	136	136	132	130	129	126	124
90	122	120	119	116	112	108	104	100	94	86
100	80									

Table B. 9 Flow Duration of Hou Xang Pheuak based on MRC Baseline model (1986-2000)

% greater	Discharge (m³/s) 0	1	2	3	4	5	6	7	8	9
0	3,958	3,200	2,944	2,716	2,598	2,463	2,352	2,276	2,202	2,159
10	2,106	2,053	1,997	1,937	1,888	1,842	1,789	1,746	1,694	1,653
20	1,605	1,557	1,495	1,437	1,374	1,312	1,262	1,210	1,170	1,126
30	1,074	1,041	997	946	911	876	814	791	761	732
40	695	663	616	578	540	502	459	411	373	342
50	312	285	263	240	222	205	189	181	175	167
60	161	149	136	127	119	112	105	97	91	86
70	79	74	68	63	58	53	48	44	39	35
80	31	28	24	21	18	16	15	13	12	11
90	10	9	8	7	6	5	4	3	3	2
100	0									

Table B. 10 Flow Duration of Hou Xang Pheuak based on MRC Definite Future model (1986-2000)

% greater	Discharge (m³/s) 0	1	2	3	4	5	6	7	8	9
0	3,765	2,971	2,719	2,543	2,419	2,317	2,206	2,131	2,066	1,994
10	1,931	1,884	1,830	1,771	1,723	1,680	1,636	1,601	1,561	1,531
20	1,496	1,468	1,429	1,386	1,341	1,288	1,236	1,188	1,143	1,108
30	1,074	1,038	1,008	979	950	917	882	843	807	760
40	701	659	619	591	557	529	497	464	436	407
50	387	358	337	320	306	293	282	270	258	243
60	234	224	215	205	195	189	183	178	173	167
70	164	159	154	150	146	142	138	134	130	127
80	122	118	116	113	109	105	103	99	97	94
90	91	89	86	84	81	78	75	71	64	60
100	29									

Table B. 11 Flow Duration of Hou Xang Pheuak based on Observed Pakse Discharge (1986-2007)

% greater	Discharge (m³/s) 0	1	2	3	4	5	6	7	8	9
0	4,002	3,245	2,997	2,866	2,742	2,634	2,556	2,470	2,406	2,335
10	2,272	2,206	2,128	2,047	1,980	1,912	1,860	1,784	1,716	1,661
20	1,608	1,561	1,511	1,454	1,400	1,338	1,285	1,221	1,175	1,138
30	1,086	1,041	993	947	905	864	819	779	739	696
40	657	622	589	548	515	475	436	401	368	339
50	311	289	270	256	240	226	208	191	176	166
60	155	144	136	129	121	114	109	104	98	94
70	91	86	84	81	78	75	73	71	68	65
80	62	61	58	56	54	51	49	46	43	40
90	37	33	29	24	21	19	18	16	13	9
100	2									

Table B. 12 Flow Duration of Hou Xang Pheuak based on Observed Pakse Discharge (2011-2014)

% greater	Discharge (m³/s) 0	1	2	3	4	5	6	7	8	9
0	3,796	3,420	3,243	3,122	2,971	2,822	2,664	2,471	2,336	2,228
10	2,158	2,107	2,079	2,004	1,965	1,938	1,878	1,814	1,764	1,704
20	1,639	1,588	1,523	1,439	1,362	1,314	1,224	1,163	1,110	1,080
30	1,044	990	960	916	884	844	798	776	745	703
40	669	637	600	574	547	527	483	459	416	382
50	368	350	336	323	303	290	278	270	258	241
60	233	225	221	217	216	212	209	205	202	196
70	193	187	181	168	156	148	143	140	137	133
80	132	129	129	126	126	121	118	117	114	111
90	108	106	105	100	96	92	86	82	75	67
100	60									

Table B. 13 Flow Duration of Hou Sadam based on MRC Baseline model (1986-2000)

%	Discharge (m^3/s)									
greater	0	1	2	3	4	5	6	7	8	9
0	255	204	187	171	164	155	148	143	138	135
10	131	128	124	121	117	114	111	108	105	102
20	99	96	92	89	85	81	78	74	72	69
30	66	64	61	58	56	54	50	48	47	45
40	43	41	38	36	33	31	29	27	25	24
50	22	21	19	18	17	16	15	15	14	14
60	14	13	12	11	11	10	10	9	9	9
70	8	8	7	7	6	6	6	5	5	5
80	4	4	4	4	3	3	3	3	2	2
90	2	2	2	2	1	1	1	1	0	0
100	0									

Table B. 14 Flow Duration of Hou Sadam based on MRC Definite Future model (1986-2000)

%	Discharge (m^3/s)									
greater	0	1	2	3	4	5	6	7	8	9
0	242	188	172	160	152	145	138	133	129	124
10	120	117	114	110	107	104	101	99	96	95
20	92	91	88	85	83	79	76	73	70	68
30	66	64	62	60	58	56	54	52	49	47
40	43	40	38	36	34	33	31	30	28	27
50	26	25	23	23	22	21	21	20	19	18
60	18	17	17	16	16	15	15	15	14	14
70	14	13	13	13	13	12	12	12	12	11
80	11	11	11	10	10	10	10	10	9	9
90	9	9	9	8	8	8	8	7	7	6
100	4									

Table B. 15 Flow Duration of Hou Sadam based on Observed Pakse Discharge (1986-2007)

%	Discharge (m^3/s)									
greater	0	1	2	3	4	5	6	7	8	9
0	258	207	190	181	173	166	161	155	151	146
10	142	138	133	128	123	119	116	111	106	103
20	99	96	93	90	86	82	79	75	72	70
30	67	64	61	58	55	53	50	48	45	43
40	40	38	36	34	32	30	28	27	25	24
50	22	21	20	19	18	17	16	15	15	14
60	13	13	12	12	11	11	10	10	9	9
70	9	9	8	8	8	8	8	7	7	7
80	7	7	6	6	6	6	6	5	5	5
90	5	5	4	4	4	3	3	3	3	2
100	0									

Table B. 16 Flow Duration of Hou Sadam based on Observed Pakse Discharge (2011-2014)

%	Discharge (m^3/s)									
greater	0	1	2	3	4	5	6	7	8	9
0	244	218	207	198	188	178	168	155	146	139
10	135	132	130	125	122	121	117	113	109	106
20	101	98	94	89	84	81	75	71	68	66
30	64	61	59	56	54	52	49	48	46	43
40	41	39	37	35	34	33	30	29	27	26
50	25	24	23	23	22	21	20	20	19	18
60	18	17	17	17	17	17	16	16	16	16
70	16	15	15	14	13	13	12	12	12	12
80	12	12	12	11	11	11	11	11	11	10
90	10	10	10	10	9	9	9	8	8	7
100	7									