ANNUAL MEKONG HYDROLOGY, FLOOD, AND DROUGHT REPORT 2018

The Synergy among Reports on Hydrological, Flood, and Drought Conditions in the Lower Mekong River Basin
Annual Mekong Hydrology, Flood, and Drought Report 2018

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List of Abbreviations and Acronyms

AMHR  Annual Mekong Hydrology Report
CCI   Climate Change Initiative
CDC   The Ministry of Health’s Communicable Disease Control Department, Cambodia
CDI   Combined Drought Index
DAHITI Database for Hydrological Time Series of Inland Waters
DC    Drought Conditions
DDPM  Department of Disaster Prevention and Mitigation, Thailand
DEM   Digital Elevation Model
DMS   Drought Management Strategy
DMH   Department of Meteorology and Hydrology, Lao PDR
DR    Days without Rainfall
DWR   Department of Water Resources, Thailand
ECMWF European Centre for Medium-Range Weather Forecasts
EGAT  Electricity Generating Authority of Thailand
ENSO  El Nino Southern Oscillation
EPC   Engineering, Procurement, and Construction
ESA   European Space Association
FFGS  Flash Flood Guidance System
GDCG  General Department of Cadastre and Geography (Ministry of Land Management, Urban Planning, and Construction, Cambodia)
GFAS  Global Flood Alert System
GDAL  Geospatial Data Abstraction Library
GDP   Gross Domestic Product
GISTDA Geo-Informatics and Space Technology Development Agency, Thailand
GPCC  Global Precipitation Climatology Centre
HAI   Hydro and Agro Informatics Institute, Thailand
HM    Hydrological and Hydraulic Modelling
HYCOS Hydrological Cycle Observing System
IDF   Intensity-Frequency-Duration
IPE   Independent Panel of Experts
JICA  Japan International Cooperation Agency
JRC   Joint Research Centre of the European Commission
LMB   Lower Mekong Basin
MAF   Weather Forecasting Division, Climate and Agrometeorology Division and Hydrology Division, Ministry of Agriculture and Forestry, Lao PDR
mASL  Metres above Sea Level
MEF   Ministry of Economy and Finance, Cambodia
MRC   Mekong River Commission
MWP   MODIS Water Product
MODIS Moderate-resolution Imaging Spectroradiometer
MONRE Ministry of Natural Resource and Environment, Lao PDR
MOWRAM Ministry of Water Resources and Meteorology, Cambodia
NASA  National Aeronautics and Space Administration
NBC   National Bank of Cambodia
NCDM  National Committee for Disaster Management, Cambodia
NDMI  National Disaster Management Institute, Lao PDR
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>NDVI</td>
<td>Normalized Differenced Vegetation Index</td>
</tr>
<tr>
<td>NGO</td>
<td>Non-Governmental Organisation</td>
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<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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<tr>
<td>NWP</td>
<td>Numerical Weather Prediction</td>
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<tr>
<td>PHSI</td>
<td>Palmer Hydrologic Drought Index</td>
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<tr>
<td>PMP</td>
<td>Probable Maximum Precipitation</td>
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<tr>
<td>RFDMC</td>
<td>Regional Flood and Drought Management Centre</td>
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<td>RFMMC</td>
<td>Regional Flood Management and Mitigation Centre</td>
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<tr>
<td>RFSS</td>
<td>River Flood Forecasting System</td>
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<td>RID</td>
<td>Royal Irrigation Department, Thailand</td>
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<tr>
<td>SDI</td>
<td>Streamflow Drought Index</td>
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<tr>
<td>SMDI</td>
<td>Soil Moisture Deficit Index</td>
</tr>
<tr>
<td>SPI</td>
<td>Standardized Precipitation Index</td>
</tr>
<tr>
<td>SQI</td>
<td>Standardized Discharge Index</td>
</tr>
<tr>
<td>SPEI</td>
<td>Standardised Precipitation-Evapotranspiration Index</td>
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<tr>
<td>SRE</td>
<td>Satellite Rainfall Estimates</td>
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<tr>
<td>TMD</td>
<td>Thai Meteorological Department</td>
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<tr>
<td>URBS</td>
<td>Unified River Basin Simulator</td>
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<td>VCI</td>
<td>Vegetation Condition Index</td>
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<tr>
<td>WMO</td>
<td>World Meteorological Organisation</td>
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1 SYNOPSIS

This is the first Annual Mekong Hydrology, Flood, and Drought Report (AMHR). After 13 years, starting in 2005, the Annual Mekong Flood Report (AMFR) is replaced by this new format.

In 2019, the Joint Committee – the MRC’s governing body – decided to integrate drought monitoring and management functions into the Regional Flood Management and Mitigation Centre (RFMMC) and to rename the RFMMC to the Regional Flood and Drought Management Centre (RFDMC). Taking the vulnerability of the basin to more extreme weather events into account, the need to address flood and drought in an integrated way is logical.

In the wake of the structural change, the new RFDMC introduced new approaches and embarked upon assessing drought conditions by means of drought indices. The scope of information that is now published by the MRC on its website covers not only flood data and forecasts but also drought-relevant information. The AMHR builds on these new assessments.

The high variability of climate and resulting conditions that occur from year to year, but also intra-annually, calls for an integrated approach. 2018 is a good example with extreme rainfall in July and August followed by rather dry conditions with distinct below average soil moisture as of September in the lower half of the Lower Mekong Basin (LMB). Generally marked as a wet year, the last quarter of 2018, however, was the beginning of an exceptionally dry period that fully developed in 2019.

This and subsequent AMHRs will cover and combine different hydrological subjects (i.e. flood, hydrology, drought recognition, monitoring and early warning, remote sensing, modelling, and water management) to provide an annual summary of the previous year and to enhance knowledge and awareness. This first edition introduces these topics in Section 2 and provides a combined analysis of flood and drought in Section 3. Those familiar with the AMFRs will still find the known and well-established evaluations and graphs related to rainfall maps, water level and streamflow hydrographs, flood volumes, etc., as well as the section with the country reports. In addition, as with the previous annual flood reports, the AMHR will include a specific theme. Since the frame of the AMHR is wider in scope, the themes will be more diversified.

In the new format, the LMB is subdivided into six regions in accordance and similar to the segmentation used in the Council Study. The Council Study is the comprehensive state-of-the-art, integrated, cross-sectoral report on sustainable management and development of the Mekong River generated by the MRC (MRC, 2018b). If possible, analyses were performed so as to address these regions separately.

The year 2018, however, brought about a negative headline, too: the dam break of Xe-Pian Xe-Namnoy Dam in Lao PDR. This incident is described in the report.

Taking expected impacts of climate change, development in the LMB, and enhancement of advanced hydrological techniques into consideration, the new format is necessary to inform and update on the complex hydrology of the LMB and its socio-economic implications from year to year.
2 THE SYNERGY AMONG REPORTS ON HYDROLOGICAL, FLOOD, AND DROUGHT CONDITIONS IN THE LOWER MEKONG BASIN

In 2019, the Mekong River Commission (MRC) embarked upon a new format of annual reports when its Joint Committee decided to integrate drought monitoring and management functions into the Regional Flood Management and Mitigation Centre (RFMMC) and to rename the RFMMC into the Regional Flood and Drought Management Centre (RFDMC). The new RFDMC will remain in Phnom Penh where the RFMMC had been successfully operating for years. The decision was made to address the changing context of the basin and its vulnerability to more extreme weather events. Drought is considered a hydrological hazard in the same magnitude as flooding, and thus integrating and addressing drought in annual reports is vital.

This report is the first edition of the new format. The theme of this report takes the integrated approach into account, and information around flood and drought topics were compiled. Hydrology in the sense of the AMHR is not restricted to describing physical hydro-meteorological aspects. It is understood as a frame in which cognate subjects given below are embedded.

The AMHR aims to provide information in the context of these topics related to the Lower Mekong Basin. Not all subjects given in the figure above will be addressed every year, but a selection will be made according to burning questions and new findings relevant to each year.

In addition to the description of the hydrology in 2018, an introduction to the following subjects are provided within this report, demonstrating the synergy among various disciplines:

- Geographical overview of the Lower Mekong Basin
- Climate of the Lower Mekong Basin
- Hydrological regime of the Mekong and major tributaries
- Overview of the monitoring systems
- Introduction to the modelling framework used at the RFDMC
2.1 Geographical Overview of the Lower Mekong Basin

The Tibetan Plateau at 5,000 m or higher is the origin of large rivers like the Yangtze, Salween, Irrawaddy, Red River, and the Mekong. From its source, the Mekong continues south for approximately 4,800 km to the Sea and drains a catchment area of approximately 810,000 km². The Mekong flows through six countries: China, Myanmar, Lao PDR, Thailand, Cambodia, and Viet Nam.

The Greater Mekong can be divided into two parts: the Upper Basin in Tibet and China, where the river is called the Lancang, and the Lower Mekong Basin from Yunnan to the Sea (MRC, 2005).

Figure 1: Overview of the Mekong River Basin
The Upper Basin (China and Myanmar) covers 24% of the total catchment with a contribution of about 15% of flow. There are no significant tributaries and any development of water resources will be conducted along the mainstream Mekong. In contrast, the Lower Mekong Basin is also fed by large tributaries contributing roughly 85% of the annual flow. The Lower Mekong Basin is also home to a unique situation called the Tonle Sap Reverse Flow. During the flood season when the water level in the Mekong is high at the confluence with the Tonle Sap River, the Tonle Sap outflow reverses and Tonle Sap Lake expands. This remarkable hydrologic phenomenon gives birth to the Tonle Sap Lake flood pulse, which has a high significance for the environment and fisheries in the Cambodian plain.

2.1.1 Sub-regions in the LMB

The Mekong flows for almost 2,100 km from its source and decreases in altitude by nearly 5,000 metres before it enters the Lower Basin where the borders of Thailand, Lao PDR, China, and Myanmar join in the “Golden Triangle”. Downstream of the Golden Triangle, the river flows for a further 2,700 km through Lao PDR, Thailand, and Cambodia before entering the Sea via a complex delta system in Viet Nam.

The Mekong River, according to the MRC (2005), can be subdivided into six different river zones with respect to

- hydrological regime
- physiography
- land use
- existing, planned, and potential resource developments

Five regions are derived from the six river zones:
1) Headwater Region
2) Mountainous Region
3) Transition (from the mountains to the plain with Thailand on the right bank and Lao PDR on the left bank)
4) Tonle Sap Region
5) Mekong Delta

These sub-regions largely follow the ecological zones used in the Council Study.
Future themes could be framed around topics from one or more sub-regions, such as:

<table>
<thead>
<tr>
<th>Sub-region</th>
<th>Possible topics for future AMHR</th>
</tr>
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<tbody>
<tr>
<td>Headwater region</td>
<td>Land-use change: Analysing flow changes or sediment</td>
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<td>Dam development: Analysing flow regime</td>
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<td></td>
<td>Climate change: Depletion of glaciers</td>
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<tr>
<td>Mountainous region and Transition zone (Lao PDR)</td>
<td>Land-use change: Analysing flow changes or sediment</td>
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<td>Dam development: Analysing flow regime</td>
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<td></td>
<td>Flash floods: Analysing forecasts and lead time for a pilot catchment</td>
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<tr>
<td>Transition zone (Thailand)</td>
<td>Crop patterns: Analysing spatio-temporal change in water demand</td>
</tr>
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<td>Water abstraction: Analysing impact of water abstraction plans</td>
</tr>
<tr>
<td>Tonle Sap</td>
<td>Monitoring: Analysing stage-discharge curve of Prek Kdam with 2D modelling</td>
</tr>
<tr>
<td></td>
<td>Hydraulics: Analysing flood pulse with changed mainstream behaviour</td>
</tr>
<tr>
<td>Mekong Delta</td>
<td>Natural storage: Analysing storage effect of Tonle Sap</td>
</tr>
<tr>
<td></td>
<td>Salinity: Analysing correlation of salinity with Mekong discharge</td>
</tr>
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</table>

Some of the topics have already been addressed in scenarios in the Council Study (MRC, 2018b, 2018c, 2018d), and could be used as starting points and data sources.
2.1.2 Headwater region

The headwater area is mainly formed by the Tibetan Plateau and is a rather thin and elongated catchment with steep slopes and high sedimentation rates. The main source of water originates from melting snow and glaciers. The headwater region is of particular importance to maintain low flow during the dry season. Even at Kratie, 30% of the low flow component stems from this region.

The headwater area is outside the administrative borders of the MRC and so is the water resources development. The dam projects in the headwater area carried out by China directly affect the flow regime downstream. The dams in this region bring benefits but also threats. The benefit might come from possible low flow augmentation to maintain minimum flow in the Mekong in dry years. This requires a good partnership with China and transboundary water agreements. On the other side, large scale water abstraction reducing the total amount of water left for the LMB can pose a risk for water management further downstream.

2.1.3 Mountainous region

The area downstream from Chiang Saen up to Nong Khai is almost entirely mountainous with the largest share on Lao PDR territory. The riverbed is relatively narrow without large flood plains. The area has limited scope for large scale agriculture but potential for hydropower development mainly in the tributaries. This area is also known for frequent flash floods.

The mountainous landscape means that only a low proportion is farmed. The proportion of agricultural land in Lao PDR increased from 4.4 to 7.9 percent of the country’s total
land area (LMAF [Lao Ministry of Agriculture and Forestry], 2014). This comparably low percentage is due to its mountainous terrain, low population density, lack of capital investment for agricultural conversion, and the government’s forest conservation policies. Further, since the mountainous region has limited infrastructure, this also partially limits agricultural expansion in some areas. However, agricultural land area calculations often underestimate areas used for shifting cultivation as significant amounts of fallow land is classified as forest land in the 2010/11 Agricultural Census (LMAF, 2014).

This region has been facing the problem of deforestation. As elsewhere in the basin, forest cover has been steadily reduced during the last three decades by shifting and permanent agriculture. The cumulative impacts of these activities on the river regime have not yet been investigated.

2.1.4 Transition region

The transition region is the zone in which the Mekong changes its characteristics due to the alteration from fast responding catchments to a plain terrain. Basically, this zone covers two distinct kinds of river basins. The Mun-Chi River enters from the right bank and drains approximately 119,500 km². This river basin has undulated to plain terrain with low runoff potential but significant reservoir storage. It is fully developed in terms of agriculture. In contrast, the tributaries from the left side: the Nam Ngum, Nam Theun, Nam Hinboun, Se Bang Fai, Se Bang Hieng, Se Done, Se Kong, Se San, and Sre Pok rivers, have a high runoff potential with fast responding catchments. They drain the mountainous area of Lao PDR with high potential for hydropower development but also high potential for flash floods. These tributaries from the left side provide the largest share of flow in the LMB.

Analysing the left and right sub-basins separately is difficult since the gauging stations with the longest records of flow are located along the Mekong mainstream. As a result, evaluation is an aggregation of both the largely anthropogenically affected Mun-Chi River system and the hilly to rugged terrain of the Lao PDR sub-basins.
2.1.5 Tonle Sap

The Tonle Sap is a sub-system within the LMB with unique hydrological characteristics and complexity. The terrain is a huge plain. The hydrology is dominated by overbank storage, flooding of large areas and backwater conditions in the Mekong mainstream causing reverse flow into the Tonle Sap. As a result of the plain, the hydrology evolves into a complex hydrodynamic system with interplay of flow, backwater, and flood plains downstream of Kratie with vast inundated areas during the flood season (Figure 3).

Tonle Sap is also one of the world’s most productive ecosystems. The lake is regarded as the world’s richest water system with respect to fisheries and provides a livelihood for the majority of Cambodians.

In Cambodia, the agricultural sector accounts for half of the GDP and employs 80 to 85% of the labour force. Wet rice is the main crop and is grown on the flood plains of the Tonle Sap, Mekong, and Bassac rivers. More than half of Cambodia remains covered with mixed evergreen and deciduous broadleaf forest, but forest cover had decreased from 73% in 1973 to 63% in 1993 (MRC, 2005).
2.1.6 Mekong Delta

In the Mekong Delta, the Mekong River is distributed into different branches from which irrigation canals abstract water. Water from the Mekong forms the source for the most intensively used agricultural area in the LMB. Up to three rice harvests are not a rare case in the Mekong Delta. A particular problem in the Mekong Delta is salinity. Saltwater intrusion in the lower Mekong Delta is known to extend more than 50 km inland during the dry season, affecting close to 2 million ha of land. Salinity is a serious constraint to agriculture, and rice yields are negatively affected by high salinity levels. Saltwater intrusion is increasing with rising sea levels and is exacerbated in dry years by low flow volumes.

The interaction with the Tonle Sap Lake is extremely important for the Delta. The Tonle Sap Lake acts as a huge natural reservoir storing water during the peak flood season and releasing the water with a significant delay when the water level decreases, usually in September to November. The Mekong Delta benefits from this natural storage in terms of:

- Peak rates of flood discharge in the Mekong mainstream are reduced, mitigating adverse effects from flooding
- High flow rates are maintained for a longer time in the Mekong Delta, supporting irrigation
- Higher dry season flows prevent saltwater from the Sea from intruding into the rivers and channels.
2.2 Climate in the Lower Mekong Basin

The climate of the Lower Mekong Basin (LMB), which is almost always hot and often humid, is classified as tropical monsoonal. In the warmest months of March and April, average temperatures range from 30°C to 38°C. Cooler temperatures prevail from November to February. At higher elevations in the Lao PDR, the winter temperature averages 15°C.

