Mekong River Commission

Regional Flood and Drought Management Centre

Wet Season Situation Report of the Mekong River

Analysis of the MRC - River Flood Forecasting System (RFFS)

Covering the period from 1st June to 31st October 2019

(Final)

Prepared by:

Regional Flood and Drought Management Centre

January 2021

Certification of Approval
of Internal RFDMC Technical Document

Wet Season Situation Report of the Mekong River

Covering the period from 1st June to 31st October 2019

No	Name of Person	Position	Date	Signature
1	Dr. Khem Sothea	River Flood Forecasting Specialist	15/05/2021	K. Sothea
2	Mr. Nguyen Quoc Anh	Operational Hydro-Meteorologist/Forecaster	25/05/2021	
3	Ms. Nike Hestermann	Technical Advisor GIZ	30/05/2021	
4	Dr. Son Lam Hung	Head of the RFDMC	30/05/2021	

Table of Contents

List of Figures

List of Tables

Abbreviation

CHRHMC	Central Highlands Regional Hydro-Meteorological Center
DFEWS	Drought Forecasting and Early Warning System
DHRW	Department of Hydrology and River Works (Cambodia)
DMH	Department of Meteorology and Hydrology (Lao PDR)
DWR	Department of Water Resources (Thailand)
DOM	Department of Meteorology (Cambodia)
FFGS	Flash Flood Guidance System
FTP	File Transfer Protocol
GFS	Global Forecast System
GIS	Geographic Information System
GPM	Global Precipitation Measurement
HYDMET	Data collection system
ICTZ	Intertropical Convergence Zone
JMA	Japan Meteorological Agency
LA(s)	Line Agency (-ies)
LMB	Lower Mekong Basin
LTA	Long-Term Average
MC(s)	Member Country (ies)
MED	Mean-Absolut-Differences in centimetres
MoU	Memorandum of Understanding
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
RFDMC	Regional Flood and Drought Management Centre
RFF	River Flood Forecast
RFFS	River Flood Forecasting System
RFMMC	Regional Flood Management and Mitigation Centre (former name of RFDMC)
SRE	Satellite Rainfall Estimates
SRHMC	Southern Regional Hydrometeorological Centre (Viet Nam)

TD	Technical Support Division
TSR	Tropical Storm Risk
SST	Sea Surface Temperature
URBS	Unified River Basin Simulator
WMO	World Meteorological Organizations

1 Introduction

1.1 Main objective of the report

This situation report on the wet season 2019 presents an analysis of the Mekong River and the MRC River Flood Forecasting System (RFFS) of the Regional Flood and Drought Management Centre (RFDMC).

The RFDMC is part of the Technical Support Division (TD) of the MRC Secretariat (MRCS), the operational arm of the Mekong River Commission (MRC), an intergovernmental organization established by the 1995 Agreement on Cooperation for the Sustainable Development of the Mekong River Basin, between the governments of Cambodia, Laos, Thailand and Viet Nam, further referred to as member countries (MCs).

The seasonal situation report gives a general overview on the hydrological situation, analysing and verifying the summaries of rainfall and water levels, highlights the system performance regarding observed flood events and special weather conditions (Tropical Low Pressure and Inter Tropical Convergence Zone (ITCZ), Tropical Depressions, Storms and Typhoons), summarizes and evaluates the performance of data collection and transfer from the national Line Agencies (LAs) to the RFDMC FTP data terminal, and compares the MRC-RFFS different models and data sources available, giving recommendations for further improvement.

It is a combination of the three former seasonal reports, “Data Collection and Transfer Performance Evaluation Report”, “System Performance Evaluation Report” and “Seasonal Flood Situation Report”.

The analysis is based on the daily hydro-meteorological data provided by the MCs and on satellite data. All water levels indicated in this report refer to a above zero gauge of each station.

1.2 Further References

The Weekly Wet Season Situation Report in the Lower Mekong River Basin (LMB) is available at:

http://ffw.mrcmekong.org/reportflood.php

The Mekong River water levels are updated daily and can be accessed from:
http://ffw.mrcmekong.org/bulletin_wet.php

Further information about the hydrological situation in the LMB can be found in the following reports of RFDMC:

- Annual Mekong Hydrology Report
- Seasonal Flash Flood Situation Report in the Lower Mekong River Basin
- Seasonal Drought Situation Report in the Lower Mekong River Basin

1.3 Sub-regions of the Lower Mekong Basin

With a total catchment area of about 571,000 km^2, the LMB covers a large part of north-eastern Thailand, almost the entire countries of Lao PDR and Cambodia, and the southern tip of Viet Nam. The report is following the functional subdivision of the LMB into four geographic regions.

The Upper Part: is the Northern Highlands form the upland region, covering north-eastern Myanmar, northern Thailand and the northern areas of Lao PDR, in between Chaing Saen and Vientiane/Paksane. Large tributaries, including the Nam Ta, Nam Ou, Nam Soung and Nam Khan, enter on the Mekong's left bank, while the Nam Mae Kok and Nam Mae Ing enter on the right bank.

The Middle Part: is lying largely within north-eastern Thailand; the Khorat Plateau is a vast, low-lying terrain consisting mainly of sediment and eroded bedrock and surrounded by a rim of highly resistant sandstone, in between Thailand' Nakhon Phanom and Laos' Pakse. Here the Mekong River is joined by the Songkhram and Mun Rivers on the right bank and the Nam Ca Dinh, Se Bang Fai, and Se Bang Hieng Rivers on the left bank.

The Lower Part including the Tonle Sap Lake: the area starting from Stung Treng to Kampong Cham with the inflow from Pakse and the inflow of the 3S (Sekong, Sesan and Srepok) area, followed by the connection of the Tonle Sap lake at Phnom Penh Port.

During the wet season, the high flows in the Mekong River cause the Tonle Sap River to reverse its flow direction to flood the Lake. During the peak of the wet season, the Lake's surface area increases six-times, from around 2,500 km^2 to around 15,000 km^2, and its volume increases from around 1.5 km3 to around 60-70 km^3. At the end of the wet season, the flow of the Tonle Sap River reverts to the downstream direction, draining excess water off the inundated floodplain surrounding the Lake.

The Mekong Delta: At Chaktomuk in Phnom Penh, the Bassac River, the largest distributary river channel, splits from the mainstream, marking the beginning of the Mekong Delta. Along their course, the Mekong and Bassac Rivers branch off into numerous smaller watercourses, and the delta expands to form a wedge-shaped plain that covers an area of 62,520 km^2.

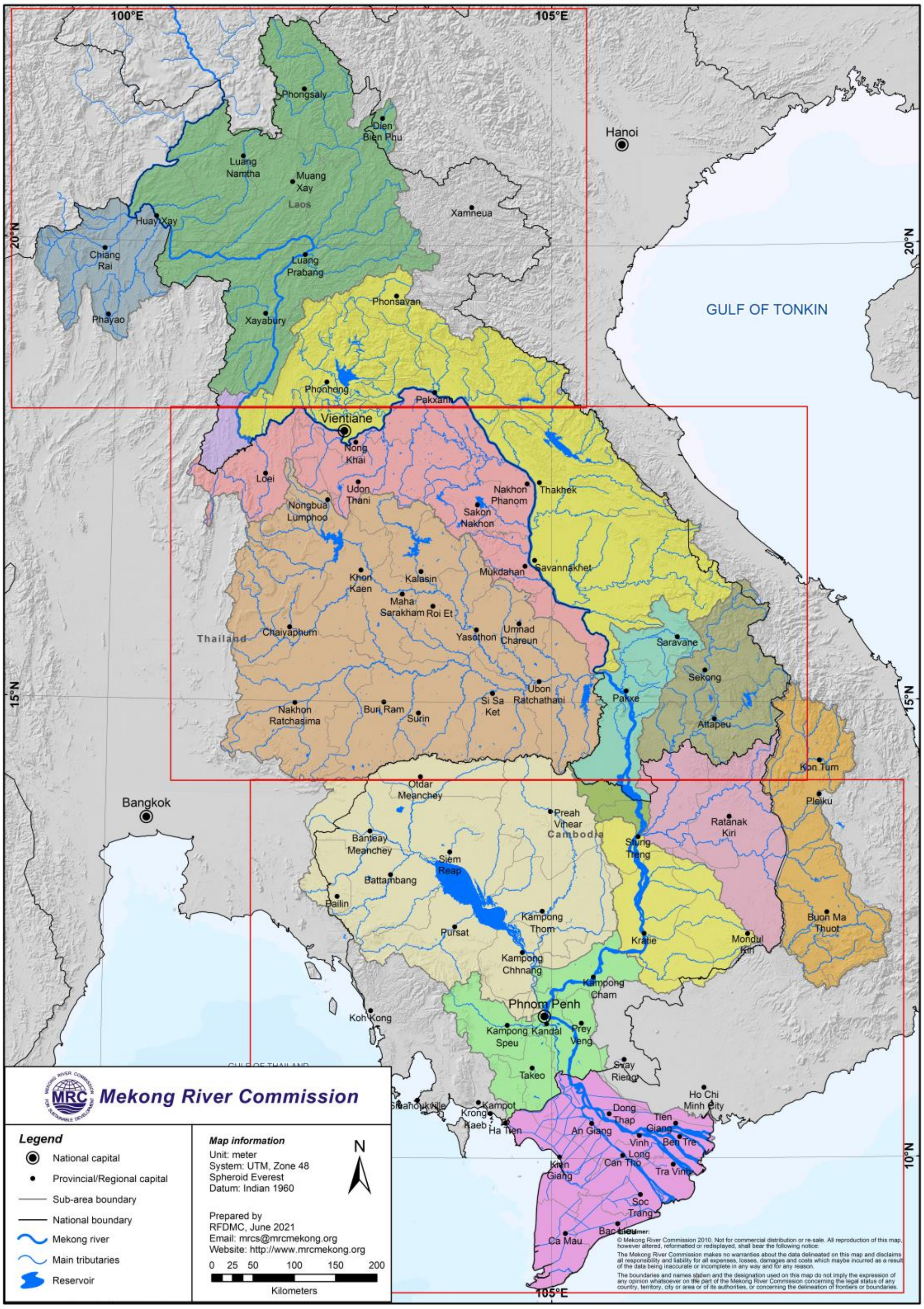


Figure 1: Sub-regions of the LMB

2 General Weather Patterns

2.1 Rainfall situation

During the five months of the wet season 2019, the critical rainfall in the LMB spread from the months of July to November. The phenomenon was caused by multi-influencing factors known as the southwest monsoon, low-pressure troughs, the ITCZs, storms and typhoons taking place in the East Sea.

In general, the total seasonal rainfall in 2019 in the LMB was lower than its average, in particular the total rainfall recorded from June to October was less than in the wet season 2018 and its long-term average-LTA (2008-2018). The onset of the southwest monsoons started later than in previous flood year in 2018 with rainfall in June. **Table 1** shows the onset and offset of the southwest monsoon in 2018 and 2019 compares with its LTA (2008-2018) at the hydrological stations along the Mekong mainstream.

Table 1**:** Onset and offset of the southwest monsoon

Station	Average		2018		2019	
	Onset	**Offset**	**Onset**	**Offset**	**Onset**	**Offset**
Chiang Saen	02-May	13-Oct	04-May	6-Oct	01-Jun	21-Sep
Luang Prabang	04-May	08-Oct	05-May	8-Oct	01-Jun	23-Sep
Chiang Khan	03-May	18-Oct	20-May	9-Oct	02-Jun	24-Sep
Vientiane	07-May	08-Oct	27-May	10-Oct	03-Jun	24-Sep
Nong Khai	08-May	09-Oct	27-May	10-Oct	03-Jun	24-Sep
Paksane	13-May	10-Oct	28-May	10-Oct	01-Jun	24-Sep
Nakhon Phanom	10-May	08-Oct	28-May	11-Oct	02-Jun	24-Sep
Thakhek	10-May	08-Oct	28-May	11-Oct	02-Jun	25-Sep
Mukdahan	10-May	13-Oct	29-May	12-Oct	02-Jun	25-Sep
Savannakhet	11-May	12-Oct	29-May	12-Oct	02-Jun	25-Sep
Khong Chiam	08-May	14-Oct	30-May	12-Oct	05-Jun	25-Sep
Pakse	13-May	15-Oct	28-May	11-Oct	06-Jun	26-Sep
Stung Treng	18-May	21-Oct	29-May	18-Oct	04-Jun	29-Sep
Kratie	21-May	24-Oct	29-May	17-Oct	03-Jun	04-Oct
Kompong Cham	18-May	26-Oct	30-May	14-Oct	02-Jun	06-Oct
Bassac Chaktomuk	21-May	06-Nov	31-May	15-Oct	05-Jun	12-Oct
Phnom Penh Port	21-May	06-Nov	31-May	15-Oct	05-Jun	12-Oct
Koh Khel	22-May	06-Nov	31-May	16-Oct	05-Jun	15-Oct
Neak Luong	24-May	04-Nov	31-May	17-Oct	05-Jun	16-Oct
Prek Kdam	24-May	02-Nov	31-May	17-Oct	03-Jun	16-Oct
Tan Chau	28-May	06-Nov	02-Jul	22-Oct	04-Jun	25-Oct
Chau Doc	28-May	06-Nov	02-Jul	22-Oct	04-Jun	25-Oct

The spatial and temporal variation of rainfall was 'high', indicating that the intensity of heavy rainfalls along the LMB from upstream to downstream took place as a function of time. **Table 2** shows the distribution of the total monthly rainfall during the wet season 2019 from May to October in the LMB compared to its Long-Term Average (LTA) (2008-2018) and the total monthly rainfall in 2018. The percentage indicates the total monthly rainfall 2019 compared to the LTA. **Figure 2** shows the same in a histogram. The rainfall in 2019 was smaller than the LTA in June, July, October, November and December. However, in August and September the total rainfall was higher than its LTA.

Table 2: Total monthly rainfall in the LMB from May to Oct 2019, 2018 and LTA

Month	Obs 2019Y	Obs.2018Y	Avg. LTA (2008-2018)	Percentage (%)
May	148.95	216.19	127.27	117%
Jun	168.04	276.14	171.78	98%
Jul	212.84	362.78	249.07	85%
Aug	364.45	331.66	237.40	154%
Sep	259.84	216.70	234.05	111%
Oct	67.99	102.00	122.41	56%
Nov	15.00	30.50	46.77	32%
Dec	0.7	24.75	11.44	6%

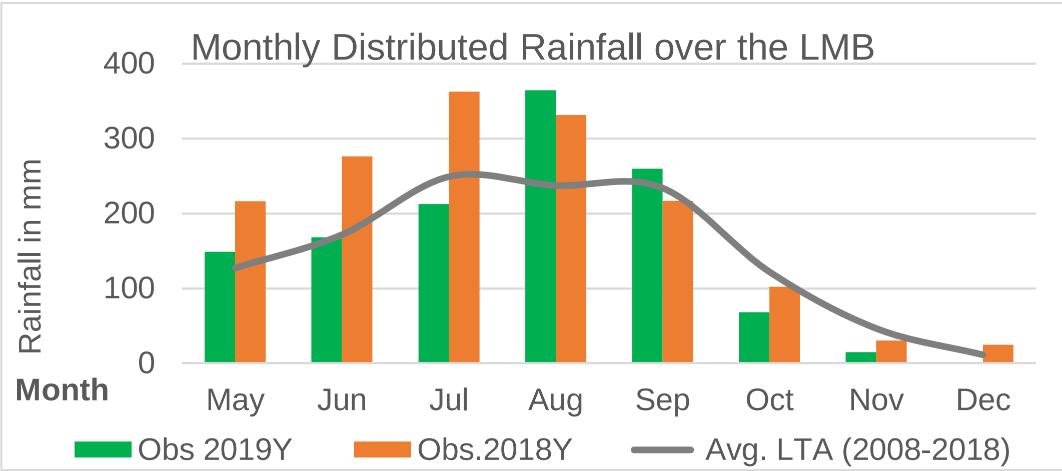


Figure 2: Total monthly rainfall in the LMB from May to Oct 2019, 2018 and LTA

Figure 3 shows the rainfall distribution over the LMB, counting from May to October 2019. Rainfall in 2019 mainly was concentrated from the catchment upstream of Paksane to the lower part in Cambodia. Table 3 showed Average monthly rainfall in the LMB from Jun to Oct 2000 – 2019.

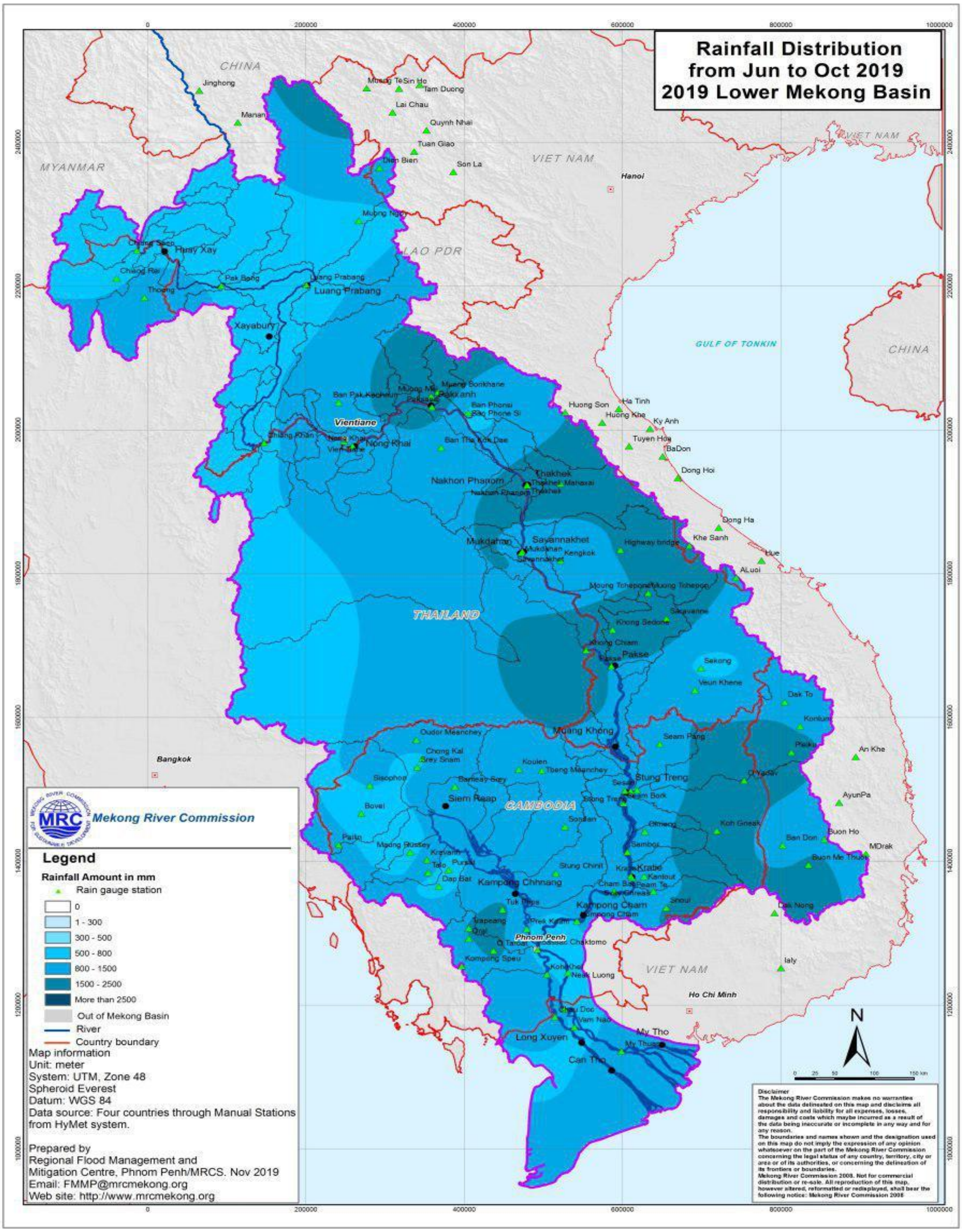


Figure 3: Total rainfall in the LMB from Jun to Oct 2019

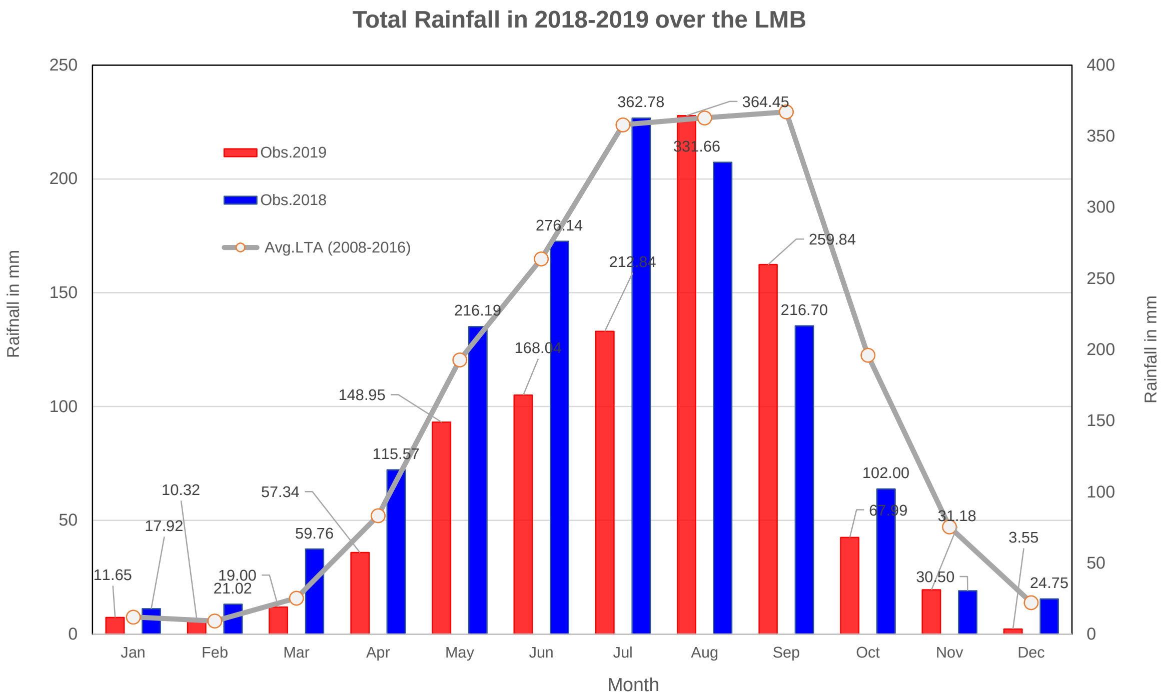


Figure 4: Total rainfall by station from 2019, 2018 and LTA

Table 3: Average monthly rainfall in the LMB from Jun to Oct 2000 – 2019

	2018	2019	Aver 2008-2016
Jan	17.92	7.52	7.52
Feb	21.02	5.77	5.77
Mar	59.76	15.84	15.84
Apr	115.57	52.04	52.04
May	216.19	120.50	120.50
Jun	276.14	164.92	164.92
Jul	362.78	223.80	223.80
Aug	331.66	226.80	226.80
Sep	216.70	229.47	229.47
Oct	102.00	122.56	122.56
Nov	30.50	47.10	47.10
Dec	24.75	13.88	13.88

2.2 Tropical Low-Pressure Throughs and Inter Tropical Convergence Zone (ITCZ)

Low-pressure throughs and the ITCZ periodically appeared from July to November 2019 with a 3 to 7 days duration. The frequent appearances of these phenomena during almost the entire wet season 2019 caused tropical storms that brought heavy rainfall and rising water levels in some parts of the LMB.

2.3 Tropical Depressions, Tropical Storms and Typhoons

During the wet season 2019 there were about six Tropical Depressions and Storms, that hit the Mekong region, with the storms Podul and Kajiki being the strongest. At the end of August and early

September, the Podul and Kajiki storms brought very heavy rainfall in the middle part from Khong Chiam to Stung Treng, of which water levels rose over the flood levels causing flooding for almost 2 weeks at Laos's Pakse and Cambodia's Stung Treng. **Table 4** shows the list of Tropical Depressions, Storms and Typhoons from July to November 2019 in the LMB. **Figure 5** illustrates the Tropical Storms over the LMB from July to November 2019.

