

Annual Mekong Flood Report 2016



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In addition, Felix Froehlich from SYDRO provided valuable contribution about web-based techniques and compiled the latest development with particular reference to South-East Asia.

Principal locations referred to in the text

Table of Contents

1. Synopsis	1
2. Emerging technology to cope with flood	2
2.1. The MRC tools.....	2
2.2. Flash flood guidance system – MRC	5
2.3. Remote sensing	9
2.4. Modelling.....	22
2.5. Static Flood Risk Analysis	27
2.6. Sensor web and real-time control.....	28
2.7. News aggregation and analysis	30
2.8. Examples from the region	35
3. The Regional Flood Situation 2016	41
3.1. Tropical storms and cyclones.....	41
3.2. The regional climate 2016.....	44
3.3. The flood hydrology of 2016	49
3.4. Regional flash floods 2016	54
4. Country Reports	57
4.1. Cambodia	57
4.2. Lao PDR.....	66
4.3. Thailand	70
4.4. Viet Nam.....	76
5. Conclusions.....	81
6. References.....	82

List of Figures

Figure 1:	Overview about the MRC DSF / Toolbox (Bakker, 2014).....	3
Figure 2:	Screenshot from the MRC portal MRC DSF / Toolbox: Application in LMB (http://portal.mrcmekong.org/mrc_application)	4
Figure 3:	Screenshot of the MRC web-service within the portal MRC DSF / Toolbox: Application	4
Figure 4:	MRC FFG system accessed from the MRC homepage (http://ffw.mrcmekong.org/mrcffgs.htm)	6
Figure 5:	MRC FFG system accessed from the HRC-lab homepage (https://mrcffg.hrc-lab.org/DASHBOARD/index.php?region=0)	7
Figure 6:	Quick Look images from TRMM Microwave Imager (TMI) data for April 08, 2015.....	10
Figure 7:	GPM Constellation Status	11
Figure 8:	GSMaP_NRT map of the Mekong region showing near-real time precipitation amounts as of August 23, 2017	13
Figure 9:	Flood signal and magnitude data in the Mekong region for August 21, Surface Water Mapping Tool, 2017	14
Figure 10:	Current Flood Conditions, Sheet 100E020N, dated May 12, 2016.	16
Figure 11:	River Watch data for the Mekong in Cambodia.....	16
Figure 12:	3-day composite MODIS Flood Map of the Mekong region for August 20-22, 2017	18
Figure 13:	72h alerts as of August 23, 2017	19
Figure 14:	GRACE gravity model 01 Asia.....	20
Figure 15:	Land water storage anomalies in July 2017, as observed with the GRACE satellites	22
Figure 16:	GloFAS viewer.....	23
Figure 17:	Streamflow modelled at 12 km resolution for the Mekong region as of August 23, 2017 Forecasting	24
Figure 18:	6 hr rain forecast as of August 23, 2017 for the typhoon “Hato” Climate Forecast System (CFS)	25
Figure 19:	9-month forecast of Precipitation rates for central Cambodia made on August 21, 2017 (ECMWF).....	26
Figure 20:	Seasonal forecast of precipitation in East Asia for December 2017	27
Figure 21:	Flood Risk in Cambodia.....	28
Figure 22:	TaMIS website providing real-time information and simulation of a German dam.	29
Figure 23:	Search results in the category “Flooding” for the source countries Cambodia, Lao P.D.R., Thailand and Vietnam as of August 23, 2017	31
Figure 24:	Global Flood News reports for the Mekong region as of August 24, 2017.....	32
Figure 25:	Aggregated 24 hours filtered flood signal from Twitter for 24th of July 2013 in form of a heat map (red color=high signal).....	32
Figure 26:	FloodList website with articles regarding floods in Asia as of August 23, 2017.....	33
Figure 27:	Real-Time Integrated Global Flood Map (Experimental) as of August 22, 2017	34
Figure 28:	Early Warning System’s website and key station in the field (source: DWR).....	36
Figure 29:	Telemetry System’s website for flood plain areas (source: DWR)	36
Figure 30:	Telemetry System for Khong-Chi-Mun basins	37
Figure 31:	RID telemetry System (source: Royal Irrigation Department (RID)).....	38
Figure 32:	Thailand Flood and Rainfall Monitoring System by GISTDA	39
Figure 33:	HAII Rainfall and Telemetry system	39
Figure 34:	EGAT Telemetry systems (source: http://watertele.egat.co.th/PakMun/).....	40
Figure 35:	Asia land temperature anomalies, Jan-Dec 1910-2016 (source: NOAA).....	44
Figure 36:	Monthly mean rainfall data 2006-2010 compared with 2016 from 169 stations located within the LMB	45
Figure 37:	Cumulative rainfall and anomaly for the year 2016	46

Figure 38:	Precipitation percentage of normal 2016 (source: GPCC)	46
Figure 39:	Rainfall intensities 2016 at selected stations	47
Figure 40:	Cumulative rainfall 2016 and long-term average at selected stations	48
Figure 41:	Hydrographs comparing mean with 2016 at selected stations	49
Figure 42:	Hydrograph of Tonle Sap Lake at Kampong Luong in 1999-2001, 2007, 2010-2011, 2013-2016.....	50
Figure 43:	Comparison of annual discharge volume in km ³ (1980-2015) with 2016.....	51
Figure 44:	Hydrograph 2016 and list of flood volumes at selected stations	52
Figure 45:	Range of maximum to minimum discharge per year at selected stations.....	53
Figure 46:	Flood volume / peak discharge relationship at selected stations 2016	53
Figure 47:	Maximum daily rainfall over the LMB in 2016	54
Figure 48:	Rainfall intensities for each month at Luang Prabang.....	55
Figure 49:	Time series of daily rainfall for Luang Prabang in 2016.....	55
Figure 50:	Cumulative rainfall along the mainstream hydrological station in [mm].....	58
Figure 51:	Flood map from Sentinel 1 on 12/10/2016 and 24/10/2016, upper part of Phnom Penh ..	62
Figure 52:	Depleted West Baray reservoir in Siem Reap and empty Banteay Meanchey's Sisophon River (photo left: Thik Kaliyann, photo right: Alessandro Marazzi Sassoon; Phnom Penh Post, accessed November 2017).....	62
Figure 53:	Development of the Flood Forecasting Tool for Cambodia (NFFC and DHRW)	64
Figure 54:	Flash flood events in Xekong Province.....	68
Figure 55:	Districts affected by floods and flash floods in 2016, Lao PDR	68
Figure 56:	Flood events in Nan and Chiang Rai province (source: Tipaporn Homdee, 2017).....	71
Figure 57:	Floods in Khon Kean and Ubolratchathani provinces, September 2016 (source: Tipaporn Homdee, 2017)	71
Figure 58:	Rainfall and meteorological variables observed in Viet Nam, 2016	77
Figure 59:	Provinces most affected by floods, Viet Nam, 2016	80

List of Tables

Table 1:	List of tropical storms and cyclones during 2016 (source: National Centre of Hydrology and Meteorology Forecasting, Viet Nam, 2016).....	41
Table 2:	Peak water levels at main tributaries exceeding warning levels in 2016	50
Table 3:	Annual rainfall in Cambodia from 2000-2016	58
Table 4:	Maximum water level in 2016 and long-term average in Cambodia	59
Table 5:	Impacts of floods and droughts compiled for Cambodia from 1996 to 2016.....	60
Table 6:	Peak water and warning levels along Mekong River in 2016, Lao PDR	66
Table 7:	Peak water level and warning levels in tributaries in 2016, Lao PDR	66
Table 8:	Summary of flood and flash flood related damages in 2016, Lao PDR.....	67
Table 9:	Summary of damages and losses in relation to floods, 2016, Thailand	72
Table 10:	Summary of damages and losses in relation to floods, 2016, Viet Nam.....	79

1. SYNOPSIS

The Annual Mekong Flood Report 2016 with the theme “Emerging technologies to cope with flood” is the attempt to look ahead in which direction flood management could go. There is no doubt about the fact that remote sensing largely affects the way how information is gathered and used nowadays. It is taken for granted to apply globally available data, satellite images, remote sensing information and derived products thereof. For example, the USGS EarthExplorer provides more than 400 different data sets. This can even be enhanced by adding ESA Sentinel products.

Not only the fact that data are made available in a wide range of formats and by various organisation, but also the timely availability is impressing. Both spatial and temporal resolution in combination with near real-time availability is key for most of the emerging technologies with respect to flood detection, flood assessment and early warning.

This paves the way to reconsider the use of hydrological models, especially the provision of model input, initial conditions and parameter estimates. At the same time, there are new options for the verification of results.

MRC has already embarked on new technology. This can be demonstrated by two topics, namely the MRC Decision Support Framework / Toolbox (DSF and the Flash Flood Guidance System (FFGS).

Underlying models capitalise on new technology, which is almost a must considering the area of the river basin with the comparatively low number of ground stations.

One hour is the shortest interval the FFGS is updated. This means that new satellite-based precipitation estimates come every hour and the whole underlying process is subsequently performed. As such, automation is a prerequisite to make full use of the incredibly amount of data.

During the 1st Rhine-Mekong Symposium “Climate change and its influence on water and related sectors”, held 8-9 May 2014, Koblenz, Germany, it was stated that

“... The Flood Simulation and Impact Assessment System, as part of the MRC DSF / Toolbox, provides a comprehensive and promising vehicle for assessing the impacts of future changes and developments on future and residual flood risks ...”

and further

“... it is expected that a) Integrated Land-Use- / Spatial Planning will prove to be the most effective means of limiting the growth in future flood risk, and b) flood forecasting, and the effective uptake and response to flood warnings, will emerge as a key management measure to address residual flood risk ...” (Bakker, 2014).

It is very likely that in a few years from now, all these computer applications will be embedded in a near real-time environment.

2. EMERGING TECHNOLOGY TO COPE WITH FLOOD

Emerging technologies to cope with floods include new remote sensing technologies and applications, new modelling and forecasting techniques and web-based services that aggregate and analyse news and data regarding floods.

2.1. The MRC tools

2.1.1. MRC DSF / Toolbox: Application in LMB

The MRC Toolbox is the main tool for various study within MRC and outside, like:

- Impacts of Scoping Development Scenarios in the Lower Mekong Basin (BDP, MRC)
- Impacts of Climate Change Scenarios in the Lower Mekong Basin (CCAI, MRC)
- Impact of Chinese Dam to Lower Mekong Basin (MT, MRC)
- Impact of Flood and Salinity Intrusion in Mekong Delta (MT, MRC)
- Flow contribution for entire basin (MT, MRC).
- Study on the changing of Flow regime in Mekong mainstream year 2010 (MT, MRC)
- Study on the changing of Flow regime in Mekong mainstream year 2010 (MT, MRC)
- Study on Erosion and Sedimentation of LMB (MT, MRC)
- 3S River Basin Development Study - Application of MRC Modelling Tools (MRC and ADB).
- Ongoing: study Impact of Flow and Sediment for Xayaburi HP Dam project in process of PNPCA (MRC)

The toolbox itself consists of a number of models and applications, partly used in the online flood forecast process or used offline for particular topics. For example, the SWAT model was applied for assessing the water balance, runoff, yield, soil erosion with a high spatial resolution. The ISIS model, used in the flood forecasting provides the means to address hydraulic issues downstream of Kratie with interactions of the Mekong mainstream with the Tonle Sap Lake.

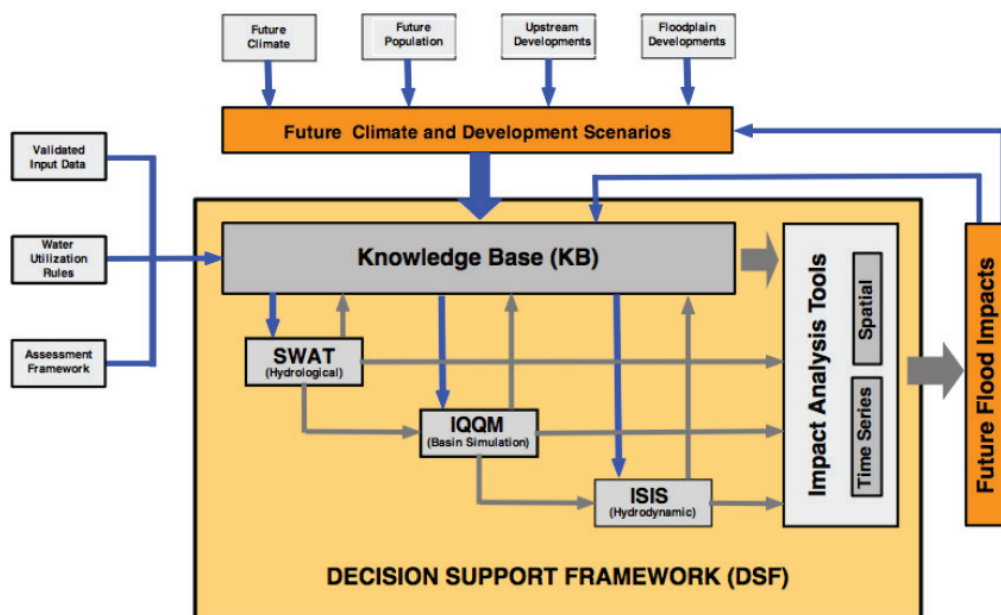


Figure 1: Overview about the MRC DSF / Toolbox (Bakker, 2014)

Since the formation of the Mekong Committee in 1959 and following the 1995 "Mekong Agreement" between the governments of Cambodia, Lao PDR, Thailand and Viet Nam, MRC has actively developed and acquired a range of atlases of the Mekong River basin. These atlases cover a range of subjects, including socio-economics, the natural and physical environment, and culture. They provide information spanning decades and represent an extremely valuable source of information for researchers and the general public who are interested in the history and development of the basin. Another tool reflecting emerging technology in terms of web-gis application is the web service launched at MRC portal.

There is a user community site aiming at facilitating communication in different forums like the MRC Toolbox, climate, hydrology, sediments, nutrients, crops, fisheries and people. Another tool is the Virtual Mekong Basin. The Virtual Mekong Basin is a learning tool to enhance the knowledge and understanding of the Mekong River Basin.