June to October is the wet season in the LMB with the exception of two brief transition periods. The rest of the year in the LMB is the dry season. The wet season results from the flow of moisture-laden air from the Indian Ocean in the summer. During the rest of the year, high-pressure systems over the Asian continent give rise to the dry season in the LMB.

The distribution of mean annual rainfall over the basin follows a distinct east-to-west gradient. In the LMB, the uplands in Lao PDR and Cambodia receive the most precipitation (3,000 mm) and the semi-arid Khorat Plateau in northeast Thailand the least (1,000 to 1,600 mm). The Upper Mekong Basin is similar to the LMB in that rainfall is regulated by the global monsoon system. In the Upper Basin, annual rainfall can be as little as 600 mm in the Tibetan Plateau and as much as 1,700 mm in the mountains of Yunnan (Figure 4).

The climate of the Mekong Basin is dominated by the southwest monsoon, which generates wet and dry seasons. The monsoon season usually starts in May and lasts until late September or early October. This is overlaid by the season for tropical cyclones and tropical storms that can occur over much of the area so that August and September and even October (in the Delta) are the wettest months.

The northeast monsoon, with its onset usually in late October, brings lower temperatures. The monsoon mainly brings rainfall to Viet Nam but not to the rest of the Lower Mekong since the Annamite Mountains or the Central Highlands act as a natural barrier for the moist air.

The headwater area also has a monsoonal climate regime but varies strongly depending on the topography. Tropical to subtropical monsoons prevail in the south of Yunnan while temperate monsoons occur in the north as the land rises from a mean elevation of 2,500 metres above sea level (mASL) to 4,000 mASL on the Tibetan Plateau (MRC, 2005).
Figure 4: Long-term annual rainfall and water yield in the Mekong Basin (https://portal.mrcmekong.org/toolbox/application)
2.3 Hydrological Regime of the Mekong River

In the Upper Mekong Basin, some of the taller peaks of the Tibetan Plateau are glaciated. In fact, much of this part of the basin is snow-covered in winter. Melting snow from the Tibetan Plateau feeds the Mekong River’s dry-season flow, especially in the middle reaches.

For the analysis of the hydrological regime of the Mekong’s long-term flow conditions, report stations at significant locations following the regions describe in Section 2.1 were selected. The timeframe for evaluation went back prior to 1960 (partly back to 1920) up to 2018. An overview of the locations is depicted in Figure 5. Long records of flow were used to assess mean, minimum, and maximum flow conditions along the selected gauging stations (Figure 6). The record stations at Phnom Penh Port and downstream are affected by backwater conditions and discharge derived from water level is highly uncertain, so that point 5 and 6 were compared with their water levels to see the effects of delay due to the plain territory.

![Regions and gauging stations for evaluation](image_url)

Figure 5: Regions and gauging stations for evaluation

Monthly flow distribution and water levels can be shown using the downstream point of each of the six reaches.
From north to south, the flood peak gradually moves towards September/October.

Although the distance is rather short between downstream point 5 (Kratie) and 6 (Phnom Penh Port), the delay of the flood peak is significant (see Water Level).

The main reason is the interaction with the Tonle Sap Lake and the flat topography of the Cambodian flood plain.

Low flow mainly depends on the contribution from the headwater area. Up to point 4 (Pakse) the main source is still snowmelt from the Tibetan Plateau.

The water level shows the delay for minimum conditions.
The maximum flow explains the impact of various climate zones. The impact of tropical storms and typhoons widens the plateau of maximum values while the headwater area shows less variations since it follows less typhoon affected behaviour.

Again, plain terrain and reverse flow to the Tonle Sap are the main causes for the significant retention effects.

Figure 6: Mean, minimum, and maximum monthly distribution for selected stations along the Mekong

Mean, minimum and maximum values clearly show the storage effect that occurs due to the interaction with Tonle Sap Lake.

Streamflow analysis of the hydrological regime can be enhanced with the use of the Standardized Discharge Index (SQI). The SQI is a well-suited method to effectively evaluate the actual river discharge in comparison to a pre-determined reference period. The calculation of SQI follows the algorithms of the well-known Standardized Precipitation Index (SPI) and can be calculated for different aggregation periods. These periods typically range from 1 month to show the short term, current situation without considering any significant water storage, up to 12 months or even multiple years to assess the long-term behaviour of the discharge. For regions with a distinct annual wet and dry season, it is most suitable to use an aggregation period for at least the length of the major seasons. Thus, SQI was calculated for selected gauges in the Mekong where adequate data were available. The SQI was calculated with a reference period of the full length of records available to allow a classification of the recent runoff conditions against all available data.

In contrast to SPI, which allows the assessment of meteorological drought conditions, SQI indicates hydrological drought. Hydrological drought is usually preceded by a meteorological drought and followed by an agricultural drought. Thus, SQI is a strong indicator for explaining water availability excluding groundwater aquifers not connected to surface waters.

Figure 7 below shows the SQI for 1-, 3-, 6-, 12- and 15-month aggregation with red: drier than average; green: average; blue: wetter than average conditions along the
mainstream from upstream to downstream (upper panels, from Chiang Saen to Chau doc) and at the three tributaries Ou, Mahaxai and Se Kong (lower panels). The stations are sorted from up to downstream to allow a visual interpretation along the flowpath of the Mekong. Even though individual gauges have longer time periods of discharge observations, results are shown from 1990-2018 because of the temporal overlap and to enable comparability across all gauges. With each subsequent prolongation of the aggregation period, the severity of the actual situation on long-term water storage (e.g. in terms of drought) or flooding can be distinguished more clearly. It must be noted that exceptionally dry or wet conditions occurring individually in a few months (e.g. dry months at the end of 1998 or wet months from 1999-2002 for the one-month aggregation) have a shifted and longer lasting effect on the hydrological conditions when looking at the 12-month aggregated SQI. The 2000-2002 conditions can therefore be classified as a consistent period of wetter than usual conditions also for groundwater and reservoir storage that recharge within the course of a year.

Figure 7 also reveals interesting spatial dependencies. For instance, the 1998-1999 drought period, shown by the 6- and 12-month aggregation, becomes worse downstream of Nakhon Phanom. The drier than normal condition is also visible in the SQI of the tributary Mahaxai. The below average inflow from the transition region, mainly supported from Lao PDR areas, has of course adverse effects on the mainstream. The negative effect is more visible in the six to 12 months’ aggregation, meaning that an exceptionally low streamflow from the Lao PDR transition zone has long lasting effects (minimum 12 month) in the mainstream Mekong. Similarly, the 2000-2002 wet period occurred mainly from the headwater and mountainous regions since the whole mainstream Mekong shows above average wet conditions, while the tributaries do not (assuming data from the tributaries are error free). Other examples exist of conversely caused hydrological drought conditions; e.g. in 1992-1993 from the upstream region. 2008 and 2011 are examples where wet periods were caused by spatial differences. Looking at the one- and three-month aggregation for the year 2018 reveals the same pattern as can be seen in Figure 40, with an initially wetter than usual period in the first half of the year and then a drier than usual situation in the second half, especially in the downstream part of the LMB.

The SQI also shows the droughts of 2015 and 2016 as events with more severity in the downstream part of the LMB. The prolonged regional drought event in 2015 and 2016 caused by the extreme El Niño brought serious economic impacts on agriculture in the Lower Mekong Basin (LMB) region and the consequences extended until the beginning of the monsoon season in April 2017. This period is marked dark red in Figure 7. The severity rises with the aggregation period, meaning that the dry spell lasted over a minimum of 12 months without a significant recovery period in between. Short aggregation periods, however, show a short recovery with average to wet conditions but with no significance for agriculture. It is also visible in Figure 7 that this situation affected the transition zone, Tonle Sap, and the Delta much more than the mountainous area.
15-month aggregation

Figure 7: SQI for mainstream Mekong and three tributaries

Aforementioned explanations are exemplarily demonstrated in a graphical manner below:
Aggregation: 12 month

Drought in Headwater and mountainous area but partly compensated through transition zone (Lao PDR)

-2 (extremely dry)
0 (normal)
+2 (extremely wet)

Luang Prabang
Stung Treng
Aggregation: 12 month

-2 (extremely dry)
0 (normal)
+2 (extremely wet)

Normal in Headwater, dryer than usual in mountainous area and severe drought in transition zone
Aggregation: 12 month

-2 (extremely dry)
0 (normal)
+2 (extremely wet)

Luang Prabang
Stung Treng

wet years with major flood events
## Aggregation: 12 month

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-2 (extremely dry)
0 (normal)
+2 (extremely wet)

- Luang Prabang
- Stung Treng
Aggregation: 12 month

Stations

-2 (extremely dry)
0 (normal)
+2 (extremely wet)

With Multivariate ENSO Index Version
The comparison of SQI with the Multivariate ENSO index could be a starting point for long-range streamflow forecasts and drought conditions in the LMB. Five out of six severe droughts in the LMB were visible in the Multivariate ENSO index as well as three wet periods. However, the challenge is that lead time is not homogeneous, which makes any prediction difficult.

2.4 Tonle Sap Reverse Flow

The hydrology of the Tonle Sap Lake is characterised by the interaction with the Mekong River. During the flood season, the water level in the mainstream rises so that the Tonle Sap River reverses its flow. Water from the Mekong River and overland flow from the Mekong downstream of Kratie enters the lake. Calculating reverse flow is complex and results differ depending on the data and approach used. Since all flow observation points downstream of the Tonle Sap Lake area are subject to backwater effects, the introduction of new backwater unaffected data sources for cross-checks would be an advantage. Possible data sources are satellite altimetry and model results. The following chapter aims at demonstrating the integration of satellite altimetry.

Additional data sources unaffected by backwater effects are:
- water levels at Prek Kdam from satellite altimetry
- simulated flow at Tan Chau and Chau Doc from a hydrological model
- digital elevation model of the Tonle Sap Lake and the surrounding area

Flow observations at Phnom Penh Port, Prek Kdam, Tan Chau, and Chau Doc are subject to backwater conditions or affected by tides and must be handled with care. Flow observations at Tan Chau and Chau Doc derived from discharge rating curves are not reliable and could be replaced by model results from the SWAT and ISIS models that have been set up and calibrated for the whole Mekong Basin (MRC, 2018b).

The hydrological situation is shown in Figure 8.

Figure 8: Overview map of the Tonle Sap / Mekong hydrological system
The water level observation at Prek Kdam can be checked by means of the water levels of the Tonle Sap Lake satellite altimetry (see Figure 9).
The correlation between Prek Kdam and satellite observations has a $R^2$ coefficient of 0.89. The satellite altimetry was taken from the Database for Hydrological Time Series of Inland Waters (DAHITI, 2019). Plotting both Prek Kdam and water levels from satellite in a chart (Figure 10) reveals the different reference base elevation of the satellite observations and Prek Kdam measurements. A perfect match would be if all dots lie on a 45° straight line. This is not the case. The satellite data was therefore adjusted by approximately 2.16 m on average (right chart in Figure 10).

This elevation-corrected data was further used in the analysis of the Tonle Sap reverse flow.

Since calculating reverse flow implies a high uncertainty due to low accuracy of the flow observations, a verification is possible when a water level–storage relationship of the Tonle Sap Lake is determined from a digital elevation model (DEM) and the potential storage volume for a given water level is then compared with reverse flow volumes. Water level–storage relationships were calculated from two DEMs with the bottom of the Tonle Sap at 4 m ASL. Hence, the relationships do not contain the Tonle Sap Lake’s volume below 4 m. The DEMs used were SRTM and MERIT (Yamasaki, 2017). MERIT is based on SRTM but is vegetation corrected, thus the volumes based on MERIT are larger. Figure 11 shows the water level–storage relationships.
A verification is successful when the potential storage volume associated with a given water level from the water level–storage curve is larger than the calculated reverse flow volume. This can be regarded as the minimum boundary condition to accommodate reverse flow.

Using these two additional data sources it is possible to check whether or not the calculated reverse flow fits with the terrain and satellite altimetry. The data sources are readily available and could be included in the calculation procedure.

### 2.5 Monitoring System

A hydro-meteorological observation network is established in the LMB (Figure 12). It consists of rainfall and discharge stations. MRC obtains records from the member countries following a mechanism of data exchange but also has direct access in real-time to a number of hydrological stations.
Figure 12: Flow and water quality observation network (MRC, 2019c)

Twenty-two (22) streamflow stations are provided with forecasting results and used to generate situational reports (Table 1). These 22 report stations are located along the mainstream Mekong, including Tonle Sap River (Prek Kdam) and Bassac River downstream of Phnom Penh. The records of the 22 report stations are presented in near-real time (daily) on the MRC’s website and are used to generate seasonal, flood, and dry-season situation reports.
Table 1: Period of available streamflow data records of the 22 report stations

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<td>LA_012703_Paksan_</td>
<td>07:00</td>
<td>now</td>
</tr>
<tr>
<td>LA_013102_Thakhet</td>
<td>07:00</td>
<td>now</td>
</tr>
<tr>
<td>LA_013401_Svannakhet</td>
<td>07:00</td>
<td>now</td>
</tr>
<tr>
<td>LA_013901_Pakse</td>
<td>07:00</td>
<td>now</td>
</tr>
<tr>
<td>TH_010501_Chiang Saen</td>
<td>07:00</td>
<td>now</td>
</tr>
<tr>
<td>TH_011903_Chiang Khan</td>
<td>07:00</td>
<td>now</td>
</tr>
<tr>
<td>TH_012001_Nong Khai</td>
<td>07:00</td>
<td>now</td>
</tr>
<tr>
<td>TH_013101_Nakhon Phanom</td>
<td>07:00</td>
<td>now</td>
</tr>
<tr>
<td>TH_013402_Mukdahan</td>
<td>07:00</td>
<td>now</td>
</tr>
<tr>
<td>TH_013801_Kong Chiam</td>
<td>07:00</td>
<td>now</td>
</tr>
<tr>
<td>VN_019803_Tan Chau</td>
<td>07:00</td>
<td>now</td>
</tr>
<tr>
<td>VN_039801_Chau Doc</td>
<td>07:00</td>
<td>now</td>
</tr>
</tbody>
</table>

There are also a number of existing dams in the LMB and many new dams are in the pipeline, mainly in the mountainous region, in the eastern part of the transition zone,
and a few in Cambodia around Tonle Sap (see Figure 13). Monitoring at dam sites is mandatory and comprises at least the water level of the reservoir, releases, and sometimes climate data observed at the dam site and monitoring of inflow. Records from dam sites are not yet available. It is recommended this issue is brought to the attention of the member countries as to whether data from dam sites can be made available to the MRC.

Figure 13: Hydropower dam development (MRC, 2019b)
Table 2: Availability of water-level and streamflow data for the 22 report stations

This table does not reflect the ongoing data recovery and data management process.
The number of hydrological and meteorological stations was given as 22 + 118 in 2001 (MRC, 2014a) and rose to 168 stations in 2012 (MRC, 2014b). With an additional 131 dam locations given in the year 2040 scenario, the number of sites for streamflow observation could almost be doubled, highlighting the value of integrating data at dam sites into the monitoring network.

In addition, the ongoing project on data management at the MRC will bring significant progress in data management and data conformity not only among different entities within the MRC but also for data exchange mechanisms with third parties.

The World Meteorological Organisation (WMO) provides policy documents, guidelines, standards, and technical regulations about hydrological observation networks. A part of its technical regulation is the recommendation on a certain network density of stations. WMO says a minimum network is appropriate and necessary to develop and manage water resources on a scale commensurate with an overall level of economic development and environmental needs of a country or region (2008). In other words, a minimum observation network is required to facilitate information needs of specific water uses.

The minimum requirements for an observation network to be established for making climate and hydrological investigations are given in WMO (2008). Since the MRC’s data repository is a mirror for the countries’ data situation, the stations can be analysed with respect to their coverage and compared to WMO criteria.

Table 3: WMO standards for observation networks (WMO, 2008)

<table>
<thead>
<tr>
<th>Physiographic unit</th>
<th>Precipitation</th>
<th>Evaporation</th>
<th>Streamflow</th>
<th>Sediment</th>
<th>Water quality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-recording</td>
<td>Recording</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coastal</td>
<td>900</td>
<td>9,000</td>
<td>50,000</td>
<td>2,750</td>
<td>18,300</td>
</tr>
<tr>
<td>Mountains</td>
<td>200</td>
<td>2,000</td>
<td>50,000</td>
<td>1,000</td>
<td>6,700</td>
</tr>
<tr>
<td>Interior plains</td>
<td>575</td>
<td>5,750</td>
<td>5,000</td>
<td>1,875</td>
<td>12,500</td>
</tr>
</tbody>
</table>

These recommendations must be seen as very general and need site-specific adjustments. Applying these minimum requirements as a buffer around each station in the LMB demonstrates its actual network coverage (Figure 14).
The circles were calculated using the numbers from Table 3. Coastal areas have a radius of 53.5 km (9,000 km²), rainfall stations in the plain have a radius of 42.8 km (5750 km²), and the stations located in the mountains have a radius of 25 km (2,000 km²). The smaller radius of stations in the mountains is due to a higher variability of climate conditions that can occur in mountainous regions, requiring a higher network density.

The coverage for a streamflow station is less compared to a rainfall station. The radius for coastal locations is 29.6 km (2,750 km²), for the plains 42.8 km (1,875 km²), and for mountainous region 25.2 km (1,000 km²). The right map in Figure 14 indicates the coverage with all potential dams in the pipeline.