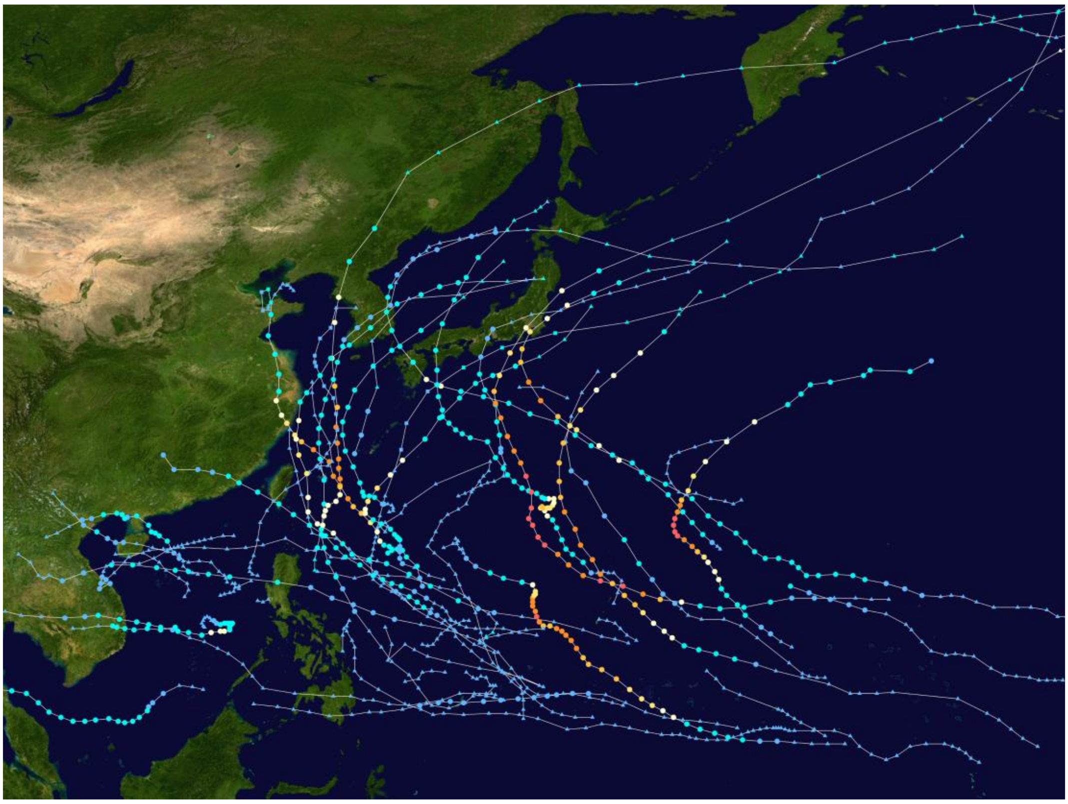


Figure 5: Tracks of Tropical Depressions, Storms and Typhoons entering the Pacific Ocean from Jun to Oct 2019 (Source: Thai Meteorological Department)

Table 4: List of Tropical Depressions, Storms and Typhoons in the LMB in 2019

Name	Dates Active	Type of Storm	Sustained Wind Speed	Pressures	Areas affected
Mun	July 1 – 4	Tropical storm	65 km/h (40 mph)	992 hPa (29.29 inHg)	South China, Vietnam, Laos
Wipha	July 30 – August 4	Tropical storm	85 km/h (50 mph)	985 hPa (29.09 inHg)	South China, Vietnam, Laos
Podul (Jenny)	August 24 – 31	Tropical storm	75 km/h (40 mph)	992 hPa (29.29 inHg)	Yap, Philippines, Vietnam, Laos, Thailand, Cambodia
Kajiki (Kabayan)	August 30 – September 6	Tropical storm	65 km/h (40 mph)	996 hPa (29.41 inHg)	Philippines, South China, Vietnam, Laos
Matmo	October 28 – November 1	Severe tropical storm	95 km/h (60 mph)	992 hPa (29.35 inHg)	Philippines, Vietnam, Cambodia, Laos, T hailand
Nakri (Quiel)	November 4 – 11	Typhoon	120 km/h (75 mph)	975 hPa (28.79 inHg)	Philippines, Vietnam, Cambodia

2.3.1 Tropical Storm PODUL

Following the passage of Tropical Storm PODUL on 29 August 2019 and under the influence of the Tropical Depression KAJIKI on 3 September 2019 which strengthened the southwest monsoon, the Department of Disaster Prevention and Mitigation (DDPM) of Thailand reported that flooding had affected 32 provinces across Thailand in the north-eastern part. It also hit Champasak at Pakse and downstream at Stung Treng and Kratie in Cambodia. Error! Reference source not found. displays the track of the Tropical Storms Podul in 2019.

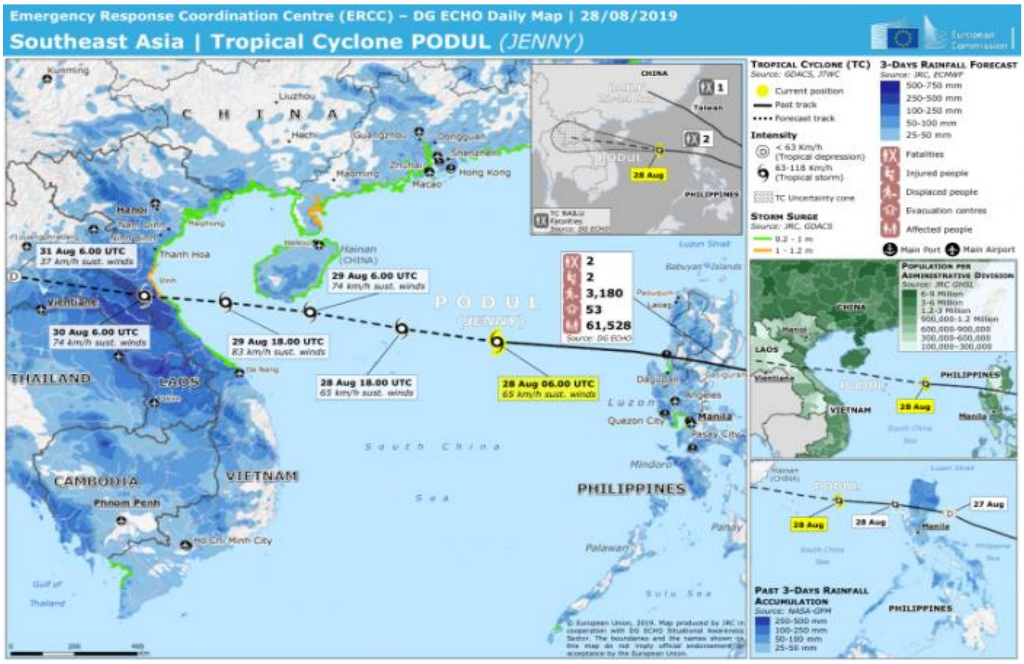


Figure 6: Track of Tropical Storm Podul from the East Sea to the LMB (Source ERCC)

Error! Reference source not found.**7** presented the Weather Chart issued during the Tropical Storm PODUL (Source: Thai Meteorological Department).

Thailand

In the 2019 flood, at least 9 provinces were affected by flooding: Phitsanulok, Phichit, Amnat Charoen, Chaiyaphum, Mukdahan, Yasothon, Khon Kaen, Ubon Ratchathani and Roi Et. Over 1,200 people remained displaced. Khon Kaen was one among the worst hit provinces, where 19,124 households had been affected and 500 people were displaced. In Roi Et Province, flooding damaged 5 roads and 1 bridge and affected 3,476 households. Around 8,000 households were affected in Yasothon, 3,445 in Phichit and 1,223 in Ubon Ratchathani.

Viet Nam

On 30 August, Viet Nam's Disaster Management Authority (DMA) reported that 3 people had died as a result of severe weather brought by storm Podul. Strong winds in Hanoi and Quang Binh left 2 people dead. One person died after being swept away by flood waters in Hoa Binh. Over 1,100 houses were damaged, mostly by strong winds including 652 in Yen Bai. DMA said that 282 houses were flooded in Thanh Hoa. Heavy rain was reported in Viet Nam since 29 August, particularly in Thanh Hoa, Quang Binh, and Quang Tri Provinces. Within a 24-hour period, on 30 August, Cam Thuy in Thanh Hoa Province recorded 297 mm of rain.

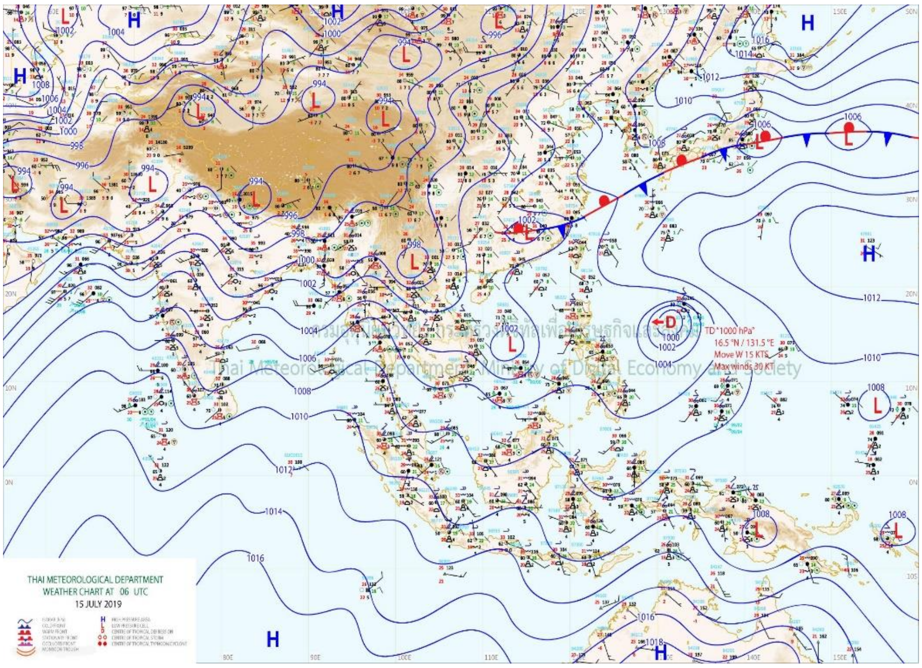


Figure 7: Weather Chart issued during the Tropical Storm PODUL (Source: Thai Meteorological Department)

2.3.2 Tropical Storm Kajiki

Storm Kajiki, which closely followed the Tropical Storm Podul, brought heavy rain to parts of Viet Nam and Lao PDR causing further flooding and landslides was hit the Mekong region on 30-31 August 2019. Authorities reported at least 2 people had died and 2 were missing in Lao PDR, while 5 fatalities were reported in Viet Nam with 3 people still missing. Heavy rain in the catchment areas induced a significant increase of water levels of the Mekong River, which reached flood stage in parts of Thailand, Lao PDR and Cambodia on 30-31 August 2019. In Lao PDR heavy rain brought by the consecutive storms Podul and Kajiki led to severe flooding in Khammuan, Savannakhet, Saravan, Xekong, Attapeu and Champassak provinces. Based on the local news, flooding had affected more than 54,200 families in 788 villages of 37 districts in the central and southern provinces. Over 3,400 families had been evacuated. In Viet Nam, local media said that "Over the past few days, torrential rains brought by a tropical depression were recorded from Nghệ An to Thừa Thiên-Huế Province. In many areas, total rainfall rose to more than 1,000 mm, causing widespread flooding in low areas, leading to the loss of human lives and damage to property." Roads across the province had been submerged causing major transport problems. Flooding also caused severe losses or damage for farmers. According to the reports from Provincial Committees for Disaster Management, 237 communes in 51 districts in 10 provinces had been affected in Cambodia. Error! Reference source not found.**8** presents the track of tropical storm Kajiki from the East Sea to the LMB (Source: Tropical Storm Risk (TSR)) and Error! Reference source not found.**9** shows the Weather Chart issued during the Tropical Storm Kajiki (Source: Thai Meteorological Department) .

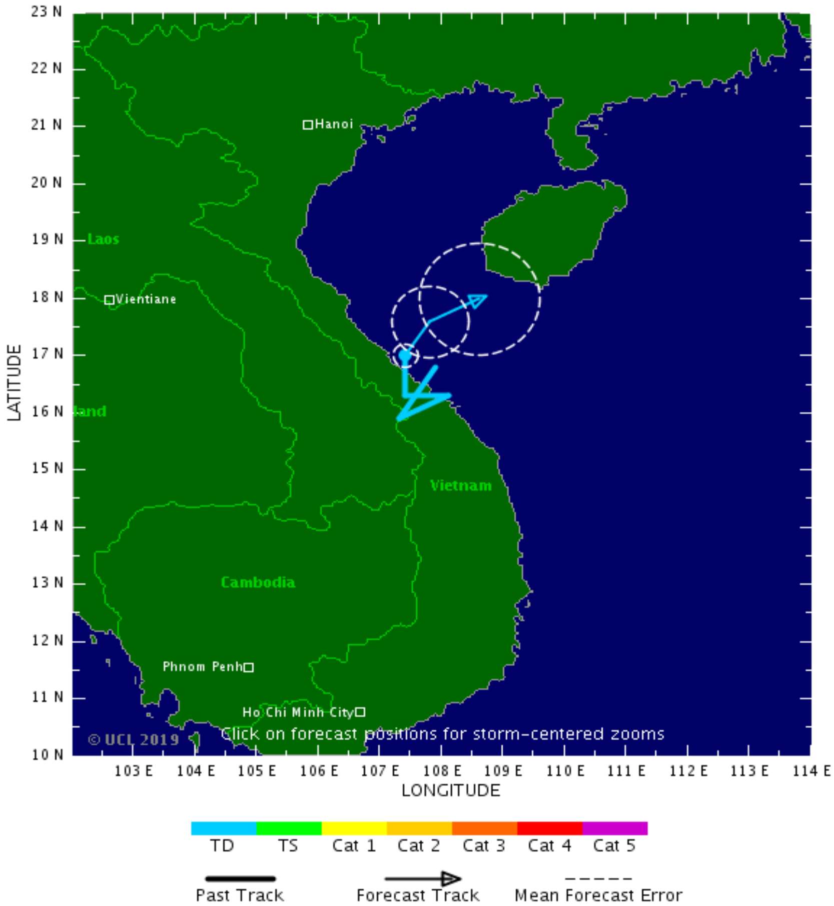


Figure 8: Track of Tropical Storm Kajiki from the East Sea to the LMB

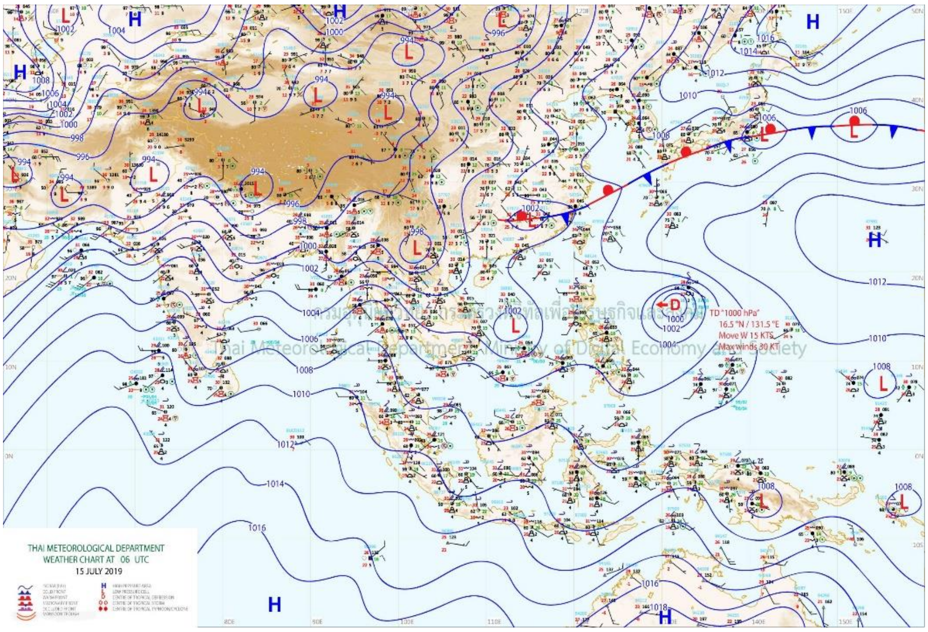


Figure 9: Weather Chart issued during the Tropical Storm Kajiki (Source: Thai Meteorological Department)

3 Water Levels in the Lower Mekong River

In general, water levels at all mainstream key stations along Mekong River were under their LTAs from the beginning of the wet season (01 June) until the end of July 2019. At the end of August and early September, following the storms Podul and Kajiki, the water levels rose significantly in the middle and downstream parts at Khong Chiam, Pakse, Stung Treng and some stations in the low-lying area of the Mekong Delta. **Annex A** shows the water levels hydrographs at each key station along the Mekong river and its main tributaries, the Bassac and the Tonle Sap compared to other years and Min, Max, LTA. The wet season 2019 reached flood level at Thailand's Khong Chiam and Lao's Pakse on 05 September 2019, and in Cambodia's Stung Treng on 07 September 2019. **Table 5** presents the flood peaks and flood characteristics at each key station along the Mekong mainstream in 2019.

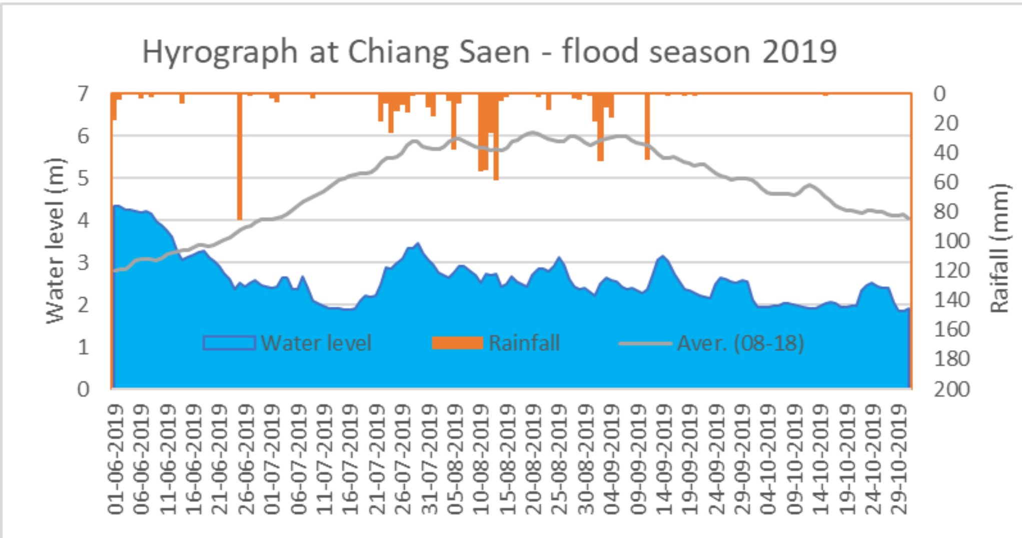
Table 5: Flood peaks of the key stations from Jun to Oct 2019

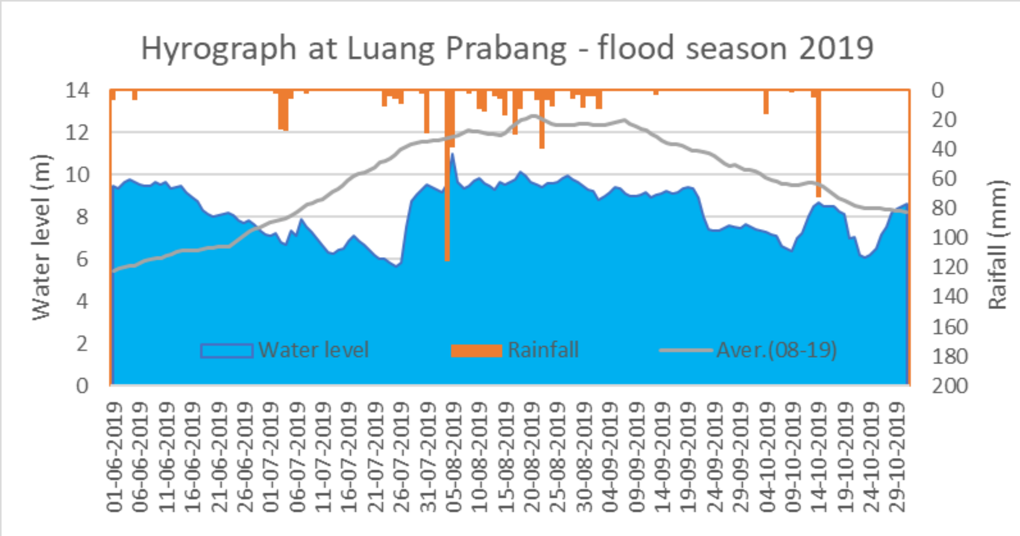
Stations	Number of Flood events	Beginning of Flood Event		Peak of Flood Event		Rising time	Flood Amplitude (m)	Intensity of Flood Rising			Comment
		Date	H_b (m)	Date	H_p (m)	T_p (day)		Interval of I_{max} (Date)	I_{max} (m/day)	Iaverage (m/day)	
Chiang Saen	No Flood event	(from 02 June 2019)									
		01-Jun	4.32	02-Jun	4.33	1	0.01	No	No	No	Below Alarm Level
Luang Prabang	No Flood event	(from 15 - July to 15 Aug 2019)									
		25-Jul	5.66	05-Aug	11.00	11	5.34	No	No	No	Below Alarm Level
Chiang Khan	No Flood event	(from 15 Jul to 6 Aug 2019)									
		15-Jul	3.68	06-Aug	9.35	22	5.67	No	No	No	Below Alarm Level
Vientiane	No Flood event	(from 16 Aug to 28 Aug 2016)									
		16-Aug	8.20	18-Aug	9.65	2	1.45	No	No	No	Below Alarm Level
Nong Khai	No Flood event	(from 16 Aug to 02 Sep 2016)									
		16-Aug	8.75	20-Aug	10.66	4	1.91	No	No	No	Below Alarm Level
Paksane	No Food event	(from 11 July to 18 July 2016)									
		11-Jul	5.07	13-Jul	6.77	2	1.70	No	No	No	Below Alarm Level
Nakhon Phanom	No Food event	(from 11 July to 21 July 2016)									
		11-Jul	5.87	16-Jul	7.57	5	1.70	No	No	No	Below Alarm Level
Thakhet	No Food event	(from 11 July to 21 July 2016)									
		12-Jul	7.1	16-Jul	8.64	4	1.54	No	No	No	Below Alarm Level
Mukdahan	No Food event	(from 11 July to 22 July 2016)									
		12-Jul	5.85	17-Jul	7.20	5	1.35	No	No	No	Below Alarm Level
Savannakhet	No Flood event	(from 4 Jul to 24 Jul 2016)									
		04-Jul	5.02	08-Jul	6.51	4	1.49	No	No	No	Below Alarm Level
Khong Chiam	Flood event	(from 3 Sep to 9 Sep 2019)									Tropical Storms Podul and Kajiki
		03-Sep	15.29	08-Sep	15.72	5	0.43	4-9/Sep		0.09	Above Flood level
Pakse	Flood event	(from 4 Sep to 10 Sep 2019)									Tropical Storms Podul and Kajiki
		04-Sep	11.94	10-Sep	13.60	6	1.66	04-10/Sep		0.28	Above Flood level
Stung Treng	Alarm event	(from 31 August to 19 September 2019)									Tropical Storms Podul and Kajiki
		31-Aug	8.79	07-Sep	11.96	7	3.17	31/Aug-07/Sep		0.45	Reached to Flood level
Kratie	Alarm event	(from 01 Sep to 08 Sep 2019)									Tropical Storms Podul and Kajiki
		01-Sep	19.29	08-Sep	22.72	7	3.43	01-08/Sep		0.49	Above Alarm level
Kompong Cham	Alarm event	(from 02 Sep to 15 Sep 2019)									Tropical Storms Podul and Kajiki
		02-Sep	13.06	15-Sep	15.73	13	2.67	02-15/Sep		0.21	Above Alarm level
Koh Khel	Alarm event	(from 13 September to 06 October 2019)									Tropical Storms Podul and Kajiki
		04-Sep	6.84	12-Sep	7.67	8	0.83	04- 12/Sep		0.10	Above Alarm level

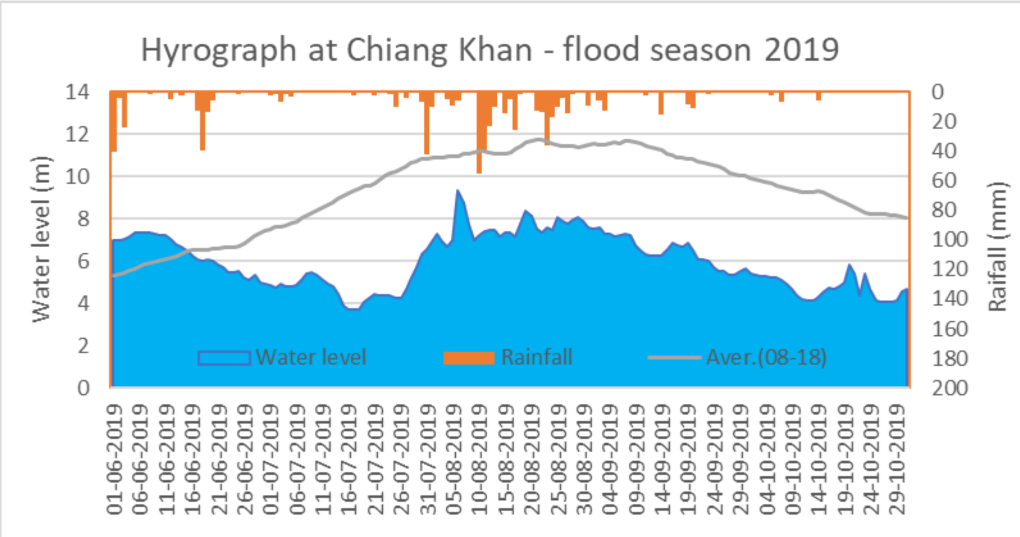
3.1 The flood situation in the Upper Part

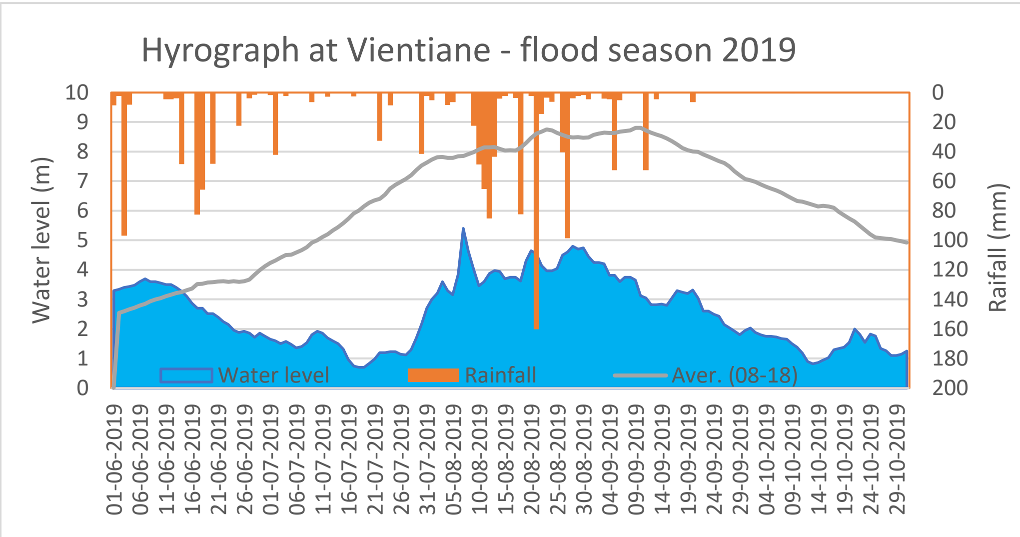
In general, water levels in the upper part from Chiang Saen to Paksane during the wet season 2019 were considered below their LTAs and even lower than their historical minimum levels. Water levels at Chiang Saen, Chaing Khan, Vientiane, Nong Khai and Paksane were below their historical long-term minimum levels during the wet season 2019.