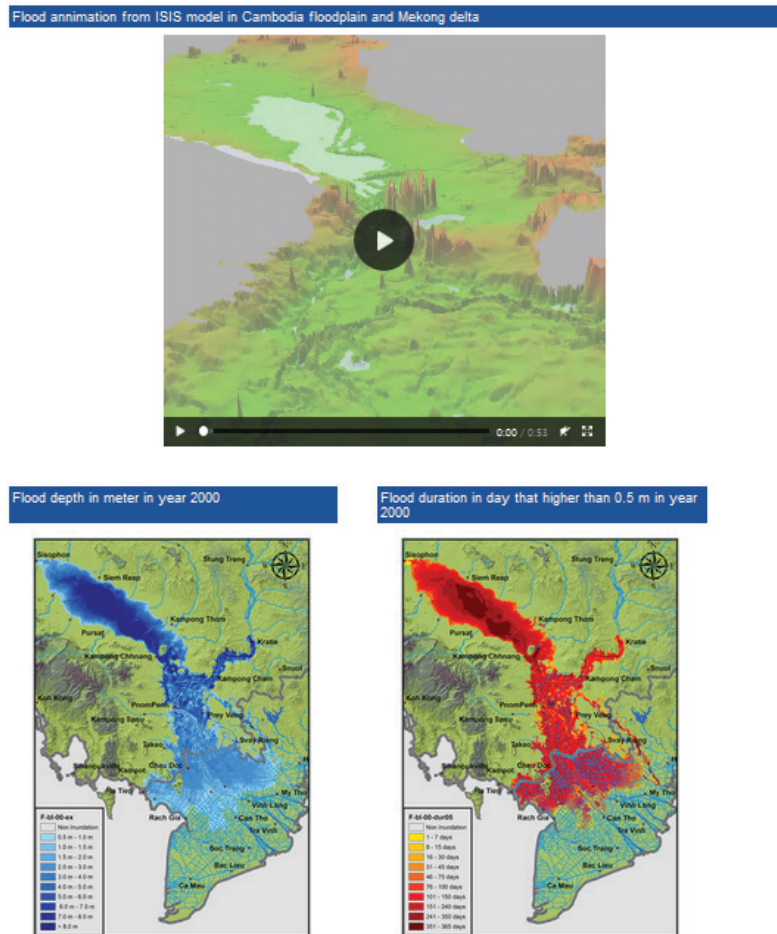


Figure 2: Screenshot from the MRC portal MRC DSF / Toolbox: Application in LMB (http://portal.mrcmekong.org/mrc_application)

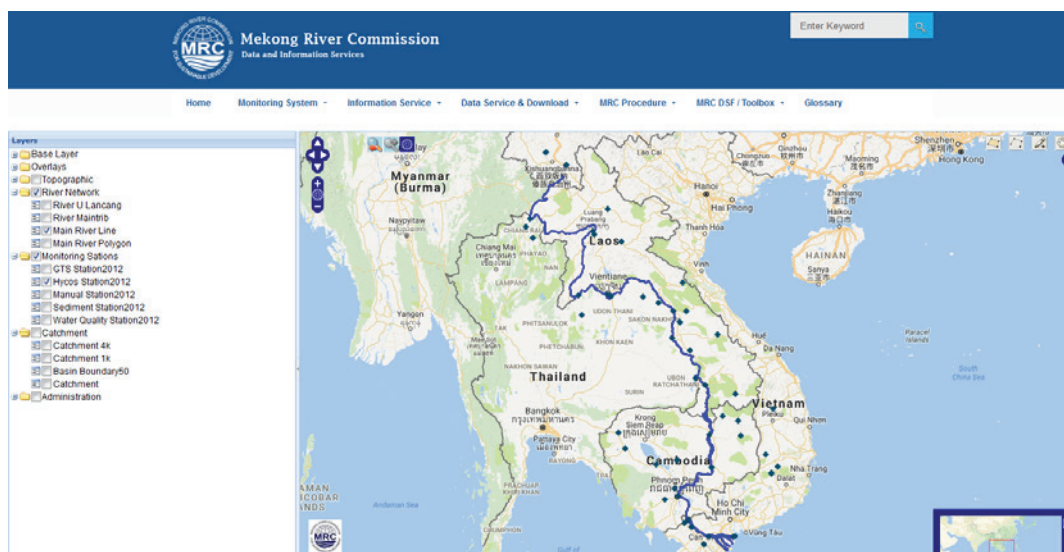


Figure 3: Screenshot of the MRC web-service within the portal MRC DSF / Toolbox: Application

2.2. Flash flood guidance system – MRC

Since 2010, a flash flood guidance system is in operation at MRC's Regional Flood Management and Mitigation Centre (RFMMC) in Phnom Penh. This system provided access for MRC member countries to the Flash Flood Guidance products for operational purposes but also for training. The system was described in (MRC, 2015).

The system is driven by satellite imagery providing three main components:

- Mean areal precipitation (MAP) for the catchment
- Average Soil Moisture, updated every 6 hours
- Flash flood risk indicator, updated every 6 hours

The information received from the system is processed, updated and then posted to the MRC flood forecasting webpage in parallel with the Mekong mainstream flood forecast.

The homepage of HRC further describes the FFG system as a Real-Time Product providing a collection of near real-time data products in text, image and CSV file formats. The text products are available for direct review as well as download using the web interface. Each hour, the system provides images and text tables related to estimated and forecast precipitation products. All other products are updated every six hours. Even though the system's primary product is the FFG data, the other products are made available so that the forecaster can leverage that information in their efforts for quality control and in their assessments when further applying the FFG data in their operational forecasting activities.

The system can be accessed from the MRC homepage and from the mrcffg.hrc-lab.org beta-version.

This page was last updated on 29 October 2017 08 : 30

**Products of the MRC Flash Flood Guidance System (MRCFFGS)
On 29 October 2017 at 00:00 UTC (07:00 local time)**

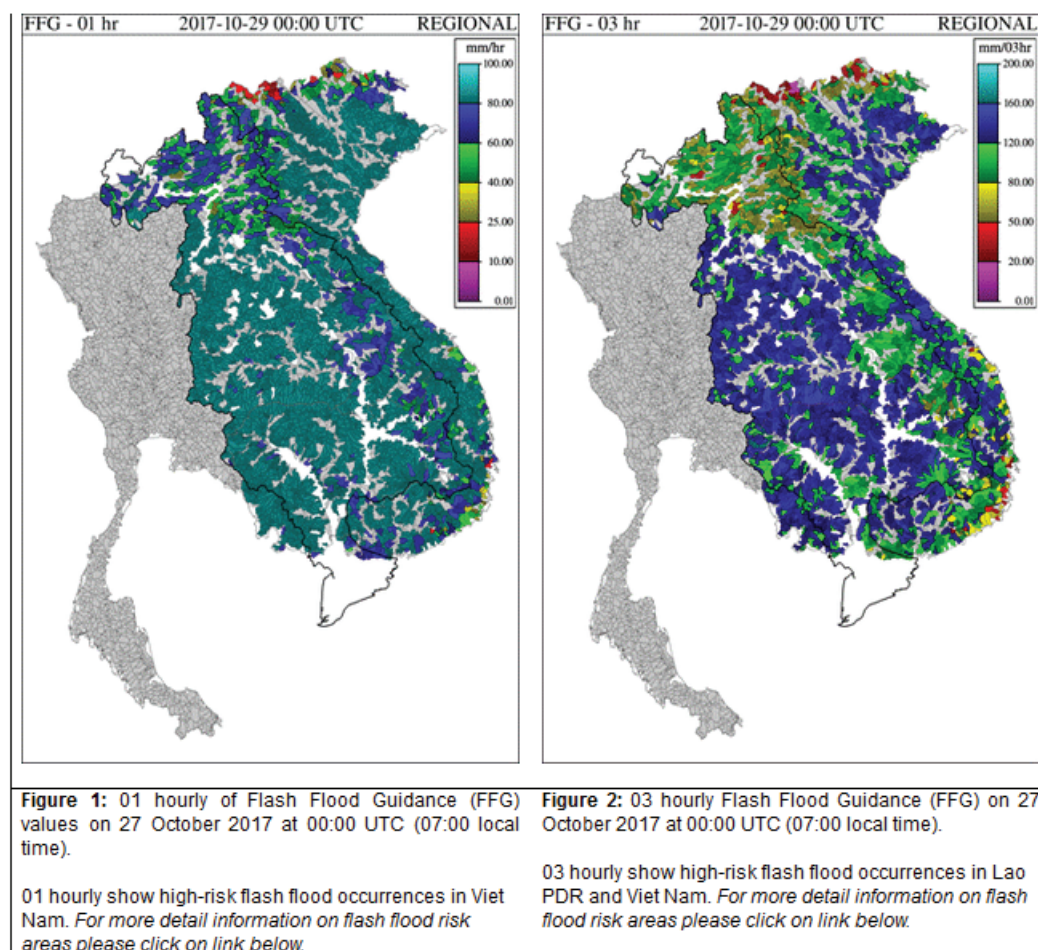


Figure 4: MRC FFG system accessed from the MRC homepage
(<http://ffw.mrcmekong.org/mrcffgs.htm>)

The MRC FFG system can also be accessed from the MRC HRC lab web site. The Hydrologic Research Center (HRC) was established in 1993 as a nonprofit research, technology transfer, and training organization. HRC was created to help bridge the large gap existing between scientific research in hydrology and applications for the solution of important societal problems that involve water.

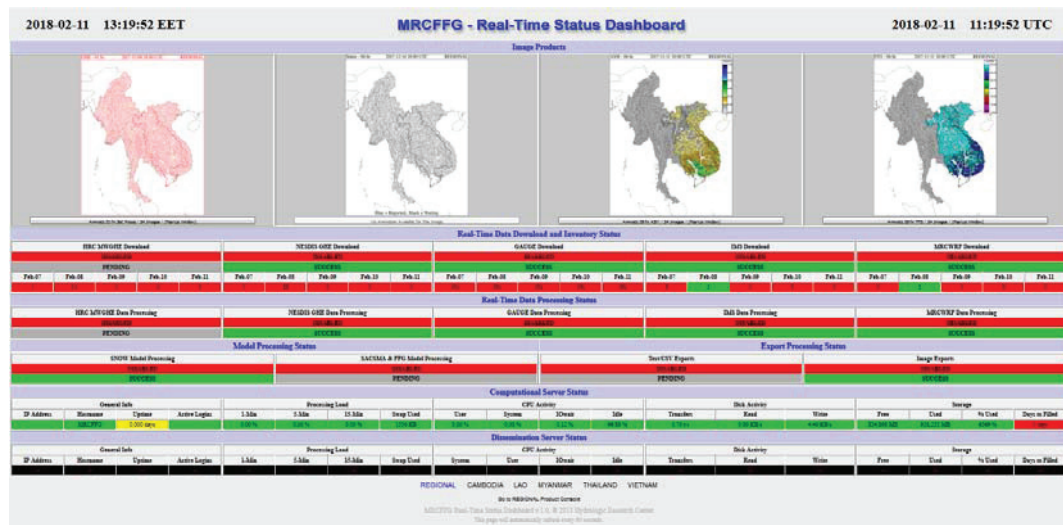
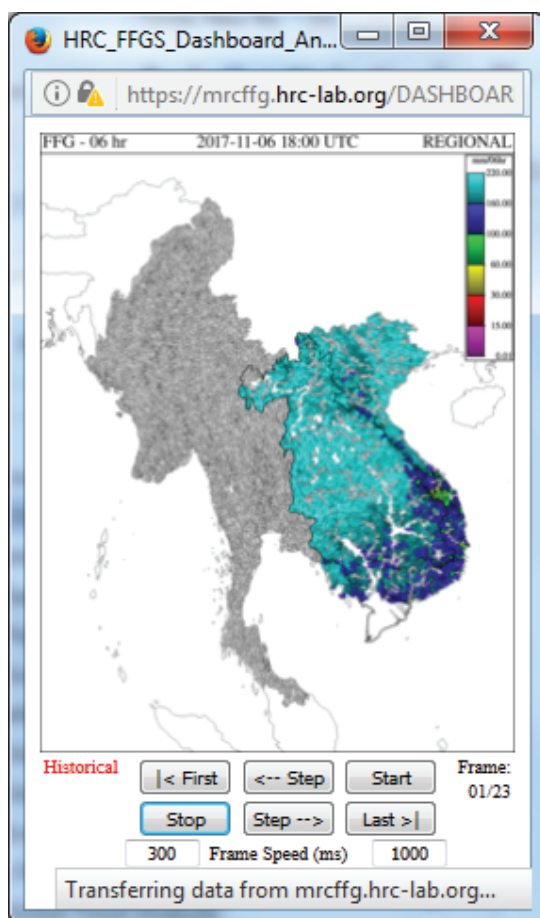


Figure 5: MRC FFG system accessed from the HRC-lab homepage (<https://mrcffg.hrc-lab.org/DASHBOARD/index.php?region=0>)



Three different views can be animated from the system.

- 1 hourly satellite precipitation for the previous 24 hours
- 6 hourly satellite precipitation for the previous 6 days
- 6 hourly flash flood risk for the previous 6 days

The picture to the left shows the mask provided by the system to animate flash flood risk.

The last update happened on October 2017. The system runs only in a pre-defined time window during the rainy season.

Microwave-adjusted Global HydroEstimator Satellite-based Precipitation Estimates are updated hourly.

The images and text provide gridded 1-hour, 3-hour, 6-hour and 24-hour accumulations of satellite-based rainfall estimates (mm) ending on the current hour from the NOAA-NESDIS Global HydroEstimator (infrared-based) and adjusted by the NOAA-CPC CMORPH microwave-based satellite rainfall product. The satellite-based rainfall estimates are provided on a grid which is displayed over a background of the system sub-basin boundaries. The MWGHE data products are updated every hour with a latency of approximately 45 minutes and are not bias-corrected. This product is provided for visual quality control assessment of the adjusted satellite input.

The Global HydroEstimator Satellite-based Precipitation Estimates are updated at an hourly basis. The images and text provide gridded 1-hour, 3-hour, 6-hour and 24-hour accumulations of satellite-based rainfall estimates (mm) ending on the current hour from the NOAA-NESDIS HydroEstimator. The satellite-based rainfall estimates are provided on a grid which is displayed over a background of system sub-basin boundaries. The data products are updated every hour with a latency of approximately 25 minutes and are not bias-corrected. This product is provided for visual quality control assessment of the satellite input.