As a consequence, coverage regarding rainfall is much better in comparison to streamflow. Following the mainstream Mekong, the data situation could be regarded as suitable. However, streamflow records in the tributaries require more stations. Most likely, more stations with reliable records might be in place but not yet readily available for exchange with third parties in near-real time. In particular, the analysis of droughts should be a driver to improve this situation and to enhance data exchange and incorporate more streamflow stations; e.g. including data from the dams.

Another aspect becomes obvious when analysing the results: future drought analyses require climate data. The minimum set of parameters contains temperature, sunshine duration, humidity, air pressure, and wind speed. This must be taken into consideration when assessments focusing on drought are carried out in the future within the format of the AMHR.

In conclusion, there is a need to enhance the hydrological observation network in terms of:

- enhancing the number of streamflow stations in the tributaries
- including climate data (temperature and evaporation)

One possible way forward in order to fill the gaps is certainly the step-by-step integration of dam sites as observation points and the application of satellite-based estimates with ground truthing.
2.6 Hydrological Modelling

Modelling of the Lower Mekong Basin at the MRC is a task that was started soon after the MRC was established. Since forecasting is one of the core tasks of the MRC, modelling has become an essential element and is performed at the RFDMC in Phnom Penh. Nowadays, a number of modelling tools are in place for different purposes, namely:

- SWAT
  Rainfall – Runoff Model. Used to assess the impacts of climate change, land-use change, and basin development on runoff.
  Comprises 870 sub-basins from China down to the Great Lake in Cambodia.
- IQQM
  Basin Simulation Model (Water Balance). Used to simulate water use (Irrigation, water supply, hydropower, in-stream demands, etc.) and to route SWAT inflows downstream.
  More than 800 nodes with gauged or computed flow (not water level).
- URBS
  Basin Simulation Model. Used for conducting the hydrological forecasts and to generate the input for the ISIS model.
- ISIS
  Hydro-dynamic Model. Used to simulate water levels and discharges along river canal systems and across floodplains.
  Applied downstream of Kratie, consists of some 2,900 cross-sections, 600 floodplain cells, and 800 reservoir cells linked by some 450 hydraulic links/junctions.
  Output consists of 6-hourly WL data at nearly 2,000 locations.
  DS boundary conditions include tidal, storm surge- and sea level rise effects.

Figure 15: Overview of the MRC DSF/Toolbox (Bakker, 2014)
Taking a closer look at the URBS model as the tool for the operational forecast reveals spatial resolution and the sub-models. The conceptual runoff routing model, URBS, is a hydrologic modelling programme that enables the simulation of catchment storage and runoff response by a network of conceptual storages representing the stream network and reservoirs. It combines two hydrological modelling processes into one model:

- A rainfall runoff model, which converts the gross rainfall into net or excess rainfall; and
- A runoff routing model, which takes the excess rainfall as input and converts it into flow.

Currently, the URBS model has a set of 52 URBS sub-models, covering over 740,000 km² represented by over 2,217 sub-basins.


Figure 16: Overview of the river basin model spatial resolution used for forecasts

ISIS is a generic 1D model for the simulation of unsteady flow in channel networks by applying an implicit solver for the Saint-Venant equations. The ISIS model covers the Mekong Basin from Stung Treng to the Delta, including the Tonle Sap floodplain, the Cambodia floodplain, and the Viet Nam Mekong Delta.

(http://help.floodmodeller.com/elearning/riverhydraulics/Teaching_Hydraulics_Using_ISR.htm)

Figure 17: Overview of the 1D hydraulic model and its spatial resolution used for forecasts
2.7 Remote Sensing and Satellite Data

The usefulness of remote sensing data is unquestioned. The MRC makes use of remote sensing data for streamflow forecasts based on Satellite Rainfall estimates (SRE) and applies other products as well; for example, the Flash Flood Guidance System (FFGS) is sourced by remotely sensed rainfall and climate data.

Two additional remote sensing data sources are recommended for future use; both are applied within this report for different analyses. First, the MODIS-based flood mapping has proven its usefulness in previous Mekong Flood Reports. A regular check of these flood maps with different composition is a reliable method to check observed water levels with associated inundation areas. Second, satellite altimetry to observe water levels can enhance monitoring when it is used in combination with flood mapping. Since satellite data can be used to obtain time series for many locations, it could be considered an integral part of the hydrological data management system.

2.8 Water Demand

Drought has become an integral part of the AMHR as stated in the introduction of Section 2.

Drought is a natural hazard that differs from other hazards in that it has a slow onset, evolves over months or even years, affects a large spatial region, and causes little structural damage. Its onset and end are often difficult to determine, as is its severity. Like other hazards, the impacts of drought span across economic, environmental, and social sectors and can be reduced through preparedness if countermeasures are launched in time.

Population growth and water demand patterns – in particular from the agricultural sector but also from industry – are factors that define the vulnerability of a region, an economic sector, or a population group. As such, the knowledge of water demand, and its spatial and temporal distribution is crucial to analyse the severity and impact of a drought.

Water demand has been captured by the MRC for the LMB as part of modelling climate change and infrastructure development for the Council Study (MRC, 2018b). The figures cover irrigation demand and are based on an analysis of land use, crop patterns, and related water requirements, mainly rice. But there are data constraints according to the MRC (2018c) that impact calculated water demand values, calling for a systematic assessment of water demand.

The main prerequisite for assessing water demand is to understand agricultural activities as the main consumer of water. Population growth is a major driver as well and must be considered, too. It is of utmost importance to analyse the current and projected water demand up to 20-30 years ahead including trends of land use change and water-use efficiency similar to the assessment performed in the Council Study within scenarios with a perspective of 2020 and 2040 (MRC, 2015). All activities (e.g. policies and plans) should be performed in close collaboration with the member countries and should be updated based on the latest national surveys.
A systematic water demand assessment starts with an inventory of water consumers and their current and expected water demand, including their losses/efficiency. The knowledge of all major crop patterns – as it is already existing for rice – is required to estimate the distribution of demand within a year.

The need to study water demand and the consequences caused by droughts becomes evident when considering population growth in the LMB and the existing and planned irrigation schemes (Figure 18).

Understanding the consequences of droughts is a prerequisite for analysing their socio-economic impacts. This is typically done by addressing economic and environmental impacts. If it is intended to relate costs with water deficiencies caused by a drought, the impact of historical, (if applicable) current, and potential droughts needs to be analysed. Checklists for a comprehensive assessment of impacts from droughts and states exist (Wilhite, Hayes, Knutson, & Smith, 2000) (Table 4): To perform an assessment based on this checklist, the boxes in front of each category need to be checked accordingly if they have been affected by drought in the selected study area. The selections can be based on common or extreme droughts, or a combination of the two. For example, if drought planning was going to be based on the “drought of record,” the tasks would be to complete a historical review to identify the drought of record for the area of concern and assess the impacts of that drought. Then the impacts must be recorded on this checklist by marking the appropriate boxes under the “historical” (H) column. Next, with the knowledge available about the study area, if another drought on record were to occur tomorrow, consider what the local impacts may be and record them on the checklist under the “current” (C) column. Finally, consider possible impacts of the same
drought for the study area in 5 or 10 years and record these in the “potential” (P) column.

Table 4: Checklist for drought impact assessment

<table>
<thead>
<tr>
<th>H</th>
<th>C</th>
<th>P</th>
<th>Economic Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>Annual and perennial crop losses</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>Damage to crop quality</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>Reduced productivity of cropland</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>Insect inflation</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>Plant disease</td>
</tr>
<tr>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>Wildlife damage to crops</td>
</tr>
</tbody>
</table>

2.9 Overview of Water Related Management in the Countries

2.9.1 Cambodia

The National Committee for Disaster Management (NCDM), which was established in 1995, is the entity responsible for emergency preparedness and response. The Ministry of Water Resources and Meteorology (MOWRAM) assumes responsibility for hydro-meteorological observation, data management, and forecasts and early warning. MOWRAM issues flood and weather warnings through mass media for local authorities, line agencies, NGOs and related users. The National Committee for Disaster Management uses this information for early warning at community level.

2.9.2 Lao PDR

The Government of Lao PDR coordinates disaster preparedness and response activities through two key entities: the National Disaster Management Committee (NDMC) chaired by the Vice Prime Minister, and the Department of Disaster Management and Climate Change (DDMCC) under the Ministry of Natural Resources and Environment (MoNRE), which also acts as secretariat to the NDMC. Disaster management committees are established to inform and implement preparedness, assessment, and response efforts of the government at the provincial, district levels, and Village Disaster Management Committees (VDMCs) at the village level.

The DDMCC has a key role in communicating and reporting disaster situations, planned emergency responses, and recovery activities to line ministries, including through the NDMC. In coordination with the Department of Meteorology and Hydrology (DMH), it is responsible for disseminating early warning information to the Provincial Disaster Management Committees (PDMCs). The DDMCC is responsible for providing technical and capacity building support to provinces and districts.

The Department of Meteorology and Hydrology (DMH), under MoNRE, is responsible for weather related early warning information, including weather forecasts, precipitation levels, and flood risk.

2.9.3 Thailand

In response to the 2011 flood, the Royal Thai Government drafted a Master Plan on flood management, after which it established the National Water Resources and Flood Policy Committee (NWFPC) and the Water and Flood Management Commission (WFMC).
These bodies formulate policies, approve investment projects monitor implementation, and evaluate projects. Besides these national committees, there are three major ministerial departments involved in flood management:

- The Royal Irrigation Department (RID), under the Ministry of Agriculture and Cooperatives, plays a significant role in constructing and maintaining waterways and flood protection systems.
- The Department of Disaster Prevention and Mitigation, Ministry of Interior, is responsible for coordination during disasters and recovery management.
- The Department of Water Resources (DWR), Ministry of Environment and National Resources, monitors flood mitigation in the 25 river basins.

In terms of flood management, Thailand still has many agencies responsible for providing response measures. The government has designated the Ministry of Interior by the Department of Disaster Prevention and Mitigation to collaborate and coordinate with the provincial office, Bangkok Metropolitan Authority, and the Military to support a proactive flood emergency response and provide all-inclusive victim assistance.

2.9.4 Viet Nam

The Central Steering Committee for Flood and Storm Control (CSCFSC) is responsible for the emergency response in relation to floods and storms.

The National Committee for Search and Rescue (NCASR) is responsible for coordinating, controlling, and implementing the national warning system and provides technical assistance/expertise to search and rescue victims of natural disasters. This agency was formed based on the Strategy and Action Plan for Mitigating Water Disasters in Viet Nam.

The Department for Dyke Management, Flood Control, and Storm Preparedness (DDMFCSP) oversees development in flood prone areas. This statute also empowers authorities to take necessary steps to prepare for floods and typhoons and to participate in emergency repairs and protective works. The DDMFCSP approves the Disaster Management Plans.

At province, district or community level, the chairs of province, district and commune people’s committees issue the decision to establish the committees for flood and storm control. The members of the Committee include: the Chair - Chair of the people’s committee; Vice Chair - Chief of the water sector; and the members are Chiefs or Vice Chiefs of sectors related to local flood and storm control work. Committees for flood and storm control at local levels have the responsibility to assist, develop, and implement flood and storm control measures; to protect industrial, commercial and residential areas; and overcome the aftermaths of floods and storms and to implement preparedness.
THE YEAR 2018

3.1 Tropical Storms

Tropical storms and cyclones mostly enter the LMB along the coast of Viet Nam, which is situated in one of the World’s five largest typhoon areas. Observational data from 1960 to 2018 show that on average five-six tropical storms occur annually. The number of storms in previous years is shown in Figure 19.

![Number of Storms and Tropical depressions](image)

Figure 19: Number of storms and wind speed levels in the previous nine years

An overview of the historical storm situation is given in Chapter 4.4.2 (Vietnamese Country Report). In 2018, ten storms (typhoons) and five tropical depressions occurred in Viet Nam’s East Sea. A summary of the storms and depressions are given in Table 5 and an overview of the migration paths of the individual storms is given in Figure 20. For more detailed information on the individual storms, please refer to Chapter 4.4.2 (Vietnamese Country Report).

**Table 5: List of tropical storms that have entered Viet Nam during 2018 (Hung, 2019)**

<table>
<thead>
<tr>
<th>Sea region</th>
<th>Date of Occurrence</th>
<th>Storm name</th>
<th>Wind speed level</th>
</tr>
</thead>
<tbody>
<tr>
<td>South East Sea</td>
<td>03-04/01/2018</td>
<td>Bolaven</td>
<td>Level 8 (65 km/h)</td>
</tr>
<tr>
<td>South East Sea</td>
<td>05-08/06/2018</td>
<td>Ewiniar</td>
<td>Level 8 (65 km/h)</td>
</tr>
<tr>
<td>North East Sea</td>
<td>15-17/06/2018</td>
<td>Gaemi</td>
<td>Level 6 (39 - 49 km/h)</td>
</tr>
<tr>
<td>East Sea</td>
<td>17-18/06/2018</td>
<td>Tropical depression</td>
<td>Level 6 (39 - 49 km/h)</td>
</tr>
<tr>
<td>East Sea</td>
<td>16-17/07/2018</td>
<td>Tropical depression</td>
<td>Level 6 (39 - 49 km/h)</td>
</tr>
<tr>
<td>North East Sea</td>
<td>17-19/07/2018</td>
<td>Son-Tinh</td>
<td>Level 9 (75 - 83 km/h)</td>
</tr>
<tr>
<td>North East Sea</td>
<td>20-23/07/2018</td>
<td>Tropical depression</td>
<td>Level 6 (39 - 49 km/h)</td>
</tr>
<tr>
<td>North East Sea</td>
<td>21-24/07/2018</td>
<td>Tropical depression</td>
<td>Level 6 (39 - 49 km/h)</td>
</tr>
<tr>
<td>North East Sea</td>
<td>13-17/08/2018</td>
<td>Bebinca</td>
<td>Level 12 (130 km/h)</td>
</tr>
<tr>
<td>North East Sea</td>
<td>07-17/09/2018</td>
<td>Mangkhut</td>
<td>Level 12 (130 km/h)</td>
</tr>
<tr>
<td>North East Sea</td>
<td>11-13/09/2018</td>
<td>Barijat</td>
<td>Level 12 (130 km/h)</td>
</tr>
<tr>
<td>North East Sea</td>
<td>21/10-2/11/2018</td>
<td>Yutu</td>
<td>Level 12 (130 km/h)</td>
</tr>
<tr>
<td>Middle East Sea</td>
<td>17-18/11/2018</td>
<td>Toraji</td>
<td>Level 12 (130 km/h)</td>
</tr>
<tr>
<td>South East Sea</td>
<td>22-25/11/2018</td>
<td>Usagi</td>
<td>Level 12 (130 km/h)</td>
</tr>
</tbody>
</table>
3.2 Rainfall

Rainfall conditions over the LMB are observed daily at about 119 ground stations in the basin out of the existing 178. The observed rainfall has been quality controlled and analysed by the MRC to represent the overall condition of rainfall in the LMB (Figure 21).

The spatially distributed monthly rainfall over the LMB is presented in Figure 22.

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Figure 20: Migration paths of the Typhoons in 2018 affecting the LMB; dates indicate the onset of the storm (Source of storm paths: National Institute of Informatics [NII, 2018], background image: Stamen Terrain)

Figure 21: Monthly rainfall for 2016-2018 over the Lower Mekong Basin compared to the long-term condition for 2008-2015
The average rainfall pattern for 2008-2015 over the LMB typically peaks in July. In 2017 and 2018, rain generally began over the Lower Mekong Basin from mid-May to mark the
onset of the southwest monsoon as indicated in Table 6. In 2018, the onset of the wet season started later at the end of May.