The trend of water levels from Chiang Sean to Paksane decreased due to the low inflows from upstream and less rainfall from the catchments. In general concept, water level at Chiang Sean relies on the inflow at Jinghong Hydropower Station on Lancang river and its catchment rainfall (Adamson. 2010). Starting early wet season 2019, China's Ministry of Water Resources sent an official notification to the MRCS on 03rd July 2019, informing that the outflow of water from the Jinghong hydropower station could fluctuate from 05 to 19 of July 2019. Chiang Saen station mostly relied on rainfall and inflows from upstream and tributaries. The maximum rainfall distribution in the upper part was approximately 400 mm, which was about 200 mm less than the previous years (rainfall in 2018 was 600 mm). Error! Reference source not found.**0** shows the water levels hydrograph associated with the rainfall in the upper part of the Mekong River from Chiang Saen to Paksane, compared with their LTA. Water levels from Thailand's Chaing Saen to Lao PDR's Paksane were below their LTAs, during the wet season 2019.




Hyrograph at Luang Prabang - flood season 2019
Water level (m)
Raifall (mm)
Water level
Rainfall
Aver.(08-19)


Hyrograph at Chiang Khan - flood season 2019
Water level (m)
Raifall (mm)
Water level
Rainfall
Aver.(08-18)


Hyrograph at Vientiane - flood season 2019
Water level (m)
Raifall (mm)
Water level
Rainfall
Aver. (08-18)

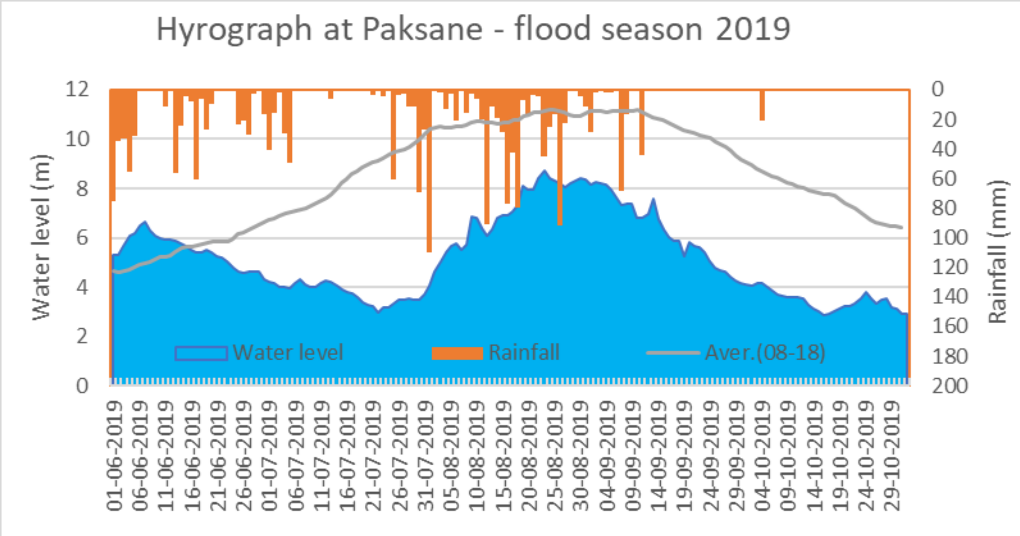


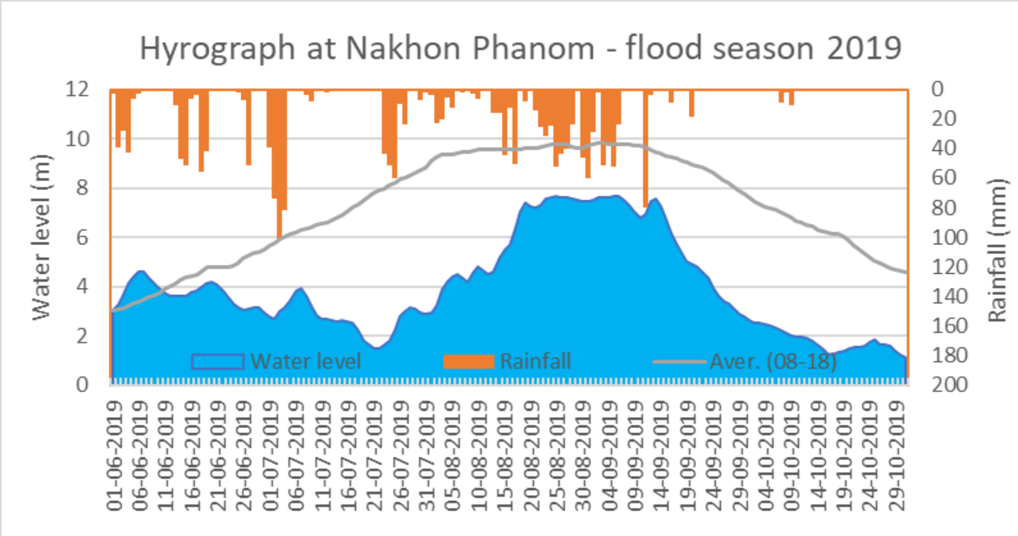
Figure 10: Water level hydrographs with rainfall in the Upper Part

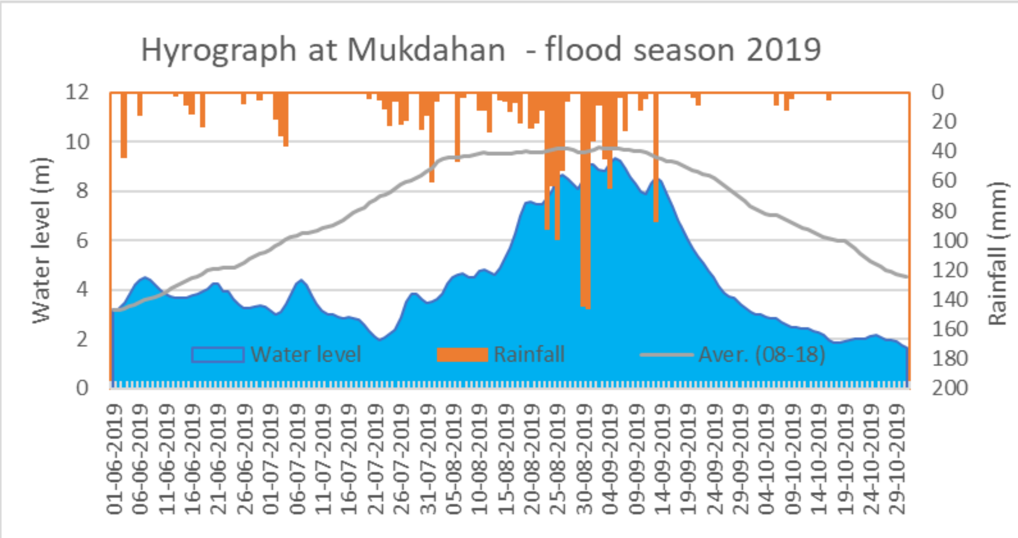
3.2 The flood situation in the Middle part

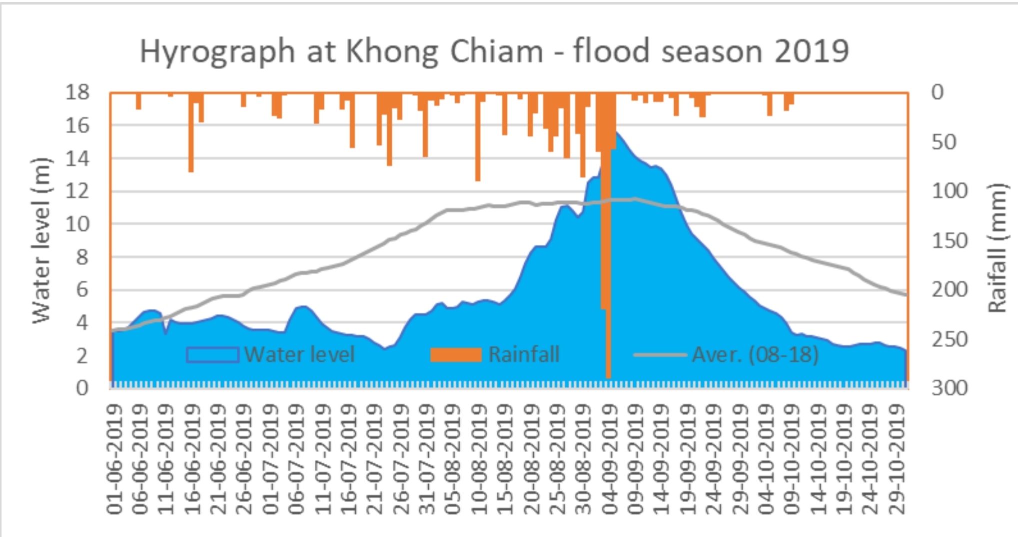
Water levels during the wet season in 2019 in the middle part from Nakhon Phanom to Mukdahan stations followed the same trend as upstream stations, in which water levels significantly decreased and stayed below their historical minimum levels (1980-2018).

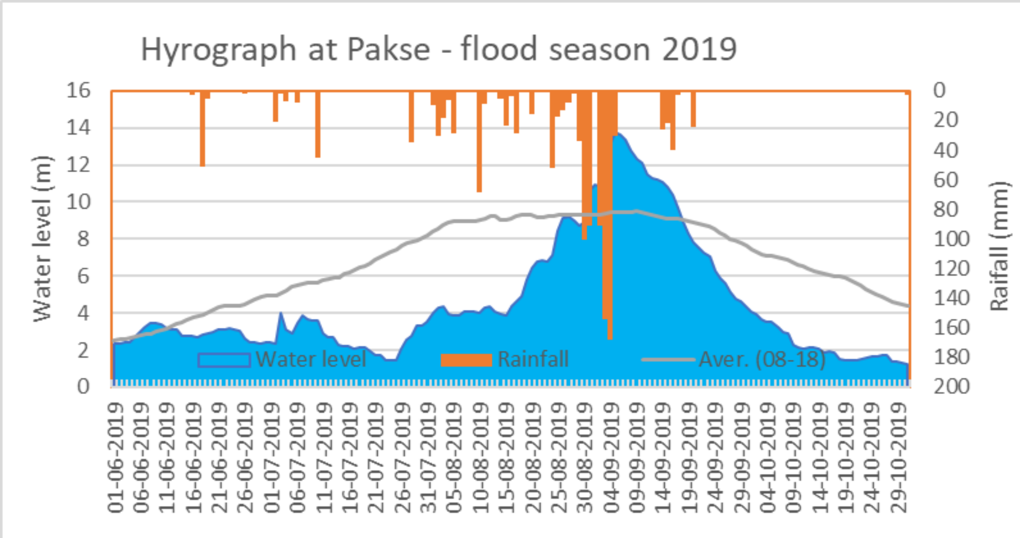
However, it was observed that water levels at the middle part from Nakhon Phanom to Pakse raised with different levels, in which the stations at Nakhon Phanom to Mukdahan did not reach their LTAs but the water levels at the stations Khong Chiam and Pakse reached their flood levels. The flood events happened at Khong Chiam and Pakse began from 30 August to 5 September 2019 due to the tropical storms Podul and Kajiki which brought heavy rainfall. The total maximum rainfall in this area reached over 2000 mm in early September 2019. However, the total rainfall distribution in the middle part was about 800 mm. **Figure 111** shows the water level hydrographs associated with rainfall in the middle part of the Mekong River from Nakhon Phanom to Pakse and the flood effected at Khong Chiam and Pakse due to the Tropical Storms of Podul and Kajiki. **Table 5** shows the flood event characteristics in the Middle Part from Nakhon Phanom in Thailand to Pakse in Lao PDR.

The maximum flood level at Khong Chiam was 15.72 m, which was about 1.22 m higher than its defined flood level (14.50 m). Also, at Pakse the maximum level reached 13.75 m that was about 1.75 m higher than its defined flood level (12 m). These high levels induced overland flows and floods over the area of Khong Chaim and Pakse towns. The flood duration was about 10 days in Pakse.


Hyrograph at Nakhon Phanom - flood season 2019
Water level (m)
Rainfall (mm)
Water level
Rainfall
Aver. (08-18)


Hyrograph at Mukdahan - flood season 2019
Water level (m)
Rainfall (mm)
Water level
Rainfall
Aver. (08-18)


Hyrograph at Khong Chiam - flood season 2019
Water level (m)
Raifall (mm)
Water level
Rainfall
Aver. (08-18)



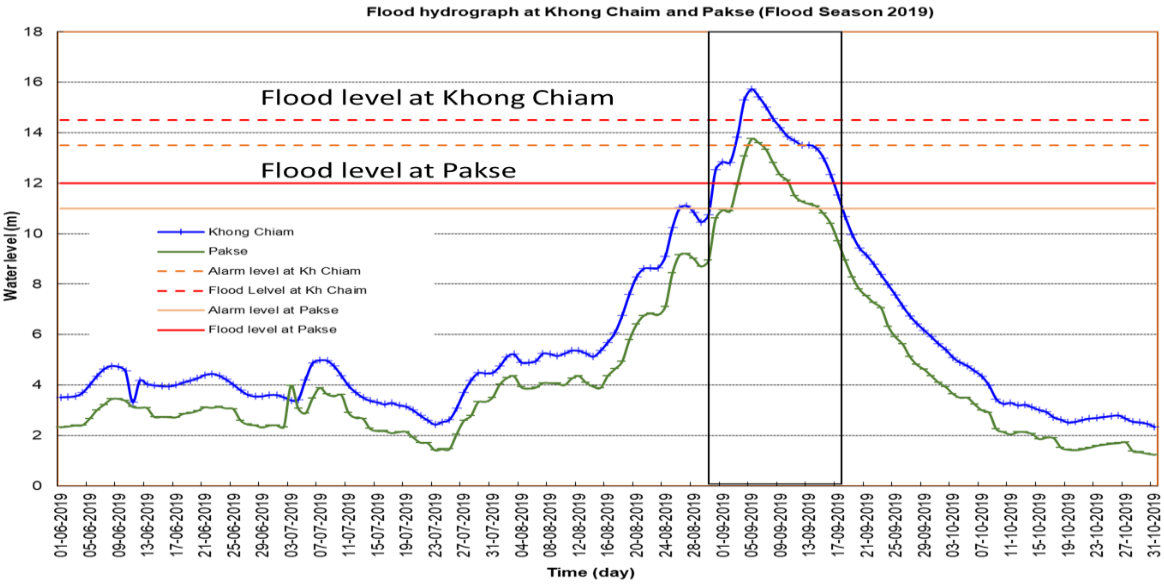


Figure 11: Water level hydrographs with rainfall in the Middel Part

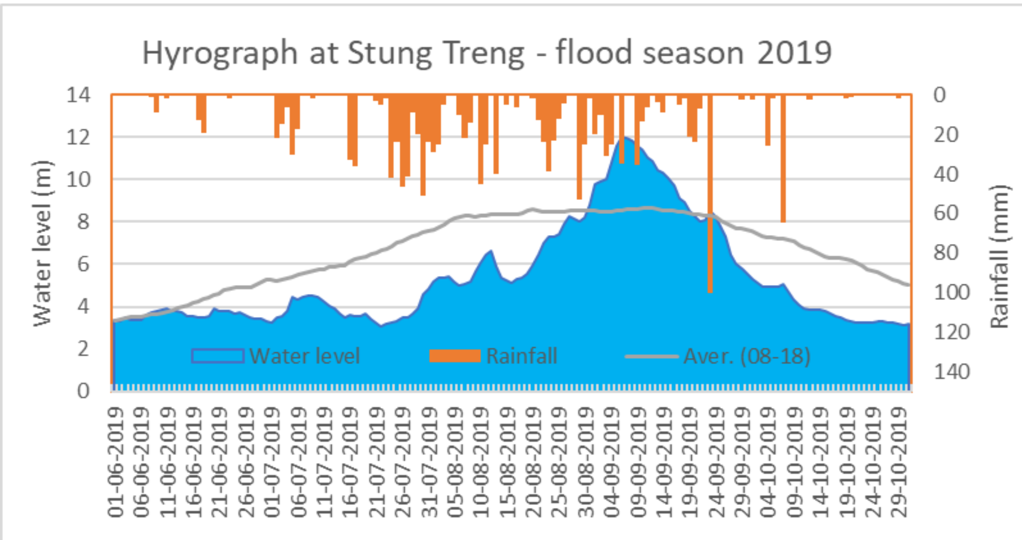
Table 6: Flood event characteristics in the Middle Part

Stations	Number of Flood events	Beginning of Flood Event		Peak of Flood Event		Rising time	Flood Amplitude (m)	Intensity of Flood Rising			Comment
		Date	H_b (m)	Date	H_p (m)	T_p (day)		Interval of I_{max} (Date)	I_{max} (m/day)	Iaverage (m/day)	
Nakhon Phanom	No Food event	(from 11 July to 21 July 2016)									
		11-Jul	5.87	16-Jul	7.57	5	1.70	No	No	No	Below Alarm Level
Thakhet	No Food event	(from 11 July to 21 July 2016)									
		12-Jul	7.1	16-Jul	8.64	4	1.54	No	No	No	Below Alarm Level
Mukdahan	No Food event	(from 11 July to 22 July 2016)									
		12-Jul	5.85	17-Jul	7.20	5	1.35	No	No	No	Below Alarm Level
Savannakhet	No Flood event	(from 4 Jul to 24 Jul 2016)									
		04-Jul	5.02	08-Jul	6.51	4	1.49	No	No	No	Below Alarm Level
Khong Chiam	Flood event	(from 3 Sep to 9 Sep 2019)									Tropical Storms Podul and Kajiki
		03-Sep	15.29	08-Sep	15.72	5	0.43	4-9/Sep		0.09	Above Flood level
Pakse	Flood event	(from 4 Sep to 10 Sep 2019)									Tropical Storms Podul and Kajiki
		04-Sep	11.94	10-Sep	13.60	6	1.66	04-10/Sep		0.28	Above Flood level

3.3 The flood situation in the Lower part

From Stung Trend to Kratie maximum water levels were considered high, in which water levels at Stung Treng reached flood level (12 m), while at Kratie and Kampong Cham they were only over their alarm levels. This was triggered by heavy rainfall in early September due to the storm Kajiki and inflow from Pakse and the upstream of the 3S (Sekong, Sesan and Srepok) area.

Figure 122 presents the water level hydrographs and total rainfall and the peak hydrograph from Stung Treng to Kompong Cham. **Table 7** shows the flood event characteristics in the Lower Part from Stung Treng to Koh Khel in Cambodia.



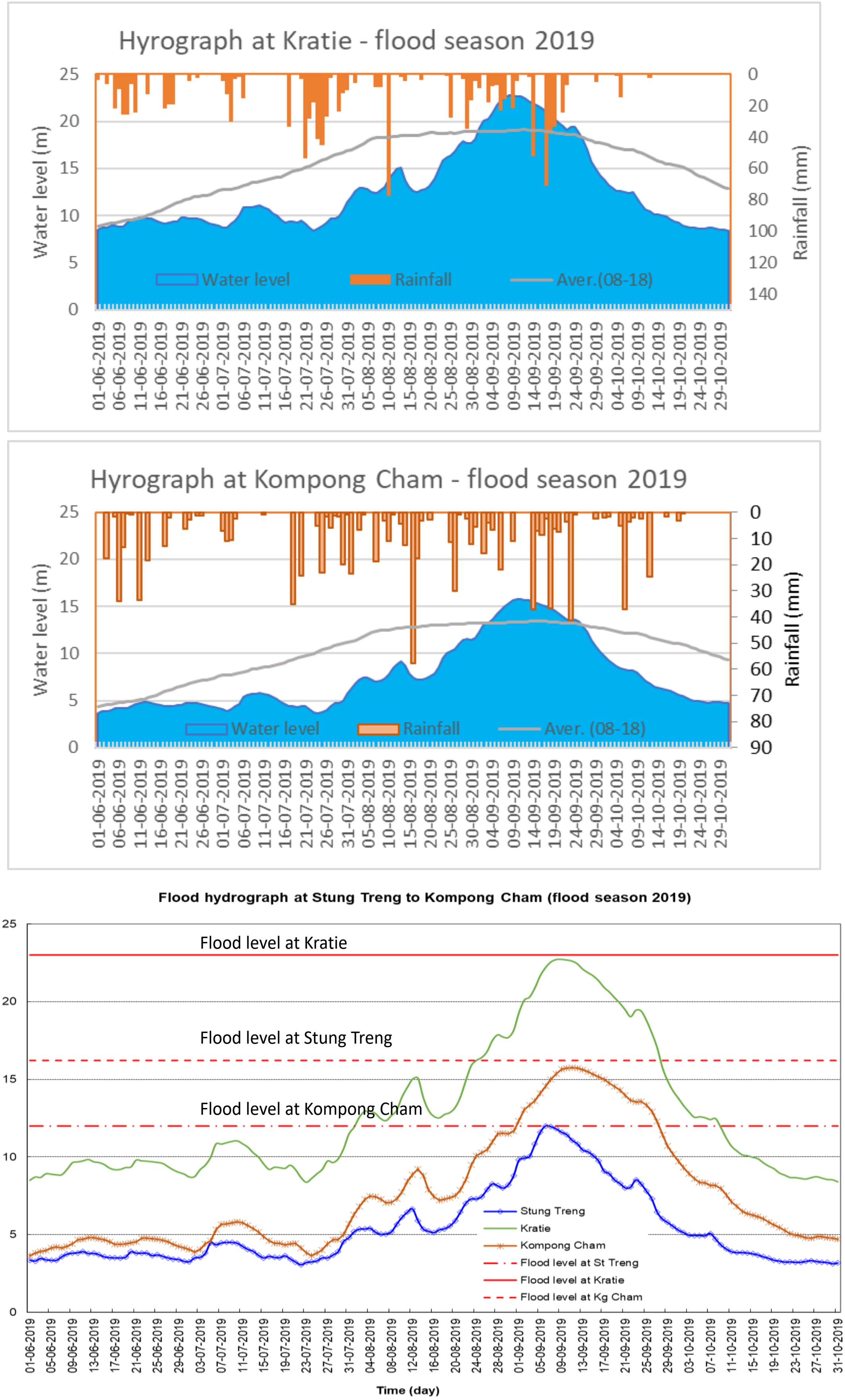
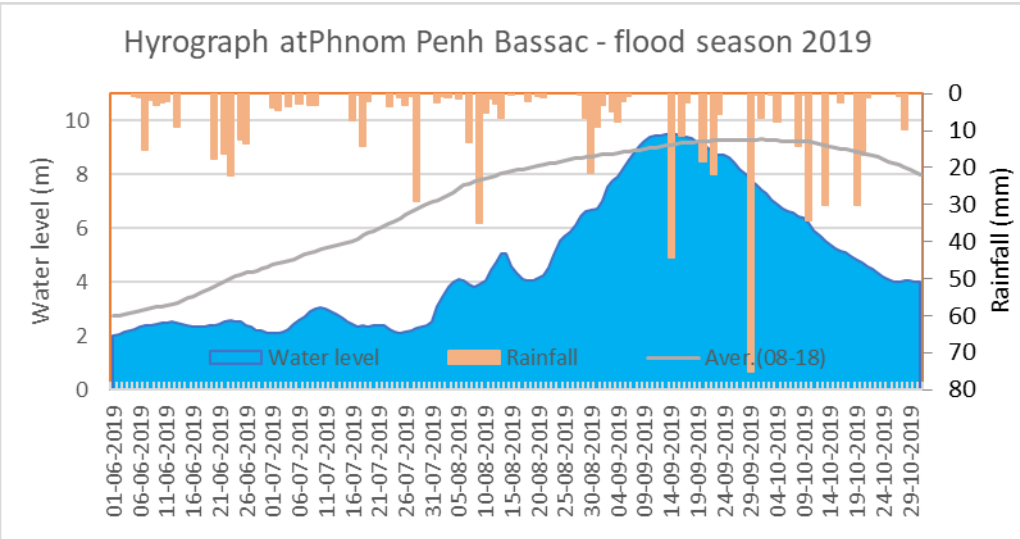


Figure 122: Water level hydrographs with rainfall in the Lower Part (Stung Treng to Kampong Cham)

Table 7: Flood event characteristics in the Lower Part (Stung Treng to Koh Khel)

Stations	Number of Flood events	Beginning of Flood Event		Peak of Flood Event		Rising time	Flood Amplitude (m)	Intensity of Flood Rising			Comment
		Date	H_b (m)	Date	H_p (m)	T_p (day)		Interval of I_{max} (Date)	I_{max} (m/day)	Iaverage (m/day)	
Stung Treng	Alarm event	(from 31 August to 19 September 2019)									Tropical Storms Podul and Kajiki
		31-Aug	8.79	07-Sep	11.96	7	3.17	31/Aug-07/Sep		0.45	Reached to Flood level
Kratie	Alarm event	(from 01 Sep to 08 Sep 2019)									Tropical Storms Podul and Kajiki
		01-Sep	19.29	08-Sep	22.72	7	3.43	01-08/Sep		0.49	Above Alarm level
Kompong Cham	Alarm event	(from 02 Sep to 15 Sep 2019)									Tropical Storms Podul and Kajiki
		02-Sep	13.06	15-Sep	15.73	13	2.67	02-15/Sep		0.21	Above Alarm level
Koh Khel	Alarm event	(from 13 September to 06 October 2019)									Tropical Storms Podul and Kajiki
		04-Sep	6.84	12-Sep	7.67	8	0.83	04- 12/Sep		0.10	Above Alarm level

Water levels during the wet season 2019 at Phnom Penh Bassac and Koh Khel on the Bassac River, Neak Luong on the Mekong, and Prekdam and Phnom Penh Port on the Tonle Sap River were influenced mostly by inflow and rainfall from upstream. During the rainfall season, water levels at Phnom Penh Bassac, Prekdam and Neak Luong increased up to their LTAs, except Koh Khel where water levels reached over the Alarm Level at 7.68 m on 15 September 2019. **Figure 133** shows the water level hydrographs at these stations with the total rainfall from Phnom Penh Bassac, Koh Khel, Prekdam and Neak Luong downstream of the Mekong River in Cambodia. Total maximum rainfall in this area was about 250 mm at the flood peak period by end of September 2019.