Gauge Mean Areal Precipitation are updated every 6 hours (00, 06, 12, and 18 UTC). The images and text provide 6-hour and 24-hour accumulations of mean areal precipitation (mm) estimates for each sub-basin produced from interpolation of precipitation gauge data. The Gauge MAP data products are updated every six hours and reflect accumulations of basin-average precipitation of a given duration ending on the current navigation hour.

The interpolation of the gauge precipitation is performed on the observations made by a predefined list of "Active" stations. Only observations from these stations are incorporated into the gauge precipitation interpolation. Zero precipitation is assigned to active stations that did not report an observation. The Gauge MAP product is then derived for all sub-basins from the interpolated 6-hourly station observations. Gauge data availability can be monitored using the system Dashboard.

Merged Mean Areal Precipitation is calculated every 6 hours (00, 06, 12, and 18 UTC). The images and text provide 1-hour, 3-hour, 6-hour and 24-hour totals of the Merged Mean Areal Precipitation (mm) for each system sub-basin. This product is derived for each basin based on the best available mean areal precipitation estimates from bias-adjusted MWGHE or bias-adjusted GHE or the gauge-interpolations. The Merged MAP data products are updated every hour and reflect accumulations of basin-average precipitation of a given duration ending on the current navigation hour. The Merged MAP 06-hour accumulation product is applied during model processing as the precipitation input to the Snow17 Model and the Sacramento Soil Moisture Accounting Model.

Average Soil Moisture calculation follows the 00, 06, 12, and 18 UTC processing. The images and text provide soil water saturation fraction (dimensionless ratio of contents over capacity) for the upper zone (approximately 20-30 cm depth) of the Sacramento Soil Moisture Accounting Model for each of the sub-basins. The prod-

ucts are updated every six hours at the model processing hour (00, 06, 12, and 18 UTC).

Finally, the Flash Flood Guidance product is provided with the same 6 hourly interval. The images and text provide 1-hour, 3-hour and 6-hour Flash Flood Guidance (mm) for each sub-basin. For a given sub-basin and duration (1-hour, 3-hour or 6-hour), the FFG value indicates the total volume of rainfall over the given duration which is just enough to cause bankfull flow at the outlet of the draining stream. Consequently, rainfall volumes of the same duration that are greater than the FFG value indicate a likelihood of overbank flows at the draining stream outlet. Each of the FFG products is updated every six hours at the model processing hour (00, 06, 12, and 18 UTC). This product is appropriate to use in real time with nowcasts or forecasts of rainfall and other local information to estimate the risk of flash flooding in the sub-basins.

2.3. Remote sensing

Remote sensing technology is continuously developing and improving. Not only is the amount of satellites in orbit increasing, but each new generation of satellites also improves upon the previous ones. The spatial and temporal resolution, as well as the accuracy of measurements, are also on the rise.

At the same time, computer processing techniques are becoming more sophisticated and computer processing power becoming cheaper.

Remote sensing data and derived results and products are increasingly being made available to the public via the internet, many of them even on an operational basis (in “near-real time”), and free of charge.

The increasing adoption of standards for climate and geospatial data, the latter most markedly pushed by the Open Geospatial Consortium (OGC), simplifies the process of integrating and processing data from multiple providers.

All of these factors contribute to an increasing availability and usefulness of remote sensing data for conducting flood detection and forecasting.

In regions where ground-based measurements are sparse, data acquired by remote sensing technology can fill in the gaps.

The main fields of interest in remote sensing with regards to floods are satellite-based precipitation measurements and satellite-based flood detection and monitoring. However, new techniques such as using gravity measurements to derive water storage are also emerging. Below are some examples of projects in these fields:

2.3.1. Satellite based precipitation measurements

2.3.1.1. Tropical Rainfall Measuring Mission (TRMM)

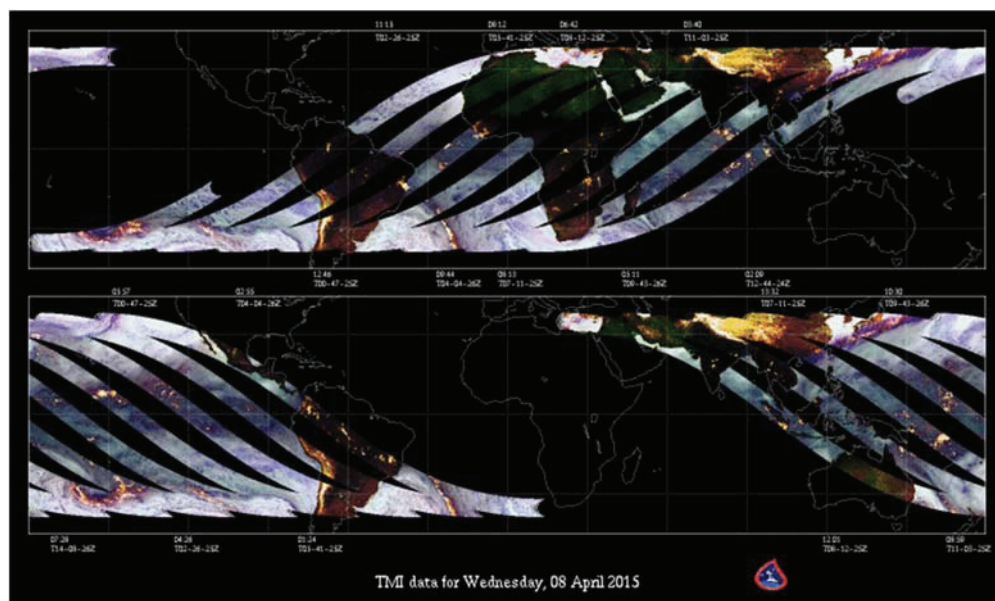
The data is obtained from the Tropical Rainfall Measuring Mission (TRMM), a joint mission between NASA and the Japan Aerospace Exploration (JAXA) Agency. The TRMM satellite was launched in 1997 with a design lifetime of 3 years.

Satellite based rainfall estimates from TRMM have been used by MRC since 2005 to augment the ground station-based rainfall measurements, which are then used to force rainfall-runoff models.

TRMM observed rainfall rates over the tropics and subtropics, where two-thirds of the world's rainfall occurs. TRMM carried the first precipitation radar flown in space, which returned data that were made into 3-D imagery, enabling scientists to see the internal structure of storms for the first time. TRMM also carried a microwave imager, a state-of-the-art instrument that had the highest resolution images of rainfall at the time. Together with three other sensors – the Visible and Infrared Scanner (VIRS), the Lightning Imaging Sensor (LIS), and the Clouds and the Earth's Radiant Energy System (CERES) instrument – scientists used TRMM data to explore weather events, climate, and Earth's water cycle.

The original goal was to provide monthly averages of rainfall over Earth's surface divided into large grid boxes, roughly 500 km square. TRMM eventually generated rainfall estimates at a higher resolution and in near-real time, every three hours.

After having produced over 17 years of data, the satellite ended collecting data on April 15, 2015 after the spacecraft depleted its fuel reserves and re-entered earth's atmosphere and disintegrated shortly thereafter.¹



(Source: https://trmm.gsfc.nasa.gov/data/quicklook/last_2_cal.html)

Figure 6: Quick Look images from TRMM Microwave Imager (TMI) data for April 08, 2015

2.3.1.2. Global Precipitation Measurement Mission (GPM)

Since TRMM's launch, many other space programs, including those in Europe and Japan, have launched precipitation measurement satellites containing microwave

¹ Sources:

<https://trmm.gsfc.nasa.gov/>

<https://pmm.nasa.gov/trmm/mission-end>

radiometers that measure radiated energy from rainfall and snowfall. The Global Precipitation Measurement (GPM) mission, initiated by NASA and the Japan Aerospace Exploration Agency (JAXA) as a global successor to TRMM, comprises a consortium of international space agencies, including the Centre National d'Études Spatiales (CNES), the Indian Space Research Organization (ISRO), the National Oceanic and Atmospheric Administration (NOAA), the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), and others. GPM harnesses the combined scope of multiple spacecraft and uses the GPM Core Observatory to standardize the measurements from the individual satellites. Together, they are combined into uniform data sets that are made available online. The GPM mission was launched in February 2014.

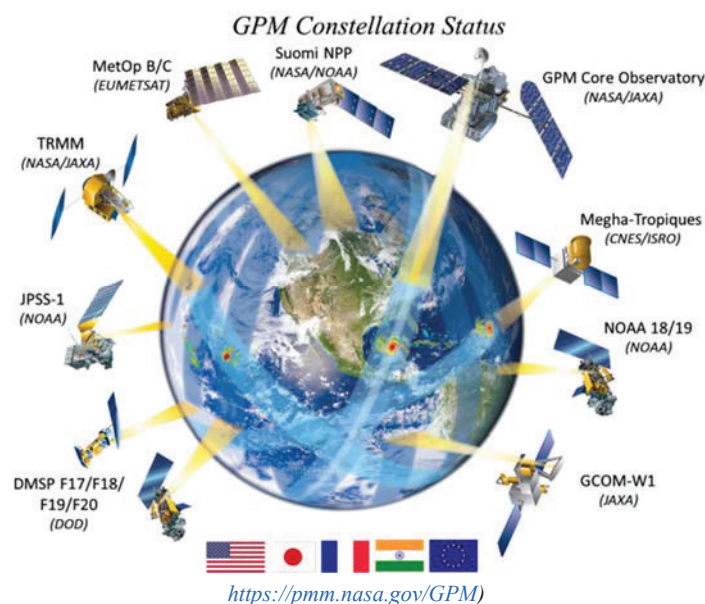


Figure 7: GPM Constellation Status

The GPM Core Observatory carries the first space-borne Ku/Ka-band Dual-frequency Precipitation Radar (DPR) and a multi-channel GPM Microwave Imager (GMI). Relative to the TRMM precipitation radar, the DPR is more sensitive to light rain rates and snowfall. In addition, simultaneous measurements by the overlapping of Ka/Ku-bands of the DPR can provide new information on particle drop size distributions over moderate precipitation intensities. In addition, by providing new microphysical measurements from the DPR to complement cloud and aerosol observations, GPM is expected to provide further insights into how precipitation processes may be affected by human activities. GPM provides global precipitation measurements with improved accuracy, coverage and dynamic range for studying precipitation characteristics. GPM is also expected to improve weather and precipitation forecasts through assimilation of instantaneous precipitation information.

Furthermore, GPM's orbit passes above a larger portion of the world. TRMM's orbit covered the latitude ranging from 35 degrees north to 35 degrees south, but

GPM's coverage of latitude from 65 degrees north to 65 degrees south stretches nearly to the Arctic and Antarctic Circles.²

NASA's Precipitation Processing System (PPS), formerly known as the TRMM Science Data and Information System (TSDIS), processes all the data returned by GPM constellation satellites, provides validation from ground radar sites, and makes data products available to the science community and general public. The transition from data obtained from the TRMM satellite to that of the GPM constellation satellites was seamless, so that MRC is now essentially using rainfall estimates produced by GPM for its rainfall-runoff models.

2.3.1.3. Global Flood Alert System (GFAS)

Global Flood Alert System Ver.2 (GFAS II) is a system to display the global flood risk map by displaying the probability of the rainfall for global rainfall data obtained from satellite observations. GFAS II is a revised version of GFAS, which was published in June 2015 and revised as ver.2.1 in June 2017, by the Infrastructure Development Institute (IDI), Japan.

GFAS II utilizes the Global Satellite Mapping of Precipitation, GSMaP (NRT and NOW), as a means of rainfall estimation, which the Japan Aerospace Exploration Agency (JAXA) makes open to the public on their website.

GSMaP_NRT data is among the highest levels of precision and resolution in the world (temporal resolution: 1-hour, spatial resolution: Grid latitude-longitude of 0.1 degrees).

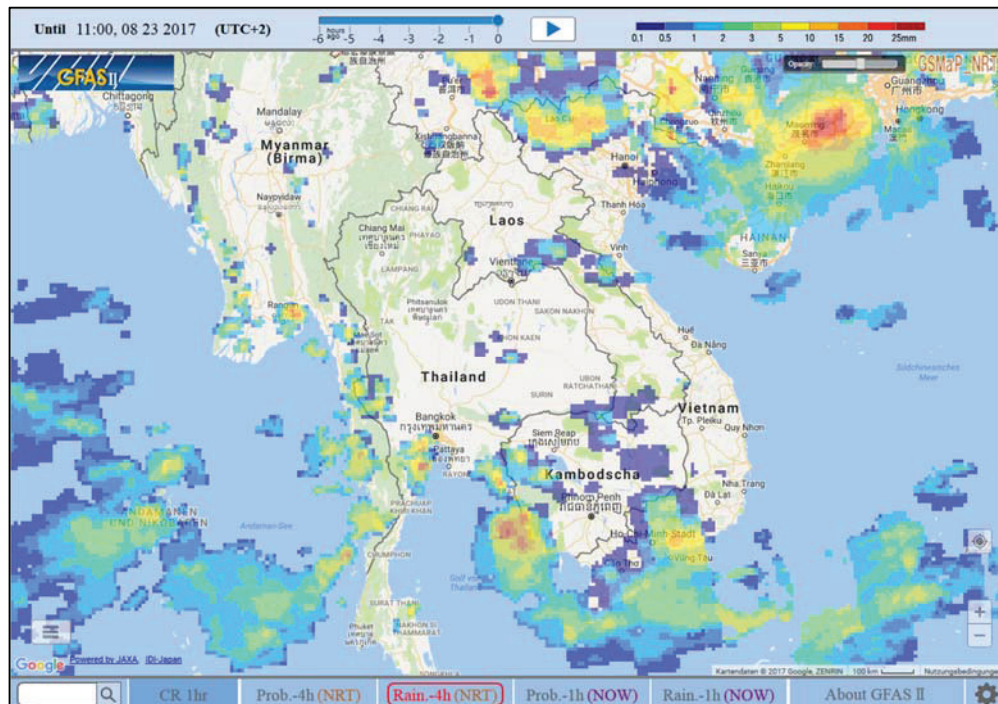
GSMaP_NOW is a quasi-realtime version of GSMaP_NRT. It is a rainfall map over the observation area of the geostationary satellite "Himawari" and applies a half-hour extrapolation of future rainfall towards a future direction by using cloud movement vectors. This allows for the estimation of "quasi-realtime" hourly rainfall maps.³