Table 6: Onset and offset of the southwest monsoon for 2016-2018 at hydrological stations along the Mekong mainstream

<table>
<thead>
<tr>
<th>Station</th>
<th>2016 Onset</th>
<th>2016 Offset</th>
<th>2017 Onset</th>
<th>2017 Offset</th>
<th>2018 Onset</th>
<th>2018 Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiang Saen</td>
<td>2 May</td>
<td>26 Oct</td>
<td>3 May</td>
<td>23 Oct</td>
<td>04 May</td>
<td>6 Oct</td>
</tr>
<tr>
<td>Luang</td>
<td>25 May</td>
<td>11 Oct</td>
<td>4 May</td>
<td>24 Oct</td>
<td>05 May</td>
<td>8 Oct</td>
</tr>
<tr>
<td>Chiang Khan</td>
<td>14 May</td>
<td>26 Nov</td>
<td>8 May</td>
<td>26 Oct</td>
<td>20 May</td>
<td>9 Oct</td>
</tr>
<tr>
<td>Vientiane</td>
<td>30 April</td>
<td>24 Oct</td>
<td>10 May</td>
<td>27 Oct</td>
<td>27 May</td>
<td>10 Oct</td>
</tr>
<tr>
<td>Nong Khai</td>
<td>30 April</td>
<td>24 Oct</td>
<td>10 May</td>
<td>27 Oct</td>
<td>27 May</td>
<td>10 Oct</td>
</tr>
<tr>
<td>Nakhon</td>
<td>16 May</td>
<td>26 Oct</td>
<td>12 May</td>
<td>29 Oct</td>
<td>28 May</td>
<td>11 Oct</td>
</tr>
<tr>
<td>Thakhek</td>
<td>16 May</td>
<td>27 Oct</td>
<td>12 May</td>
<td>29 Oct</td>
<td>28 May</td>
<td>11 Oct</td>
</tr>
<tr>
<td>Mukdahan</td>
<td>19 May</td>
<td>29 Oct</td>
<td>13 May</td>
<td>30 Oct</td>
<td>29 May</td>
<td>12 Oct</td>
</tr>
<tr>
<td>Savannakhet</td>
<td>19 May</td>
<td>30 Oct</td>
<td>13 May</td>
<td>30 Oct</td>
<td>29 May</td>
<td>12 Oct</td>
</tr>
<tr>
<td>Khong Chiam</td>
<td>20 May</td>
<td>31 Oct</td>
<td>17 May</td>
<td>31 Oct</td>
<td>30 May</td>
<td>12 Oct</td>
</tr>
<tr>
<td>Pakse</td>
<td>19 May</td>
<td>30 Nov</td>
<td>15 May</td>
<td>01 Nov</td>
<td>28 May</td>
<td>11 Oct</td>
</tr>
<tr>
<td>Stung Treng</td>
<td>21 May</td>
<td>4 Nov</td>
<td>16 May</td>
<td>02 Nov</td>
<td>29 May</td>
<td>18 Oct</td>
</tr>
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<td>Kratie</td>
<td>23 May</td>
<td>6 Nov</td>
<td>17 May</td>
<td>03 Nov</td>
<td>29 May</td>
<td>17 Oct</td>
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<td>Kompong</td>
<td>24 May</td>
<td>7 Nov</td>
<td>19 May</td>
<td>04 Nov</td>
<td>30 May</td>
<td>14 Oct</td>
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<td>Bassac</td>
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<td>25 Nov</td>
<td>20 May</td>
<td>05 Nov</td>
<td>31 May</td>
<td>15 Oct</td>
</tr>
<tr>
<td>Phnom Penh</td>
<td>30 May</td>
<td>26 Nov</td>
<td>20 May</td>
<td>05 Nov</td>
<td>31 May</td>
<td>15 Oct</td>
</tr>
<tr>
<td>Koh Khel</td>
<td>30 May</td>
<td>26 Nov</td>
<td>20 May</td>
<td>05 Nov</td>
<td>31 May</td>
<td>16 Oct</td>
</tr>
<tr>
<td>Neak Luong</td>
<td>31 May</td>
<td>28 Nov</td>
<td>19 May</td>
<td>05 Nov</td>
<td>31 May</td>
<td>17 Oct</td>
</tr>
<tr>
<td>Prek Kdam</td>
<td>31 May</td>
<td>28 Nov</td>
<td>19 May</td>
<td>06 Nov</td>
<td>31 May</td>
<td>17 Oct</td>
</tr>
<tr>
<td>Tan Chau</td>
<td>6 Jun</td>
<td>6 Dec</td>
<td>13 Jun</td>
<td>31 Oct</td>
<td>02 Jul</td>
<td>22 Oct</td>
</tr>
<tr>
<td>Chau Doc</td>
<td>6 Jun</td>
<td>6 Dec</td>
<td>13 Jun</td>
<td>31 Oct</td>
<td>02 Jul</td>
<td>22 Oct</td>
</tr>
</tbody>
</table>

For 2018, the driest month was January with subsequent higher rainfall up to the peak in July and August.

During May 2018, the highest rainfall occurred over the north-western areas of the basin, centered in Xiang Khoang Province and the east of Cambodia – centered in Kratie and Stung Treng Provinces. A similar pattern occurred during June 2018 with the highest rainfall over the north-western areas of the Basin, which also covered Vientiane and Bolikhamsai in Lao PDR, and Nong Khai in Thailand. In the lower part of the basin, the highest rainfall moved to Ratanakiri in Cambodia, Gia Lai in Viet Nam, and Savannakhet and Khammouan in Lao PDR.

Rainfall amounts during July and August 2018 were unexceptionally high, exceeding 700 mm within 4 weeks at some locations. The highest rainfall in July prevails over both sides of the Mekong mainstream in the upper and middle parts of the LMB. Along the left side of the Mekong River, intensive rainfall covered most areas in Lao PDR from Luang Prabang down to Stung Treng in Cambodia. The right side of the Mekong River in northeast Thailand also received surplus rainfall with a focus on Mukdahan. In August, intensive rainfall in the lower part moved downward to Sekong and Sesan basins. By September, the monsoon was waning with significant rainfall confined to the Central Highlands in the east and remained in Vangvieng, Bung Kan, and Sakhon Nakhon.

Even though rainfall was extreme in July and August mainly in eastern areas, many parts of the LMB experienced drier conditions compared to the long-term average from
September onwards (see also Figure 21). This explains the rapid recession of the hydrograph along the mainstream Mekong.

Cumulative rainfall for the year 2018 is illustrated in Figure 23.

Figure 23: Annual rainfall distribution 2018

Cumulative rainfall for selected stations is shown in Figure 24.
Figure 24: Cumulative rainfall in 2018 against the long-term average at selected stations

The figure below shows the anomaly of annual rainfall in 2018. The rainfall stations are indicated as dots on the map.
3.3 Hydrological conditions in 2018

The hydrological regimes of the Mekong mainstream are illustrated by recorded water levels and related discharges at key stations (Figure 26):

- at Chiang Saen to capture mainstream flows entering from the Upper Mekong Basin
- at Vientiane to present flows generated by climate conditions in the upper part of the Lower Mekong Basin
- at Pakse to investigate flows influenced by inflows from Mekong tributaries
- at Kratie to capture overall flows of the Mekong Basin
- at Tan Chau and Chau Doc to monitor flows to the Mekong Delta

The impact of the mainstream dams on the flood hydrographs within the LMB have become increasingly evident, particularly at Chiang Saen and Luang Prabang. Frequent increases and decreases in discharge can be observed during the low flow season. The frequent short-term fluctuations in discharge are still evident further downstream at Vientiane. A sharp rise at most stations starting from July 2018 is the response to a
prevailing low-pressure condition caused by storms Son-Tinh and Bebinca. The water levels, respectively streamflow, at the reach between Nakhon Phanom and Pakse nearly touched the flood levels of 2000. A picture of the storm responses is given in the water level hydrographs at the stations at major tributaries in Lao PDR as depicted in Figure 27.

Figure 26: Hydrographs in 2018 and long-term conditions at selected stations

Considering the cumulative flood volume until September 2018 compared with previous years, the 2018 flood season can also be regarded as historically “extreme”.
During Tropical Storm Son-Tinh in July 2018, water levels rapidly rose in the upper and middle reaches of the LMB from Luang Prabang down to Stung Treng. Water levels at four stations (Nakhon Phanom, Mukdahan, Khong Chiam, and Pakse) along the Mekong mainstream reached flood levels in July 2018, while at Thakhek and Stung Treng, only alarm levels were reached. Water levels at these locations dropped at the beginning of August and started to rise again in the middle of the month after the occurrence of Storm Bebinca.

In summary, flood levels in 2018 were reached at 6 stations and alarm levels were reached at 10 stations in the mainstream (Table 7).

Table 7: Alarm level (yellow), flood level (red) and maximum water level observed in 2018

<table>
<thead>
<tr>
<th>Station</th>
<th>Alarm level (m)</th>
<th>Flood level (m)</th>
<th>Date (2018)</th>
<th>Water level (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiang Saen</td>
<td>11.5</td>
<td>12.8</td>
<td>05 Sep 2018</td>
<td>7.30</td>
</tr>
<tr>
<td>Luang Prabang</td>
<td>17.5</td>
<td>18.0</td>
<td>01 Sep 2018</td>
<td>17.26</td>
</tr>
<tr>
<td>Chiang Khan</td>
<td>14.5</td>
<td>16.0</td>
<td>19 Aug 2018</td>
<td>15.00</td>
</tr>
<tr>
<td>Vientiane</td>
<td>11.5</td>
<td>12.5</td>
<td>03 Sep 2018</td>
<td>11.67</td>
</tr>
<tr>
<td>Nong Khai</td>
<td>11.4</td>
<td>12.2</td>
<td>03 Sep 2018</td>
<td>12.83</td>
</tr>
<tr>
<td>Paksane</td>
<td>13.5</td>
<td>14.5</td>
<td>04 Sep 2018</td>
<td>14.51</td>
</tr>
<tr>
<td>Nakhon Phanom</td>
<td>11.5</td>
<td>12.0</td>
<td>31 Aug 2018</td>
<td>12.71</td>
</tr>
<tr>
<td>Thakhek</td>
<td>13.0</td>
<td>14.0</td>
<td>31 Aug 2018</td>
<td>13.83</td>
</tr>
<tr>
<td>Mukdahan</td>
<td>12.0</td>
<td>12.5</td>
<td>31 Aug 2018</td>
<td>12.92</td>
</tr>
<tr>
<td>Savanakhet</td>
<td>12.0</td>
<td>13.0</td>
<td>31 Aug 2018</td>
<td>11.83</td>
</tr>
<tr>
<td>Khong Chiam</td>
<td>13.5</td>
<td>14.5</td>
<td>31 Jul 2018</td>
<td>15.22</td>
</tr>
</tbody>
</table>
Figure 28 shows a schematic view of the Mekong River. The mean annual discharge volume is illustrated with simple symbols. The width of each element represents the annual volume; both schematic views use the same scale. The labels indicate the annual flow volume in km³. Flow from tributaries was calculated from the difference between flow volumes of neighbouring up- and downstream stations. Losses are indicated as yellow arrows. A loss occurs if the downstream station from two adjacent stations has less annual volume than the upstream station and the delta between both becomes negative. Two stations were used to calculate total flow volume in the Delta: Tan Chau and Chau Doc. The fading colour indicates the uncertainty of the discharge due to backwater and tidal effects.

Figure 28: Comparison of annual discharge volume in km³ during 1980-2017 with 2018’s

Surprisingly, the calculated volume for 2018 based on the streamflow between Chiang Kahn and Nong Khai indicates a loss. It is not very likely that a loss between these stations is true, so the reason must be inherent in the observed water level.
The observed water level at Chiang Khan shows a trend and has been rising in recent years. This means that streamflow calculated with the current rating-curve at Chiang Khan most likely is an overestimation and thus creates a loss when compared with the next downstream station. As a consequence, the rating curve should be reviewed and adapted to avoid errors.

Using representative report stations, the flood season for 2018 is illustrated in the following diagrams.

- **Upper left**: Monthly distribution of flow
  Shows the monthly distribution of the discharge compared to the long-term historical mean, minimum, and maximum.

- **Upper right**: Sorted annual flow volumes
  All annual flow volumes (1980-2017) were sorted and the red dot indicates the year 2018. The year was a wet year when the red dot is right and a dry year when it occurs more to the left.

- **Lower left**: Peak/Volume chart without baseflow
  This chart shows the annual flood volume compared with the flood volume for the years 1980 to 2017. The inner rectangle in the peak/volume charts indicates the derivation in the magnitude of the standard deviation for both peak discharge and annual flood volume. The outer rectangle simply doubles the standard deviation. Baseflow was simplified as the average flow in April and was subtracted.

- **Lower right**: Peak/Volume chart with baseflow
  This chart shows the annual flood volume compared with the flood volume for the years 1980 to 2017. The inner rectangle in the peak/volume charts indicates the derivation in the magnitude of the standard deviation for both peak discharge and annual flood volume. The outer rectangle simply doubles the standard deviation. The flood volume was calculated with baseflow.
• Chiang Saen

Without baseflow

with baseflow

• Vientiane

Without baseflow

with baseflow
• Pakse

Without baseflow

With baseflow

• Kratie

Without baseflow

With baseflow
• Tan Chau

(Flood volume is not calculated since streamflow at Chau Doc is largely affected by backwater)

Figure 30: Flow and flood characteristics in 2018 at selected stations

3.4 Riverine floods

Flood extent over the whole LMB has been analysed using remote sensing data, which provides useful spatial and temporal information regarding the location and magnitude of flooding. The information was compared with country records collected by national experts and shown in the chapters Impact of Flood and Drought 2018 in each country section and Socio-economic impacts from flood, flash floods, and droughts. However, the comparison has the limitations that: a) data collected indicated affected locations but not the flood extent and b) flash floods are not captured by remote sensing data.

The Moderate-resolution Imaging Spectroradiometer (MODIS) Water Product (MWP) in 250 m spatial and three-day temporal resolution was acquired from NASA’s Near Real
Time Global Flood Mapping product\(^1\) (NASA, 2017). The maps are still flagged as experimental but have the advantages of:

- covering both pluvial and riverine types of flooding
- are available free of charge
- cover all regions with a similar methodology and results are hence comparable

Main disadvantages are:

- inundation under dense vegetation and cloud cover is not visible
- that short events (e.g. flash floods or dam breaks) are usually not depicted due to the satellite revisiting interval of about two days
- misclassification of water areas is possible

Due to these disadvantages, inundation obtained from MWP should be plausibility-checked. For further information regarding the MWP, the interested reader is referred to the AMHR 2017.

All analyses in this chapter are carried out against the 2006-2017 reference period (henceforth designated “reference period”) due to the availability of other datasets such as precipitation. Figure 31 shows an overview map of the LMB with the maximum inundation (black) during the reference period and the inundation in 2018 (red). The description of the flooding situation is separated in four subchapters according to the spatial regions (Figure 2). For the flood analysis, the regions are cropped to the areas where significant flooding was observed for being able to show more spatial detail (black boxes in Figure 31). In July 2018, the dam break in Lao PDR caused widespread destruction and a concise analysis is given in chapter 3.5.2 (Flash Floods).

Figure 31: Overview of the flooding in the LMB in 2018 compared to the long-term maximum flood extent (NASA’s Near-Real-Time Global Flood Mapping [NASA, 2017], MODIS satellite, Background image: Open Street Map)
3.4.1 Mountainous region

Figure 32 shows the flooding situation in the upper part of the LMB in 2018 compared to the reference period. The inundation in the eastern part of the region are the two reservoirs Nam Theun 2 and Nam Gnouang and in the central northern part an additional reservoir. The reduction of reservoir inundation in the two eastern ones from June to August is assumed to be part of their typical seasonal filling and emptying phase.

The additional flood waters detected east of the Mekong River near the two reservoirs in January, February, November, and December are located in a hilly region with elevations above 600m. It is difficult to assess the validity of these flood waters without additional on-the-ground validation. Rainfalls in the region during the respective period do not support the results from MODIS.

Inundation south of the Mekong River in the central part of the mountainous region occurs from July to November. These flood waters are located near rivers and streams and are likely riverine flooding. While flooding during the reference period already starts in July, significant flooding in 2018 was observed in September, receding fast during October and November. In some places the magnitude reached an all-time high in 2018.
Figure 32: Flooding in the mountainous region of the LMB in 2018 compared to the long-term maximum flood extent (Data Source: NASA’s Near-Real-Time Global Flood Mapping [NASA, 2017], MODIS satellite, Background image: Stamen Terrain)
3.4.2 Transition region

Figure 33 shows the MWP-derived inundation for the transition region. Significant flooding during the reference period occurred from May to September near the main rivers. In 2018 however, flooding was only observed in August and September in the central part around Latitude 16 and longitude 104 (Nakhon Phanom province). In addition, it must be kept in mind that cloud cover, especially during the wet season, may cover on-ground inundation and hamper flood water detection.

Figure 33: Flooding in the transition region of the LMB in 2018 compared to the long-term maximum flood extent (Data Source: NASA’s Near-Real-Time Global Flood Mapping [NASA, 2017], MODIS satellite, Background image: Stamen Terrain)
Tonle Sap

In contrast to hilly and forested terrain, a plain terrain can be better captured by MODIS. Figure 34 shows the monthly distribution of flooding in the Tonle Sap region. Flooding in May during the reference period occurred in the western part, while no flooding was visible on MWP there in 2018. Flooding in 2018 began in August, apparently through return flow from the Mekong from the southeast. It quickly reached maximum inundation in September, which almost coincides with the most extensive inundation during the reference period. Flooding then receded quicker than usual during October and November, with almost no inundation prevailing in December 2018. A separate investigation of the Tonle Sap flood volumes and inundation processes is given in Chapter 2.4.

Figure 34: Flooding in the Tonle Sap region of the LMB in 2018 compared to the long-term maximum flood extent
3.4.3 The Mekong Delta

Monthly inundation of the Mekong Delta is shown in Figure 35. No significant inundation was observed on the MWP in January and December 2018. From February to July, only the southern tip of Cambodia was subject to flooding, which almost reached the historical maximum in May. Mekong flood waters reached the Delta in August and, similar to the situation in the Tonle Sap, reached almost the all-time maximum extent in September and October. Flooding in the Mekong Delta region, especially in the south-eastern part may be obscured by dense vegetation and therefore Figure 35 may not show the full extent of flooding in the Delta.

Figure 35: Flooding in the Mekong Delta in 2018 compared to the long-term maximum flood extent
3.5 Flash floods

Flash floods are a dangerous, unexpected, catastrophic and destructive natural disaster, which usually occur on small rivers and springs, mountainous provinces, and in urban basins and have most severe impact where residential and economic centres exist. Flash floods are mostly caused by high intensity rainfalls on already saturated soils or on soils/surfaces with low permeability. Due to the difficulty in predicting the time and location of flash floods, they can potentially cause devastating impacts on livelihoods, and on the socio-economic situation. Figure 36 shows the regions in the LMB where flash floods were recorded. More detail is provided in the subchapters below.