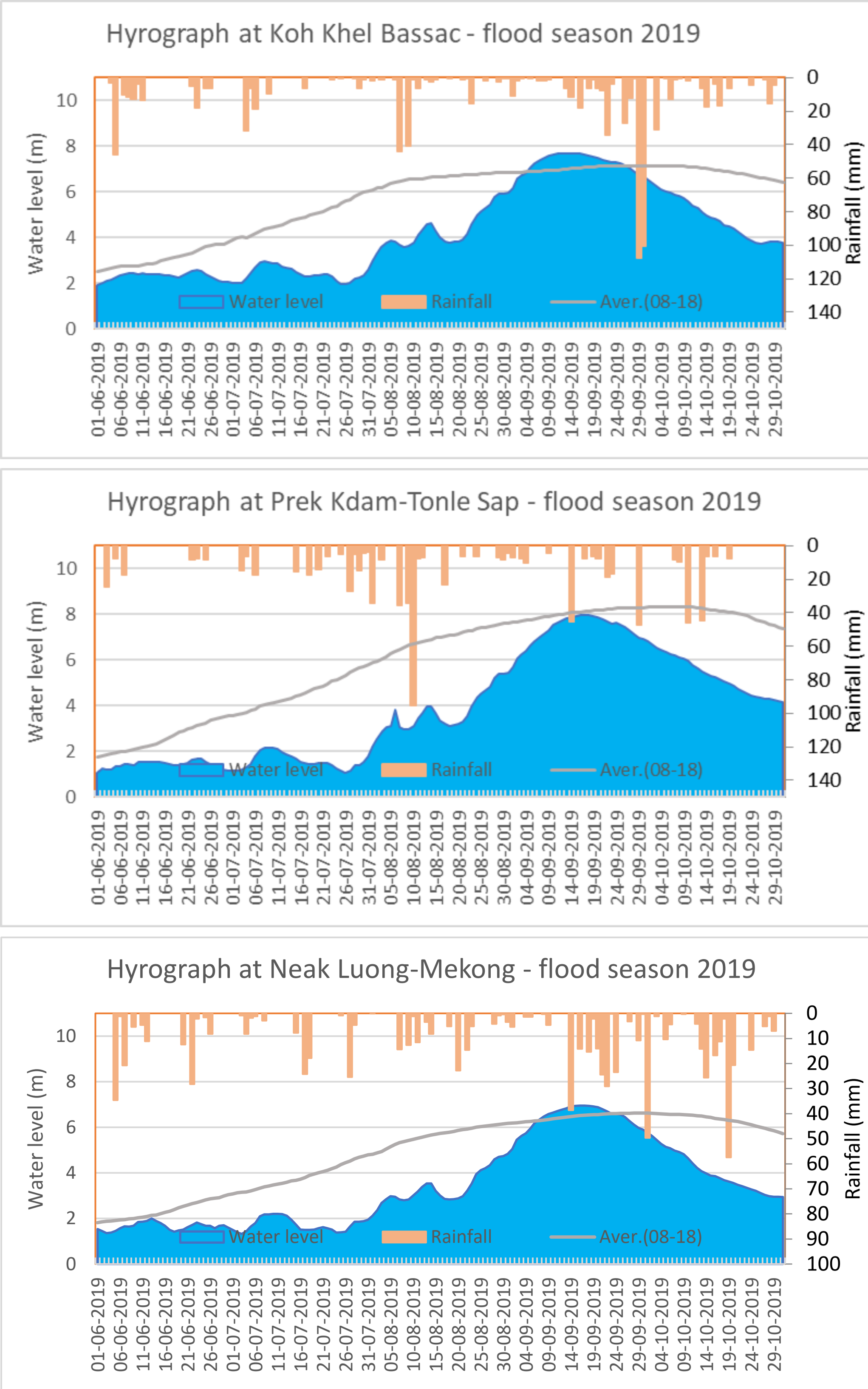


Figure 133: Water level hydrographs with rainfall in the Lower Part (Downstream)

3.4 The flood situation in the Mekong Delta

In the Mekong Delta there are two tide cycles per day. Examination of the data shows that there are also two tide cycles per month. At Tan Chau and Chau Doc, the high cycle peaks are just over 1.2 m gauge height while the low cycle peaks are around 0.5 m or slightly lower (FMMP, 2013). It was observed that, at Tan Chau and Chau Doc, there was evidence of tidal influence even at the peak of the flood in early October. Close examination of the recorded hourly water levels around this time indicated that this influence of the daily tide has an effect of less than 50 mm on the level of the flood peak on a particular day. This means that the highest water levels at Tan Chau and Chau Doc during high flows will be co-incident with the highest tide of the day and will only be about 50 mm higher than the water level co-incident with the lowest tide of the day.

From the beginning of June to October 2019 water levels at these stations were fluctuating below their LTAs but did not follow the same trend as previous years as indicated in **Annex C**. However, at the end of September water levels at these statins reached Alarm Levels at about 3 m to 3.5 m.

Figure 144 shows the water levels hydrographs with total rainfall at Tan Chau and Chau Doc

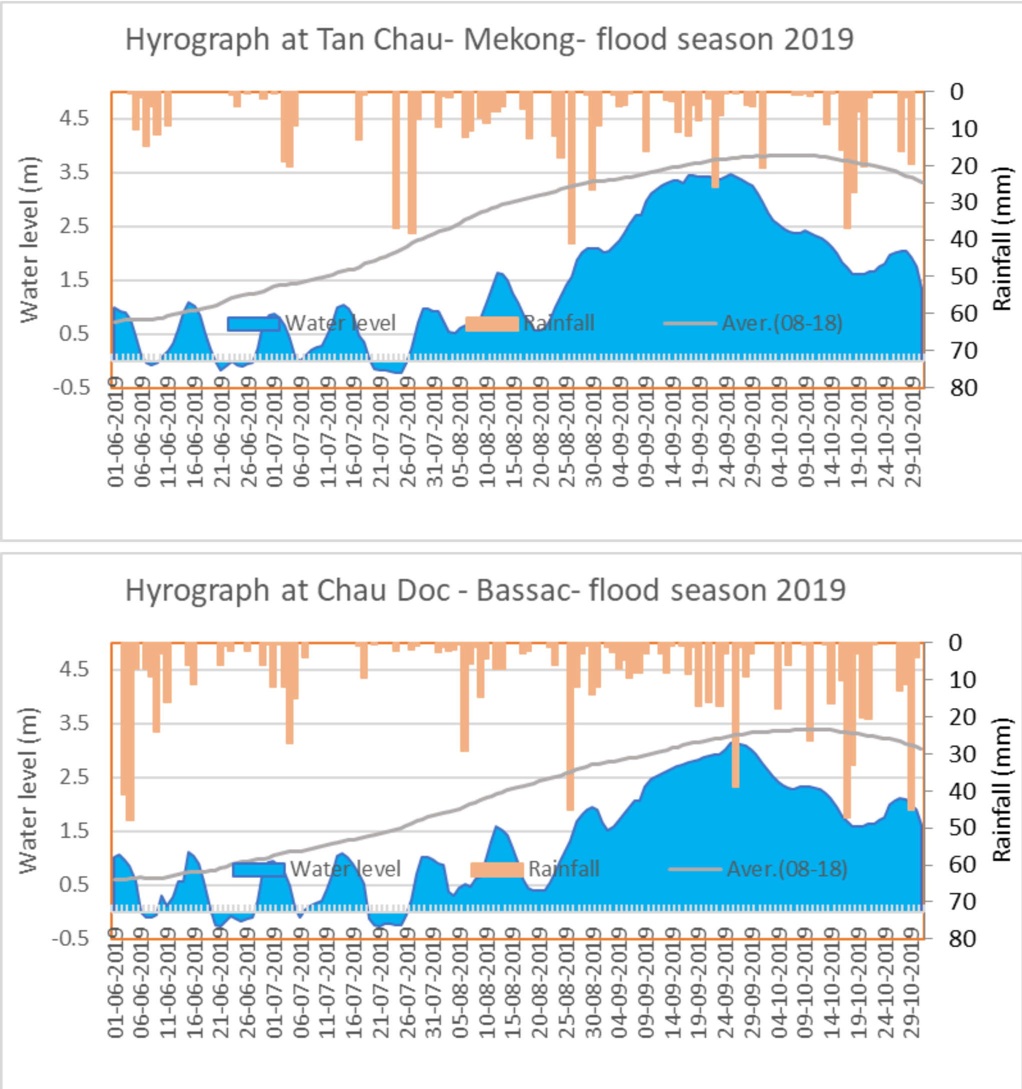


Figure 144: Water level hydrographs with rainfall in the Mekong Delta

The total maximum rainfall was about 250 mm in the Delta area. This might have been affected by the El Nino process in the South China Sea, based on the information provided by the Japan Meteorological Agency (JMA).

According to the JMA the sea surface temperature (SST) variability in the tropics could significantly impact on the global climate through atmospheric circulation. The El Niño event, which was identified by the SST fluctuations from the central to the eastern equatorial Pacific (NINO.3) is a widely known examples of this impact. The five-month running mean of the SST deviation for NINO.3 predicted by JMA's El Niño prediction model is presented in **Figure 155**.

YEAR	MONTH	mean period		
2019	APR	FEB2019–JUN2019	100	
	MAY	MAR2019–JUL2019	100	
	JUN	**APR2019–AUG2019**	70	30
	JUL	**MAY2019–SEP2019**	70	30
	AUG	**JUN2019–OCT2019**	60	40
	SEP	**JUL2019–NOV2019**	60	40
	OCT	**AUG2019–DEC2019**	60	40

El Niño ENSO neutral La Niña

Figure 155: Five-month running mean of the SST deviation for NINO.3 predicted (JMA/MRI-CGCM2)

4 Data Collection from Line Agencies (LAs)

Hydro-meteorological data collection is a core activity of the Mekong River Commission (MRC) since the establishment of the Mekong Committee in 1957. The daily data collection consists of observed water levels and rainfall data collected from the LAs.

The MRC has established data sharing memorandums of understanding (MoUs) with the principal water resource agencies in each MC. They provide a formal agreement between the MRCS and the MC for data collection and transfer from the national LA to the RFDMC. The objective of these MoUs is to secure understanding and agreement in principle to deliver from the MCs directly to the RFDMC daily real time and near-real time water level and rainfall data (operational data) to be used in the production of the flood and drought monitoring and forecasting. The data serves as main input for the MRC-RFFS. **Table 8** showed the National Line Agencies at each member country that provided daily and weekly operational data for RFF. **Table 9** showed the received operational data via HydMet Software from each member country and China via HydMet software for RFDMC. **Figure 136** and **Figure 137** shows the water levels and rainfall data stations, sending by National Line Agencies to RFDMC via Hydmet software.

Table 8: Name of National Line Agencies

Country	National Line Agencies
Cambodia:	Department of Meteorology (DOM), Ministry of Water Resources and Meteorology
Lao PDR:	Department of Meteorology and Hydrology (DMH), Ministry of Natural Resources and Environment
Thailand:	Department of Water Resources (DWR), Ministry of Natural Resources and Environment
Viet Nam:	1.Highland Regional Hydro-Meteorological Center (HRHMC) and,
	2. Southern Regional Hydro-Meteorological Center (SRHMC)

All the gauged manual and automatic water level and rainfall data is collected by the HYDMET system as a data collection software with import/export routines for data transfer from the LAs of each MC to the RFDMC. The data transfer is based on an FTP server. The following data is transferred:

1. **Manual water level** from 63 stations **and rainfall data** from 127 stations are sent by the Line Agencies (LAs) of each MC. Two recordings a day of the water level (7 am and 7 pm) and 24-hr rainfall data are received every day till 9:00 am local time during the wet season starting from 1st June to 31st October and weekly on Monday during dry season;
2. **Automatic water levels and rainfall data** from the MCs are sent automatically every 15-minutes time-steps from 58 stations from the telemetric stations network, 45 stations belong to the Mekong-Hydro Meteorological Cycle Observation System (Mekong-HYCOS) and 13

stations belong to drought project;

Table 9: List of Hydro-meteorological stations which provided the data to RFDMC during the wet season 2019

Country	Number of Water level Stations	Number Telemetry Stations
Cambodia	15	12
Lao PDR	26	12
Thailand	13	11
Viet Nam	9	10
China	2	
Total	**63**	**45**

Country	Number of Rainfall Stations
Cambodia	42
Lao PDR	28
Thailand	13
Viet Nam	42
China	2
Total	**127**

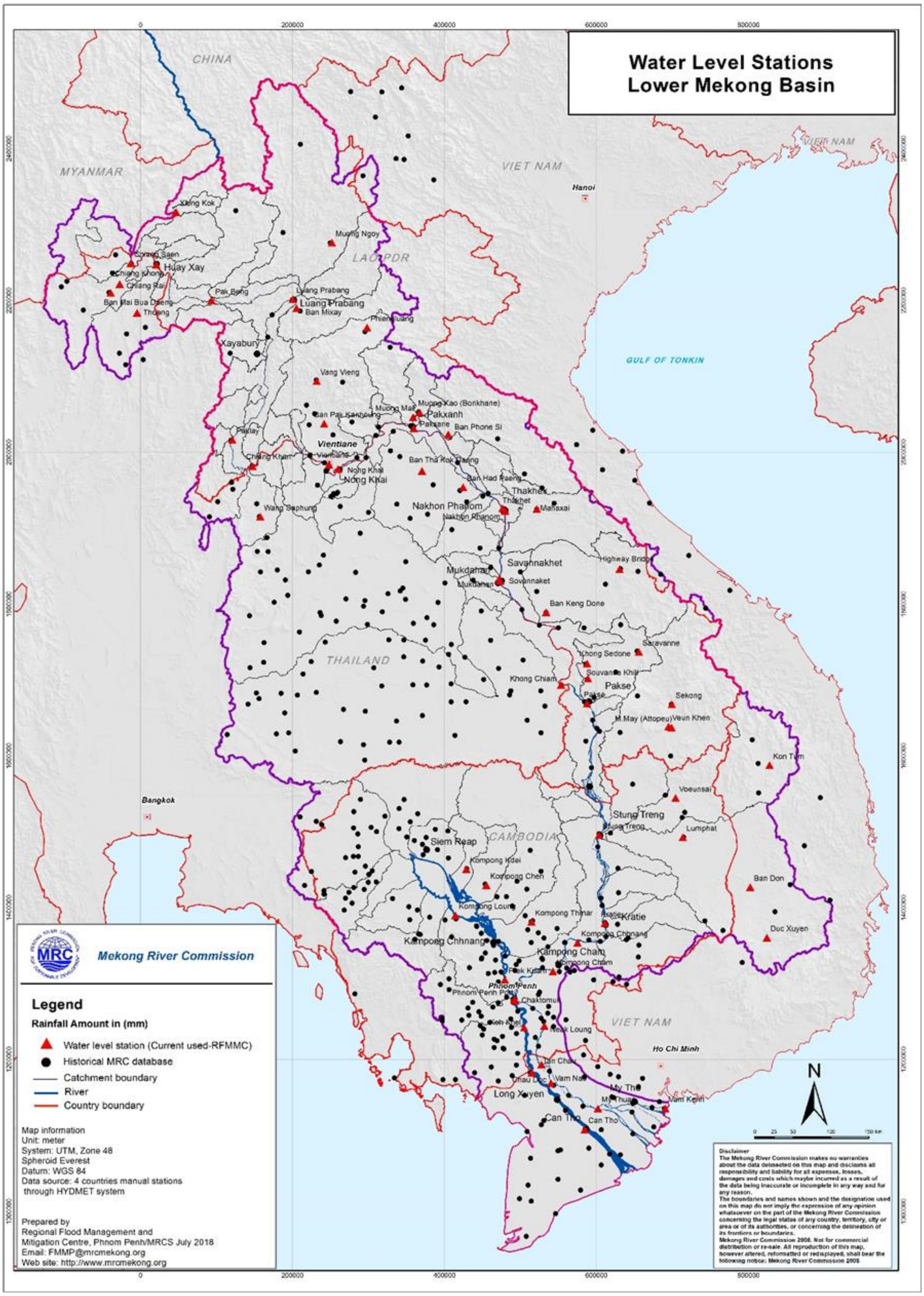


Figure 16: Map of water level stations data sending by Naitonal Line Agencies for wet season 2019

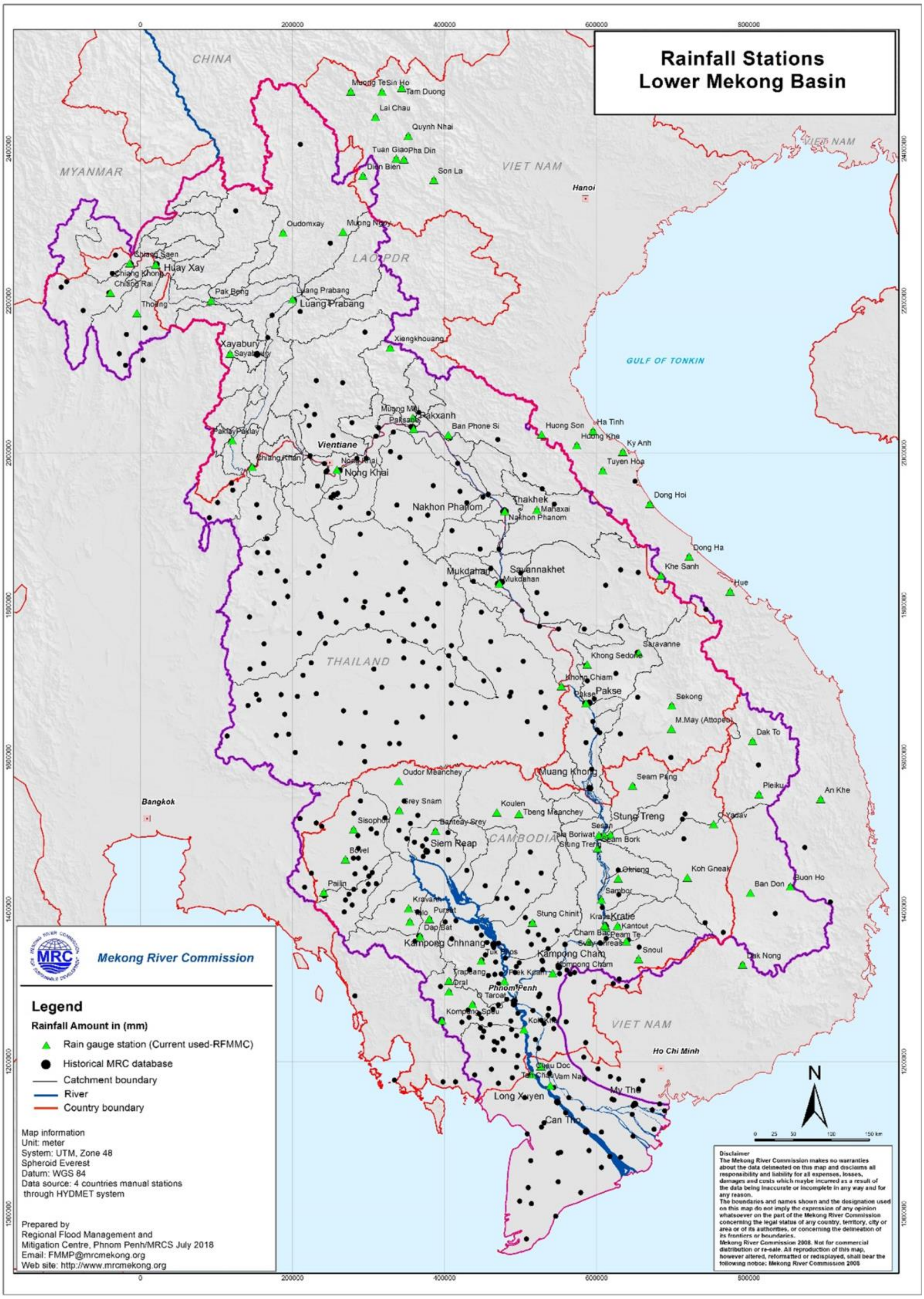


Figure 17: Map of rainfall stations data sending by Naitonal Line Agencies for wet season 2019

As normal practise, hydro-met data should arrive before 09:00 am. However, in 2019 there were some problems of data sending on time due to low internet frequencies at countries levels, software problems and human issues (late data transfer from observers).