² Sources:

<https://pmm.nasa.gov/trmm/mission-end>

<https://pmm.nasa.gov/GPM>

³ Source: http://gfes.internationalfloodnetwork.org/n-gfas-web/PC/frmAvt_E.html



(source: <http://gfas.internationalfloodnetwork.org/n-gfas-web/PC/firmMain.aspx>)

Figure 8: GSMaP_NRT map of the Mekong region showing near-real time precipitation amounts as of August 23, 2017

2.3.2. Flood warning, detection and monitoring

Flood warning, detection and monitoring using near-real time satellite data is a field of remote sensing that is still being actively developed. Below are some example systems and products, some of them still experimental:

2.3.2.1. Global Flood Detection System

The Global Flood Detection System (GFDS) web application publishes the results of a new processing technique for remote sensing data that allows near real-time detection of flooded areas worldwide. GFDS provides maps, alerts, and the raw data for users ranging from emergency managers and public authorities to scientists and web developers.⁴

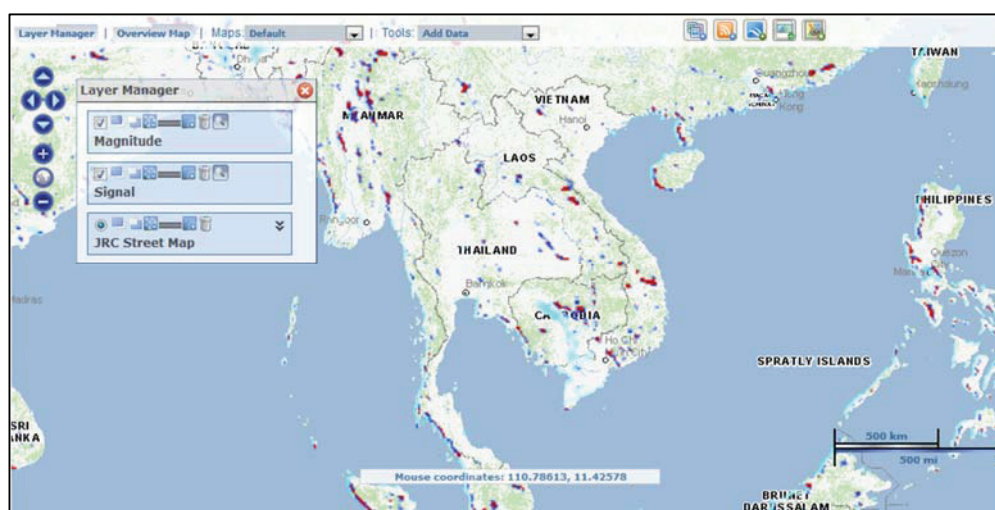
Using AMSR-E data, De Groeve et al. (2007) developed a method for detecting major floods on a global basis in a systematic, timely and impartial way appropriate for humanitarian response. In collaboration with the Dartmouth Flood Observatory and the Joint Research Center (JRC) of the European Commission, the methodology has been implemented and automated as the Global Disaster Alert and Coordination System's (GDACS) Global Flood Detection System (GFDS). The system is currently in version 2 but is still labelled as experimental.

⁴ Source: <https://ec.europa.eu/jrc/en/scientific-tool/global-flood-detection-system>

The GFDS monitors floods worldwide using near-real time satellite data. Surface water extent is observed using passive microwave remote sensing (AMSR-E and TRMM sensors). When surface water increases significantly (anomalies with probability of less than 99.5%), the system flags it as a flood. Time series are calculated in more than 10.000 monitoring areas, along with small scale flood maps and animations. GFDS currently monitors around 10.000 areas, defined in collaboration with partners. For these areas, the flood signal is further processed to generate time series, flood maps and flood animations.

Additionally, the satellite observations are converted to raster products on a daily basis and with global coverage, effectively providing water surface metrics with daily frequency for any location in the world.⁵

GFDS has two products: the signal (proportional to percentage surface water in a pixel) and the magnitude (the anomaly of the current value expressed as standard deviations from the mean). Depending on the use, either the signal or the magnitude is used. For detection floods, the magnitude is more appropriate, since it is a measure of anomaly, scaled by the local signal variability (the standard deviation) and offset by the reference value for normal flow (the average). For measuring flood surface, mapping flood extent or comparing with optical data, the flood signal is more appropriate, since it is proportional to the surface water area.⁶



(source: http://www.gdacs.org/flooddetection/global_map.aspx)

Figure 9: Flood signal and magnitude data in the Mekong region for August 21, Surface Water Mapping Tool, 2017

The Surface Water Mapping tool was developed by Deltares, Technical University Delft, SERVIR-Mekong, earth2Observe, Google, ADPC, Stockholm Environment Institute (SEI) and Spatial Informatics Group (SIG). The tool leverages the extensive archive of Landsat data in the Google Earth Engine archive and Google's cloud processing power to quickly calculate past patterns of surface

⁵ Source: <http://www.gdacs.org/flooddetection>

⁶ Source: De Groeve et al. (2013)

water extent from multiple layers of Landsat imagery. The tool consists of a Google Earth Engine application and a user-friendly web interface which allows the user to specify the period evaluated and other calculation parameters that are then executed in a cloud service. Results are displayed on screen and can be downloaded for specified areas.

The Surface Water Mapping Tool was initially developed to document the historical dynamics of seasonal flooding cycles on the Mekong River in order to better understand some of the likely impacts of completed and proposed dams. Other uses include flood risk assessment for disaster preparedness, identifying areas of permanent water (valuable in the context of severe drought response), and numerous water resources management applications.

The web-based application allows users to carry out live calculations using a sophisticated water detection algorithm for the SERVIR-Mekong region. It is based on the algorithm described in Donchyts et al. (2016).⁷

According to the web site (<https://servir.adpc.net/tools/surface-water-mapping-tool>), the list of users of the Surface Water Mapping Tool includes

- Vietnam: Institute of Meteorology, Hydrology and Environment
- Cambodia: Ministry of Water Resources and Meteorology
- Lao PDR : Ministry of Natural Resources and Environment; Ministry of Energy and Mines
- Thailand: Department of Water Resources
- Mekong River Commission (MRC)

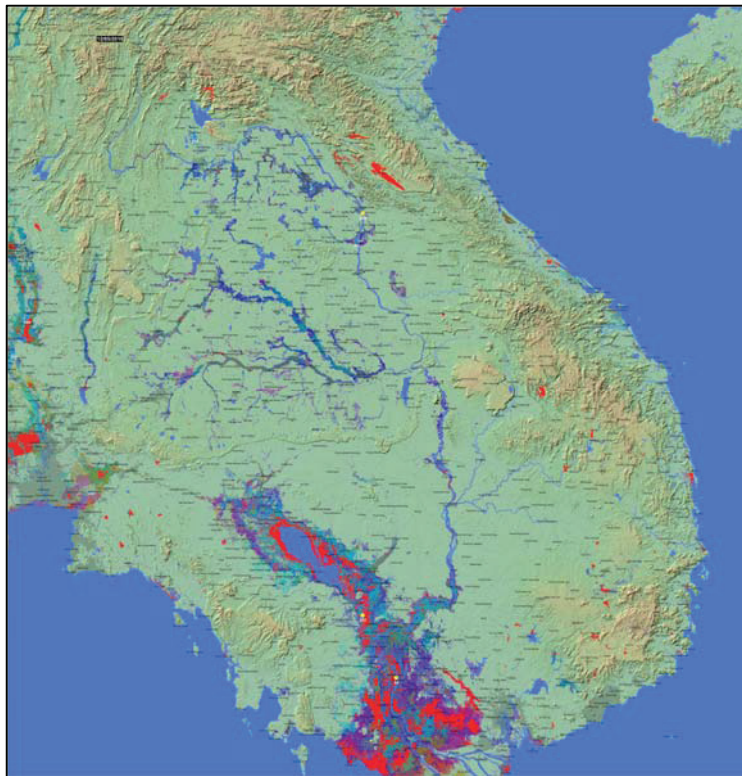
2.3.2.2. Dartmouth Flood Observatory

The Dartmouth Flood Observatory (DFO) is a not-for-profit organization within the University of Colorado, USA. Since late 1999, the DFO has obtained satellite data, processed it to detect water/land boundaries, and analysed it to produce flood inundation limits in vector GIS format. The DFO facilitates use of space-based information for international flood detection, flood response, future risk assessment, and hydrological research.⁸

Major flood events around the world are mapped and these maps are made available to the public via the DFO's website. DFO also carries out daily monitoring of the earth's surface waters. The most recent maps available for the Mekong region were, however, as of the writing of this report, last updated in May 2016 (see Figure 10).

⁷ Source: <https://servir.adpc.net/tools/surface-water-mapping-tool>

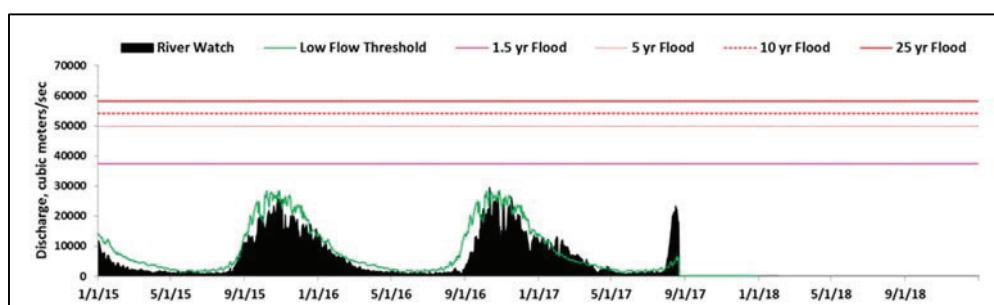
⁸ Source: <http://floodobservatory.colorado.edu/>



(source:
<http://floodobservatory.colorado.edu/GlobalFloodplains/100E020NCurrent.html>)

Figure 10: Current Flood Conditions, Sheet 100E020N, dated May 12, 2016.

The DFO also conducts experimental satellite-based river discharge measurements (“River Watch”) using passive microwave radiometry for selected sites, which are updated daily (Brakenridge et al., 2016). An example graph from a site on the Mekong River is shown in Figure 11.



<http://floodobservatory.colorado.edu/SiteDisplays/34.htm>

Figure 11: River Watch data for the Mekong in Cambodia

2.3.2.3. NRT Global Flood Map

The twice daily near-global coverage of the MODIS instruments (on NASA’s Terra and Aqua satellites) at approximately 250 m resolution provides a unique resource for monitoring rapidly evolving events, such as large-scale flooding. Since late 2011, NASA Goddard’s Office of Applied Science (OAS) has operationalized

daily, near real-time, global flood mapping using these data, building on the expertise and long-time efforts of the Dartmouth Flood Observatory (DFO) to MA floodwater extent. The daily OAS products are now used as input for the more detailed DFO flood maps.

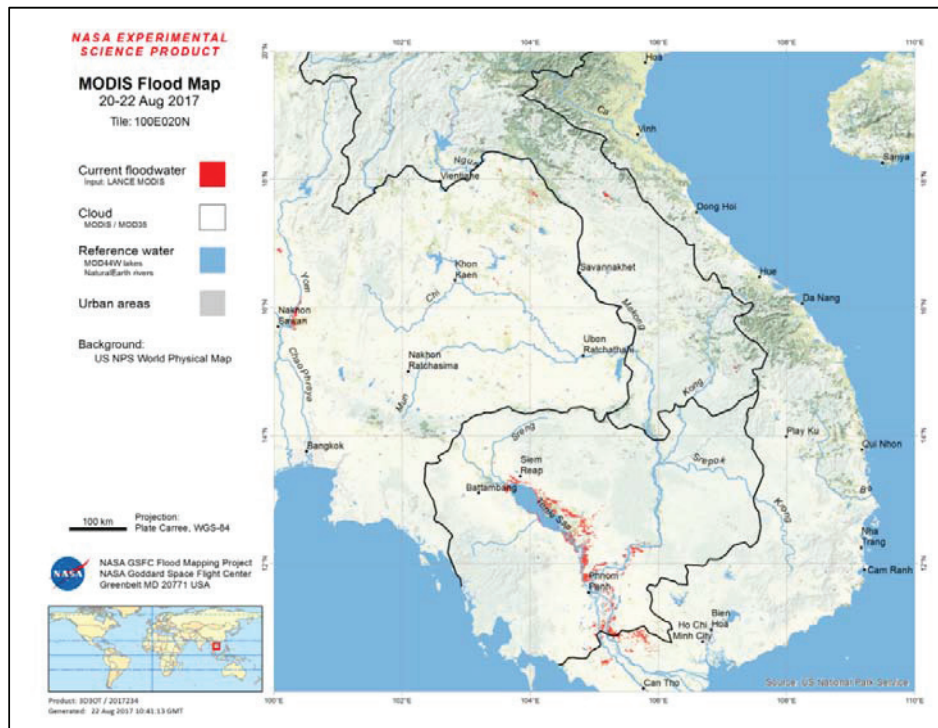
Water is detected via empirically-derived thresholds on MODIS bands 1, 2, and 7 (pansharpened to 250 m resolution). Due to the spectral similarity of water and cloud shadow in these bands, cloud shadows will often be initially flagged as water. To overcome this limitation, and to provide a product less affected by cloud cover, observations from each daily overpass are composited over 2 or 3 days. When water is detected in a pixel 2 (or 3) times over the 2 (or 3) day period, the pixel is flagged as water. Requiring these multiple water observations greatly limits false positives due to cloud shadow, which rarely recur in the same location over a short period of time. Compositing over several days also helps fill in cloudy areas. The cost is in the timeliness of the data. And despite these efforts, some regions are so consistently cloudy that no useful products may be available during or soon after flood events.