![Figure 36: Regions that reported flash floods in the LMB in Lao PDR (blue), Viet Nam (red), and Cambodia (green) in 2018](image)

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Page 60
3.5.1 Mountainous region

According to the national reports, numerous flash flood events occurred in the mountainous regions of Lao PDR and Viet Nam. However, only two districts in Viet Nam are located inside the LMB. In the districts marked in Figure 36, flash floods, debris flow, and landslides caused serious damage to people, houses, traffic, roads, and highways. Table 8 lists a summary of the flash flood events and their impacts. For Viet Nam, impact was not reported for each flash flood and also not within the LMB. Within the whole of Viet Nam, 82 people died due to flash floods and landslides in 2018.

Table 8: Summary of flash floods in the mountainous regions of the LMB collected by national experts

<table>
<thead>
<tr>
<th>Date</th>
<th>Region</th>
<th>Affected number of people</th>
<th>Casualties</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-25.07. and 15-20.08.</td>
<td>Phongsali</td>
<td>1435</td>
<td></td>
<td>Lao</td>
</tr>
<tr>
<td></td>
<td>Bokeo</td>
<td>1486</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Luangnamtha</td>
<td>929</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oudomxay</td>
<td>86456</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Huaphane</td>
<td>3936</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Xayabouly</td>
<td>5422</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Luangprabang</td>
<td>5734</td>
<td>10</td>
<td>Lao</td>
</tr>
<tr>
<td></td>
<td>Xiengkhuang</td>
<td>3162</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vientiane prov.</td>
<td>15338</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bolikhamxay</td>
<td>41396</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>28-31.08</td>
<td>Dien Bien</td>
<td>NA</td>
<td>NA</td>
<td>Viet Nam</td>
</tr>
<tr>
<td>NA</td>
<td>Tuan Giao</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

3.5.2 Transition region

In the transition zone in Thailand, no flash flooding was recorded in 2018. In the Cambodian part of the transition zone, flash floods occurred in Ratanakiri (Figure 36), affecting 1,871 people. The Lao PDR side faced a disastrous incident. On 23 July 2018, the Xe-Pian Xe-Namnoy dam, under construction at the time, broke in Attapeu and Champasak provinces (Latitude 15.01, Longitude 106.56) as a result of Tropical Storm Son-Tinh. The incident is described in Section 3.8.
3.5.3 Tonle Sap

Flash floods occurred in 12 provinces in the Tonle Sap region of Cambodia (Figure 36), affecting a total of 22,652 people.

<table>
<thead>
<tr>
<th>Date</th>
<th>Region</th>
<th>Affected number of people</th>
<th>Casualties</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>Pursat</td>
<td>1,719</td>
<td>NA</td>
<td>Cambodia</td>
</tr>
<tr>
<td></td>
<td>Battambang</td>
<td>6,256</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pailin</td>
<td>20</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Banteay</td>
<td>3,051</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Meanchey</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kompong Thom</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Preah Vihear</td>
<td>21</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Svay Rieng</td>
<td>36</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kompong Speu</td>
<td>1,196</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Preah Sihanouk</td>
<td>547</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kampot</td>
<td>6,172</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Koh Kong</td>
<td>1,201</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kep</td>
<td>606</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Siem Reap</td>
<td>1,827</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

3.5.4 The Mekong Delta

In the Mekong Delta, no flash flooding was recorded in the Vietnamese national report.

3.6 Catchment and river conditions affecting drought

As explained in Section 2.3, streamflow was analysed by calculating the Standard Discharge Index (SQI). In addition, soil moisture conditions were evaluated to better address the complexity of the runoff and streamflow generation process. Both SQI and soil moisture conditions are suitable to indicate hydrological and agricultural drought relevance. All analyses in this chapter were carried out against the 2006-2017 period (henceforth designated “reference period”) to be in line with other evaluations in this report and to capitalize on the availability of a maximum number of monitoring stations.

In addition to the assessment of streamflow records, soil moisture was analysed from remote sensing sources. The ESA CCI soil moisture product covers the globe in 25km spatial and daily resolution. Data was acquired and analysed for the reference period against 2018. Detailed information regarding the soil moisture product and the analysis procedure for the interested reader is provided in the Annual Mekong Flood Report 2017 (AMFR 2017) (MRC, 2019a).

Overlaying the soil moisture difference with the SQI yields hydrologically relevant information. Figure 37 shows both the soil moisture situation over the whole LMB (grid cells without outline) and the SQI of the mainstream Mekong, the Ou, Mahaxai and Kong tributaries (grid cells with thin black outline). The soil moisture layer contains remote-sensing-observed values for each pixel, while the SQI was calculated for a 12-month aggregation period and linearly interpolated between the discharge gauges. For the
tributaries, where only one station was available, the SQI value of this station was assigned for the whole tributary of the respective station. Figure 37 shows the reference situation, the 2018 conditions and the differences (anomalies) between 2018 and the reference period. In the reference period, wetter soil moisture regime prevails in the mountainous, eastern transition and the Mekong Delta region compared to the central and western transition region. The mostly negative SQI for the reference period indicates that this period was drier than the long-term average (1990-2018). Especially upstream of Vientiane and downstream of Phnom Penh, the discharge situation became drier in the reference period as compared to previous decades. In 2018 (middle panel in Figure 37), the soil moisture situation follows the general spatial pattern of the reference period. The SQI, however, shows significantly wetter conditions across the whole river sections compared to previous decades. Regarding the difference between 2018 and the reference period, interesting patterns emerge: Along the whole Mekong, the difference of the SQI in 2018 to the average of the SQI from the reference period is positive, indicating that 2018 was a wetter year than usual in terms of discharge in the Mekong and the main tributaries. However, soil moisture shows a different picture with wetter than average conditions in the north and drier than average conditions in northern Cambodia, Viet Nam, southeast Thailand and southern Lao PDR. Apparently, the wetter than usual conditions in the mountainous region have led to a strong contribution to river flows from upstream regions causing high discharge conditions throughout the transition region and up to the Mekong Delta.

![Figure 37: Comparison of (a) annual long-term average soil moisture (2006-2017) and SQI (12-month aggregation) for 2006-2017 against the total period (1990-2018); (b) soil moisture and SQI in 2017 and (c) the percent difference in soil moisture for 2017 compared to the long-term average and SQI of 2018 against the reference period 2006-2017 in the LMB](image)

Figure 38 shows the absolute spatial soil moisture distribution over the reference period separately for each month. Results are generally similar to the analysis in the AMFR 2017 (MRC, 2019a), where the general spatial pattern, also found in the annual map.
(Figure 37), is valid over all months, with the driest region located in the transition period. The temporal distribution follows the wet and dry season in the LMB with driest conditions from December to April and wettest conditions from May to November. According to comparison with satellite images, the individual wet pixels in the transition region are either irrigated areas or forests.

Figure 39 shows the monthly soil moisture distribution for 2018, which also generally follows the spatial and temporal distribution of the reference period.
Figure 38: Monthly long-term average (2006-2017) soil moisture for the LMB
Figure 39: Monthly average (2018) soil moisture for the LMB
Figure 40: Percent difference of monthly average soil moisture in 2018 compared to the reference period (2006-2017) and SQI from 2018 against the average from 2006-2017 in the LMB

Figure 40 reveals the actual differences in soil moisture and the SQI between the reference period and the situation in 2018 on a monthly time step. This overlay of soil moisture and SQI anomalies enables a quick analysis of the spatio-temporal causes and characteristics of the hydrological situation. Please note that the scale for soil moisture is shifted towards the wetter domain, indicating that blue pixels are twice as wet as red
pixels of the same shade, while the scale for the SQI is slightly shifted towards the drier domain. Regarding soil moisture, the first half of the year was generally wetter than the reference period apart from the south-eastern transition period. The second half of the year, especially from September to December was drier than usual with soil moisture up to 45% lower than usual across the central and southern parts of the LMB. Monthly SQI up to September shows consistently higher values than during the reference period across the Mekong and the depicted tributaries. Especially, the Ou River is significantly wetter up to August and then suddenly drops and becomes significantly drier than average. In summary, the year 2018 began wetter and ended drier than usual so the flood season showed a sharp rise and fall.

The results shown above can further be confirmed by an analysis of other hydro-meteorological indices and by means of rainfall anomalies in the LMB. Monthly rainfall anomalies are shown from January 2018 up to September 2018 (Figure 41).
The situation in 2018 was very inhomogeneous. Even the wettest months, July and August, show a deficit of rain in the western part of the LMB. The deficit rises sharply in September and October. This explains the drastic recession of the hydrographs in September (see Figure 26). In other words, the rainy season brought extreme rain within two months and then dropped below average.

The analysis was complemented using the recently established Lower Mekong Basin Drought Monitoring and Forecasting portal. The Drought Monitoring and Forecasting outcomes are updated every week with a weekly summary of the drought conditions. An extended database of the drought indices is available on the website for the main characteristic drought indicators. The website is in progress and not yet available to the public. The following drought indicators are generated:

- Standardized Precipitation Index (SPI)
- Standardized Runoff Index (SRI)
- Soil Moisture Deficit Index (SMDI)
- Combined Drought Index (CDI)
- Dry spell (DS)
- Drought Conditions (DC)
- Days without Rainfall (DR)

All indices are processed in collaboration with the Asian Disaster Preparedness Centre (ADPC) in cooperation with the United States National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL) as providers for information and
technical support with the Regional Hydrologic Extremes Assessment System (RHEAS) hydrologic nowcast and forecast framework. Outputs generated by the MRC are gridded maps and jpeg illustrations to describe the drought conditions as shown in the example below. More information is available here https://portal.mrcmekong.org/home. Figure 42 shows drought indices generated on 26 September 2018.

![SPI](image1)
![SRI](image2)
![SMDI](image3)

Figure 42: Various drought indicators generated at the MRC, issued on 26 September 2018

Although 2018 was generally wet, the various drought indices show below average conditions in some areas. SPI determines deficiencies in terms of precipitation in parts of Thailand down to the Tonle Sap region and also in parts of Lao PDR and Viet Nam. SMDI shows below average conditions for soil moisture in the southern part of the LMB, predominately the low-lying land downstream of Phnom Penh and the eastern part of Cambodia. This corresponds largely to the ESA soil moisture satellite estimates.

Deficient soil moisture is more critical than deficient rain due to the slow recovery process for soil moisture. It can take a long time for soil moisture to return to normal, which has severe consequences for agriculture. SPI indicates meteorological drought while SMDI determines an agricultural drought. Dry soil moisture conditions are not
instantly recognisable in streamflow. If deficient soil moisture occurs for a longer time, it affects baseflow conditions. Since ESA shows increasing soil moisture deficits until December 2018, the outlook is that a low flow period is more likely to come in 2019 even with average rain.

Another indicator are recession curves along the mainstream Mekong (Figure 43). The sharp drop in precipitation as of September is visible in the recession of streamflow. Coming from a very high level, e.g. at Nakhon Phanom almost at an all-time high, the streamflow drops below the long-term average and remains rather low.

![Recession of hydrographs in 2018](image)

**Figure 43: Recession of hydrographs in 2018**

### 3.7 Socio-economic impacts from floods, flash floods, and droughts

Analyses from the country reports have been summarized and structured to obtain a concise overview of the socio-economic impacts of the hydrological situation in 2018. The spatial distribution of floods and flash floods are shown in Figure 44 and Figure 45. All information was collected by national experts from each country.

In Cambodia, thousands of people had to be evacuated due to the dam break in Lao PDR. In total, floods and flash floods affected 23 provinces and a total of 134,893 people, of which 123 were injured and 63 died. Affected infrastructure included 335 schools, 140 cultural buildings, 28 hospitals, 64 km of roads, and 156 bridges. Some 30,507 cattle were evacuated, of which 28 died and a total of 122,923 ha of inundated
field, of which 65,525 ha were damaged. Regarding drought, the national report mentions that some areas faced water shortages during the late drought occurrence in 2018, but no drought impacts have been reported.

In Lao PDR, floods affected all provinces. Some 116 districts, 2,400 villages, and 132,000 households were affected, with 17,000 people evacuated and 1,772 houses destroyed. In total, 633 km of roads and 47 bridges were damaged. Regarding the agricultural situation, irrigation systems and about 100,000 ha of paddy fields were damaged. As many as 17,000 large animals and 79,000 poultry were lost. Flash flooding impacts on infrastructure are not separately listed in the country report; however, the number of people affected by flash floods amounts to 166,394, of which 54 died and 97 are missing. In 2018, droughts in Lao PDR were not reported and had no effect on livelihoods or agriculture.

In Thailand, natural disasters occurred in provinces located within the LMB, namely Chian Rai and Phayao, located in the mountainous region of the LMB as well as in Sakon Nakhon and Nakhon Phanom (located in the transition region of the LMB). Impacts have not been separately listed for the different provinces. It is reported that one person died in Phayao and one in Chiang Rai. Total impacts of floods in Thailand added up to USD 27 million. Drought impacts in 2018 were not reported for Thailand.

In the LMB region of Viet Nam, 13 people died due to natural disasters and 10 were injured. Three hundred and six houses, 20 school rooms were collapsed, and 7,579 houses and 23 school rooms were submerged and damaged. Impacts of natural disasters on agriculture amount to 3,913 ha of submerged and damaged fields and farms as well as about 13 km of damaged dikes. Infrastructure was damaged (i.e. in terms of 15,600 m³ of soil displaced and about 6 km of roads damaged). Economic impacts amounted to USD 66 million. In 2018, droughts in Viet Nam were not reported and had no effect on livelihoods or agriculture.
Figure 44: Overview of flood events in 2018
3.8 Dam break of the Xe-Pian Xe-Namnoy Dam

3.8.1 The accident

The dam break of the Xe-Pian Xe-Namnoy Dam in Lao PDR (Figure 46) was the most devastating single incident in 2018. According to SK Engineering and Construction (SK E&C), which is the consultant responsible for engineering, procurement, and construction of the dam, the accident happened on 23 July after a period of two weeks with close to 1,000 mm of rainfall at the Paksong station. The observed rainfall between 9-22 July at stations located in the surroundings of the dam, with Paksong closest to the dam site, was:
Annual Mekong Hydrology, Flood and Drought Report 2018

- Attapeu with 404 mm (daily maximum 130 mm)
- Station NK34 with 501 mm (daily maximum 120 mm)
- Paksong with 972 mm (daily maximum 161 mm)

According to SK E&C, the first indication of an imminent dam break was reported on the evening of 22 July when wash out due to overflow at the saddle dam D was reported. This triggered emergency response actions and notification of the Lao Government. Wash out proceeded due to continuous overtopping and finally led to the break of the saddle dam D on 23 July.

An independent Panel of Experts (IPE) was formed to investigate the root cause of the dam break. The IPE outlined in its findings that the failure could not be considered as “force majeure”. According to Times Reporters (2019), the IPE related the root cause of the failure to:

“[…] high permeability combined with erodible horizons mainly due to the existence of canaliculus interconnected paths. As the water level rose during the filling of the reservoir, seepage flow developed in the foundation along these paths and horizons with high permeability. This resulted in internal erosion and softening of the laterite soil. When erosion and softening in the foundations reached a certain point, the dam stability was no longer ensured and a deep rotational sliding at the highest section of the saddle dam was triggered. This finally led to a complete breaching of the saddle dam and its foundations, resulting in the catastrophic uncontrolled release of water from the reservoir”.

The Joint Research Centre (JRC) of the European Commission's science and knowledge service carried out a dam break analysis to assist with emergency response efforts. The JRC followed the situation from the beginning of the event with the creation of situation maps and analysis reports for the European Commission's Emergency Response and Coordination Centre, in collaboration with UN services and under the framework of the Global Disasters Alerts and Coordination System. The JRC performed a numerical
simulation of the water discharge from the dam, propagation along the downstream valleys, and inundation of the flatter areas. The results are published on their website [https://ec.europa.eu/jrc/en/news/jrc-analysis-assists-response-laos-dam-collapse](https://ec.europa.eu/jrc/en/news/jrc-analysis-assists-response-laos-dam-collapse) from where the following pictures were taken (Figure 47).

Figure 47: Propagation of the flood wave after the dam break, according to JRC (2018)

Considering past records of rain in southern Lao PDR, rainfall of this magnitude is not totally unexpected. The observation station Pakse had one event with 450 mm in 24 hours in 1983 (07:00 to 07:00h) and 640 mm in three days within an observation period from 1980 to 2019. Veun Khen station, with an observation period of only 10 years of records, had a maximum of 123 mm in 24 hours, 185 mm in 48 hours, 230 mm in three days, and 302 mm in six days. An IDF analysis of Pakse based on 40 years of records is shown below (Figure 48).
Values at Pakse remain robust whether or not the year 2018 is included. The maximum 24-hour rainfall observed in 1983 varies depending on the empirical function used.

Comparing the estimated 10,000 year return period and PMF flood peaks at the Xe-Pian/Xe-Namnoy Dam with maximum observed floods worldwide, taken from the studies by Herschy (2003), and Chaoqun, Guoan, and Rongrong (2013) and other sources, shows that the PMF value of the Xe-Namnoy Dam results in a Francou-Rodier coefficient of 5.4 and the 10,000-year flood in a coefficient of 5.2, which represents commonly used coefficients (Figure 49).

Interesting data were determined by USACE (1970), who derived the probable maximum daily precipitation (PMP) for the LMB.
Figure 50: Probable Maximum Precipitation over the LMB (USACE, 1970)

With data up to 1970 and without climate change, USACE (1970) estimated PMP lied in the range of 340 to 500 mm in the vicinity of the Xe-Pian Xe-Namnoy dam.