4.1 Data transfer from stations to the DHRW data terminal

Table 10: Number of Late Arrival Data and Missing Data of DHRW

Station	Total	Missing	On-time(9:00)	Late-time (after 09:00)
Stung Treng	153	0	149	4
Kratie	153	0	149	4
Kompong Cham	153	0	149	4
Chaktomuk	153	0	149	4
Phnom Penh Port	153	0	148	5
Neak Loung	153	0	149	4
Koh Khel	153	0	148	5
Prek Kdam	153	0	149	4
Kompong Loung	153	0	149	4
Voeunsai	153	0	150	3
Kompong Chen	153	0	147	6
Kompong Chhnang	153	0	148	5
Kompong Kdei	153	0	147	6
Kompong Thmar	153	0	147	6
Lumphat	153	0	147	6

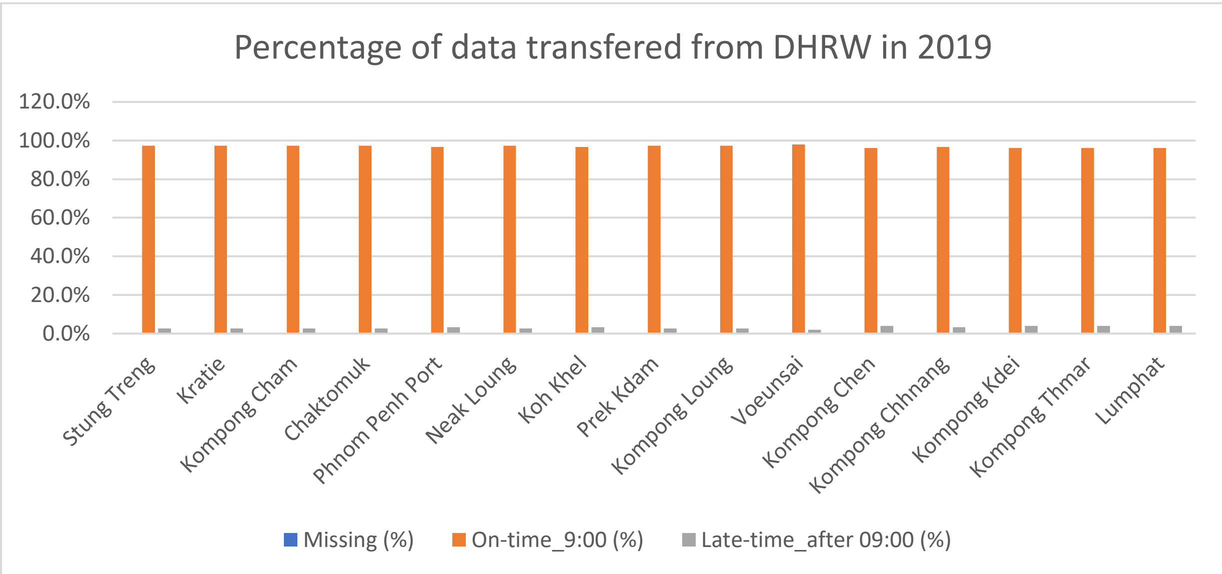


Figure 18: Percentage of Timely Arrival Data (before 8.30 am), Late Arrival Data and Missing Data collected on the Hydmet at DHWR data terminal during wet season 2019 *(histogram)*

4.2 Data transfer from stations to DOM data terminal

Table 11: Number of Late Arrival Data and Missing Data of DOM

Station	Total	Missing	On-time(9:00)	Late-time (after 09:00)
Banteay Srey	153	0	151	2
Sadan	153	0	151	2
Sambor	153	0	151	2
Snoul	153	0	151	2
Srey Snam	153	0	151	2
Talo	153	0	151	2
Sre Noy	153	0	151	2
Sisophon	153	0	151	2
Okrieng	153	0	151	2
O Yadav	153	0	151	2
Koh Gneak	153	0	151	2
Koulen	153	0	151	2
Tbeng Meanchey	153	0	151	2
Oudor Meanchey	153	0	151	2
Kompong Speu	153	0	151	2
Oral	153	0	151	2
O Taroat	153	0	151	2
Trapeang	153	0	151	2
Pailin	153	0	151	2
Pursat	153	0	151	2
Mung Russey	153	0	151	2
Dap Bat	153	0	151	2
Kravanh	153	0	151	2
Tuk Phos	153	0	151	2
Stung Chinit	153	0	151	2
Cham Bac	153	0	151	2
Peam Te	153	0	151	2
Svay Chreas	153	0	151	2
Kantout	153	0	151	2
Seam Bork	153	0	151	2
Tala Boriwat	153	0	151	2
Sesan	153	0	151	2
Seam Pang	153	0	151	2
Bovel	153	0	151	2

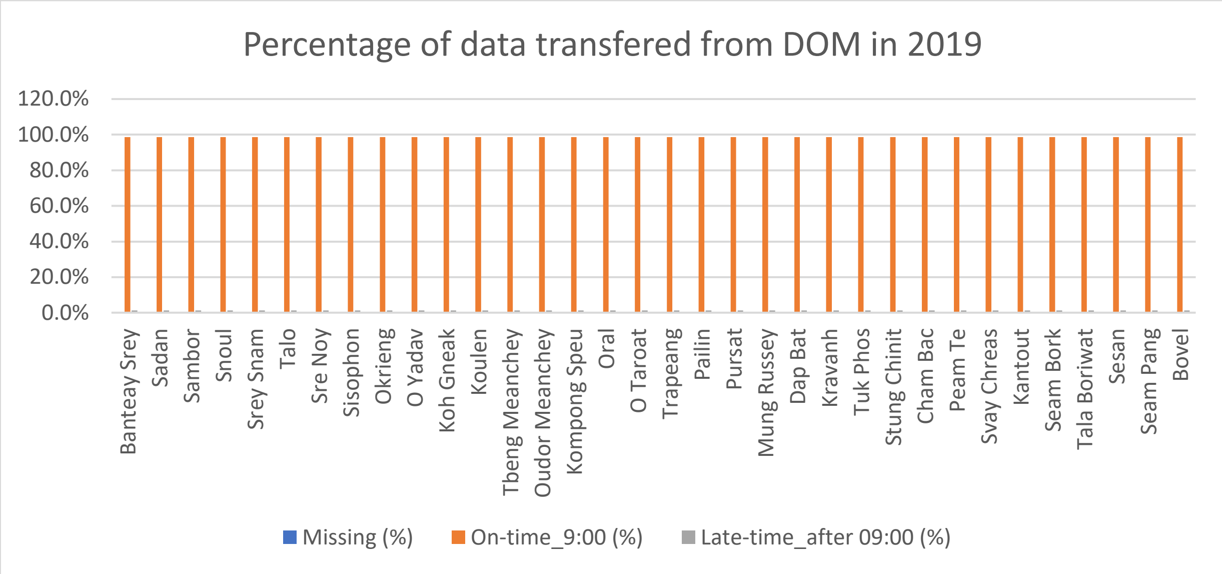


Figure 19: Percentage of Timely Arrival Data (before 8.30 am), Late Arrival Data and Missing Data collected on the Hydmet at DOM data terminal during wet season 2019 *(histogram)*

4.3 Data transfer from stations to the DMH data terminal

Table 12: Number of Late Arrival Data and Missing Data of DMH

Station	Total	Missing	On-time(9:00)	Late-time (after 09:00)
Xieng Kok	153	153	153	0
Pak Beng	153	0	124	29
Luang Prabang	153	0	122	31
Paklay	153	28	122	31
Vientiane	153	0	121	32
Paksane	153	0	118	35
Thakhet	153	0	117	36
Sovannaket	153	0	117	36
Pakse	153	0	123	30
Ban Pak Kanhoung	153	0	118	35
Muong Mai	153	0	117	36
Ban Phone Si	153	0	117	36
Muong Kao (Borikhane)	153	0	114	39
Mahaxai	153	0	117	36
Khong Sedone	153	0	114	39
Saravanne	153	0	114	39
Veun Khen	153	0	122	31
M.May (Attopeu)	153	0	125	28
Muong Ngoy	153	0	121	32
Ban Mixay	153	153	150	3
Sayaboury	153	153	153	0
Vang Vieng	153	20	140	13
Phiengluang	153	0	112	41
Oudomxay	153	153	153	0
Moung Namtha	153	153	153	0
Xiengkhouang	153	153	153	0
Ban Keng Done	153	153	151	2
Highway Bridge	153	0	115	38
Ban Kengkok	153	0	136	17
Souvanna Khill	153	0	126	27
Muong Techpon	153	0	125	28
Sekong	153	0	119	34

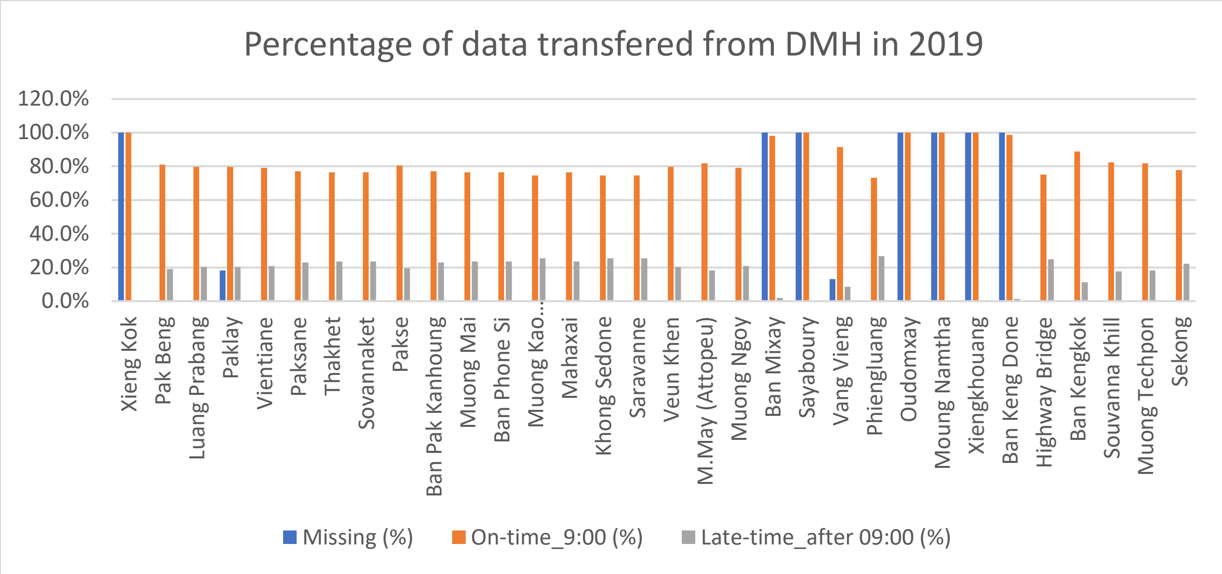


Figure 20: Percentage of Timely Arrival Data (before 8.30 am), Late Arrival Data and Missing Data collected on the Hydmet at DMH data terminal during wet season 2019 *(histogram)*

4.4 Data transfer from stations to the DWR data terminal

Table 13: Number of Late Arrival Data and Missing Data of DWR

Station	Total	Missing	On-time(9:00)	Late-time (after 09:00)
Chiang Saen	153	0	150	3
Chiang Khong	153	0	150	3
Chiang Khan	153	0	150	3
Nong Khai	153	0	148	5
Nakhon Phanom	153	0	150	3
Mukdahan	153	0	150	3
Khong Chiam	153	0	149	4
Ban Mai Bua Daeng	153	0	152	1
Thoeng	153	0	147	6
Wang Saphung	153	0	148	5
Ban Tha Kok Daeng	153	0	150	3
Ban Had Paeng	153	0	150	3
Chiang Rai	153	0	150	3

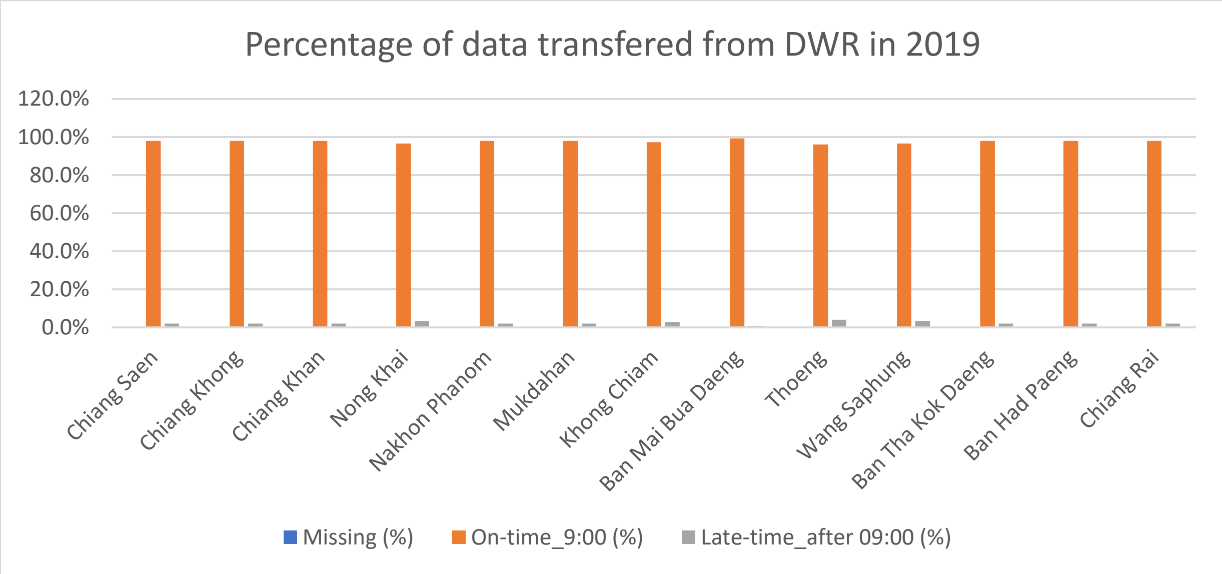


Figure 21: Percentage of Timely Arrival Data (before 8.30 am), Late Arrival Data and Missing Data collected on the Hydmet at DWR data terminal during wet season 2019

4.5 Data transfer from stations to the SRHMC data terminal

Table 14: Number of Late Arrival Data and Missing Data of SRHMC

Station	Total	Missing	On-time(9:00)	Late-time (after 09:00)
Tan Chau	153	0	150	3
Chau Doc	153	0	151	2
Vam Nao	153	0	150	3
My Thuan	153	0	149	4
Can Tho	153	0	151	2
Vam Kenh	153	0	149	4

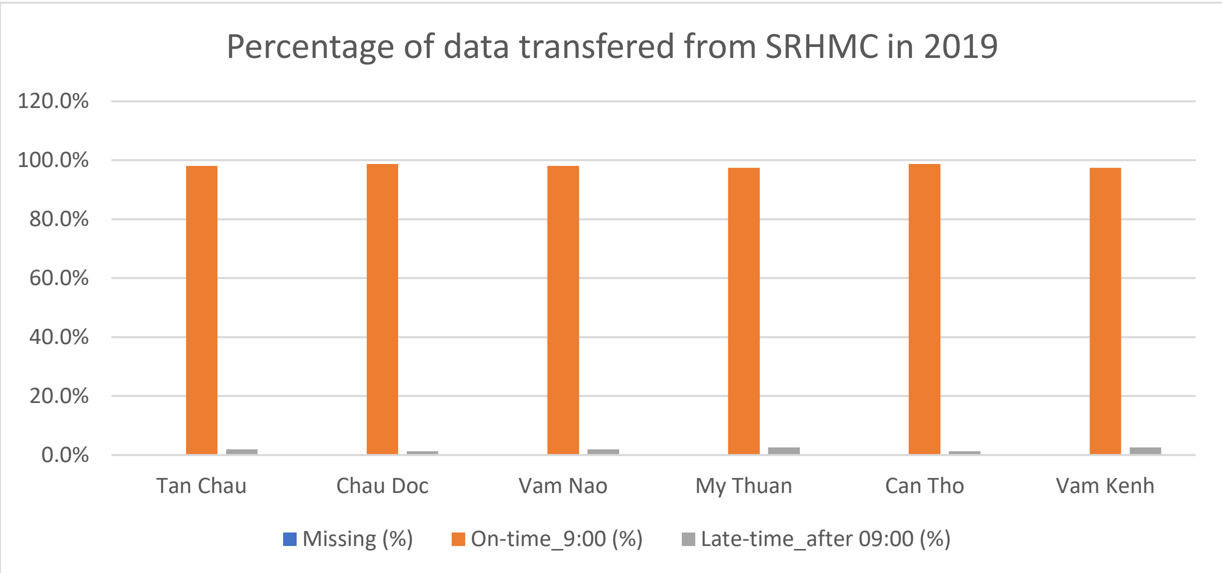


Figure 22: Percentage of Timely Arrival Data (before 8.30 am), Late Arrival Data and Missing Data collected on the Hydmet at SRHMC data terminal during wet season 2019 *(histogram)*

4.6 Data transfer from stations to the HMS data terminal

Table 15: Number of Late Arrival Data and Missing Data of HMS

Station	Total	Missing	On-time(9:00)	Late-time (after 09:00)
Ban Don	153	0	152	1
Kon Tum	153	0	152	1
Duc Xuyen	153	0	152	1
Muong Te	153	0	152	1
Tam Duong	153	0	152	1
Sin Ho	153	0	152	1
Lai Chau	153	0	152	1
Tuan Giao	153	0	152	1
Dien Bien	153	0	152	1
Quynh Nhai	153	0	152	1
Khe Sanh	153	0	152	1
Son La	153	0	152	1
Huong Khe	153	0	152	1
Ha Tinh	153	0	152	1
Ky Anh	153	0	152	1
Tuyen Hoa	153	0	152	1
Dong Hoi	153	0	152	1
Dong Ha	153	0	152	1
A Luoi	153	0	152	1
Hue	153	0	152	1
Dak To	153	0	152	1
Pleiku	153	0	152	1
An Khe	153	0	152	1
Ayunpa	153	0	152	1
Buon Me Thuoc	153	0	152	1
Mdrak	153	0	152	1
Dak Nong	153	0	152	1
Buon Ho	153	0	152	1
Huong Son	153	0	152	1
Pha Din	153	0	152	1
Yen Chau	153	0	152	1
Mai Chau	153	0	152	1
Tuong Duong	153	0	152	1
Con Cuong	153	0	152	1
Tay Ninh	153	0	152	1
Phuoc Long	153	0	152	1
Dong Xoai	153	0	152	1
Ialy	153	0	152	1

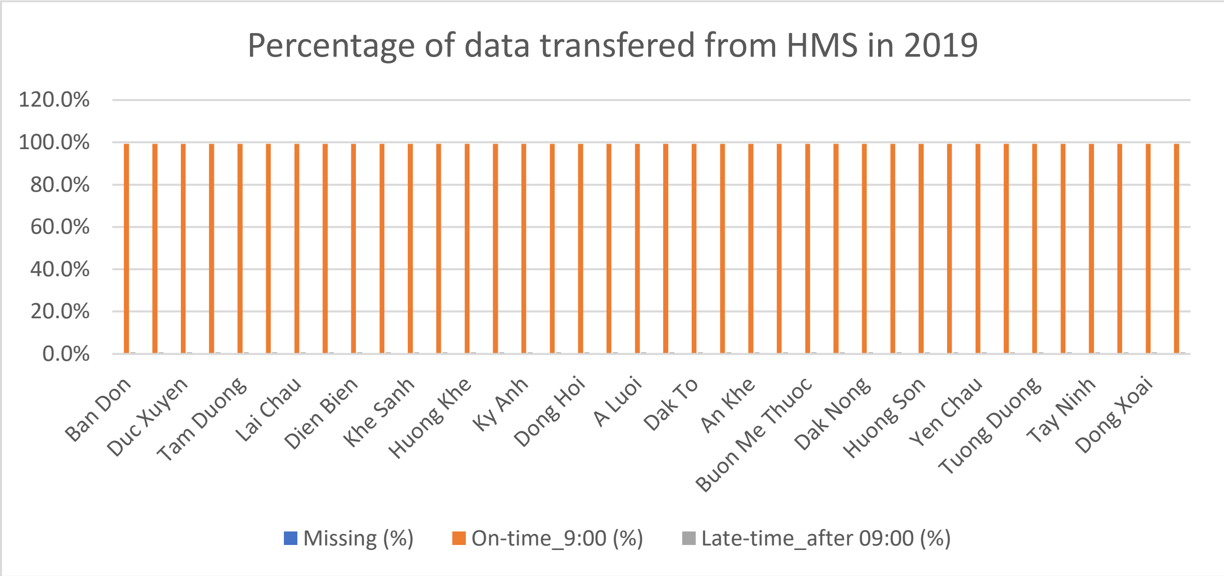


Figure 23: Percentage of Timely Arrival Data (before 8.30 am), Late Arrival Data and Missing Data collected on the Hydmet at HMS data terminal during wet season 2019 *(histogram)*

5 Performance of the River Flood Forecasting System (MRC-RFFS)

This chapter analysis the performance of the MRC-RFFS and the accuracy of the River Flood Forecasts (RFF) issued by the RFDMC in the wet season 2019.

5.1 Analysis of Dissemination

The performance indicators for timely dissemination of the daily bulletin (see **Table 16** and **Figure 24** to **Figure 26** and **26** Table 16: Overview of performance indicators from Jun to Oct 2019 show that the flood bulletins, containing flood situation information, were disseminated timely to the registered LAs, MRC website, and other interested stakeholders around 10:30 am. This corresponds to the defined timeframe of the operational procedures.

However, sometimes the bulletin was disseminated later than 10:30 am due to three main factors:

- Late transfer and incomplete data from LA's during wet season due to human issue (observers, focal point for data collection and transferring),
- Internet network cut-off at specific areas in the MCs and tool download (HYDMET) was stuck or stood still,
- Critical weather situations in the LMB, flow influenced by hydropower operation and or the significant tidal effect in the Mekong delta resulted in difficulties for the forecaster-in-charge to conduct the analysis and adjustment of the forecast results on time, leading to the late bulletin dissemination.

Table 16: Overview of performance indicators from Jun to Oct 2019

2019	FF completed and sent (time)	Stations without forecast	FF2 completed and sent (time)	Weather data available (time)	NOAA data/2dataset	China	Cambodia - DHRW	Cambodia - DOM	Lao PDR - DMH	Thailand - DWR	Viet Nam - SRHMC	Viet Nam - HMS	NOAA data/2dataset	China/2	Cambodia - DHRW/15	Cambodia - DOM/34	Lao PDR - DMH/32	Thailand - DWR/13	Viet Nam - SRHMC/6	Viet Nam - HMS/39
Jun	10:35	0	-	-	08:15	07:10	08:04	09:02	09:03	10:11	08:24	08:24	0	0	0	0	13	0	0	0
Jul	10:41	0	-	-	08:15	07:10	07:27	07:40	09:21	08:26	07:01	08:11	0	0	0	0	10	0	0	0
Aug	10:39	0	-	-	08:15	07:10	06:24	07:37	09:04	08:14	07:57	08:17	0	0	0	0	7	0	0	0
Sep	10:25	0	-	-	08:15	07:10	07:21	07:55	09:15	08:15	08:16	08:16	0	0	0	0	10	0	0	0
Oct	10:37	0	-	-	08:15	07:10	06:20	08:04	08:29	08:08	07:02	08:29	0	0	0	0	12	0	0	0

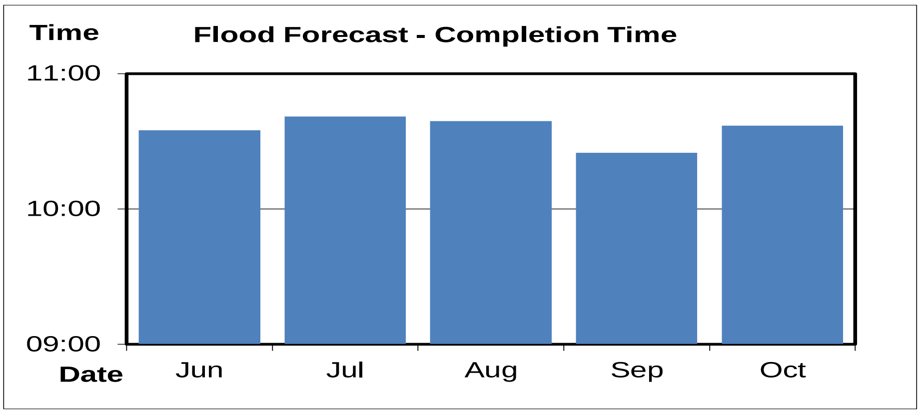


Figure 24: Flood forecast completion time from Jun to Oct 2019

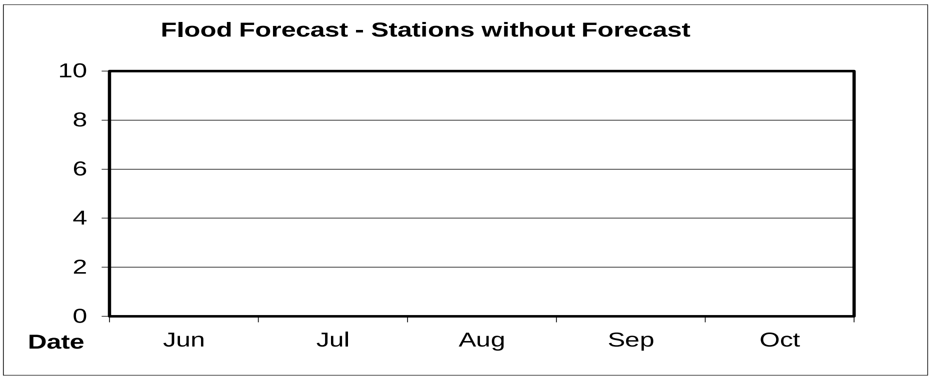


Figure 25: Number of flood forecast stations without forecast from Jun to Oct 2019

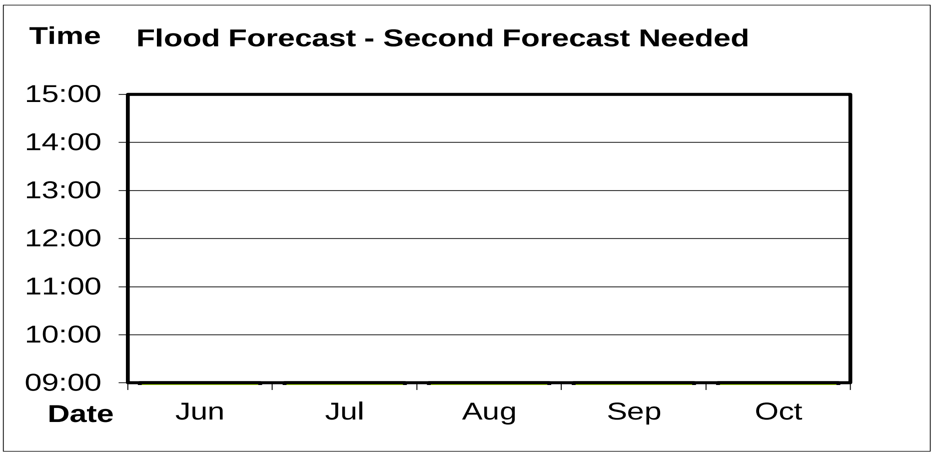


Figure 26: Number of flood forecast stations where second forecast was needed from Jun to Oct 2019

5.2 Analysis of the Accuracy of the River Flood Forecasts

Accuracy is an important factors to establish the quality of the forecast results, and is described here as the Mean Absolut Difference (MAD) in centimetres between the approved results of the MRC-RFFS ('adjusted' or 'not adjusted' by the Flood Forecaster in charge) and the measured and reported water levels by the LAs. The 'adjustment' by the Flood Forecaster in charge takes into consideration known biases in input data and the knowledge of the response of the model system and the hydrology of the LMB.