Flood is distinguished from expected surface water by comparison to the MOD44W MODIS Water Mask product: water exceeding that depicted in MOD44W is labelled as flood. However, the MOD44W water mask is temporally static and so does not provide an indication of normal seasonal water fluctuations; such areas may be labelled as flood in this product but may not actually be considered flood locally.⁹

The system is still labelled as experimental and is in active development. A number of future upgrades and enhancements are planned.¹⁰

⁹ Source: De Groeve et al. (2013)

¹⁰ Source: <https://floodmap.modaps.eosdis.nasa.gov/>



(source: <https://floodmap.modaps.eosdis.nasa.gov/getTile.php?location=100E020N>)

Figure 12: 3-day composite MODIS Flood Map of the Mekong region for August 20-22, 2017

2.3.2.4. Ithaca Extreme Rainfall Detection System

The Extreme Rainfall Detection System (ERDS), developed and implemented by ITHACA, is a service for the monitoring and forecasting of exceptional rainfall events, with a nearly global geographic coverage.

This system is conceived to be a strategic tool, providing complete, immediate and intuitive information about potential flood events, to be used during the preparedness and response phases of the emergency cycle. Information are accessible through a WebGIS application, developed in a complete Open Source environment, that processes and disseminates warnings in an understandable way also for non-specialized users. Available capabilities include the analysis of near real-time rainfall amount and of forecasted rainfall for different lead times, with the aim to deliver extreme rainfall alerts. The combination of such information with reference data allows the system to generate value-added and event-specific information, such as the list of the affected countries and an estimation of the affected population. Currently the system is one of the tools used by UN World Food Programme (WFP) Emergency Preparedness Unit.

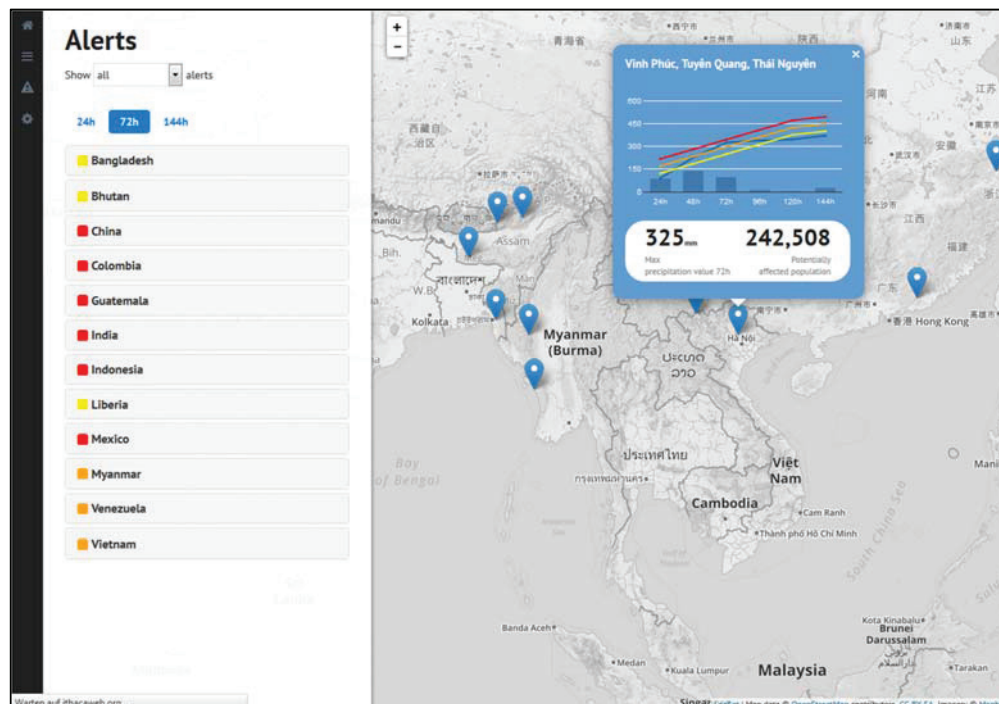
The data used for the near-real time detection of extreme events are mainly based on the Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA) data, updated on a 3-hour basis. Spatial resolution of TRMM data is 0.25x0.25 lat/lon degrees, between 50° latitude N and 50° latitude S.

This system is also able to provide a longer lead-time alerts (up to 6 days) for heavy rain and floods, using forecast rainfall data, coming from NOAA-GFS (Global Forecast System) deterministic weather prediction models, with 1.0x1.0 lat/lon degrees resolution and worldwide coverage, updated on a 6-hour basis.

Three different alert levels can be visualized (low, moderate and severe), based on specific rainfall intensity threshold, defined as the amount of precipitation for a given duration over a specific climatological area. Concerning real-time rainfall data, two kinds of events are considered: short term events, up to 24 hours cumulated rainfall, and medium terms events, up to 1-week cumulated rainfall. In case of forecasted rainfall data, three kinds of events are considered: short term events (24 hours), and medium-term events both on 72 hours basis and 6 days basis.

In order to facilitate the users in interpreting the alerts, specific information about the impact of heavy rainfall, such as the visualization of the affected countries and the calculation of the potentially affected population, are displayed in a table. Countries currently under alert are listed, ordered from the potentially most affected to the less affected in terms of population.¹¹

The data and information provided by ERDS are currently labelled as experimental and may not be accurate, especially if intended at local scale.



(source: <http://erds.ithacaweb.org/>)

Figure 13: 72h alerts as of August 23, 2017

¹¹ Source: <http://www.ithacaweb.org/projects/erds/>

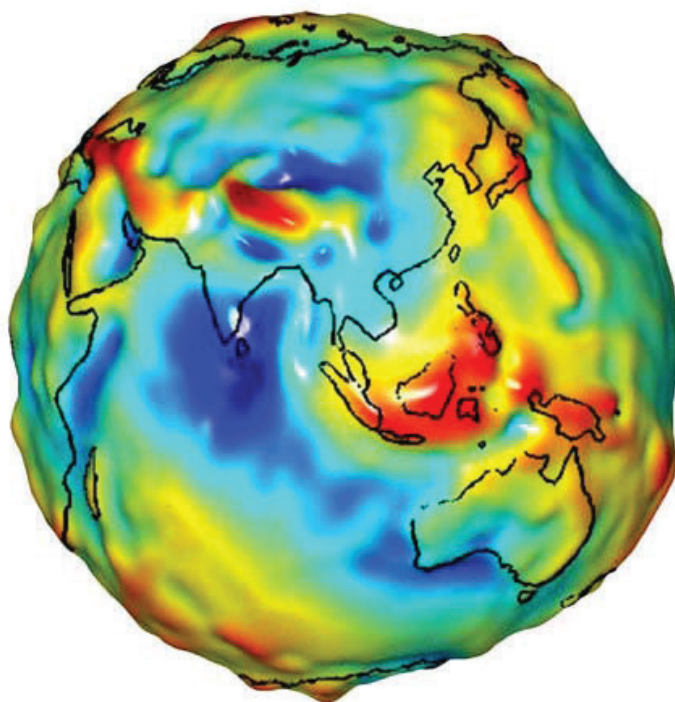
2.3.3. Gravity measurements

Measurements of the distribution and temporal changes in earth's gravity field can be used to derive surface and ground water storage on land masses, thereby contributing valuable input data to hydrological models.

2.3.3.1. Gravity Recovery and Climate Experiment (GRACE)

Launched in March of 2002, the GRACE mission is accurately mapping variations in Earth's gravity field. Designed for a nominal mission lifetime of five years, GRACE is currently operating in an extended mission phase.

GRACE consists of two identical spacecraft that fly about 220 kilometers (137 miles) apart in a polar orbit 500 kilometers (310 miles) above Earth. GRACE maps Earth's gravity field by making accurate measurements of the distance between the two satellites, using GPS and a microwave ranging system. It is providing scientists from all over the world with an efficient and cost-effective way to map Earth's gravity field with unprecedented accuracy. The results from this mission are yielding crucial information about the distribution and flow of mass within Earth and its surroundings.



source:
http://www2.csr.utexas.edu/grace/gallery/gravity/ggm01_asia.html

Figure 14: GRACE gravity model 01 Asia

The gravity variations studied by GRACE include: changes due to surface and deep currents in the ocean; runoff and ground water storage on land masses; exchanges

between ice sheets or glaciers and the ocean; and variations of mass within Earth. Another goal of the mission is to create a better profile of Earth's atmosphere.¹²

The GRACE satellite mission provides a means to observe monthly variations in total water storage within large (>200,000 km²) river basins based on measurements of changes in Earth's gravity field: when the amount of water stored in a region increases, the gravity signal in that region increases proportionately, and is detected by the GRACE mission with tremendous accuracy. The terrestrial water storage signal defines the time-variable ability of the land to absorb and process water, and accounts for the water beneath the surface.

Soil moisture data is critical in the accurate prediction of floods and general runoff. One could argue that soil moisture primarily serves as a proxy in flood studies for the more critical water balance variable of storage, and for storage deficit (Beven and Kirkby, 1979). GRACE data can show us when river basins have been filling with water over several months. When it finally rains and the basin is full, there is nowhere else for the water to go.

A remotely sensed, storage-based 'flood potential' method using GRACE observations has proven to be useful in identifying major flood occurrence globally (Reager and Famiglietti, 2009). Over the GRACE record length, each region tends to exhibit an effective storage capacity, beyond which additional precipitation must be met by marked increases in runoff or evaporation. These saturation periods indicate the possible transition to a flood-prone situation.

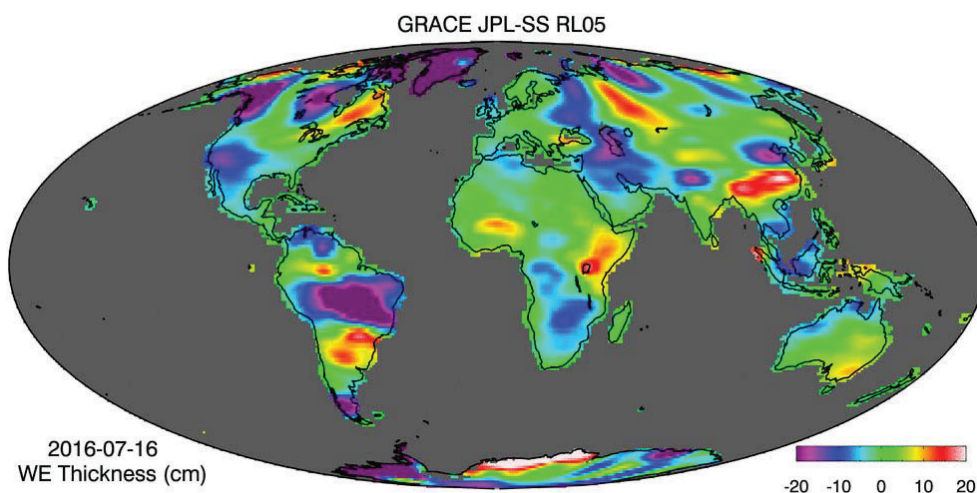
The predictive ability of a GRACE-based flood potential has been compared to flood prediction models that use traditional input data sources such as river heights, snow amounts and the wetness of surface soils (Reager et al., 2014). A case study of the catastrophic 2011 Missouri River floods showed that the inclusion of total water storage information has the potential to increase regional flood warning lead-times to as long as 5 months.¹³

NASA's GRACE mission provides the first opportunity to directly measure groundwater changes from space. By observing changes in the Earth's gravity field, scientists can estimate changes in the amount of water stored in a region, which cause changes in gravity. GRACE provides a more than 10 year-long data record for scientific analysis. Using estimates of changes in snow and surface soil moisture, scientists can calculate an exact change in groundwater in volume over a given time period.¹⁴

¹² Source: https://www.nasa.gov/mission_pages/Grace/overview/index.html

¹³ Source: <https://grace.jpl.nasa.gov/applications/flood-potential/>

¹⁴ Source: <https://grace.jpl.nasa.gov/applications/groundwater/>



(source: <https://gracefo.jpl.nasa.gov/data/grace-data/>)

Figure 15: Land water storage anomalies in July 2017, as observed with the GRACE satellites

NASA and the German Research Centre for Geosciences (GFZ) have been working since 2012 on a second GRACE mission called GRACE Follow-On (GRACE-FO), with Germany again procuring a launch vehicle and the twin satellites built at Airbus in Germany. GRACE-FO is scheduled for launch between December 2017 and February 2018. The new mission focuses on continuing GRACE's successful data record. The new satellites use similar hardware to GRACE and will also carry a technology demonstrator with a new laser ranging instrument to track the separation distance between the satellites. The laser instrument has the potential to produce an even more accurate measurement.¹⁵

2.4. Modelling

Hydrological and flood routing models on a global scale that provide near real-time results are being developed by a number of institutions. Often, they are combined with weather forecasts in order to produce streamflow or flood forecasts and warnings.

2.4.1. Global Flood Awareness System (GloFAS)

The Global Flood Awareness System (GloFAS), jointly developed by the European Commission and the European Centre for Medium-Range Weather Forecasts (ECMWF), is independent of administrative and political boundaries. It couples state-of-the art weather forecasts with a hydrological model and with its continental scale set-up it provides downstream countries with information on upstream river conditions as well as continental and global overviews.

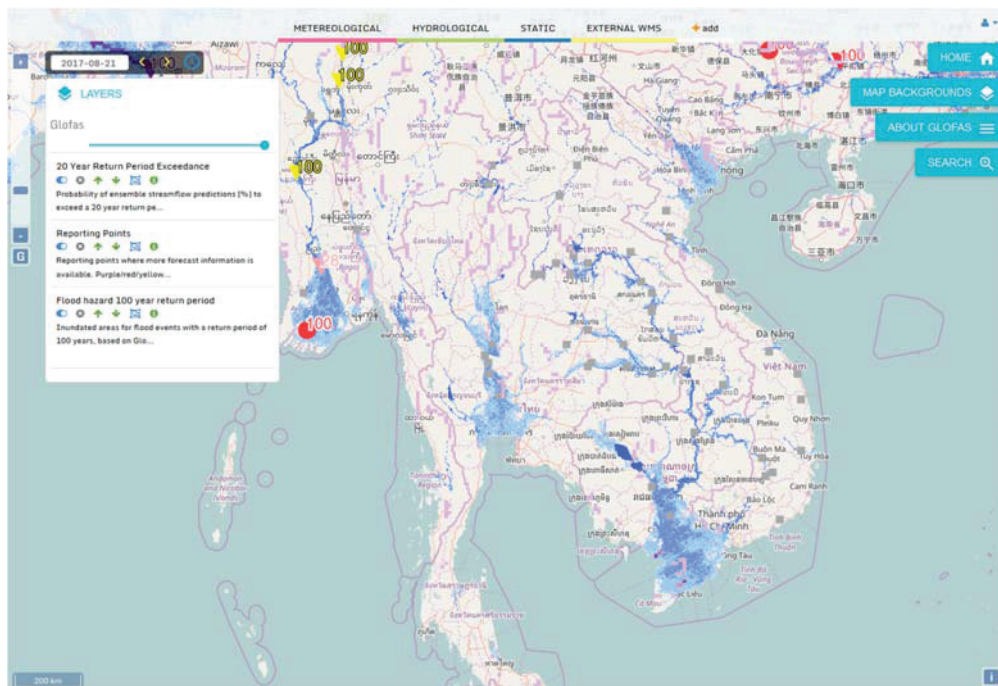
¹⁵ Source: <https://grace.jpl.nasa.gov/news/89/grace-mission-15-years-of-watching-water-on-earth/>

GloFAS produces daily flood forecasts in a pre-operational manner since June 2011. It has shown its potential during the floods in Pakistan in August 2013 or in Sudan in September 2013.