3.8.2 Actions taken by MRC

Immediately after the MRC was informed about the dam break, the RFDMC in Phnom Penh started calculating the effect of the dam break on water levels downstream (Figure 51). Since heavy rainfall occurred during that time, the additional water level rise had to be identified and forecast. The following data were used for the calculations:

- Observed water level at Veun Khen on the Se Kong River
- Observed water level at Siam Pang
- Observed water level at Pakse
- Observed water level at Stung Treng

The correlation between water levels at Veun Khen and Siam Pang shows an R-squared goodness-of-fit of 0.86 and between Pakse and Stung Treng 0.975. The correlation functions were used to estimate the expected water levels without a dam break. Water levels at Siam Pang and Stung Treng without the dam break were referred to as “Normal”, while observed water levels with the effects of the dam break were referred to as “Critical.”
Starting on 25 July, the largest difference between water levels with and without the dam break reached 4.5 m on 28 July, five days after the dam break (Figure 52). At Stung Treng, the identification was more difficult because the effect was significantly lower. It seems that 24 July marked the arrival of the flood wave at Stung Treng (Figure 53).
3.8.3 Transboundary effects

The UN Office for the Coordination of Humanitarian Affairs (OCHA), in its Asia and the Pacific’s weekly regional humanitarian snapshot, reported on 31 July the impact in Stung Treng Province in Cambodia after the dam break in Lao PDR. According to this report (OCHA, 2018),

“Flood waters caused by the break of Xepien-Xenamnoyu dam in southern Lao PDR are flowing downstream, resulting in the evacuation of more than 5,600 people in Stung Treng Province, northern Cambodia. As of 31 July, no people have been reported dead or missing. The water level at Stung Treng is at 10.7m and forecast to reach flood levels within five days. Local authorities are distributing relief items and NGOs have deployed staff to assist in monitoring the situation”.

Figure 52: Difference of water levels with and without the dam break at Siam Pang (RFDMC, 2018)

Figure 53: Difference of water levels with and without the dam break at Stung Treng (RFDMC, 2018)
3.8.4 Conclusion

According to the IPE, the root cause of the dam failure was related to base failure due to permeable soil and internal erosion. This was triggered by fast rising water levels.

Climate change will increase the intensity and probability of the occurrence of extreme rainfall and thus extreme peaks and fast rising water levels. An event formerly regarded as a 100-year flood might turn into a significantly smaller return period and makes knock-on effects more likely. The consequence is that the total probability of occurrence of dam failure paths will rise.

The experience that climate change makes it increasingly more difficult to derive reliable probabilities of occurrence based on past observations is neither new nor confined to the Mekong region. Extreme rainfall events with more than 300 mm in 24 hours have occurred more than once in Germany since 2002. One particular rainfall event brought 245 mm within two hours in Germany (DWD [German Weather Service], 2016). As a consequence, the German Weather Service re-evaluated extreme precipitation events and their probabilities and issued new values also for Probable Maximum Precipitation (PMP). With this background and the number of new dams in the pipeline in the LMB, a review of probabilities of occurrence of flood peaks is recommended.

In essence, extrapolation of extreme events based on historical records is no longer sufficient for designing water infrastructure such as dams.
4 COUNTRY REPORTS

4.1 Cambodia

4.1.1 Introduction

Cambodia is considered one of the most flood prone countries in Southeast Asia. It faces two distinct hydrological regimes. Fast rising and falling hydrographs occur in the mountainous areas in the east and southwest. In contrast, flow is primarily determined by low gradients, flat terrain, tidal, and backwater effects in the Tonle Sap region and along mainstream Mekong. At Phnom Penh, the capital city, there are four branches creating a complex hydraulic system: the Upper Mekong, the Lower Mekong, the Bassac, and the Tonle Sap River connecting the Tonle Sap Great Lake. Differences between water levels in the Tonle Sap Lake and the water levels in the mainstream Mekong cause the flow reversal from the Mekong to Tonle Sap Lake.

The main flow contribution to the mainstream within the territory of Cambodia comes from the Se Kong, Se San, and Sre Pok catchments. These rivers provide the largest hydrological subcomponent of the Lower Basin. There are a couple of hydrological observation stations in Cambodia along the Mekong. Stung Treng hydrological station is the first and furthest upstream station, and is of fundamental importance for flood forecasting in Cambodia.

The following sections describe the situation in 2018 based on rainfall data collected from 1998 to 2018 and hydrological data from 1991 to 2018 provided by MOWRAM. Data related to impacts and damage gathered from 2009 to 2018 were obtained from the National Committee for Disaster Management (NCDM). Information on flood and drought incidents were quoted from newspapers and websites.

4.1.2 Regional Climate in 2018

Cambodia has a humid tropical climate with two seasons: a rainy season from May to October and a dry season from November to April. The largest amount of rainfall occurs in the coastal areas and diminishes towards the plain and low-lying areas (Figure 54).

In 2018, two tropical storms affected Cambodia: Tropical storm Son-Tinh crossed Lao PDR and Thailand and brought heavy rain. In the aftermath of the storm water levels rose rapidly along the Mekong and reached alarm levels giving rise to flooding in the low-lying provinces. Tropical storm Bebinca reached Hainan Island in mid-August, moved down from northern Viet Nam and subsequently crossed the Mekong Basin on 16 August 2018. Water levels in the Mekong River exceeded warning levels at several locations.
Average rainfall in 2018 totals approximately 1,600 mm, which is roughly 10% lower than the long-term average from 2000 to 2018. The lowest annual rainfall with 842 mm occurred in Odor Meanchey and the highest with 4,473 mm in Koh Kong province. An overview of cumulative rainfall at observation stations along the mainstream Mekong is illustrated in Figure 55.
4.1.3 Hydrological Situation in 2018

Streamflow in 2018 was higher than the long-term average from January to late September. As of September, flow dropped sharply and remained below average giving rise to an earlier end of the flood season than usual (Figure 56).

Table 9: Peak water levels on the Mekong and tributaries in 2018, Cambodia

<table>
<thead>
<tr>
<th>Name of Station</th>
<th>Warning Level (m)</th>
<th>Peak Water Level in 2018 in m, (dd/mm)</th>
<th>Historic max. water level (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mekong-Stung Treng</td>
<td>10.70</td>
<td>11.01 (29/08)</td>
<td>12.19</td>
</tr>
<tr>
<td>Mekong-Kratie</td>
<td>22.00</td>
<td>22.27 (30-31/08)</td>
<td>23.01</td>
</tr>
<tr>
<td>Mekong-Kompong Cham</td>
<td>15.20</td>
<td>15.57 (01/09)</td>
<td>16.11</td>
</tr>
<tr>
<td>Bassac-Chaktomuk</td>
<td>10.50</td>
<td>9.96 (02/09)</td>
<td>11.20</td>
</tr>
<tr>
<td>Mekong-Neak Luong</td>
<td>7.50</td>
<td>7.50 (03-04/09)</td>
<td>8.12</td>
</tr>
<tr>
<td>Bassac-Koh Khel</td>
<td>7.40</td>
<td>7.82 (02-03/09)</td>
<td>7.94</td>
</tr>
<tr>
<td>Tonlesap-Prek Kdam</td>
<td>9.50</td>
<td>9.05 (21/09)</td>
<td>10.26</td>
</tr>
</tbody>
</table>

The water flow to Tonle Sap Great Lake started about 2 weeks earlier than usual and the water level remained higher from 1 May until late September.

The duration of flooding in 2018, defined as the number of days above warning levels, lasted 16 days at Stung Treng, 12 days at Kratie, 22 days at Kompong Cham, two days at Neak Loeung, and 62 days at Koh Khel. Warning levels at Chaktomuk and Prek Kdam were not reached. No flood levels were exceeded.
Figure 56: Water levels at Stung Treng, Chaktomuk, and Kampong Luong (Tonle Sap Lake)
4.1.4 Impact of Floods and Drought 2018

17 July marked the beginning of a major flood incident in 2018, affecting the provinces of Kampong Speu, Battambang, Koh Kong, Phreah Sihanouk, and Kampot as well as Pur Senchey District in Phnom Penh. Local authorities and armed forces cooperated with the Cambodian Red Cross to evacuate people from affected areas moving them to higher ground. The Ministry of Health’s Communicable Disease Control Department (CDC) alerted the affected population of possible water-borne diseases during the floods. There is a general trend that damages from flood events are increasing due to sustained migration from rural to urban areas.

Table 10: Impacts of floods and droughts compiled for Cambodia from 1996 to 2018

<table>
<thead>
<tr>
<th>Year</th>
<th>Disasters</th>
<th>Affected/ Damages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>Severe flood</td>
<td>In the 1996 floods, continuous heavy rainfall caused inundation affecting 1.3 million Cambodians with 600,000 hectares of crops and 50,000 homes damaged or destroyed. 13 provinces were affected.</td>
</tr>
<tr>
<td>1999</td>
<td>Flood and Typhoon</td>
<td>37,527 people in 10 provinces were affected, 17,732 ha of rice crop and 491 houses were destroyed</td>
</tr>
<tr>
<td>2000</td>
<td>Severe flood</td>
<td>3,448,629 people were affected, 768 houses were damaged and there were 347 deaths</td>
</tr>
<tr>
<td>2001</td>
<td>Severe flood</td>
<td>429,698 families, equivalent to 2,121,952 people were affected. People killed: 62 (70% were children), houses destroyed: 2,251</td>
</tr>
<tr>
<td>2002</td>
<td>Flood and Drought</td>
<td>Drought: People affected: 442,419 families (2,017,340 individuals)</td>
</tr>
<tr>
<td>Year</td>
<td>Disasters</td>
<td>Affected/ Damages</td>
</tr>
<tr>
<td>------</td>
<td>----------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>2009</td>
<td>Typhoon Ketsana</td>
<td>14 provinces affected, 43 deaths, 67 severely injured, destroyed homes and livelihoods of some 49,000 families or 180,000 people, and 80% of total land area affected.</td>
</tr>
<tr>
<td>2010</td>
<td>Flash flood</td>
<td>14 provinces affected, 22,746 families affected, 6,301 houses affected, 86 houses damaged, 11 deaths, 7 injured, 272 schools and nurseries affected, 77,629 ha affected and crop damage across 6,942 ha</td>
</tr>
<tr>
<td>2011</td>
<td>Severe flood</td>
<td>18 provinces affected, 354,217 families affected, 268,631 houses affected, 1,297 houses damaged, 250 deaths, 23 injured, 1,360 schools affected, 491 pagodas, 115 health centres, seeding 431,476 ha, crops 21,929 ha, national roads 956,638m, laterite roads 5,594,119 m</td>
</tr>
<tr>
<td>2012</td>
<td>Flash flood</td>
<td>7 provinces affected, 23,691 families affected, 22,863 houses affected, 2 houses damaged, 27 deaths, 122 schools affected, 7 pagodas, 4 health centres, seeding 57,432 ha, crops 3,585 ha, laterite roads 25,4287 m</td>
</tr>
<tr>
<td>2013</td>
<td>Severe flood</td>
<td>20 provinces affected, 377,354 families affected, 240,195 houses affected, 455 houses damaged, 168 deaths, 29 injured, 1,254 schools affected, 533 pagodas, 92 health centres, seeding 37,847 ha, crops 81,244 ha, national roads 440,572 m, laterite roads 3,569,779 m</td>
</tr>
<tr>
<td>2014</td>
<td>Flash flood</td>
<td>13 provinces affected, 165,516 families affected, 87,333 houses affected, 185 houses damaged, 49 deaths, 4 injured, 397 schools affected, 154 pagodas, 32 health centres, seeding 77,325 ha, crops 10,077 ha, national roads 96,036 m, laterite roads 973,249 m</td>
</tr>
<tr>
<td>2015</td>
<td>Flash flood/Drought</td>
<td>7 provinces affected, 789 families affected, 6,963 houses affected, 7 houses damaged, 1 death, 1 injured, affected seeding 3,707 ha, crops 7,943 ha</td>
</tr>
<tr>
<td>2016</td>
<td>Flash flood</td>
<td>16 provinces affected, 17,928 families, 413 houses, seeding 26,553 ha, crops 3,610 ha, national roads 2,422 m and 11 places, laterite roads 105,955 m</td>
</tr>
<tr>
<td>2017</td>
<td>Flood and flash flood</td>
<td>16 provinces affected, 55 districts and 194 Communities. 18,674 families affected, 1,734 families evacuated, 7 households damaged. 17 deaths, 104 schools affected, 12 pagodas and 1 hospital, 5,918 heads of livestock evacuated, 22,067 ha of rice cultivation affected and 3,456 ha damaged.</td>
</tr>
<tr>
<td>2018</td>
<td>Flood, flash flood and drought</td>
<td>Floods affected 23 Provinces, 106 districts, and 464 communities. 134,893 families were affected, 12,668 people evacuated, 241 households damaged. 63 deaths 123 injured, 335 schools, 140 pagodas and 28 hospitals affected, 30,000 cattle were evacuated and 28 killed. The agricultural sector faced losses of 54,141 ha of rice cultivation. National and provincial roads were inundated at a length of 64 km.</td>
</tr>
</tbody>
</table>
Despite flood conditions in July and August 2018 reaching the level of the year 2000 flood, the last quarter of 2018 experienced dry conditions. Water shortages for agricultural production occurred due to low rainfall, high temperatures, and the fact that water supply infrastructure is not readily available in more remote areas. The Ministry of Water Resources and Meteorology called on all Cambodians to conserve water due to anticipated drought conditions during the following year’s dry season.
4.2 Lao PDR

4.2.1 Introduction

Lao PDR is a landlocked country with an area of 236,800 km². The country stretches over 1,700 km in a north-south direction with 100 to 400 km in an east-west direction. It shares borders with Thailand and Myanmar in the west, Cambodia in the south, Vietnam in the east and China in the north. Around 80% of the country is situated within the Mekong Basin, while the remaining 20% of the area drains through Vietnam directly to the sea.

There are 12 rivers with extensive data records:

- Nam Ou basin with a total area of 24,637 km² in the northern region.
- Nam Suang and Nam Khane basins almost entirely located in Luang Prabang Province.
- Nam Ngum Basin with a total drainage area of nearly 1,700 km² covering 4 provinces.
- Nam Lik is located within the Nam Ngum Basin and shows high annual runoff compared to Nam Ngum at Naluang with approximately the same catchment area.
- Nam Lik River, not regulated by the Nam Ngum1 Dam,
- Nam Ngiep and Nam Sane in Bolykhamsay Province, both have catchments areas of less than 5,000 km² but with torrential runoff regimes due to high annual precipitation.
- Nam Cading with a complex river network occupies nearly 90% Bolikhamsay province and the upper catchment area is located in Khammouane Province.
- Se Bang Fai and Se Bang Hieng occupy a large portion of the central plain of Khammouane and Savannakhet provinces.
- Se Done River originates in the west side of the Bolaven Plateau, and flows to the plain area of two provinces, Savannakhet and Champasack.
- Se Kong with a torrential regime has a drainage area of 22,179 km².

Data sources for the following sections are derived from the Department of Meteorology and Hydrology (DMH) under the Ministry of Natural Resource and Environment (MONRE); the Weather Forecasting Division, Climate and Agrometeorology...
Division and Hydrology Division under the Ministry of Agriculture and Forestry (MAF); and the Ministry of Labour and Social Welfare. In addition, information was obtained from government staff, Non-Governmental Organisations (NGOs) and directly from farmers and people on site.

4.2.2 Regional Climate in 2018

The onset of the monsoon in Lao PDR started and ended earlier than usual with an offset of more than two weeks. Rainfall from January to October was above average and is shown in the table below.

Table 11: Rainfall in Lao PDR in 2018

<table>
<thead>
<tr>
<th>Province/district</th>
<th>Accumulated rainfall (mm)</th>
<th>Percentage of rainfall from Jan–Oct 2018 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jan – Oct 2018</td>
<td>Normal (Jan – Oct)</td>
</tr>
<tr>
<td>Phongsaly</td>
<td>2,115.1</td>
<td>1,527.1</td>
</tr>
<tr>
<td>Viengxay</td>
<td>2,198.2</td>
<td>1,503.5</td>
</tr>
<tr>
<td>Xamneua</td>
<td>2,293.6</td>
<td>1,265.1</td>
</tr>
<tr>
<td>Xiengkhuang</td>
<td>1,699.1</td>
<td>1,408.9</td>
</tr>
<tr>
<td>Oudomxay</td>
<td>1,682.9</td>
<td>1,380.3</td>
</tr>
<tr>
<td>Luangnamtha</td>
<td>1,904.6</td>
<td>1,451.2</td>
</tr>
<tr>
<td>Bokco</td>
<td>2,188.9</td>
<td>1,821.3</td>
</tr>
<tr>
<td>Luangprabang</td>
<td>1,603.4</td>
<td>1,268.8</td>
</tr>
<tr>
<td>Xattabouly</td>
<td>2,198.6</td>
<td>1,277.8</td>
</tr>
<tr>
<td>Phonhong</td>
<td>1,583.4</td>
<td>2,261.3</td>
</tr>
<tr>
<td>Vientiane</td>
<td>3,102.6</td>
<td>1,656.2</td>
</tr>
<tr>
<td>Paksane</td>
<td>2,877.4</td>
<td>3,019.3</td>
</tr>
<tr>
<td>Lak 20</td>
<td>2,703.9</td>
<td>1,613.3</td>
</tr>
<tr>
<td>Thakhek</td>
<td>2,031.8</td>
<td>2,168.6</td>
</tr>
<tr>
<td>Savannakhet</td>
<td>1,735.0</td>
<td>1,459.7</td>
</tr>
<tr>
<td>Seno</td>
<td>2,533.8</td>
<td>1,587.9</td>
</tr>
<tr>
<td>Pakse</td>
<td>4,190.6</td>
<td>1,960.1</td>
</tr>
<tr>
<td>Pakseong</td>
<td>3,364.5</td>
<td>3,352.3</td>
</tr>
<tr>
<td>Salavanh</td>
<td>3,033.4</td>
<td>2,010.4</td>
</tr>
<tr>
<td>Attapeu</td>
<td>1,868.2</td>
<td>2,158.7</td>
</tr>
<tr>
<td>Sekong</td>
<td>2,476.7</td>
<td>1,456.3</td>
</tr>
<tr>
<td>Average</td>
<td>2,351.7</td>
<td>1,790.9</td>
</tr>
</tbody>
</table>

Three tropical cyclones affected Lao PDR from 1 January to 31 October: Son-Tinh (17-25 July), Benica (11-12 August), and Bebinca (15-20 August).