5.2.1 General analysis of the Wet Season 2019

Figure 27 shows in a graphic the average flood forecasting accuracy for the wet season 2019 for all key stations and forecasting lead-times.

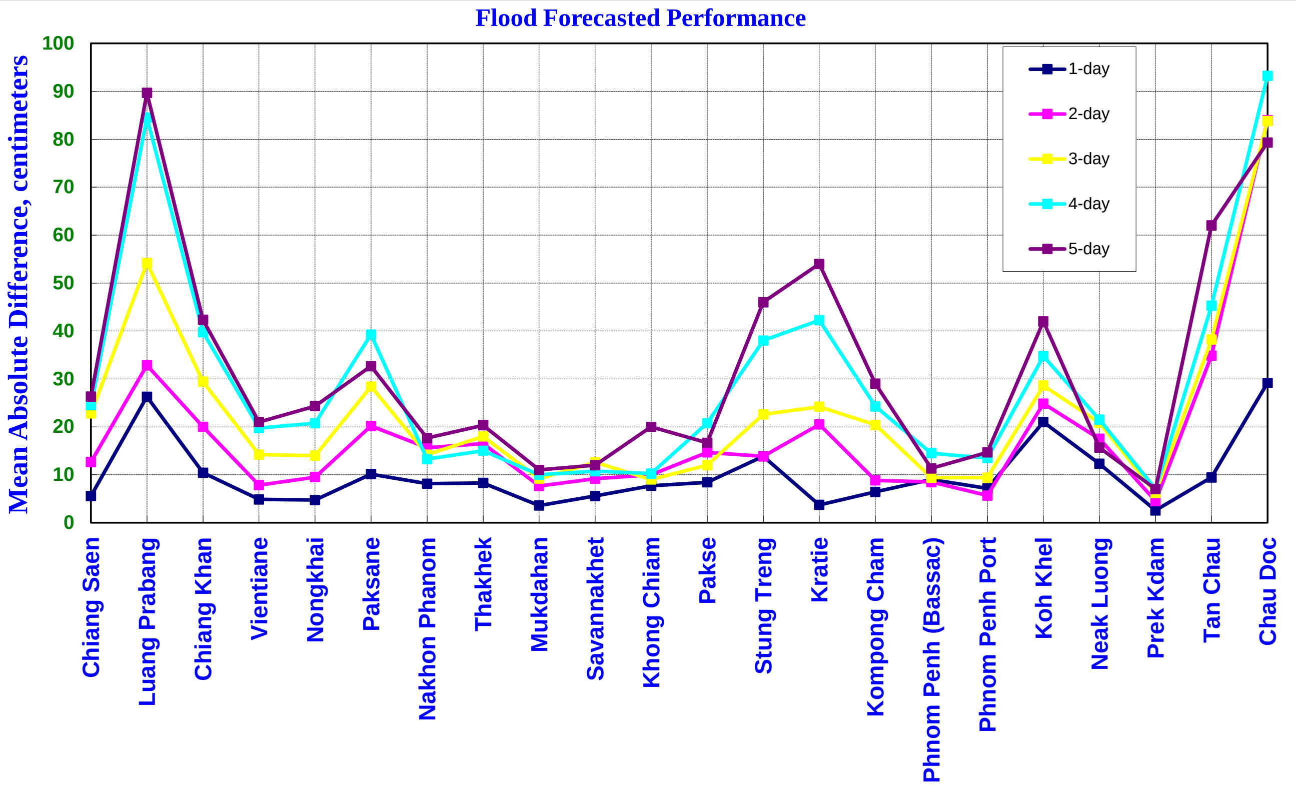


Figure 27: Average RFF accuracy along the Mekong mainstream from Jun to Oct 2019

In general, the accuracy was 'good' during the wet season 2019 for all forecast lead times. However, the accuracy for 4 and 5 day of forecasted values was considered overestimated for the stations at Luang Prabang, Kratie and the Tidal stations of Tan Chau and Chau Doc, although forecast errors for 3 - 5-day lead times were less than 0.90 m for all stations in the LMB.

Accuracy is especially influenced by heavy rainfall caused by storms and hydropower operations from upstream (Xayaburi), tributaries inflows and the lower part of the Mekong floodplain.

Luang Prabang, Chiang Khan and Paksane stations have been affected by hydropower operations of Xayaburi and Nam Nguem (water retention and release). Rainfall always accumulates at this spot, which could cause rapid high-water levels.

Rapid fluctuations of water levels at Tan Chau and Chau Doc stations due to daily tidal effects of the sea in the Mekong Delta make accuracy challenging at these stations.

In order to assess the quality of the results, a performance indicator, so called benchmark, was implemented at the RFDMC since 2009. The defined indicators vary between forecasting stations and lead time. The numeric values of the current benchmark are presented in **Table 17**.

Table 17: Benchmarks of success: Indicator of accuracy (MED in cm)

2019	Chiang Saen	Luang Prabang	Chiang Khan	Vientiane	Nongkhai	Paksane	Nakhon Phanom	Thakhek	Mukdahan	Savannakhet	Khong Chiam	Pakse	Stung Treng	Kratie	Kompong Cham	Phnom Penh (Bassac)	Phnom Penh Port	Koh Khel	Neak Luong	Prek Kdam	Tan Chau	Chau Doc
1-day	25	25	25	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
2-day	50	50	50	25	25	25	25	25	25	25	25	25	25	25	25	10	10	10	10	10	10	10
3-day	50	50	50	25	25	25	25	25	25	25	25	25	25	25	25	10	10	10	10	10	10	10
4-day	75	75	50	50	50	50	50	50	50	50	50	50	50	50	50	10	25	10	25	25	10	10
5-day	75	75	50	50	50	50	50	50	50	50	50	50	50	50	50	25	25	25	25	25	25	25

The forecast achievement indicated in % of days that the forecast at a particular station for a lead-time is successful against a respective benchmark for the wet season 2019 are presented in **Table 18**.

Table 18: Average achievement for each station from Jun to Oct 2019 against the benchmark (Unit in %)

2019	Chiang Saen	Luang Prabang	Chiang Khan	Vientiane	Nongkhai	Paksane	Nakhon Phanom	Thakhek	Mukdahan	Savannakhet	Khong Chiam	Pakse	Stung Treng	Kratie	Kompong Cham	Phnom Penh (Bassac)	Phnom Penh Port	Koh Khel	Neak Luong	Prek Kdam	Tan Chau	Chau Doc	*Average*
1-day	71.4	100.0	100.0	57.1	42.9	71.4	85.7	85.7	100.0	100.0	71.4	85.7	100.0	85.7	71.4	100.0	100.0	100.0	85.7	100.0	71.4	85.7	***85.1***
2-day	50.0	100.0	100.0	66.7	50.0	66.7	100.0	100.0	100.0	100.0	100.0	83.3	100.0	50.0	83.3	100.0	100.0	100.0	83.3	100.0	66.7	66.7	***84.8***
3-day	60.0	100.0	100.0	40.0	40.0	80.0	80.0	80.0	80.0	100.0	100.0	100.0	100.0	40.0	60.0	100.0	100.0	100.0	80.0	100.0	60.0	60.0	***80.0***
4-day	75.0	100.0	100.0	75.0	75.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	50.0	75.0	100.0	100.0	100.0	100.0	100.0	50.0	50.0	***86.4***
5-day	100.0	66.7	100.0	66.7	66.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	33.3	66.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	***90.9***

Like other wet seasons, the degree of accuracy for the wet season in 2019 varied from station to station. The shorter the lead time, the more accurate the flood forecast.

5.2.2 Analysis of the Flood Events

To analyse the forecast accuracy during the flood events following the Tropical Storm PODUL and the Tropical Storm KAJIKI (see **Chapter 2.3**), **Figure 28, 29, 30** and **31** show the flood peak event hydrograph at specific stations at Khong Chaim, Pakse, Stung Treng and Kratie during the flood effected period from August 23 to September 15 in 2019, compared with forecasted day-1 to day-3 and observed values with rainfall hyetographs. The characteristic of flood event at these stations are detail descripted in section 3, specifying the period of flood event from upstream to downstream where most effected area from Khong Chiam in Thailand to Stung Treng and Kratie in Cambodia.

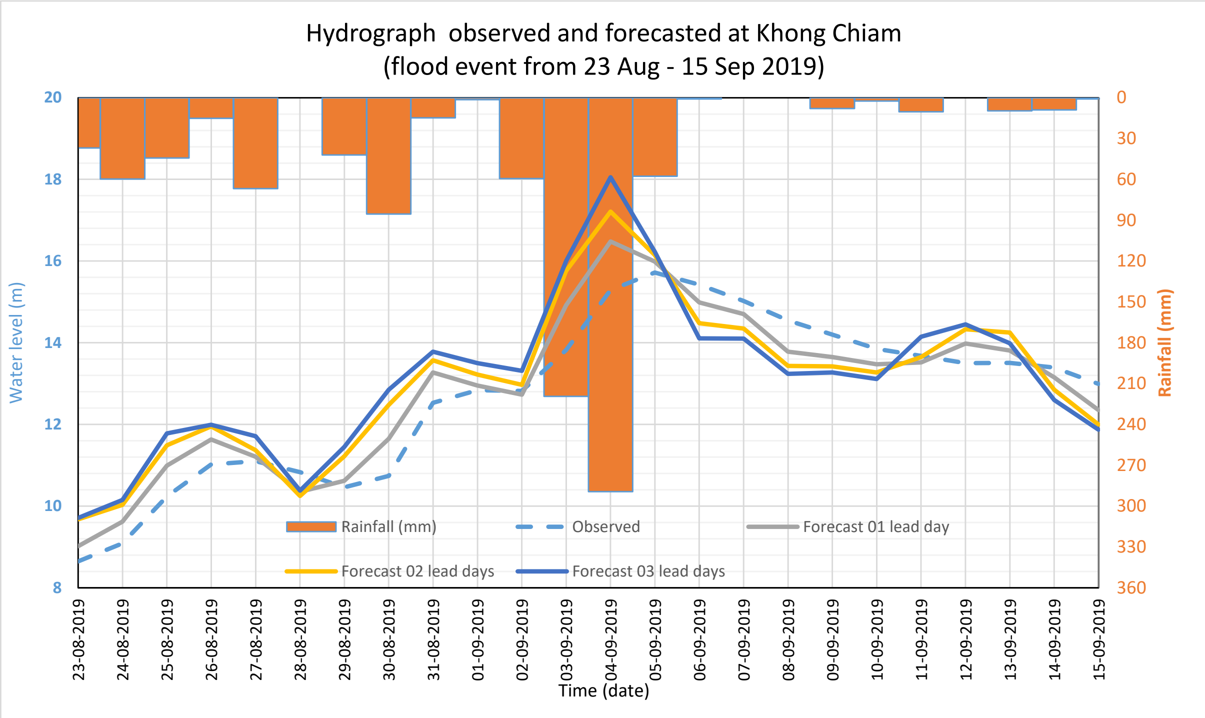


Figure 28 Observed and Forecasted WLs at Khong Chaim, during the flood period

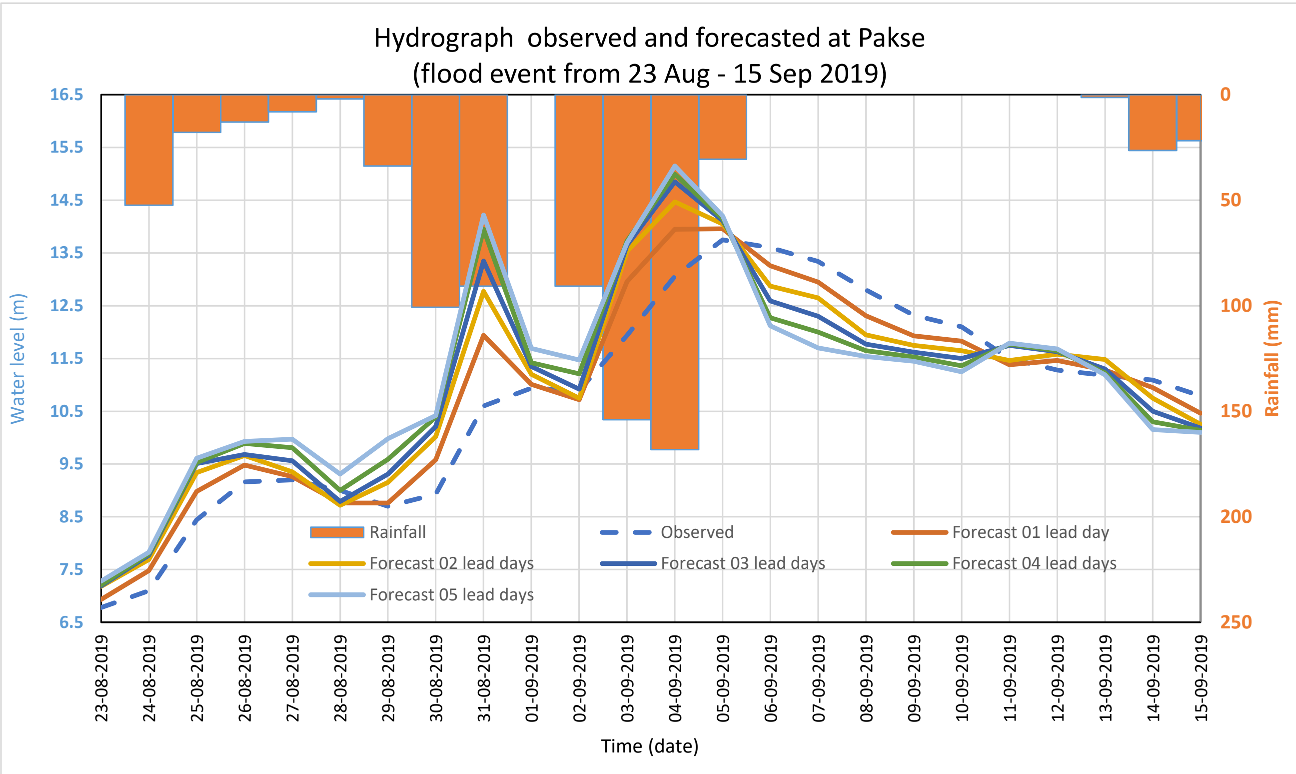


Figure 29 Observed and Forecasted WLs at Pakse, during the flood period

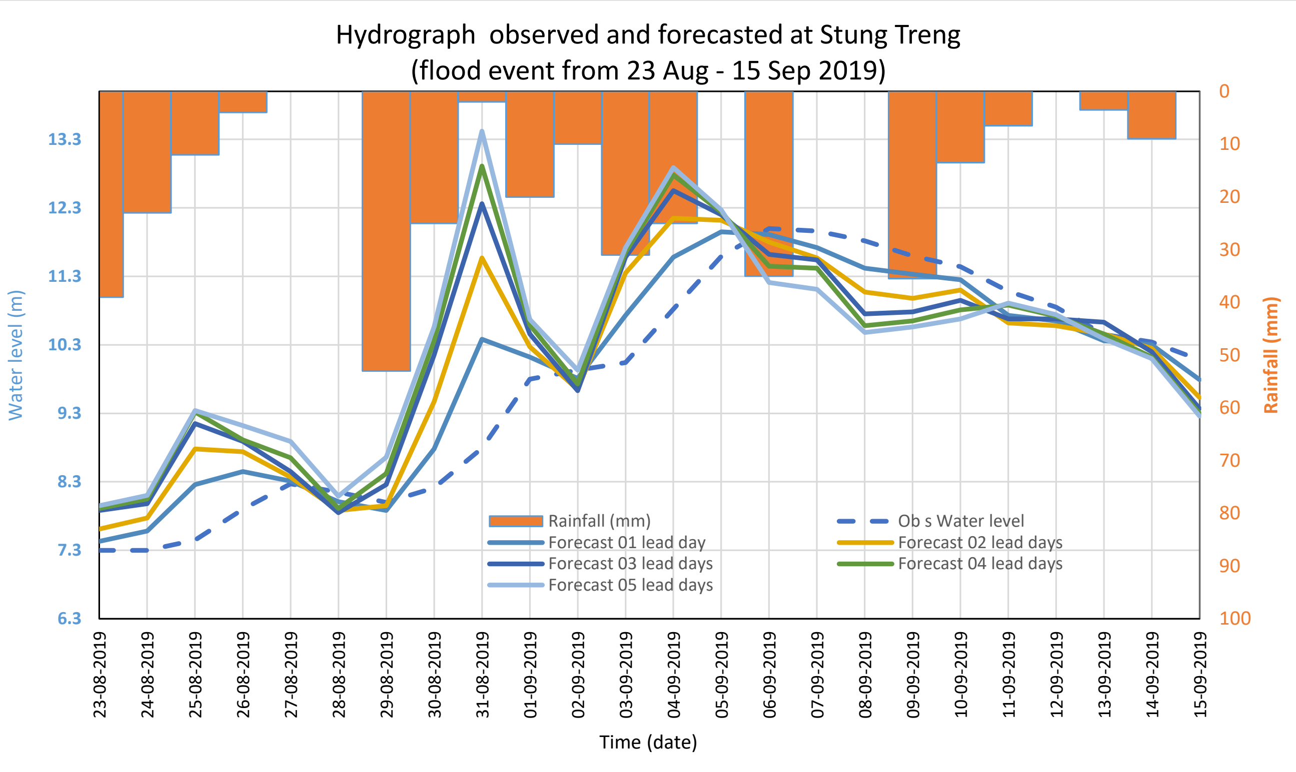


Figure 30 Observed and Forecasted WLs at Stung Treng, during the flood period

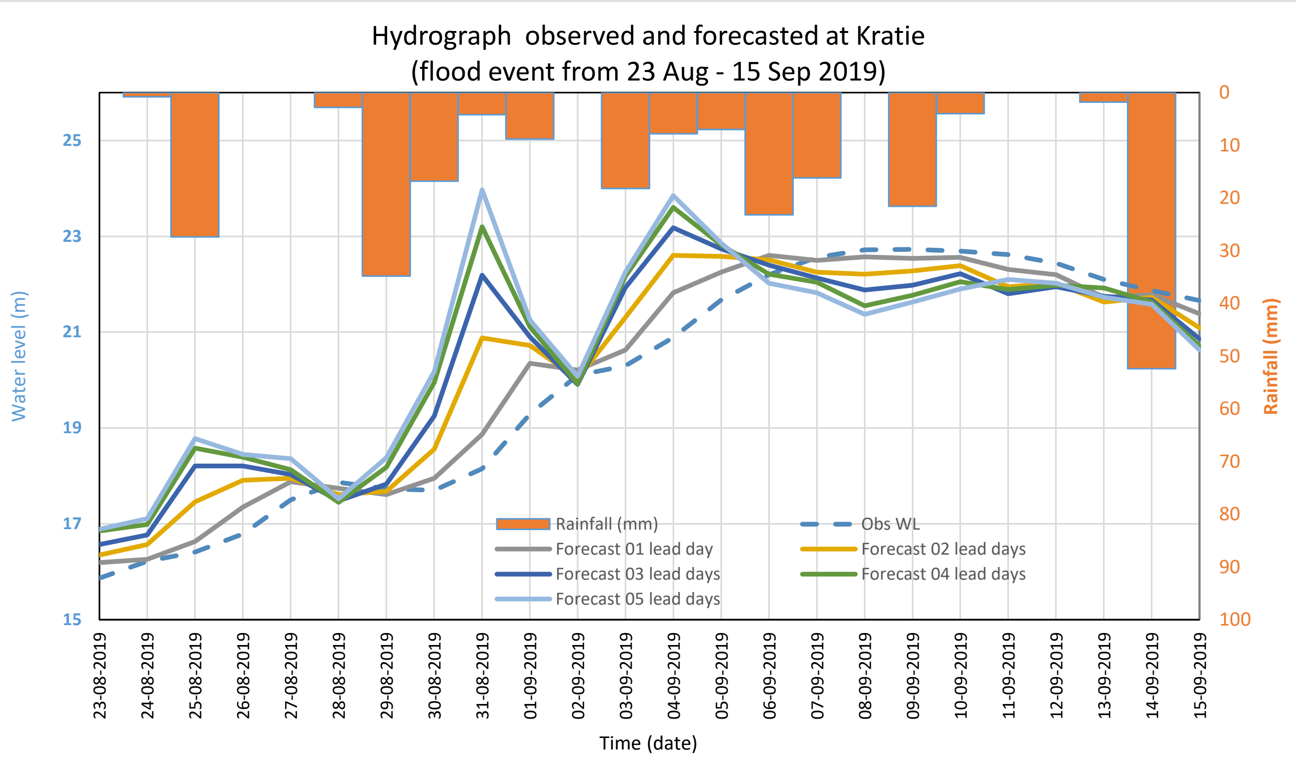


Figure 31 Observed and Forecasted WLs at Kratie, during the flood period

5.2.3 Recommendations to improve the RFF Accuracy

The manual hydro-met data and the SRE and GFS data as input for the MRC-RFFS are the most important elements for the flood forecasting outputs. Following the investigations and comments of the forecaster-in-charge in the weekly reports throughout the wet season 2019, it was found that the high variability in SRE and GFS were the main reasons which led to large errors of forecast results, especially during heavy rains as tropical storms, southwest monsoon and ITCZ. Satellite rainfall data was not representative of the actual rainfall at ground stations in some areas of the Mekong region.

Because of the high variability of the SRE data, it was merged with the observed rainfall data based on a bias-correction method. SRE provide a highly variable rainfall estimation leading to high variation of forecast results, especially at stations in the upper and middle reaches, when critical weather patterns such as tropical storms occur.

The quality and accuracy of forecast is also determined by the quality of forecast adjustment, which is usually performed by the forecaster-in-charge. So, the knowledge, expertise and experiences of the forecaster are also a prominent determinant of the final forecast results.

5.3 Analysis of different models used in the River Flood Forecasting System (RFFS)

This chapter describes the analysis of the MRC-RFFS comparing the results of different models.

Three models are available for flood forecasting in the MRC-RFFS:

1. URBS model for upstream stations from Chiang Saen to Stung Treng;
2. ISIS model for downstream stations from Kratie to the Delta;
3. Regression Model, which is used to combine the URBS and the ISIS.

Figure 32 presents all the stations of the river forecasting with the specific model applied.

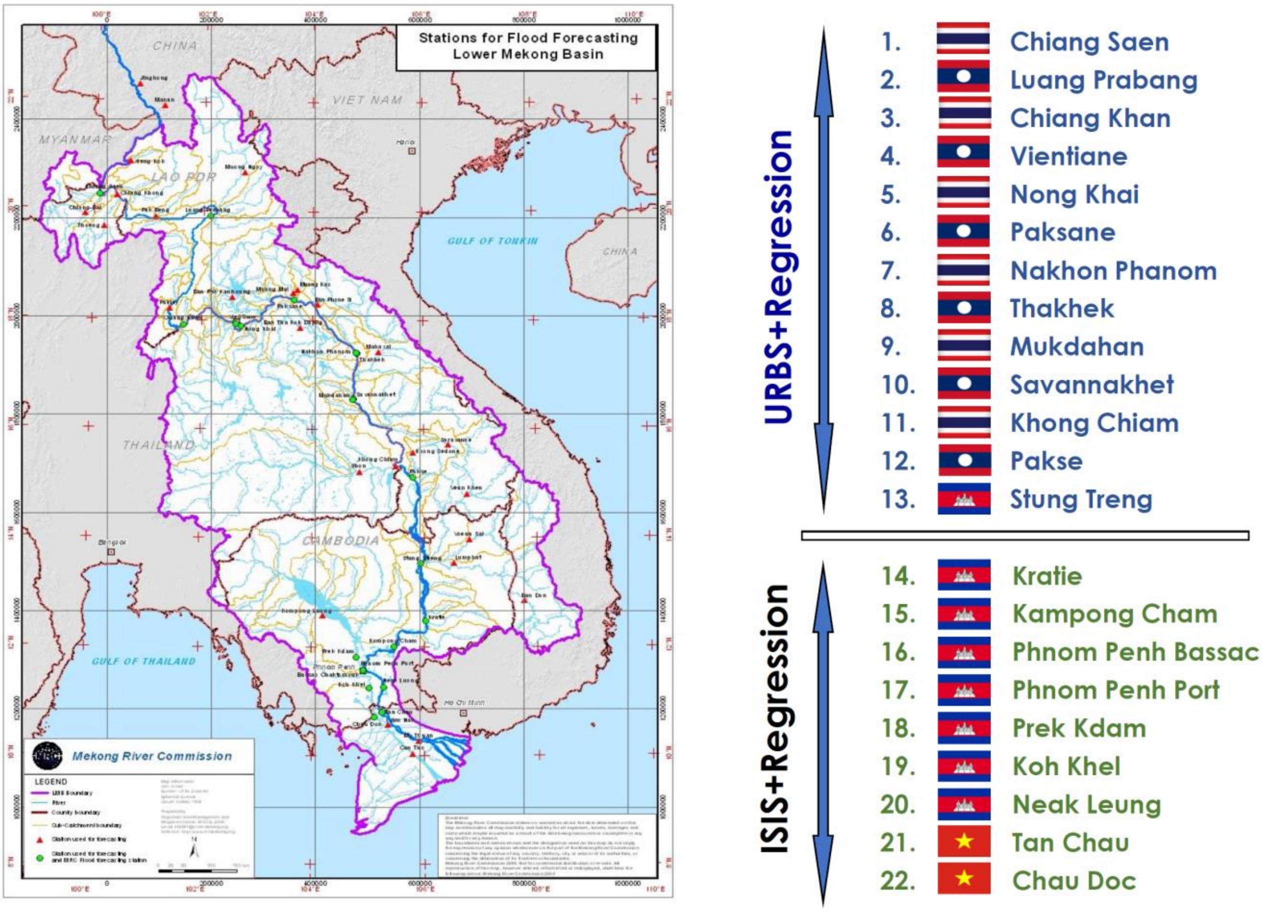


Figure 32: Forecasting stations and model application in the LMB

Since in the lower part of the LMB there are two model approaches available, the hydrodynamic model ISIS and the Regression model, the evaluation of the wet season 2019 was used for a comparison between the two models. The forecast accuracy of the URBS-ISIS and URBS-Regression model was measured in Mean-Absolut-Differences (MAD) in centimetres.