In its test phase this global forecast system was able to predict floods up to two weeks in advance. The European Commission - Joint Research Centre (JRC) will now continue with further research and development, rigorous testing and adaptations of the system to create an operational tool for decision makers, including national and regional water authorities, water resource managers, hydropower companies, civil protection and first line responders, and international humanitarian aid organisations.

GloFAS is still in research phase and is producing daily forecasts only in a pre-operational mode.¹⁶

Products currently include map layers showing precipitation probabilities, the probability of ensemble streamflow predictions to exceed a 5 and 20 year return period discharge as well as static flood hazard maps for a 100 year return period.



(source: <http://globalfloods.jrc.ec.europa.eu/glofas-forecasting/>)

Figure 16: GloFAS viewer

GloFAS viewer above shows ensemble streamflow predictions for Aug 21, 2017 as well as static flood hazard for a 100 year return period in the Mekong region

¹⁶ Source: <http://globalfloods.jrc.ec.europa.eu/>

2.4.2. Global Flood Monitoring System

The Global Flood Monitoring System (GFMS) is a NASA-funded experimental system using real-time TRMM Multi-satellite Precipitation Analysis (TMPA) precipitation information as input to a quasi-global (50°N - 50°S) hydrological runoff and routing model running on a 1/8th degree latitude/longitude grid. Flood detection/intensity estimates are based on 13 years of retrospective model runs with TMPA input, with flood thresholds derived for each grid location using surface water storage statistics (95th percentile plus parameters related to basin hydrologic characteristics). Streamflow, surface water storage, inundation variables are also calculated at 1km resolution. In addition, the latest maps of instantaneous precipitation and totals from the last day, three days and seven days are displayed.

The flood model is based on the University of Washington Variable Infiltration Capacity (VIC) land surface model (Liang et al., 1994) coupled with the University of Maryland Dominant River Tracing Routing (DRTR) model (Wu et al., 2014). The VIC/DRTR coupled model is named as the Dominant river tracing-Routing Integrated with VIC Environment (DRIVE) model. The flood detection algorithm is described in Wu et al. (2012). The real-time TMPA precipitation data product (Huffman et al., 2010) is obtained from the NASA Goddard TRMM/GPM Precipitation Processing System (PPS). The new GFMS with the DRIVE model has been evaluated based on 15-yr (1998~2012) retrospective simulation against more than 1,000 gauge streamflow observations and more than 2,000 reported flood events across the globe (Wu et al., 2014). All the calculations are updated every three hours.¹⁷

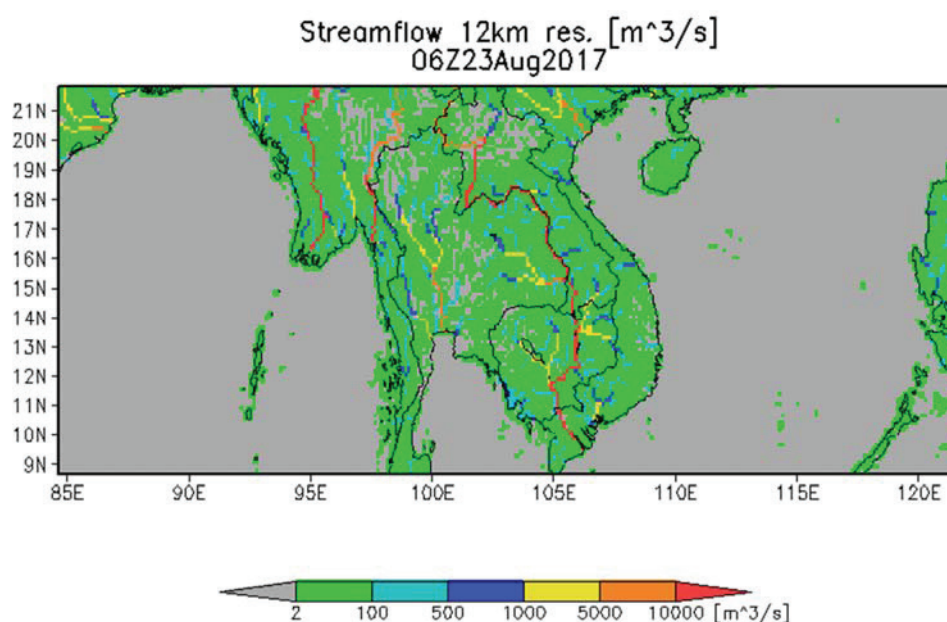


Figure 17: Streamflow modelled at 12 km resolution for the Mekong region as of August 23, 2017 Forecasting (source: <http://flood.umd.edu/>)

¹⁷ Source: <http://flood.umd.edu/>

Global weather and climate models can be used to forecast precipitation and, coupled with corresponding hydrological and stream routing models, streamflow and potential floods. Increasingly accurate and more detailed measurements acquired through remote sensing also improve the quality of the forecasts. At the same time, the weather and climate models themselves are improving in accuracy and resolution. Below are some examples of forecasting systems that provide data that can be used for flood forecasting:

2.4.3. Ensemble Tropical Rainfall Potential (eTRaP)

The eTRaP is a simple ensemble whose members are the 6-hourly totals from the single-orbit TRaPs (hereafter, simply TRaP). This ensemble approach allows for the generation of probabilistic forecasts of rainfall in addition to deterministic rainfall totals similar to what is currently provided by the TRaP product.

Each eTRaP is made up of forecasts using observations from potentially several microwave sensors—currently AMSU, TRMM, SSMI and AMSRE—initialized at several observation times, and possibly using several different track forecasts. The diversity among the ensemble members helps to reduce the large (unknown) errors associated with a single-sensor, single-track TRaP. The large number of perturbations leads to ensembles with many members, allowing probability forecasts to be issued with good precision and reliability. eTRaPs are archived by storm and year.¹⁸

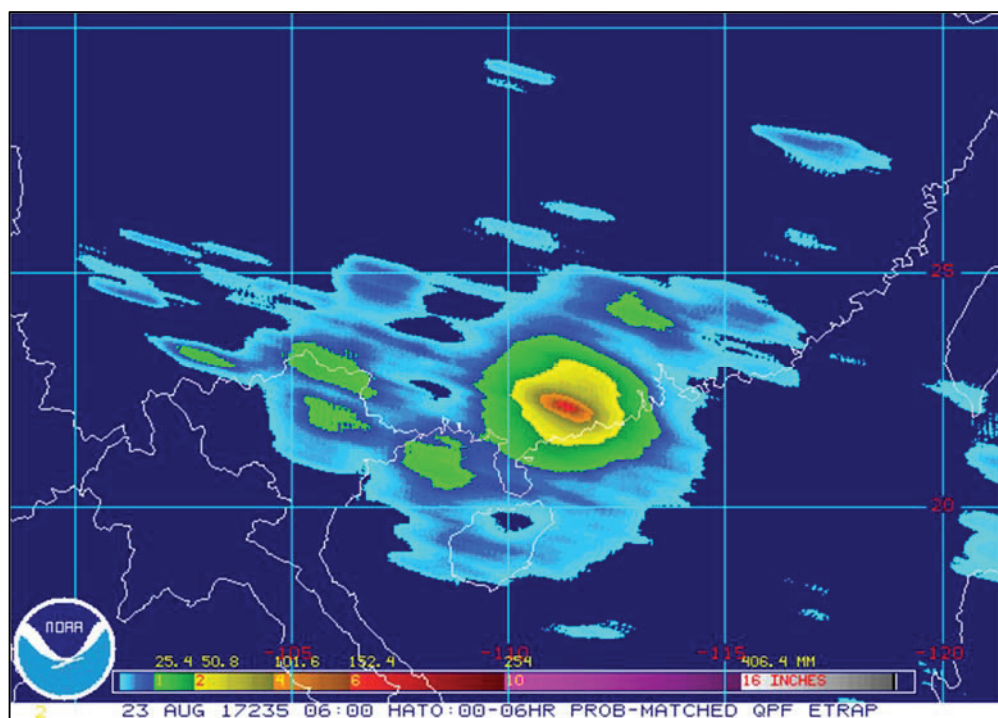


Figure 18: 6 hr rain forecast as of August 23, 2017 for the typhoon “Hato” Climate Forecast System (CFS) (source: <http://www.ssd.noaa.gov/PS/TROP/etrap.html>)

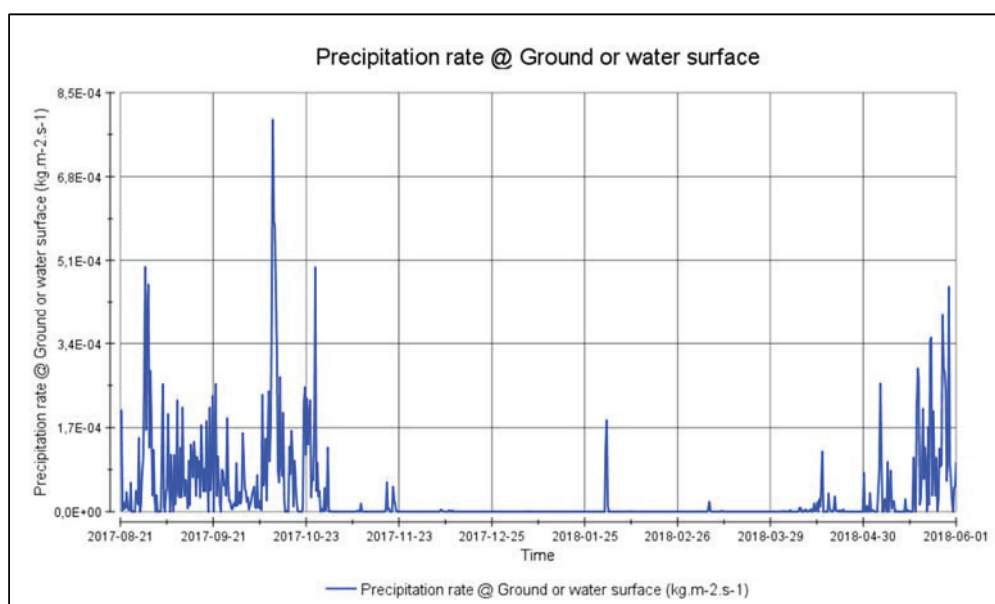
¹⁸ Source: <http://www.ssd.noaa.gov/PS/TROP/etrap-info.html>

The Climate Forecast System (CFS) is a model representing the global interaction between Earth's oceans, land, and atmosphere. Produced by several dozen scientists under guidance from the US National Centers for Environmental Prediction (NCEP), this model offers hourly data with a horizontal resolution down to one-half of a degree (approximately 56 km) around Earth for many variables. CFS uses the latest scientific approaches for taking in, or assimilating, observations from data sources including surface observations, upper air balloon observations, aircraft observations, and satellite observations.¹⁹

The second version of the NCEP Climate Forecast System (CFSv2) was made operational at NCEP in March 2011. This version has upgrades to nearly all aspects of the data assimilation and forecast model components of the system. (Saha et al., 2014)

There are a total of 16 CFS model runs every day, of which 4 runs go out to 9 months, 3 runs go out to 1 season and 9 runs go out to 45 days.

The available products from the CFSv2 real time forecasts includes a multitude of climate and weather variables, among them temperature, precipitation rate, soil moisture and potential evaporation rate, to name just the most relevant to flood modelling, all available either as daily values or as monthly means.