During the passage of Son-Tinh, heavy rain occurred with strong winds. Rainfall intensities of more than 150 mm within 24 hours occurred at three stations. Maximum rain during 24 hours totalled 291 mm at Xiengkhuang.
Central and northern parts of Lao PDR were affected by rainfall from Bebinca with more than 100 mm over two days with a maximum of 132 mm at Xayaburi.

4.2.3 Hydrological Situation in 2018

Cyclone Son-Tinh brought exceptional rain to Lao PDR. The amount of rain added up to over 1,000 mm within one month at some stations, which is nearly half of the annual rainfall. Soil moisture was saturated so that less rain in the aftermath of Son-Tinh caused almost all-time high water levels exceeding warning levels. This was the case at Paksane and in some tributaries as illustrated below.
Table 12: Peak water levels in Lao PDR in 2018

<table>
<thead>
<tr>
<th>Name of Station (with river)</th>
<th>Cause</th>
<th>Warning Level (m)</th>
<th>Peak Water Level in 2018 (m with date)</th>
<th>Historic max. water level (m with year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mekong River</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luangprabang</td>
<td>Heavy rain</td>
<td>17.50</td>
<td>17.26 (1.9.2018)</td>
<td>22.36 (2.9.1966)</td>
</tr>
<tr>
<td>Pakse</td>
<td>Heavy rain</td>
<td>11.00</td>
<td>12.68 (31.7.2018)</td>
<td>14.48 (17.8.1978)</td>
</tr>
<tr>
<td>Mekong’s Tributaries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sebangfai at Mahaxay</td>
<td>Heavy rain</td>
<td>14.00</td>
<td>17.46 (2.8.2018)</td>
<td>17.57 (11.8.2011)</td>
</tr>
<tr>
<td>Tributaries of Mekong River</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N.Sane at M. Kao</td>
<td>Heavy rain</td>
<td>8.87 (21.7.2018)</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Sechampphone at Kengkok</td>
<td>Heavy rain</td>
<td>8.62 (31.7.2018)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Sekong at Veunkhen</td>
<td>Heavy rain and Heavy rain from Vietnam</td>
<td>15.23 (16.8.2018)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>N. Song at Vangvieng</td>
<td>Heavy rain</td>
<td>5.00 (22.8.2015)</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Figure 58: Water levels at Nam Ngum and Se Bang Fai, Lao PDR

In terms of low flow conditions, the year 2018 was uniformly far above minimum water levels except for one station: Se Done at Saravan. This was apparently the effect of dry conditions since November 2017 in the catchment of the Se Done.
4.2.4 Impact of Floods and Drought 2018

According to latest government reports, all provinces in Lao PDR were affected by floods or flash floods including 116 districts, 2,400 villages, and an estimated 132,000 households.

According to the UN Information Bulletin No. 2 (UNORC, 2018), around 17,000 people were evacuated from their villages, and 1,772 houses were destroyed. This is mainly a result of the dam break (see Section 3.8). Approximately 150 km of national and provincial roads, as well as 133 km of district and 350 km of rural roads, and 47 bridges were damaged. Moreover, around 100,000 ha of paddy field were damaged, and a large number of livestock were lost, including 17,000 large animals and 79,000 poultry. Irrigation systems were heavily damaged. The most affected provinces were Khammouane, Savannakhet, Champasack, Saravan, Sekong, and Attapeu. Attapeu was the district in which the dam failure occurred.
Damage due to flash floods and landslides were reported in Phongsaly, Bokeo, Luangnamtha, Oudomxay, Huaphane, Xayabouly, Luangprabang, Xiengkhuang, Vientiane, Bolikhhamxay, and Attapeu provinces. Peak water levels observed in some tributaries of the Mekong River and the collapse of the Xe-Pian XeNamnoy dam on 23 July 2018 as a result of Tropical Storm Son-Tinh caused massive damage and affected 13,100 people; 6,000 people were displaced with 39 dead and around 97 missing (according to UN Situation Report No. 9).

Impacts due to drought were not reported in 2018.

The post-disaster needs assessment estimated the total overall cost of floods at 3,166.99 billion Lao kip (USD 371.5 million). Total damage accounted for 1,253.10 billion Lao kip, and losses totalled 1,914.02 billion Lao kip. As a result of the dam break, Attapeu Province had to face damage and losses estimated at USD 35 million. The agricultural and transport sectors ranked first in terms of economic losses.

4.2.5 Conclusion and Outlook

In 2018, the Department of Meteorology and Hydrology (DMH) issued 25 warnings and disseminated them to the Prime Minister’s Office, government line agencies, and the public. Dissemination is performed using means such as the telephone, fax, e-mail, and also internet-based tools and apps like WhatsApp and websites. Websites, of course, assume that users visit themselves and act proactively. The warning information reached risk areas on time.

DMH also issued daily, three daily, weekly, monthly and three-monthly weather forecasts based on sources from different forecasting centres under the World Meteorology Organization, which is another utilization of internet-based information. The activities are complemented by near real-time data collection from more than 40 stations. The aforementioned activities are supported by prospective developments:

- Upgrading of the hydrological networks along the Mekong River as well as its tributaries in collaboration with the Mekong River Commission (MRC).
- Upgrading 18 meteorological and 8 hydrological stations to automatic stations, supported by JICA.
- With support from the World Bank, further development of the hydro-meteorological network and establishment of a national early warning centre.
- The Asian Development Bank supports the upgrade of the hydro-meteorological network in the central part of Lao.
- With support from the Food and Agriculture Organization (FAO), the establishment of 15 agrometeorological stations.
- Under Typhoon Committee frameworks, the National Disaster Management Institute (NDMI) is supporting the establishment of a national Flash Flood Alert System.
- DMH has set up a weather TV studio with support from CMA.

In conclusion, future developments are targeting the information and data sector. Data acquisition, processing, and internet-based dissemination and notification are being
intensified to further improve disaster risk reduction management at a national and regional level.

At the same time, it is important to enhance the capacity of local communities in terms of consuming and interpreting new information and data. Locals must be informed and trained to keep pace with new information and data techniques to enhance flash flood preparedness, emergency response, and flood damage data collection skills.

Flash flood alert systems in the mountains should also be established as local and independent systems.

While DHM created a suitable environment supporting national, provincial, and local authorities with flood forecasting with a 48-hour lead time, the next improvements down to the grass root level must follow through better coordination for flood preparedness and response.
4.3 Thailand

4.3.1 Introduction

Thailand is located in the tropical area between latitudes 5°37′ N to 20°27′ N and longitudes 97°22′ E to 105°37′ E. The total area is 513,115 km². The country borders Myanmar and Lao PDR to the north; Lao PDR, Cambodia and the Gulf of Thailand to the east; Malaysia to the south; and Myanmar and the Andaman Sea to the west.

There are two regions in the LMB. The northern part called 2T region, consisting of Chiang Rai Province and the north-eastern part, called 3T & 5T MRC-sub basins (Figure 60).

![Location of Thailand](image1)

![Region of Thailand and BDP sub area](image2)

Figure 60: Thailand's sub-basins contributing to the LMB

The 3T & 5T region is a plain called the Northeast Plateau. Northwest- and southeast-oriented Phu Phan ridge in the north-eastern portion separates this part into two basins. One is a large plain in the west, the other is a smaller slope towards the east. This part is divided into 20 provinces: Nong Khai, Bung Karn, Loei, Udon Thani, Nong Bua Lam Phu, Nakhon Phanom, Sakon Nakhon, Mukdahan, Khon Kaen, Kalasin, MahaSarakham, Roi Et, Chaiyaphum, Yasothon, Amnat Charoen, Ubon Ratchathani, Sri Sa Ket, Nakhon Ratchasima, Buri Ram, and Surin.

The 2T sub basin is divided into 15 provinces: Chiang Rai, Mae Hong Son, Chiang Mai, Phayao, Lamphun, Lampang, Phrae, Nan, Uttaradit, Phitsanulok, Sukhothai, Tak, Phichit, Kamphaeng Phet, and Phetchabun. Most areas are hilly and mountainous and constitute the source of several important rivers. These north-south oriented hill ridges are parallel from west to east and are intersected by a number of major valleys, particularly those near Chiang Mai, Chiang Rai, Lampang, and Nan provinces. The highest mountain, about 2,595 mASL, is Doi Inthanon in Chiang Mai.
The river basins which have high runoff rates are the Khong River Basin (northeast), the Peninsula-East Coast River Basin, and the Mae Klong River Basin. The basins with low runoff are Sakae Krang, Wang, and Thole Sap River Basin. The highest annual runoff occurs in the East-Coast Gulf River Basin while the lowest annual runoff per area occurs in the Wang River Basin.

Data were mainly made available by DWR, RID and were taken from various sources including: storm tracks affecting Thailand; satellite images; weather maps; pressure and rainfall maps; flood images from satellite monitoring; as well as spatial data and photos.

The agricultural sector is the largest water consumer in Thailand. 23.9 million ha are agricultural land, of which 10.2 million ha (43 percent of the total agricultural land) are located in the northeast region, followed by the central region with 4.4 million ha (18%). A total of 4.8 million ha is irrigated, the remaining 19.2 million ha is rain-fed agricultural areas, which are prone to water shortages as a result of weather variability.

4.3.2 Regional Climate in 2018

Thailand is under the influence of monsoon winds during 2 seasons: the southwest and northeast monsoons. The southwest monsoon starts from mid-May and ends in mid-October. The average annual rainfall is approximately 1,455 mm (PCWRM, 2015), with a rainfall distribution as presented in Figure 61.
2018 brought unusual weather conditions in that the average annual rainfall was about 5% higher than average, among the highest in 68 years (1951-2018), and was concentrated in a few months while the rest of the year showed below average conditions. Less rain coincided with high temperatures (Figure 62).

![Figure 62: Monthly rainfall and temperature distribution in Thailand (Muangthong, 2019)](image)

Two tropical storms affected Thailand’s section of the LMB; Son-Tinh in July and Bebinca in August. Son-Tinh crossed Sakon Nakhon, Nakhon Pranom and Bueng Kan provinces on 16 July and Nan province on 17-18 July, while Bebinca moved into Thailand on 16-18 August affecting Nan, Chiang Rai and Chiang Mai provinces.

### 4.3.3 Hydrological Situation in 2018

Thailand has six key monitoring stations along the Mekong mainstream (Table 13), which are operated by DWR. Except for the upstream locations Chiang Saen and Chiang Khan, water levels were recorded above flood warning levels; however, no overbank flow occurred.

<table>
<thead>
<tr>
<th>Name of Station (with river)</th>
<th>Cause</th>
<th>Warning Level (m)</th>
<th>Peak Water Level in 2018 (m) with date</th>
<th>Historic max. water level (m) with year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.Chiang Sean</td>
<td>Mekong</td>
<td>11.50</td>
<td>7.30 m (05/09/2018)</td>
<td>14.00 m (03/09/1966)</td>
</tr>
<tr>
<td>2.Chiang Khan</td>
<td>Mekong</td>
<td>14.50</td>
<td>15.00 m (19/08/2018)</td>
<td>18.09 m (03/09/1966)</td>
</tr>
<tr>
<td>5.Mukdaharn</td>
<td>Mekong</td>
<td>12.00</td>
<td>12.92 m (31/08/2018)</td>
<td>14.22 m (19/08/1978)</td>
</tr>
</tbody>
</table>
Apart from the Mekong mainstream, other regions reported exceptional conditions. Officials struggled to deal with the overtopping of Kaeng Krachan dam in Phetchaburi and Nam Un dam in Sakon Nakhon. Khiri Than reservoir in Chanthaburi reached 99% of its capacity and was also closely monitored. The Vajiralongkorn dam in Kanchanaburi, Khun Dan Prakan Chon dam in Nakhon Nayok, and Ratchaprapa dam in Surat Thani were also monitored, seeing water levels passing 86% of their capacity.

An additional source for early flood recognition was the MRC Flash Flood Guidance System (FFGS). It was applied mainly by DWR, TMD, and DDPM in their role to disseminate information to local authorities and to the public in a timely manner. An example is provided in Figure 64.
Figure 64: Rainfall from 16-18 August 2018 in Thailand

In the past decade, Thailand has faced severe drought events. In 2005, some 11 million people in 71 provinces were affected by water shortages. In 2008, over 10 million people in rural agricultural regions were, which was also the case in 2016. The Thai Government has launched various water saving approaches to ensure water reservoirs can maintain required levels until the end of dry season. In 2018, rainfall came late in the season in the northern part of Thailand situated within the LMB and brought below average precipitation. However, drought problems were not reported.
4.3.4 Impact of Floods and Drought in 2018

The flood situation affected roads, bridges, drainage systems, official buildings, schools, and temples. Preliminary costs of the damages were estimated at 800 million Baht (USD 26.77 million).

The largest destruction was reported mid-August due to storm Bebinca. 38 districts, 146 sub-districts, 6,002 villages, and 9,106 households were reported to have been affected in Phayao, Nan, and Chiang Rai provinces. During the entire flood season, a total of 150,000 people were impacted in Nan, Chiang Mai and Chiang Rai provinces with 2 fatalities. The DDPM reported that more than 220,000 people were hit by floods with 3 casualties in Nan, Chiang Rai, Lampang, Phayao, Chiang Mai and Mae Hong Ngong provinces.

4.3.5 Conclusion and Outlook

Thailand is making significant investments in monitoring and early warning systems. The goal is to obtain near-real time information of rain, water levels, and streamflow to predict floods and drought situations. Quite a number of telemetry and early warning systems are in place, operational, or in the process of being developed. The systems in place or currently under further development are:

- Early Warning System for mountainous areas (http://ews.dwr.go.th/ews/).
• Khong-Chi-Mun Early Warning System for rain and water level observations (http://tele-khongchemun.dwr.go.th/).
• RID’s Telemetry System as part of a complex data platform with manifold information about water management, current, and forecasted water levels and flow.
• Agricultural Information System of the Hydro and Agro Informatics Institute (HAII) for weather and water watch providing information for communities on preparedness and disaster risk reduction (http://www.thaiwater.net/web/index.php/archive.html).
• The Thailand Flood, Drought, and Rainfall Monitoring System with real-time data managed by the Geo-Informatics and Space Technology Development Agency (GISTDA).
• EGAT’s telemetry system on hydropower plants, including water quality and stream gauging functions (http://watertele.egat.co.th/PakMun/).

These systems generate abundant information to help organize response and mitigation measures during floods and for early detection of drought situations. At national level, organisations like DWR, RID, or EGAT receive this information in order to prepare for hydrological incidents. The next step is to filter, pre-process, and disseminate the information to local levels, communities, and farmers so as to enable them to take action.

The challenge is to ensure that data is circulated in a timely manner and is backed with recommendations in the appropriate language. Especially, drought requires a longer lead time for adaptation. Field work has shown that farmers are able and willing to employ short-term adaptation options. For instance, farmers who changed to Cassava in time – which is a rather drought resistant plant – increased their income in comparison to farmers who continued to grow mung bean (Muangthong, 2019).

Therefore, it is recommended to further develop and link the three themes: data management, dissemination of information to the public and all stakeholders, and capacity building so that information can be fully leveraged.
4.4 Viet Nam

4.4.1 Introduction

Two regions of Viet Nam are within the Mekong River Basin: the Mekong Delta and the Central Highlands region with the Sesan, Seprok and Sekon river basins. The Mekong Delta (in total 55,000 km² of which 39,000 km² lies within Viet Nam) is part of the humid tropics and is characterized by consistently high mean monthly temperatures (25 – 29°C) and high, but seasonal rainfall (1,200 – 2,300 mm). The Central Highlands climate is subject to a mix of tropical heat and humidity with refreshing coolness typical for high altitude plains, most favourable for diverse agriculture with both food and cash crops. The topography is complex with distinctive high reliefs with mountains (1,200–2,598 mASL) and lowland areas near river valleys and alluvial plains (300-500 mASL). Seasonal climatic variations in Viet Nam are predominantly controlled by the Asian monsoon: during the wet season from May to November, dominant winds from the southwest bring over 90 % of the total annual rainfall. During the dry season from December to April, climate is characterized by long hours of sunshine and higher temperatures. Winds mainly occur from the northeast.

The data and information of the hydrological situation in 2018 were collected from the line agencies of the national government and local administrations, as well as national newspapers and online sources.