Figure 33 and **Figure 34** show the model performances for each model comparing the forecast accuracy for 1 to 5-days lead time at the key stations along Mekong River during the wet season 2019. It is recognized from the comparison of the MAD that the forecasts made with the URBS - Regression were more accurate than the forecasts made with the URBS - ISIS.

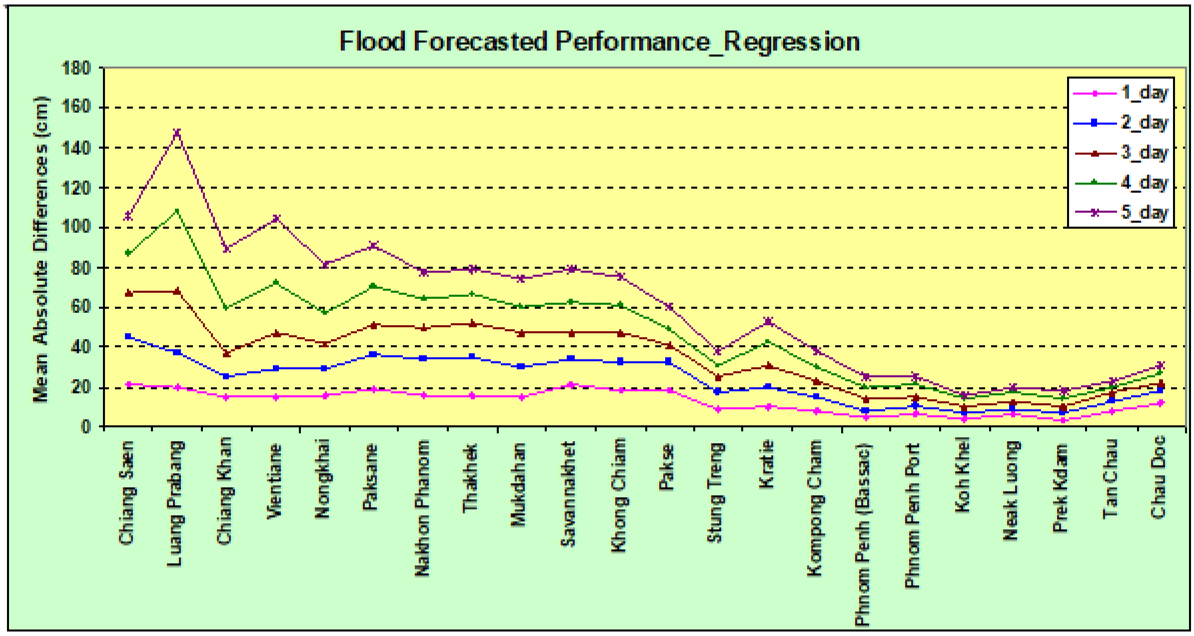


Figure 33 Forecast accuracy based on original result by URBS and Regression from Jun to Oct 2019

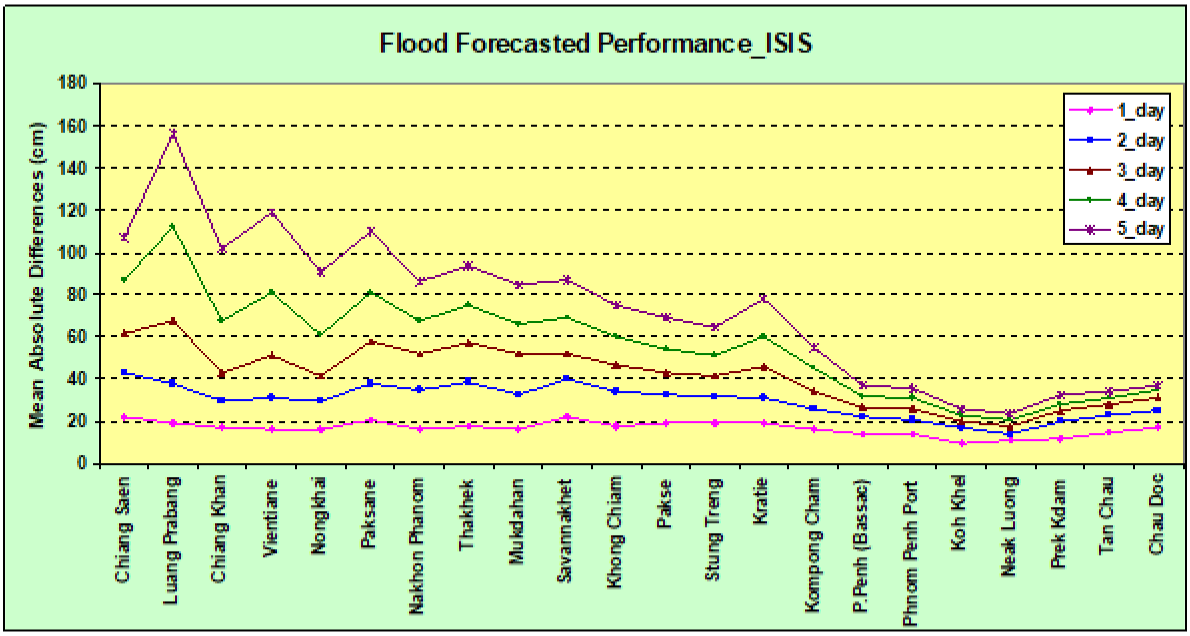


Figure 34 Forecast accuracy based on original result by URBS and ISIS from Jun to Oct 2019

6 Summary and Conclusions

The following lessons have been learned by the flood forecasting team of the RFDMC from the wet season 2019:

- The availability and quality of both hydrological and meteorological data as inputs for the models are always the highest priority because these are the deciding factors for forecast results and accuracy. A Senior International Satellite Precipitation Expert has developed a tool for bias correction of the SRE data in 2010. The corrected SRE is used in the MRC-RFFS as rainfall inputs. The tool depends very much on observed rainfall data provided from the LAs. Therefore, strengthening the relationship and cooperation with the LAs in order to improve the exchange of observed water level and rainfall data from the stations in the LMB is very important.
- The data from the stations in the upstream of the Mekong river in China is crucial for the analyses and forecasts in the LMB, not only during the wet season but also during the dry season. In the flood forecasting they are especially important for the upper parts of the Mekong river at Chiang Saen.
- The model could be improved by calibrations based on updating rating curves, dam operation curves and other parameters from the stations that belong to the MCs. The correctness and consistency of the results should be tested and verified over the upcoming wet season.
- The forecaster-in-charge should get a better understanding of the sub-basin characteristics and flow regime of left bank tributaries in the middle part of the LMB, where frequently intensive rainfall and flooding occurs. The forecaster should understand more about the influences of tidal regime at the downstream reaches in the LMB.

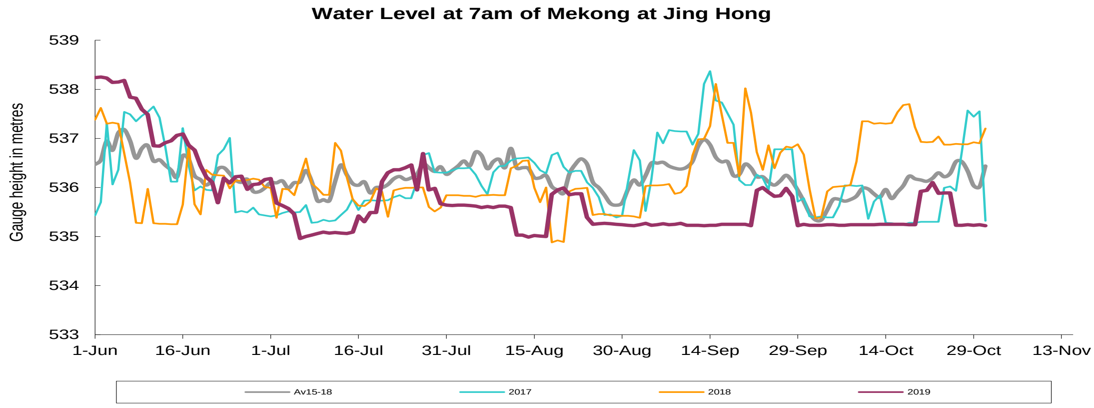
In order to improve the accuracy of the flood forecasting for next wet season 2020, the following additional actions need to be considered:

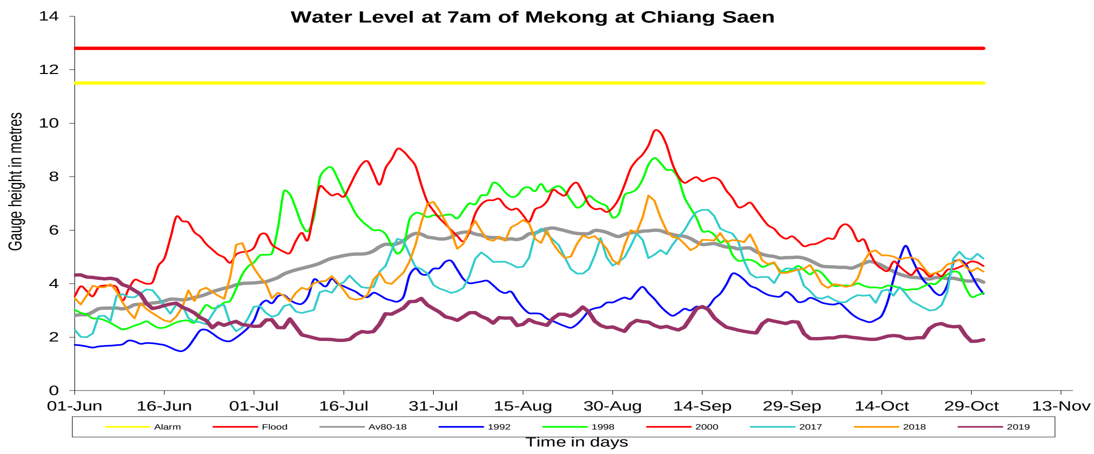
- Continue to efficiently use water level and rainfall data from the two stations (Jinghong and Manan) based on the agreement between MRCS and China.
- Analyse the impact of water release from dams to water level changes at stations in the upper part, such as at Chiang Saen, Vientiane, Nong Khai especially during transitional period between dry and wet season.
- Watch and closely follow situations of the sudden increases of water levels on the left bank tributaries in the middle part of the LMB, such as Ban Mixay and Muong Ngoy, Moung Mai, Moung Kao, Ban Phone Si, Se Kong River at Vuen Khen, Se Bang Fai River at Mahaxai in order to better understand the impacts of weather patterns with intensive rainfall, like typhoons or tropical depressions coming from the East Sea, and/or the formation of low-pressure trough and ITCZ and the critical activity of the southwest monsoon.

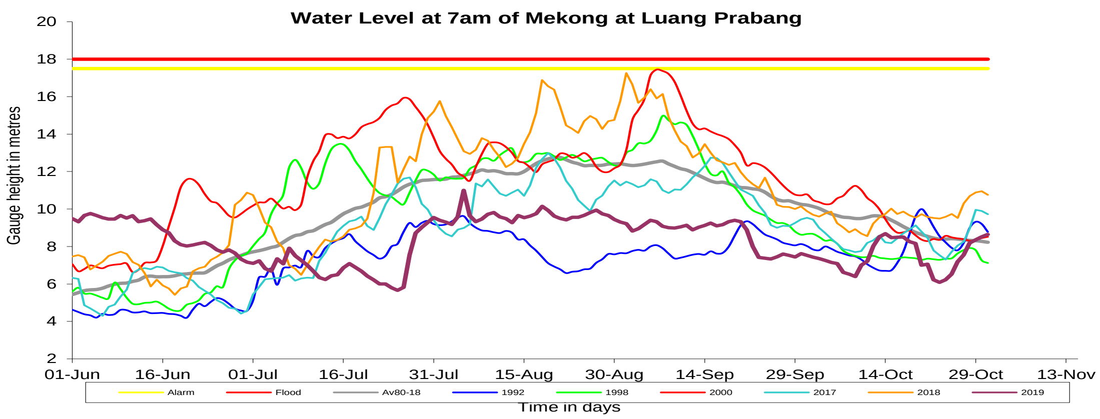
- Through forecast results of water levels during the wet season 2019 at downstream stations the Regression Model was evaluated as ‘fairly good’, it should be explained more in detail why the errors for 3-day and 4-day forecasts at Tan Chau and Chau Doc, where water levels are affected by the tide, were that “high”. Although, the flood forecaster referred to the tidal regime in the forecast documentation 2019 provided by National Centre for Hydrometeorology of Viet Nam.
- Learn more about the weather products of rainfall forecast published on the websites of the World Meteorological Organization (WMO) and their practical applications.
- Study the possibility of having 2nd run of daily flood forecast, medium-term forecast (6 - 10 days) and seasonal forecast (1 month to 3 months) with data availability and other requirements of the system. This can be done based on further evaluations of the system’s performance by using historical rainfall patterns.
- Upgrading automatic stations at the 7 mainstream stations Paksane, Thakhek, Savannakhet, Kampong Cham, Phnom Penh Port, Koh Khel and Neak Luong. These existing stations are equipped with staff-gauges manual readings which are difficult to track on hourly fluctuation and early warning information.

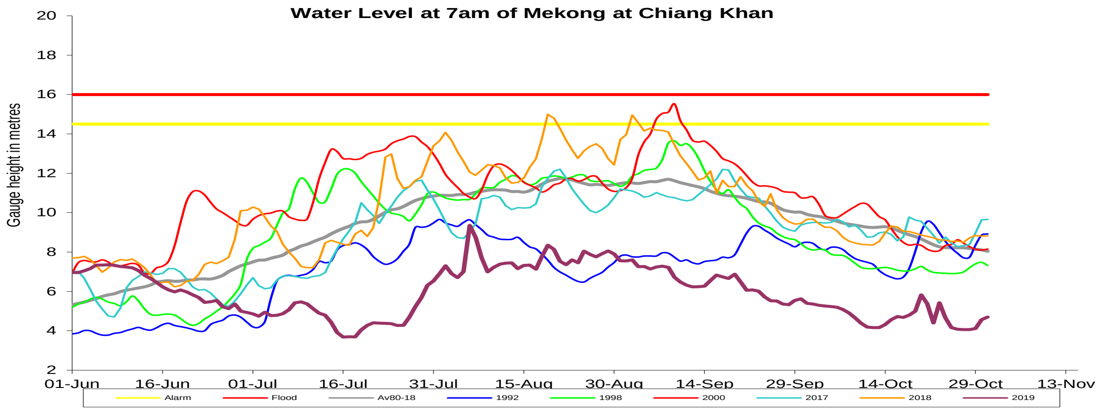
Annex A Water Level Hydrographs

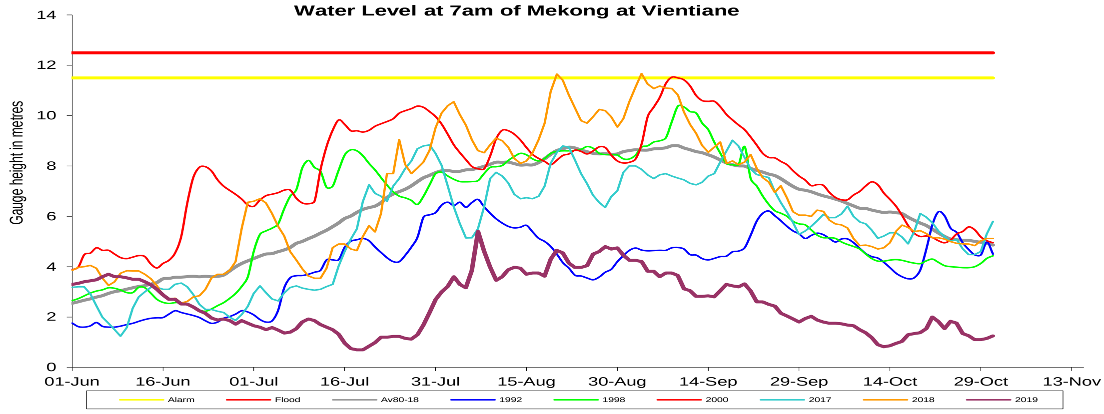
Water level hydrographs of each the key station, focused on mainstream stations covering the entire wet season 2019 from June to October compared with their LTAs (1995-2018) and other specific years (2017 and 2018). These water level graphs have been distributed daily by email together with the Flood Bulletins to all MCs and relevant stakeholders, who listed for receiving daily bulletin of the MRCS.

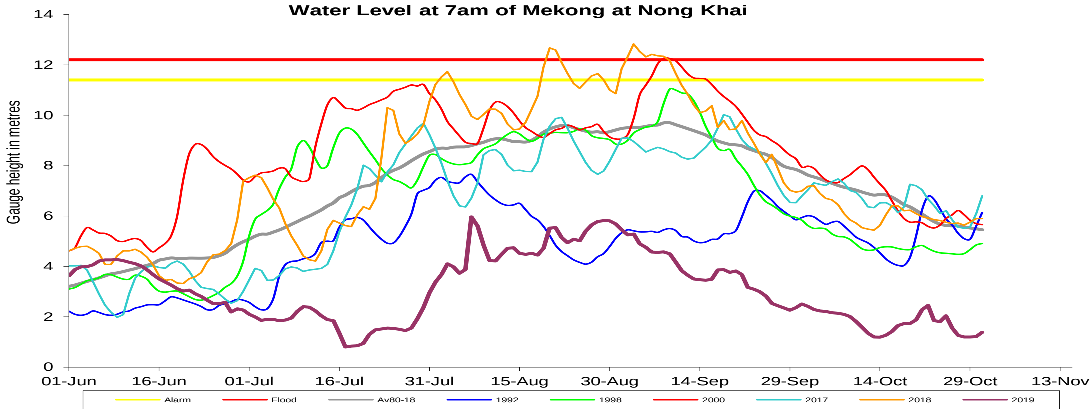


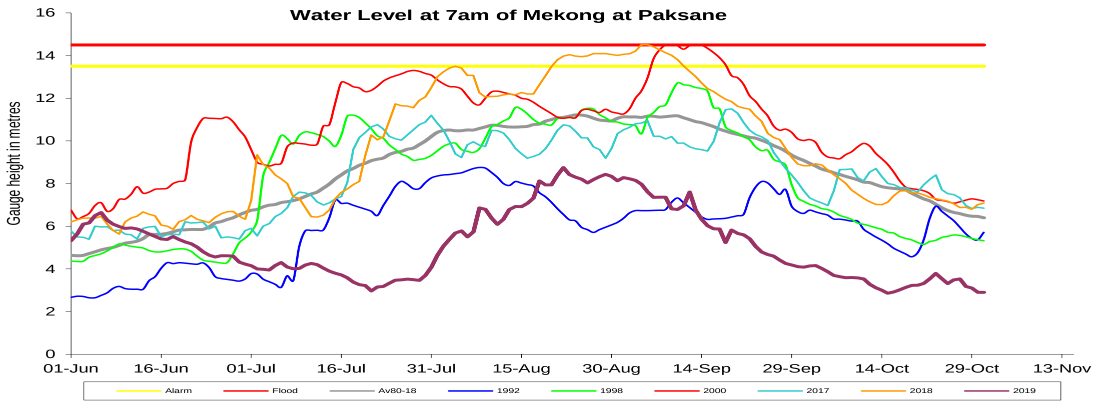


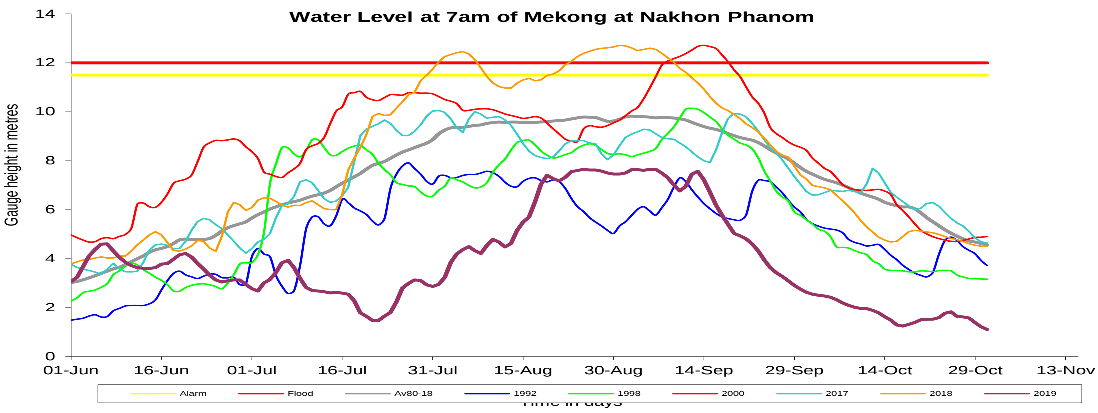


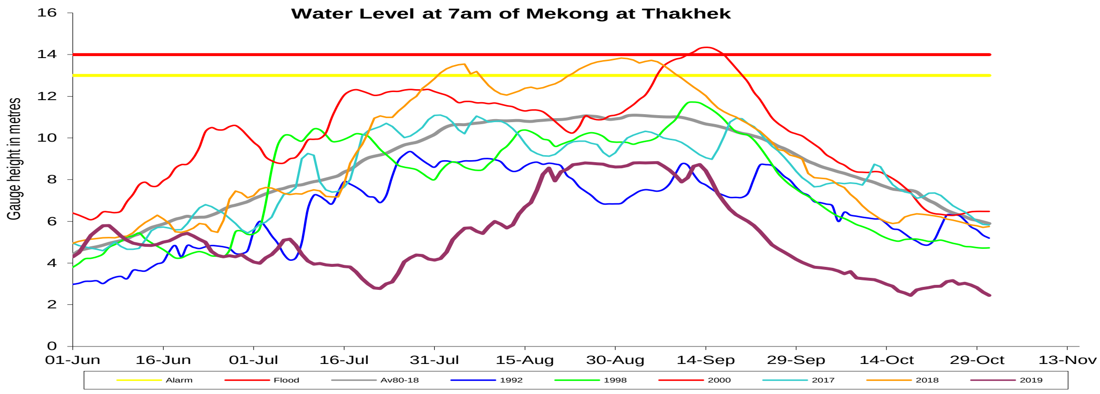

Water Level at 7am of Mekong at Chiang Khan
Gauge height in metres
20
18
16
14
12
10
8
6
4
2
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

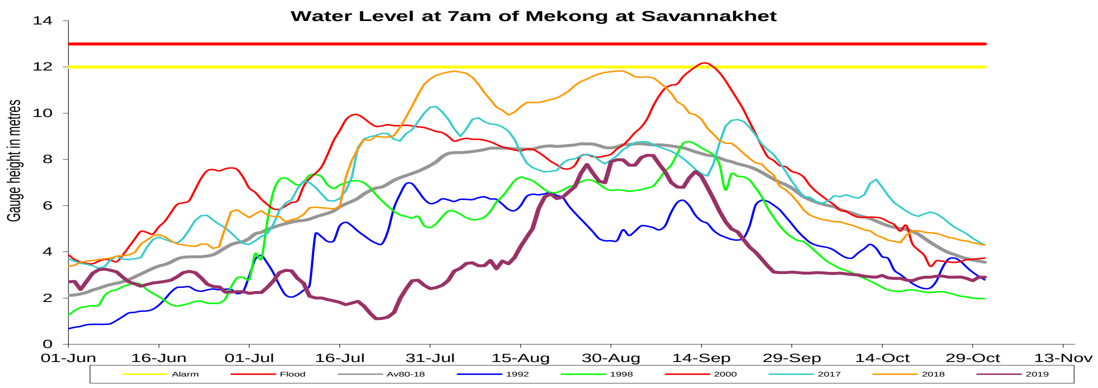

Water Level at 7am of Mekong at Vientiane
Gauge height in metres
14
12
10
8
6
4
2
0
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