(source: data from <https://www.ncdc.noaa.gov/>, visualization by SYDRO)

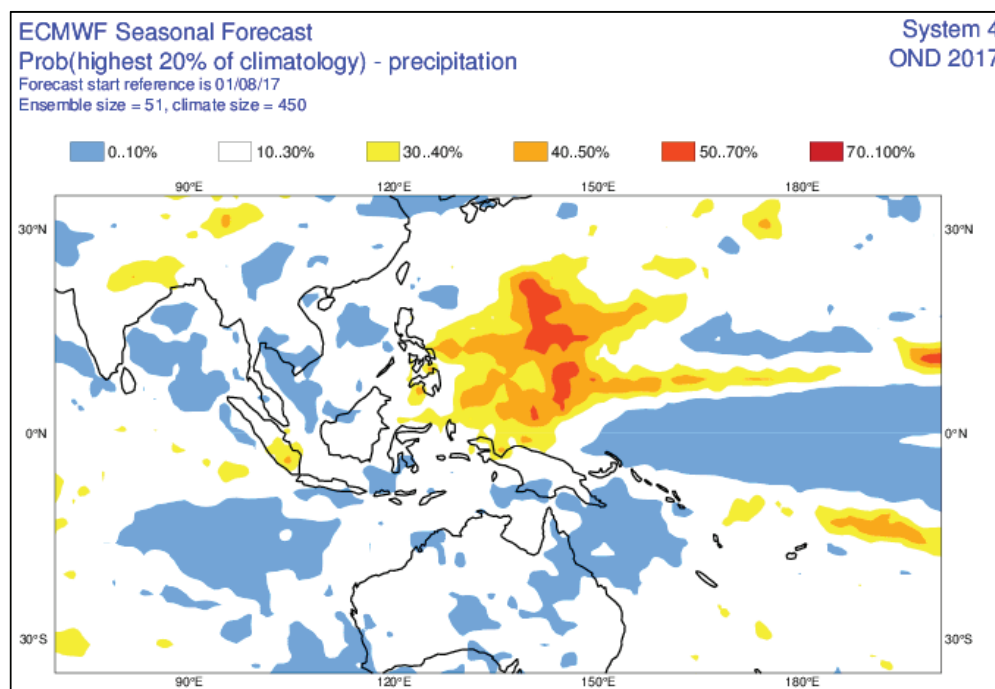
Figure 19: 9-month forecast of Precipitation rates for central Cambodia made on August 21, 2017 (ECMWF)

The European Centre for Medium-Range Weather Forecasts (ECMWF) produces operational ensemble-based analyses and predictions that describe the range of possible scenarios and their likelihood of occurrence. ECMWF's forecasts cover time frames ranging from medium-range, to monthly and seasonal, and up to a year ahead.²⁰

¹⁹ Source: <https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/climate-forecast-system-version2-cfsv2>

²⁰ Source: <https://www.ecmwf.int/en/about/what-we-do/global-forecasts>

In contrast to the Climate Forecast System described previously, access to ECMWF forecasts is restricted. There are some public datasets, but other datasets are restricted to specific user groups and may be subject to charges.²¹



(source:

[https://www.ecmwf.int/en/forecasts/charts/catalogue/seasonal_charts_public_ecmwf_precipitation?time=2017080100.3648,2017123100&area=East%20Asia&forecast_type_and_skill_measures=prob%20for%20highest%20%25\)](https://www.ecmwf.int/en/forecasts/charts/catalogue/seasonal_charts_public_ecmwf_precipitation?time=2017080100.3648,2017123100&area=East%20Asia&forecast_type_and_skill_measures=prob%20for%20highest%20%25)

Figure 20: Seasonal forecast of precipitation in East Asia for December 2017

2.5. Static Flood Risk Analysis

Static flood risk analysis is a useful tool for prioritizing flood risk management activities and investments, evaluate risk conditions and monitor the progress of risk reduction activities.

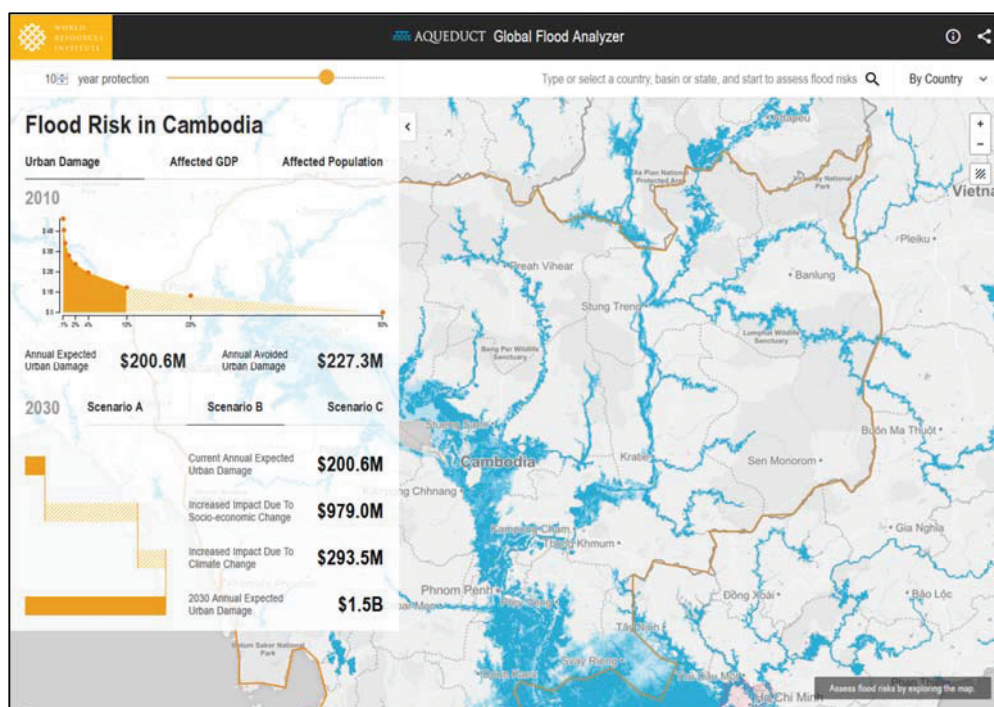
2.5.1. Global Flood Analyzer

The Aqueduct Global Flood Analyzer is a web-based interactive platform which measures river flood impacts by urban damage, affected GDP, and affected population at the country, state, **and** river basin scale across the globe, as well as 120 cities. It aims to raise the awareness about flood risks and climate change impacts by providing open access to global flood risk data free of charge.

The Analyzer enables users to estimate current flood risk for a specific geographic unit, taking into account existing local flood protection levels. It also allows users to project future flood risk with three climate and socio-economic change scenarios. These estimates can help decision makers quantify and monetize flood damage in cost-benefit analyses when evaluating and financing risk mitigation and climate adaptation projects.

²¹ For details, see <https://www.ecmwf.int/en/forecasts/accessing-forecasts>

Additionally, the analyzer identifies the future change in flood risk driven specifically by climate change and socio-economic development, which helps decision makers identify the drivers of future change and prioritize development focuses accordingly for strategic planning.²²



(source: <http://floods.wri.org/#/country/39/Cambodia>)

Figure 21: Flood Risk in Cambodia

2.6. Sensor web and real-time control

A new generation of sensors specially designed for environmental monitoring is emerging. Introduced by Kevin Delin of NASA in 1997, sensor web describes a wireless sensor network architecture with individual pieces acting and coordinating themselves as a whole.

The core of the network are spatially distributed sensor platforms (pods) that wirelessly communicate with each other. The technology is unique. It works synchronously and requires no router. The sensor platform or pod is a physical platform for a sensor and can be orbital or terrestrial, fixed or mobile and might even have real time accessibility via the Internet (source: https://en.wikipedia.org/wiki/Sensor_web).

The features of a pod can be summarised as follows:

- A pod contains one or more sensors leading to one or more data channels
- A pod requires a processing unit such as a micro-controller or microprocessor
- Radio and antenna for bidirectional communication is needed (radio ranges are typically limited by government spectrum requirements; unlicensed bands will

²² Source: <http://floods.wri.org>

allow for communication of a few hundred yards in unobstructed areas, although line of sight is not a requirement)

- Energy supply is required in form of a battery backed with solar cells
- Protecting envelope or case to make sure that the pod withstands harsh conditions

The flexibility of such a network makes it suitable for monitoring the environment. The purpose with regard to floods is obvious. A sensor web network could supply data of current conditions in headwater areas, flood prone areas, landslide prone areas and transmits them to an operational centre or other connected mobile units. Having this information at hand would enhance the detection of hazards, could mobilise response actions and improves early warning systems with online confirmation of model results and precipitation, flow and water level estimates.

The sensor web technology has already arrived in real world applications (<http://fluggs.wupperverband.de/tamis-demo/#!/>). The Germany Water Association Wupperverband is using a sensor web network for real-time observation of the reservoir Bever. The collected data is fed into a hydrological and reservoir simulation model TALSIM-NG (© SYDRO) that calculated current downstream conditions based on operating rules and decisions of the operators.

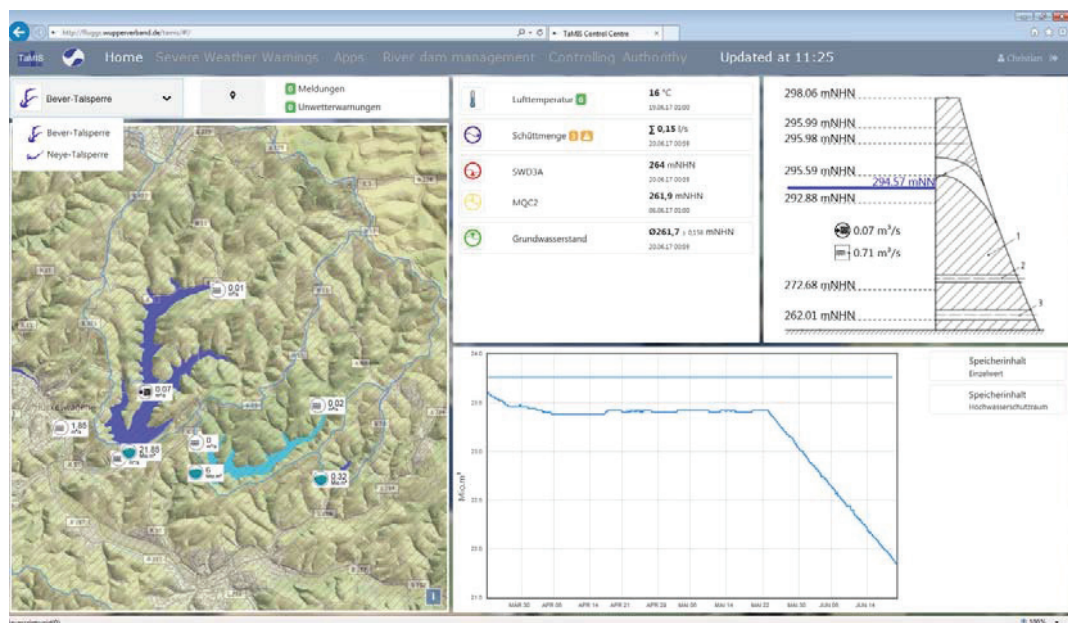


Figure 22: TaMIS website providing real-time information and simulation of a German dam.

Sensors are installed to monitor the dam in the sense of a permanent dam surveillance system, to observe the catchment area at flow gauging stations and weather stations and records water retention profiles in the soil as an indicator for landslides.

The communication uses open standards like OGC Sensor Web so that the system is scalable and performs with different monitoring and simulation systems. It applies open interfaces to make information accessible for task forces in case of emergencies.

The TaMIS project is funded by the German Ministry of Education and Research.

2.7. News aggregation and analysis

The advent of social media and continuously updated news feeds available in real time on the internet has opened up the possibility of analysing, aggregating and monitoring news feeds and social media with regard to certain topics, e.g. floods. Below are some example services:

2.7.1. Europe Media Monitor

The freely accessible Europe Media Monitor (EMM) is a fully automatic system that analyses both traditional and social media. It gathers and aggregates about 300,000 news articles per day from news portals world-wide in up to 70 languages.

EMM is the news gathering engine behind a number of applications, including the Global Disaster Alert and Coordination System (GDACS). EMM monitors the live web, i.e. the part of the web that has ever changing content, such as news sites, discussion sites and publications. It was developed and is maintained and run by the European Commission's Joint Research Centre (JRC).

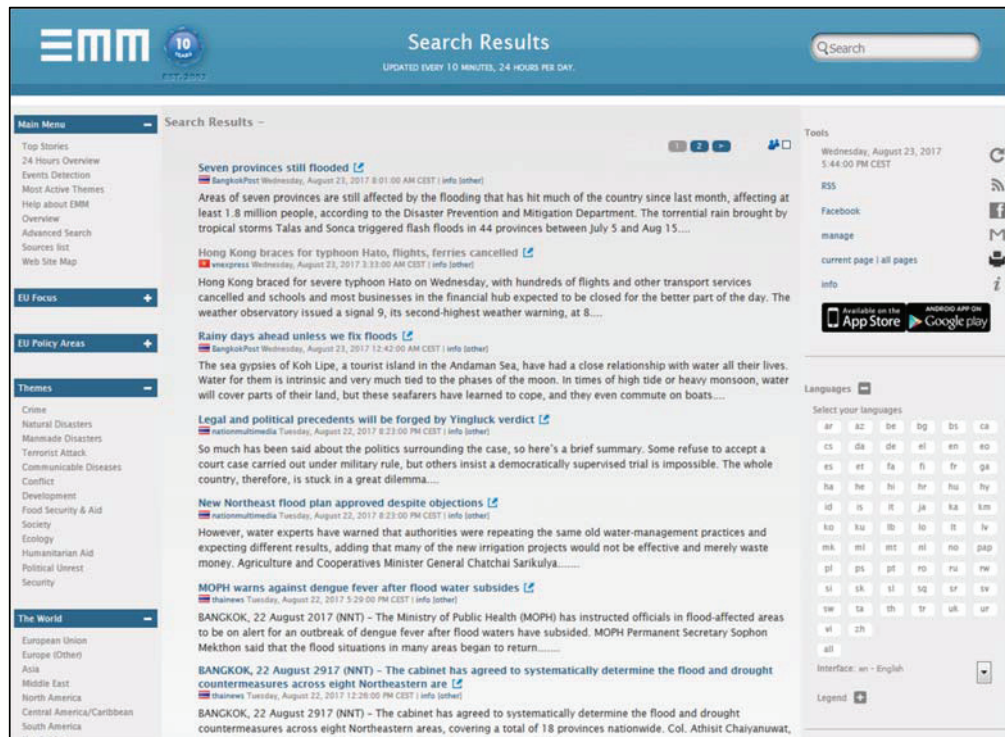
EMM-NewsBrief groups related items, categorises them into thousands of classes, extracts information, produces statistics, detects breaking news and sends out alerts. NewsBrief is updated every 10 minutes, 24 hours per day.²³

Using NewsBrief it is possible to search for news articles from specific countries regarding e.g. flooding (see Figure 23). It is also possible to receive automated alerts using subscriptions via email or RSS. There is also a free EMM app for mobile devices. Additionally, news articles can be visualized on a world map (e.g. <http://emm.newsbrief.eu/emmMap/?type=category&language=&category=Flooding>).