4.4.2 Regional Climate in 2018

The ENSO phenomenon was initially neutral and gradually changed to an El Nino state during the last months of the year. A few short, but severe and harmful cold spells occurred in 2018 while the durations of heat waves were less than 10 days and temperatures were not too harsh. Tropical storms and depressions occurred in the East Sea and directly affected Viet Nam with heavy rains in northern, central, and southern parts of the country. Figure 65 shows the temperature anomalies and rainfall distribution in 2018. While total rainfall is slightly lower than the long-term annual average, rainfall intensities of single events were more severe: The rains on 17-18 November at the south-central coast with 100-300 mm; the rains on 24-26/11 on the south-central coast and southeast region with 100-400 mm and rainfall from 8-16/12 in Thua Thien Hue to Binh Dinh provinces with 600-1,200 mm.
In 2018, nine storms/typhoons and five tropical depressions were active in the East Sea of Viet Nam, of which three storms/typhoons and five tropical depressions directly impacted Viet Nam, mostly in the northern part of the country. All storms that affected Viet Nam in 2018 directly had extraordinary directions before making landfall, since they did not follow climatic rules and the development of related intensity were very complex. Sometimes, there were multiple storms or depressions active at the same time and in neighbouring regions. The most prominent storms in 2018 are described below in more detail.

Storm No. 1 (BOLAVEN)

Bolaven was an early storm in the 2018 season and was formed from a tropical depression in the southern East Sea and became a storm after entering the East Sea

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2 See Nguyen (2018)
(Figure 66). However, when the storm reached the coast of Phu Yen and Ninh Thuan provinces, it weakened to a depression with 60km/h wind speed.

Bolaven caused heavy rains in the south-central region and southern region from Phu Yen to Ben Tre provinces. With Phu Yen, Ninh Thuan, and Binh Thuan provinces, it was considered a “gold” storm which provided significant rainfall for dry areas subject to a lack of water during the dry season.

Storm No. 2 (SANBA)

![Map of Storm No. 2 SANBA](image)

Sanba formed in the East Sea on 13 February 2018. The route of Sanba was similar to storm No. 1 (Bolaven) which occurred one month earlier (Figure 67). Sanba travelled to the southern region of Viet Nam with a velocity of 15-25km/h. The storm caused heavy rains in the southern provinces from Ninh Thuan to Ca Mau.

Storm No. 3 (SON-TINH)

![Map of Storm No. 3 SON-TINH](image)

Sanba formed in the East Sea on 13 February 2018. The route of Sanba was similar to storm No. 1 (Bolaven) which occurred one month earlier (Figure 67). Sanba travelled to the southern region of Viet Nam with a velocity of 15-25km/h. The storm caused heavy rains in the southern provinces from Ninh Thuan to Ca Mau.

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3 See Vietnamnet (2018)
4 See Hung (2019), and SCNDPC (2019)
Son-Tinh formed from a tropical depression off the coast of Luang Prabang (the Philippines) and moved very quickly to the east with relatively strong intensity, and then toward the northern and north-central regions.

The impacts of Son-Tinh and other tropical depressions from 13-17/7 caused floods in the northern and north-central provinces. The total rainfall from 13-21 July was about 300-500 mm, and in some places over 600 mm. The largest rainfall was recorded at Km46 station (Son La) with about 934 mm.

Due to the prolonged heavy rain, floods and flash floods occurred on the following rivers: Thao, Day, Hoang Long, Bui, Buoi, Ma, Ca, and rivers and small streams in the northern and north-central regions. Serious landslides occurred in Yen Bai, Son La, Lao Cai, Hoa Binh, Phu Tho, and Thanh Hoa provinces.

Storm No. 4 (Bebinca)

![Map of Bebinca Typhoon](image)

Figure 69: The direction and position of typhoon No 10 – Bebinca

Bebinca was formed in the East Sea and the movement was very complicated, alternating twice before moving to the southwest direction (Figure 69). Data observed at surface meteorological stations show that Bebinca caused strong winds of level 8; the area near the centre of the storm level 10, with a peak level of 12 in the Tonkin Gulf waters; strong winds at level 6-7, with a peak level of 8 in the coastal provinces from Thai Binh to Thanh Hoa.

Storm No. 8 (TORAJI)

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5 See Hung (2019), and Steering Committee for Natural Disaster Prevention and Control (SCNDPC, 2019)
Typhoon Toraji had a very short survival time of only 15 hours after being formed from a tropical depression. The strength of the storm was not large; however, the storm circulation caused heavy rainfall, especially in Nha Trang City, Khanh Hoa (382 mm / 24h), causing severe damage to people and property (Figure 70).

Storm No. 9 (USAGI)

At noon on 25 November, Usagi made landfall in the region from Ba Ria - Vung Tau to Ben Tre provinces (Figure 71) with strong winds of 7-8, peak level 10, before it weakened into a tropical depression continuing to the mainland and weakening into a low pressure area which gradually dissolved. Due to the influence of the storm circulation combined with cold air, from the night of 24 November to 26 November, in provinces from Quang Nam to Ben Tre, there was heavy rain with a common rainfall of 100-200 mm, which lasted 18 hours. These provinces included Minh Long (Quang Ngai) 228 mm; Phuoc Chien (Ninh Thuan) 322 mm; Nha Be (HCMC) 378 mm; and Vung Tau City (BR-VT) 211 mm.8

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6 See Hung (2019), and SCNDPC (2019)
7 See Hung (2019), and SCNDP (2019)
8 See Hung (2019), and NHMFC (2019)
4.4.3 Hydrological Situation in 2018

The year 2018 can be identified as a year with abundant water. Generally, high flow phenomena occurred in the Central Highlands mainly due to natural occurrences of rainstorms, typhoons, but also due to the opening of reservoir flood gates. Several storms and tropical depressions along with strong activity of the monsoon caused large-scale heavy rain spells across the country. Due to this, 12 major floods occurred in the northern and central regions, where flood peaks breached alarm levels 2 to 3. In Central region and Central Highland rivers, two historical flooding periods occurred on the Ca River (Nghe An) at Tuong Duong station and at Ma River (Thanh Hoa) at Hoi Xuan and Cam Thuy stations. Large floods occurred on the rivers of Thanh Hoa Province, upstream of Ca river (Nghe An), southern Quang Ngai, southern Binh Dinh, Ninh Thuan, northern Binh Thuan, and northern Kon Tum provinces. In total, 28 flash floods and landslides occurred mainly in the northern and north-central regions (Son La, Lao Cai, Cao Bang, Yen Bai, Ha Giang, Hoa Binh, Bac Kan, Thai Nguyen, Thanh Hoa, Nghe An, and Khanh Hoa provinces).

During the dry season, the flows of all rivers in the northern region were either similar to or higher than the long-term annual average. The discharges of most main rivers in the Central region and Central Highlands were slightly lower (5-10%) than the long-term average and lower than during the same period in 2017, which is also due to the impact of electricity generation of upstream hydropower stations. Some flow gauges even reported their lowest historical water levels such as: Lo River (Tuyen Quang, Vu Quang), Thai Binh River (Pha Lai), Red River (Hanoi), Ca River (Yen Thuong, Nam Dan), Ta Trach River (Thuong Nhat), Cai Nha Trang River (Dong Trang), Dakbla River (Kon Tum), Vu Gia River (Ai Nghia), and Kon River (Binh Nghi). However, the monthly water levels of most regional reservoirs (irrigation and hydropower) in the dry season were always higher than in 2017.

Figure 72 shows water level time series in 2018 and covers the flood season in the Mekong Delta, which arrived earlier in 2018 compared to the long-term average. From the beginning of the flood season to the end of September, the upstream water level of the Mekong Delta is always higher than the long-term average. Due to the lack of October rainfall in the upper Mekong region, from the beginning of October to the end of the flood season, water levels fall significantly. Therefore, water levels at downstream stations of the Mekong Delta were influenced by a strong tide in the dry season and from October 2018 onwards. The water level at Tan Chau and Chau Doc stations from the beginning of October to the end of the flood season (Figure 72) were always lower than the long-term average (Figure 73).
Figure 72: Water levels throughout 2018 in the Mekong Delta (Hung, 2019; National Centre of Hydrology and Meteorology Forecasting [NHMFC], 2019)

Figure 73: Historical levels of flood peaks at Tan Chau and Chau Doc Stations (Hung, 2019; NHMFC, 2019)
The drought situation in the Mekong Delta in 2018 can also be assessed from salinity intrusion (Figure 74). Upstream water levels and the tidal situation in 2018 caused a largely similar salinity intrusion distribution as in 2017 and significantly less intrusion than in 2016.

4.4.4 Impact of Floods and Drought in 2018

No impacts of droughts or related losses were recorded in 2018 in any of the provincial annual reports.

On the other hand, damage caused by flash floods and landslides occurred and were mainly due to natural causes such as intense rainfall in steep areas. However, in many other cases, damages were due to lack of people’s awareness — e.g. lack of understanding of natural disasters resulting in carelessness during floods; for example, leaving unstable slopes during construction of roads which caused erosion risk; mining activities; timber production; construction of infrastructure and digging soil; inappropriate bridges over rivers; and obstructions of streams and flood drainage lines.
due to construction of houses and production facilities. Extreme (storm) tides inundated historical landmarks in some southern provinces. Riverine and coastal erosion was serious in the Central region and the Mekong Delta.

Table 14: Summary of main damages in the Mekong Delta and Highland parts of Vietnam caused by disasters in 2018 (Hung, 2019; Southern Department of Natural Disaster Prevention and Control [SDNDPC], 2019)

<table>
<thead>
<tr>
<th>Category</th>
<th>Item damaged</th>
<th>Unit</th>
<th>MK</th>
<th>Highland</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>People</td>
<td>Killed</td>
<td>Person</td>
<td>13</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Injured</td>
<td>Person</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Missing</td>
<td>Person</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Affected</td>
<td>Households</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Housing</td>
<td>Houses collapsed, drifted</td>
<td>No</td>
<td>244</td>
<td>62</td>
<td>306</td>
</tr>
<tr>
<td></td>
<td>Houses submerged, damaged</td>
<td>No</td>
<td>6,223</td>
<td>1,356</td>
<td>7,579</td>
</tr>
<tr>
<td>School</td>
<td>School collapsed</td>
<td>Room</td>
<td>9</td>
<td>11</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>School submerged, damaged</td>
<td>Room</td>
<td>8</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Rice fields submerged</td>
<td>Ha</td>
<td>3,262</td>
<td></td>
<td>3,262</td>
</tr>
<tr>
<td></td>
<td>Farms submerged, damaged</td>
<td>Ha</td>
<td>463</td>
<td></td>
<td>463</td>
</tr>
<tr>
<td></td>
<td>Fruit tree area</td>
<td>Ha</td>
<td>188</td>
<td></td>
<td>188</td>
</tr>
<tr>
<td>Irrigation</td>
<td>Dyke damage</td>
<td>m</td>
<td>12,292</td>
<td></td>
<td>12,292</td>
</tr>
<tr>
<td>Transportation</td>
<td>Land drifted</td>
<td>m²</td>
<td>15,600</td>
<td></td>
<td>15,600</td>
</tr>
<tr>
<td></td>
<td>Bridge, sewer collapsed</td>
<td>Unit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roads damaged submerged</td>
<td>m</td>
<td>5,550</td>
<td></td>
<td>5,550</td>
</tr>
<tr>
<td></td>
<td>Total damage</td>
<td>10^6 USD</td>
<td>61.75</td>
<td>4.25</td>
<td>66</td>
</tr>
</tbody>
</table>

Disasters in 2018 were not as intense as in 2017 but it was still a year with many extreme and abnormal occurrences, starting early and ending late. Casualties and damage to infrastructure in 2018 are summarized in Table 14.

Based on the reports of the Central Steering Committee of Natural Disaster Prevention and Control, most damage in Vietnam’s provinces in 2018 was caused by flash floods and storms, and were recorded in the northern provinces (Lang Son, Hoa Binh, Son La, Yen Bai, and Quang Nam). Damage caused by natural disasters in 2018 were lower compared to the long-term annual average, especially compared to 2016 and 2017 (Figure 75). In summary, there were 224 deaths and 92 people missing (due to rain and floods, accounting for 41%); 82 people due to flash floods, landslides (accounting for 37%); 50 people due to other natural disasters (accounting for 22%); 1,967 houses collapsed or were damaged; 31,335 houses were flooded or damaged; 261,377 ha of rice and vegetables were flooded and damaged; 43,159 ha of industrial trees and fruit trees collapsed or were broken; 29,400 cattle and 774,427 poultry died; 11,900 ha of aquaculture were damaged; 884 km of dykes, embankments, canals, and 8.4 million cubic meters of rocky soil was dumped on national highways, provincial roads and rural roads; more than 86 km of river banks were eroded; 467 boats were sunk (including 107 ships sunk by storms and tropical low pressures). The total economic losses were estimated to reach VND 20,000 billion (USD 903 million).
Despite these losses, an objective assessment shows that in 2018 most large-scale heavy rains were forecast, which is an important contribution to prevent and mitigate damage caused by natural disasters. Three levels of hydro-meteorological forecasting exist in Viet Nam:

- At the central level by the National Centre for Hydro-meteorological Forecasting
- At the regional level by nine Regional Hydro-meteorological Centres
- At the provincial level by 54 Provincial Hydro-meteorological Centres

In 2018, storm forecast messages were broadcast for up to three days and alerts for up to five days in advance. Meanwhile, with the tropical depression news, the storm forecast also increased to two days and three days. The content of bulletins and tropical depression bulletins was more diversified to suit the requirements of natural disaster prevention, damage reduction, and the general requirements of users. In the news, official information was given regarding dangerous areas (strong winds above level 6 and strong winds above level 10) for the upcoming 24 and 48 hours. The bulletins were distributed to the Central Steering Committee for Natural Disaster Prevention and Control and to the mass media.
4.4.5 Conclusion and Outlook

In 2018, storms and tropical depressions in coastal areas of the northwest Pacific Ocean occurred early and ended late. The number of storms occurring in the region was higher than the long-term annual average. Changes in the direction and movement of storms and depressions on the sea and landfall were complex and did not follow usual climate rules.

Heavy rains caused severe floods in the north and north-central regions. Particularly heavy rains over a short time and in localized areas led to many flash floods and landslides, causing injuries and deaths to people and damage to property in the northwest mountainous region and coastal provinces in Central Vietnam. Therefore, prevention and early warning of flash floods should be further improved as well as awareness raising to actively respond to natural disasters and to mitigate damages. Flash floods are a very high risk to people, and hence, the MRC-FFGS should be improved in order to help people in reduce the damages resulting from disasters. In addition, the MRC flood forecast should be extended to cover the Mekong tributaries, and results should be widely distributed to the public.

In 2018, there was no reporting regarding drought phenomena and related impacts from provinces in the Mekong River Basin. The main reason is that the year encountered abundant rainfall and water levels in most of the reservoirs were higher than in 2017. Despite that, droughts should generally be subject to more attention by research and in assessments.
5 CONCLUSIONS

The AMHR 2018 is the first report to combine floods and drought, addressing hydrology more comprehensively. 2018 was a wet year but also contained the first indications of an upcoming dry spell in the last quarter of 2018.

The rainy season started almost two weeks earlier compared to the long-term average. Exceptionally low rainfall as of September, however, caused a quick drop in water levels below average so that the end of the rainy season also came earlier than usual.

Two periods of very intense rainfall occurred, one in July and one in August. These caused two distinct peaks of water levels and streamflow. The highest water levels in the Mekong mainstream reached or exceeded warning levels. Almost all-time high water levels and streamflow occurred between Mukdahan and Kratie due to high contributions from Lao PDR and Viet Nam tributaries.

Inundated areas downstream of Kompong Cham, around Tonle Sap and in the Mekong Delta, reached nearly the maximum extent compared to MODIS satellite data from 2006 to 2017. However, the recession of the inundation in 2018 was quicker than in other wet years due to the lack of rain in the last quarter of the year. Abundant rain in 2018 gave relief from saltwater intrusion in the Mekong Delta. The situation occurred less severe compared to the dry year of 2016.

The most devastating event in 2018 was the dam break in Lao PDR. It happened on 23 July after the first period of extreme rainfall in 2018. The newly built dam was still in the filling phase when the water level rose rapidly to unprecedented levels. A break of one of the saddle dams caused a massive flood wave rushing downstream which killed 39 people. 13,100 people were affected, 6,000 people displaced, and around 97 are still missing. The dam break also had transboundary effects since downstream areas in Cambodia were affected and had to be evacuated.

The extreme variability in rainfall in 2018 caused warning or alarm water levels in July and August but dry soil moisture conditions as of September were there in the lower half of the LMB. Even though 2018 was generally considered wet, it marked the beginning of an exceptionally dry period that fully developed in 2019.

Whether or not this variability is caused by climate change is less important than the fact that this variability is real and has consequences. Therefore, the countries are investing in the expansion of their hydrological observation networks. The MRC has begun assessing drought conditions by means of drought indices, which are published via the MRC website, and the new Annual Mekong Hydrology Flood and Drought Report is a further step in the preparation and adaptation to changes.

The conditions of 2018 confirm the usefulness of the new approach to combine floods and drought in one annual hydrology report. All hydrological subjects – such as flood hydrology, drought recognition, monitoring and early warning, remote sensing, modelling, and water management – are required to enhance knowledge, preparedness, and preventative measures.

This is also reflected by the extension of the RFMMC into the RFDMC.
6 REFERENCES


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