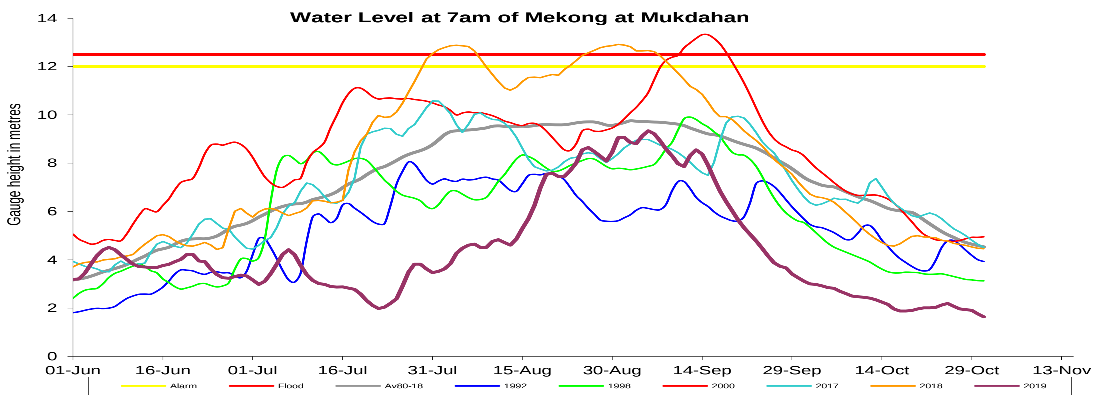

Water Level at 7am of Mekong at Nong Khai
Gauge height in metres
14
12
10
8
6
4
2
0
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

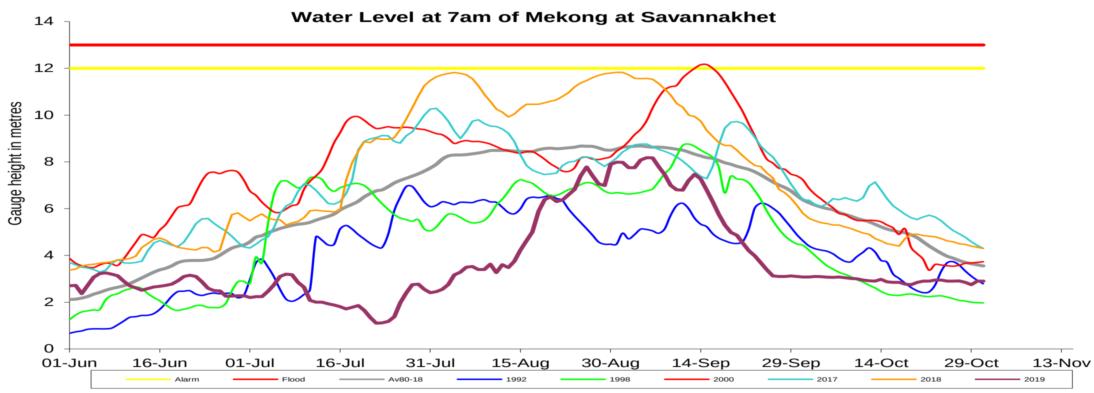

Water Level at 7am of Mekong at Paksane
Gauge height in metres
16
14
12
10
8
6
4
2
0
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

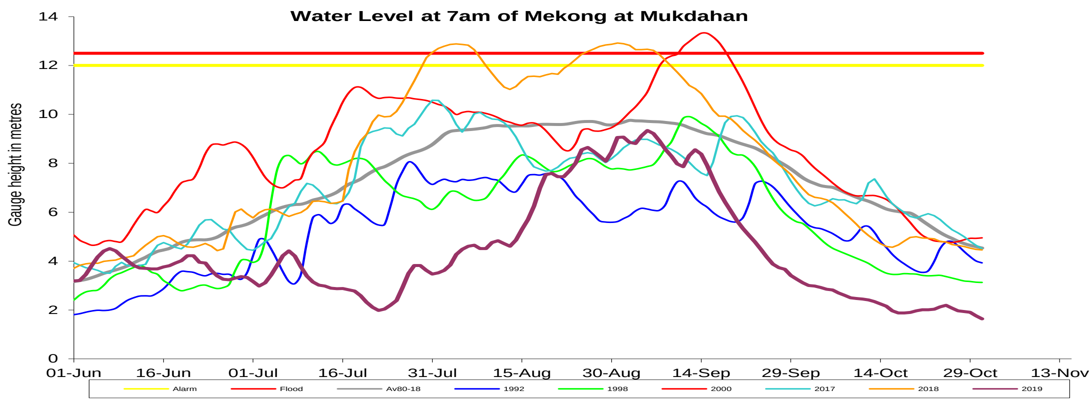

Water Level at 7am of Mekong at Nakhon Phanom
Gauge height in metres
Time in days
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

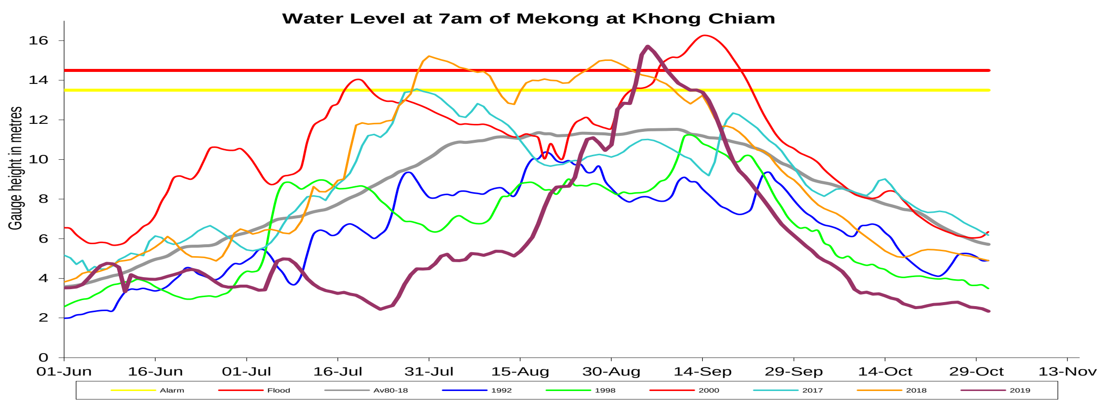

Water Level at 7am of Mekong at Thakhek
Gauge height in metres
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

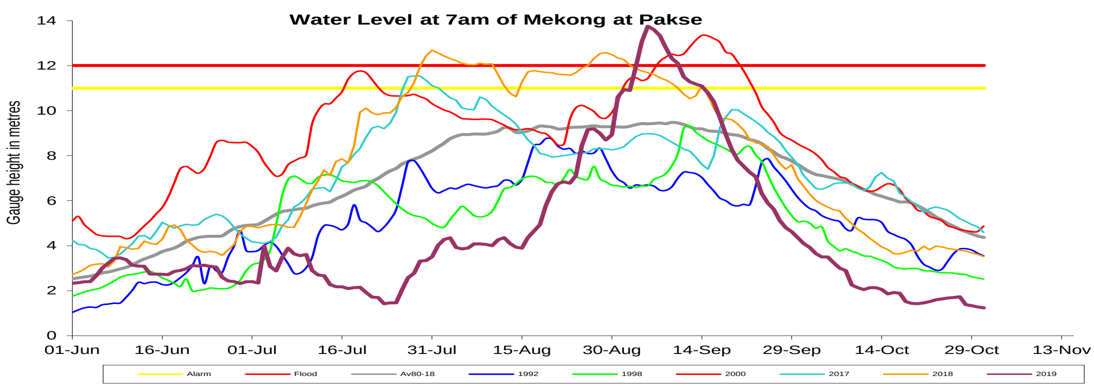

Water Level at 7am of Mekong at Savannakhet
Gauge height in metres
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

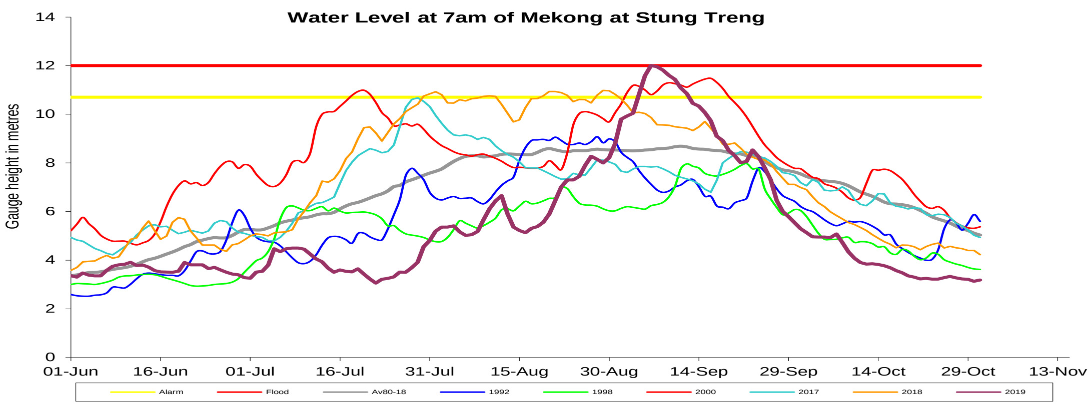

Water Level at 7am of Mekong at Mukdahan
Gauge height in metres
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

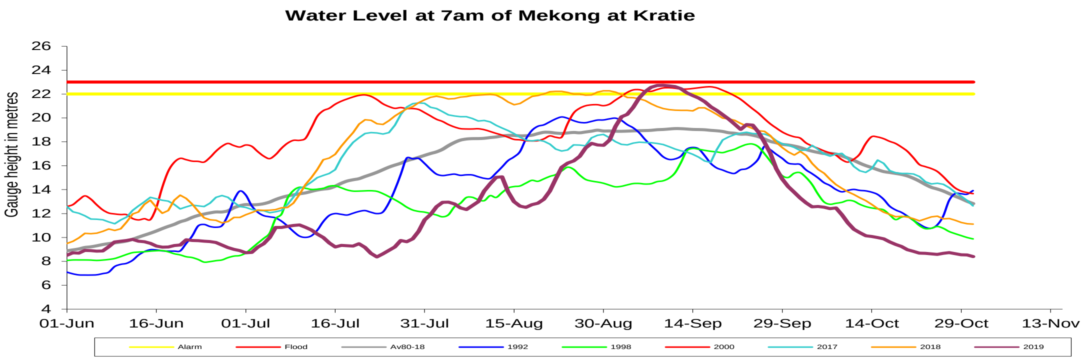

Water Level at 7am of Mekong at Savannakhet
Gauge height in metres
0
2
4
6
8
10
12
14
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

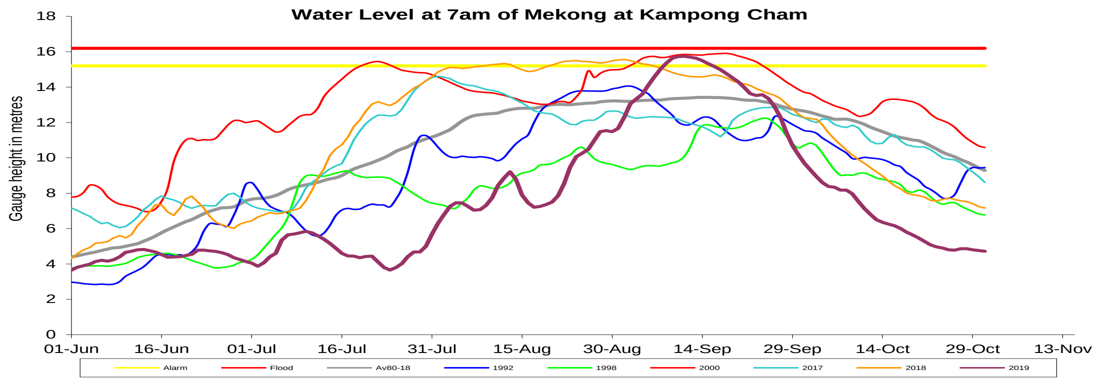

Water Level at 7am of Mekong at Mukdahan
Gauge height in metres
0
2
4
6
8
10
12
14
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

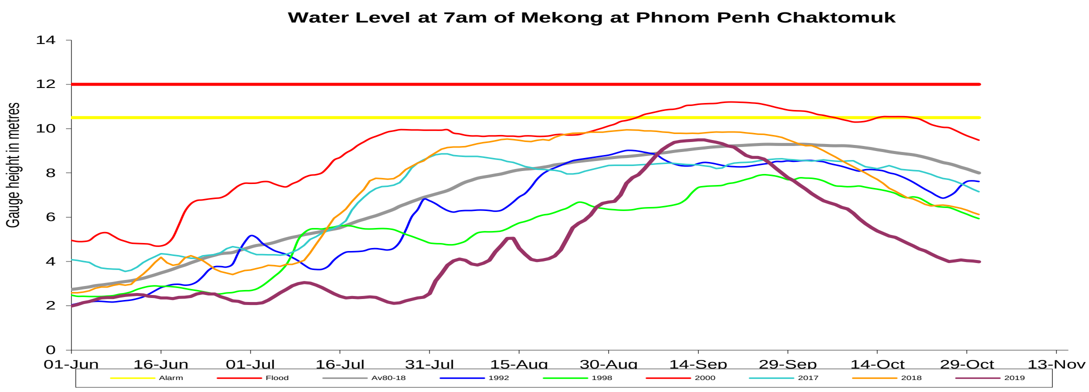

Water Level at 7am of Mekong at Khong Chiam
Gauge height in metres
0
2
4
6
8
10
12
14
16
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

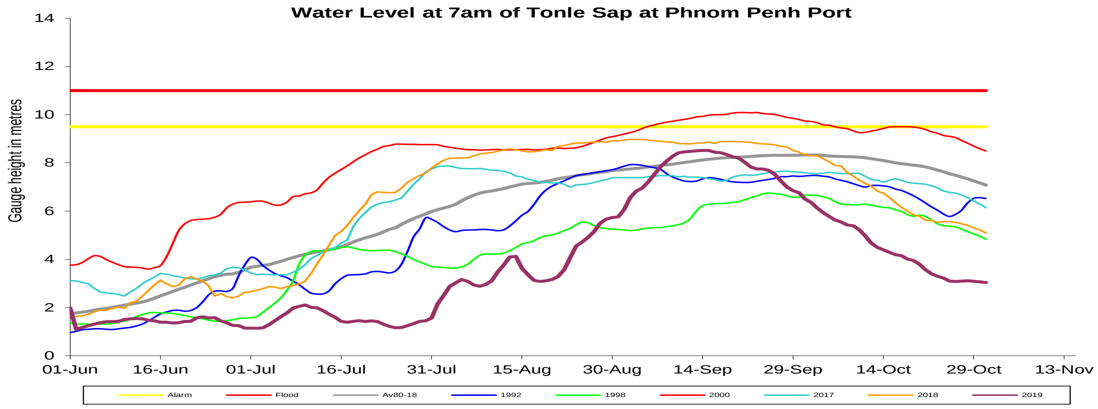

Water Level at 7am of Mekong at Pakse
Gauge height in metres
0
2
4
6
8
10
12
14
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

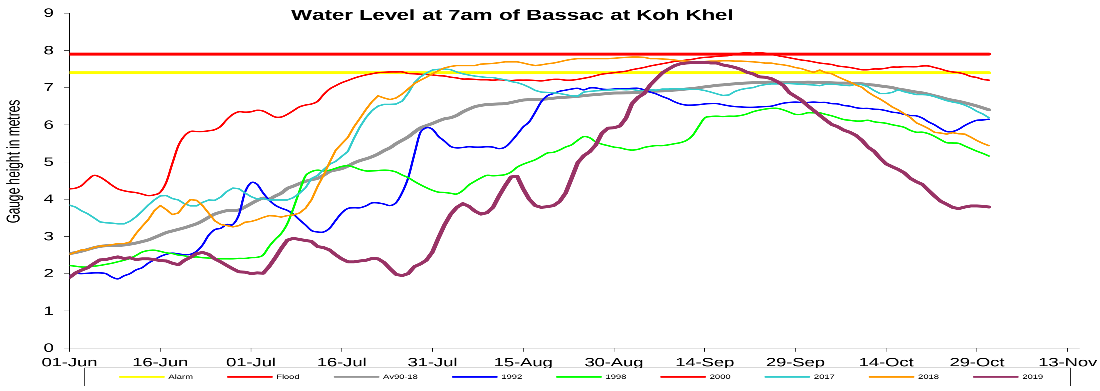

Water Level at 7am of Mekong at Stung Treng
Gauge height in metres
0
2
4
6
8
10
12
14
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

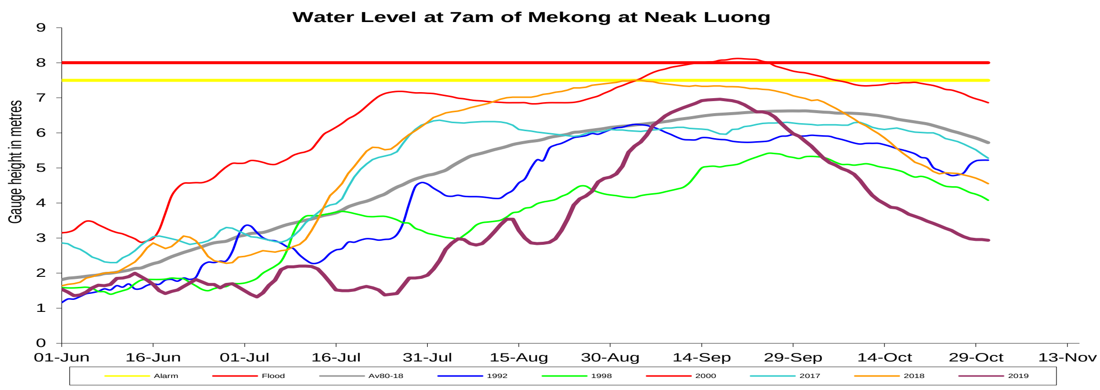

Water Level at 7am of Mekong at Kratie
Gauge height in metres
4
6
8
10
12
14
16
18
20
22
24
26
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

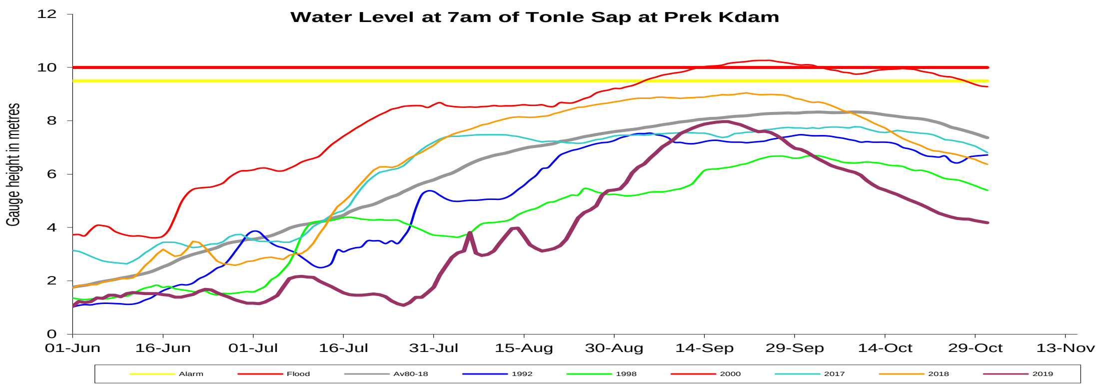

Water Level at 7am of Mekong at Kampong Cham
Gauge height in metres
0
2
4
6
8
10
12
14
16
18
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

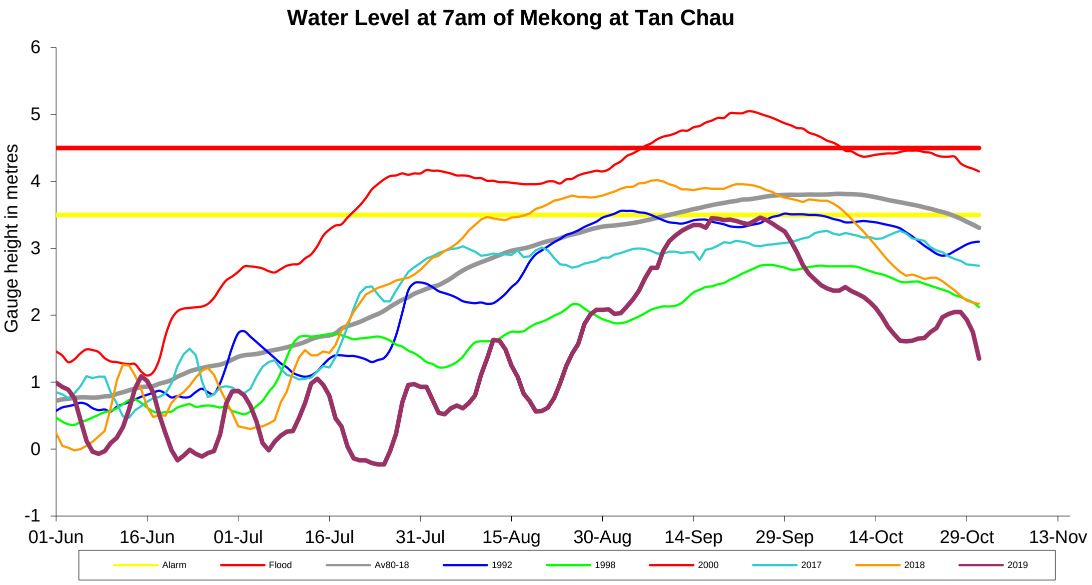

Water Level at 7am of Mekong at Phnom Penh Chaktomuk
Gauge height in metres
0
2
4
6
8
10
12
14
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019

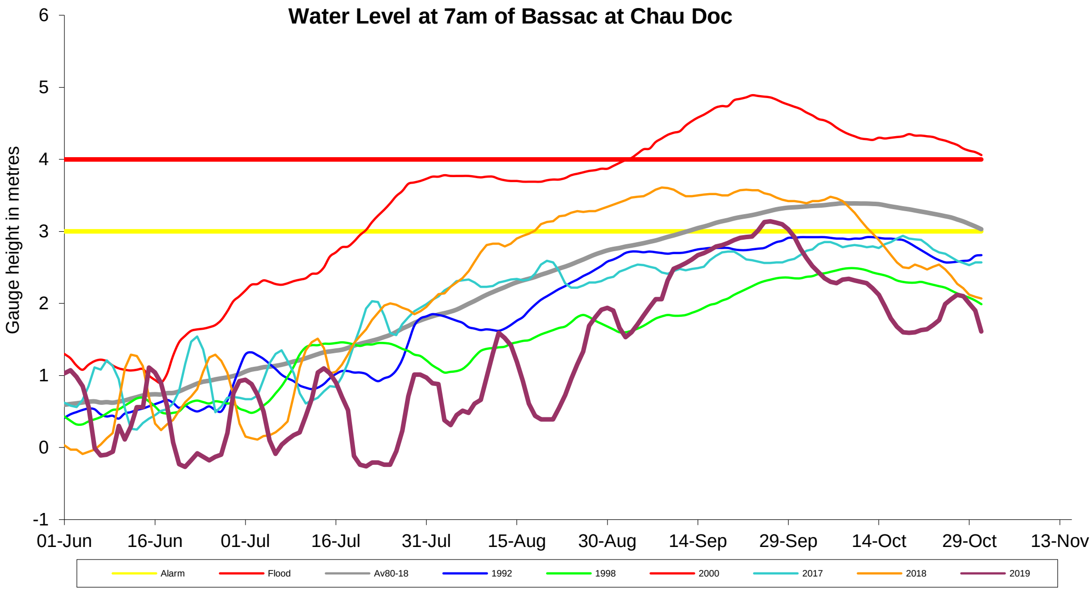

Water Level at 7am of Tonle Sap at Phnom Penh Port
Gauge height in metres
0
2
4
6
8
10
12
14
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019


Water Level at 7am of Bassac at Koh Khel
Gauge height in metres
0
1
2
3
4
5
6
7
8
9
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av90-18
1992
1998
2000
2017
2018
2019


Water Level at 7am of Mekong at Neak Luong
Gauge height in metres
0
1
2
3
4
5
6
7
8
9
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019


Water Level at 7am of Tonle Sap at Prek Kdam
Gauge height in metres
0
2
4
6
8
10
12
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019


Water Level at 7am of Mekong at Tan Chau
Gauge height in metres
6
5
4
3
2
1
0
-1
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019


Water Level at 7am of Bassac at Chau Doc
Gauge height in metres
6
5
4
3
2
1
0
-1
01-Jun
16-Jun
01-Jul
16-Jul
31-Jul
15-Aug
30-Aug
14-Sep
29-Sep
14-Oct
29-Oct
13-Nov
Alarm
Flood
Av80-18
1992
1998
2000
2017
2018
2019