²³ Sources:

De Groeve et al. (2013)

<https://ec.europa.eu/jrc/en/scientific-tool/europe-media-monitor-newsbrief>



(source:

<http://emm.newsbrief.eu/NewsBrief/searchresults/en/advanced.html?lang=all&sourceCountry=KH%2CLA%2CTH%2CVN&category=Flooding&queryType=advanced>

Figure 23: Search results in the category “Flooding” for the source countries Cambodia, Lao P.D.R., Thailand and Vietnam as of August 23, 2017

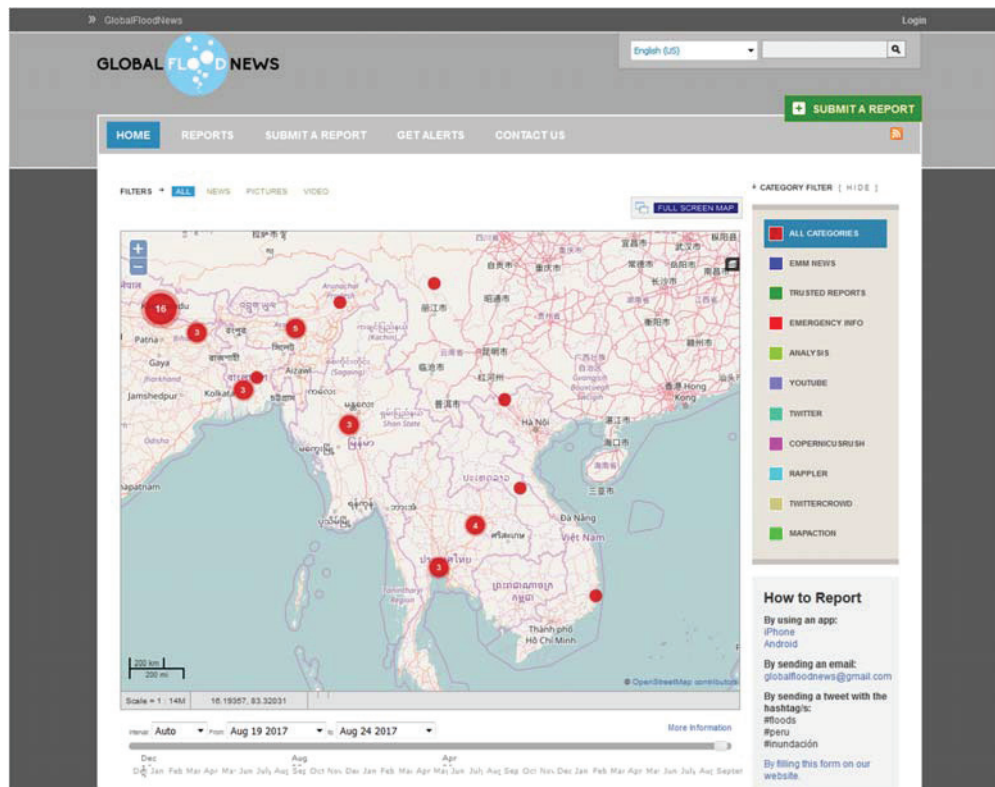
2.7.2. Global Flood News

Global Flood News monitors mainstream and social media specifically in regard to floods. It also performs crowd sourcing for flood related information and flood detection. Global Flood News works closely with the Global Flood Awareness System (GloFAS), who are also working on a prototype for social media analysis for flood events.²⁴

The crowd sourcing component utilizes the Ushahidi platform, which was initially developed to map reports of violence in Kenya after the post-election violence in 2008. Since then, Ushahidi has developed into a social enterprise that provides software and services to numerous sectors and civil society to help improve the bottom up flow of information.²⁵

²⁴ Source: <http://www.globalfloodsystem.com/>

²⁵ Source: <https://www.ushahidi.com/about>



(source: <http://www.globalfloodsystem.com/>)

Figure 24: Global Flood News reports for the Mekong region as of August 24, 2017

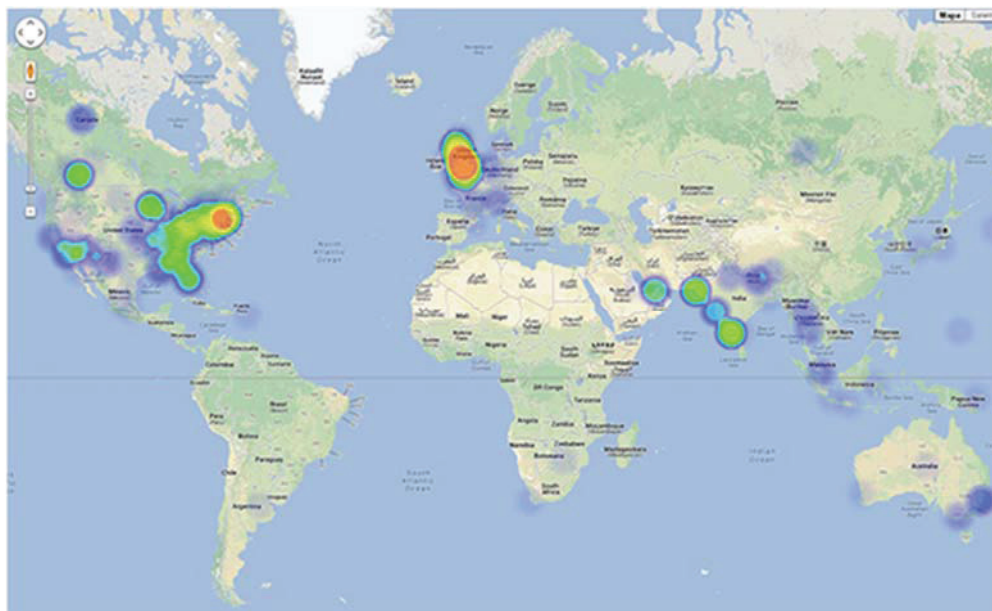


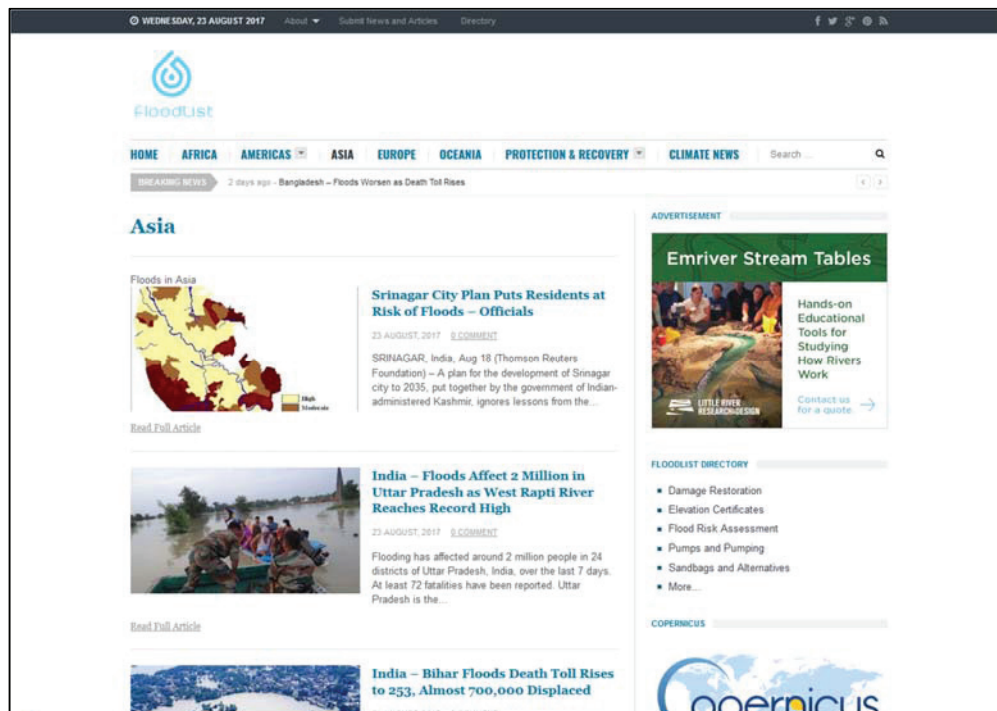
Figure 25: Aggregated 24 hours filtered flood signal from Twitter for 24th of July 2013 in form of a heat map (red color=high signal) (Source: <http://globalfloods.jrc.ec.europa.eu/>)

2.7.3. Flood List

Flood List aggregates news and information on the latest flood events from around the world. Flood List receives funding from Copernicus, the European Union (EU) programme for monitoring the Earth's environment using satellite and in-situ observations.

Flood List's aim is to raise awareness of the risks of flooding and the devastation caused by the increasing number and severity of flood events. News reports and articles help people understand more about floods, what can be done to prepare, protect, stay safe and recover.

Flood List include articles on flood-related issues such as warning systems, mitigation and control, flood recovery, flood damage repair and restoration, as well as flood insurance. The reports and articles also include information about the extraordinary humanitarian, aid and relief efforts that need to be made in the aftermath of so many flood disasters.²⁶



(source: <http://floodlist.com/asia>)

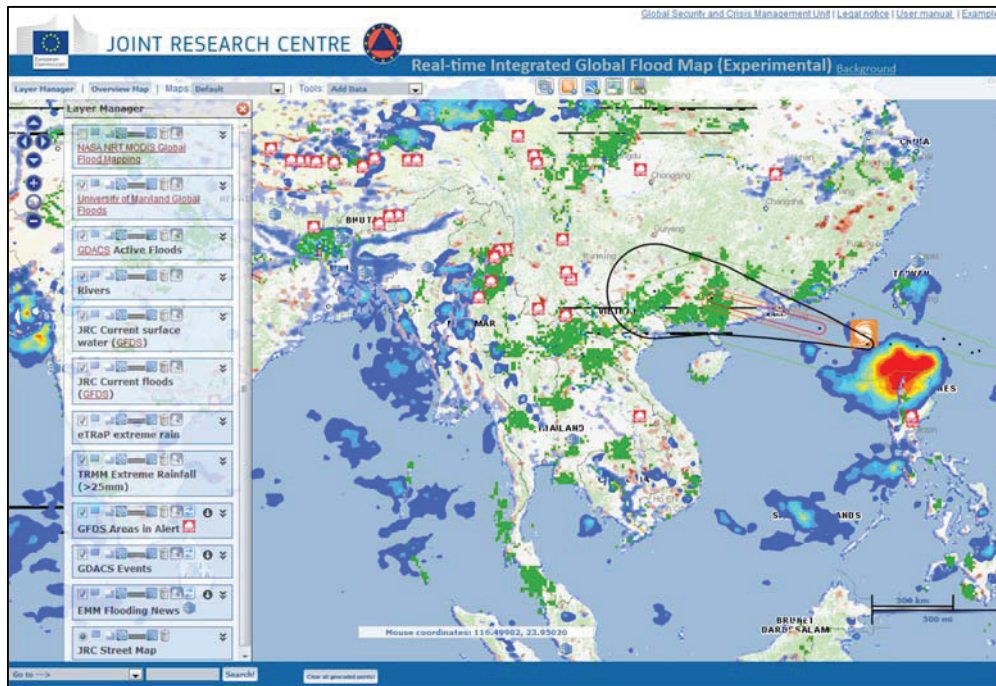
Figure 26: FloodList website with articles regarding floods in Asia as of August 23, 2017

2.7.4. Global Integrated Flood Map

The Global Integrated Flood Map is a collaborative product of the Global Flood Working Group. It integrates a number of existing pre-operational systems, many of which are described in this report. At this early stage, the Global Integrated Flood Map is not meant as an application ready for use by untrained practitioners. Instead, it is a proof of concept of how visual integration of information can enrich the situational picture for

²⁶ Source: <http://floodlist.com/about-us>

trained users. According to the developers, more work is needed to combine relevant information for specific user needs, be it risk assessments, early warning or post-disaster needs assessments.²⁷



(source: <http://dma.jrc.it/map/?application=FLOODS>)

Figure 27: Real-Time Integrated Global Flood Map (Experimental) as of August 22, 2017

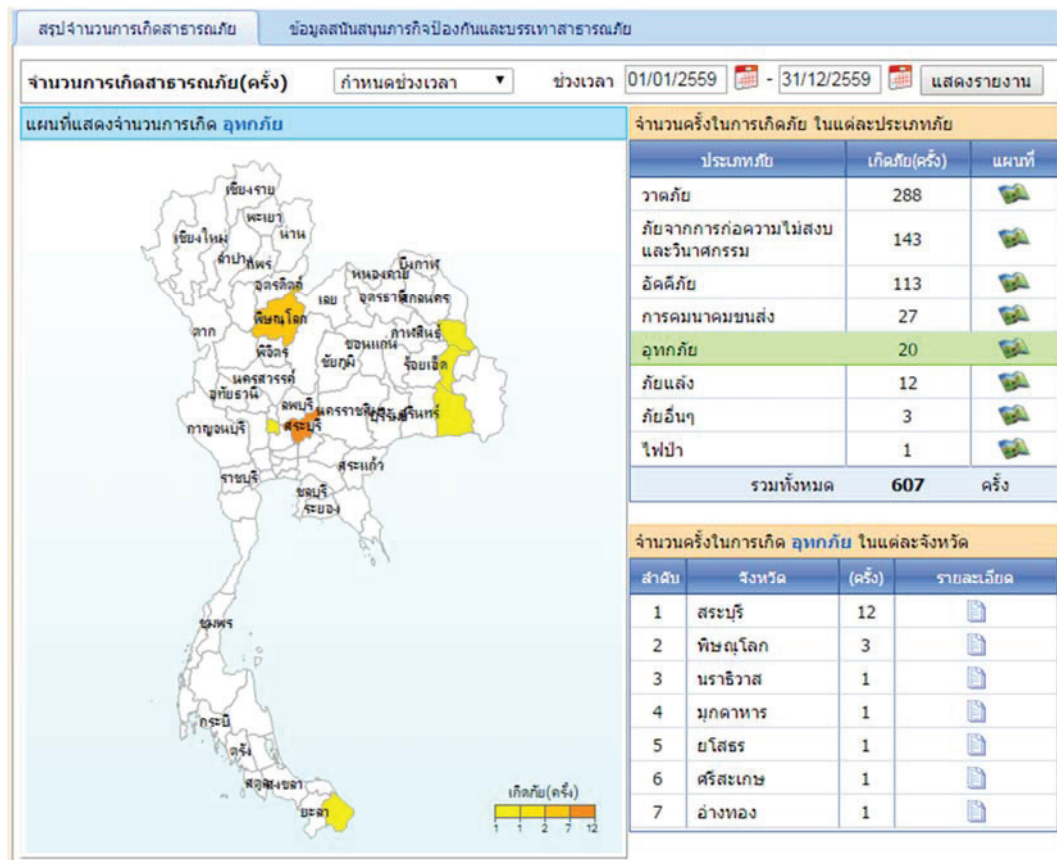
²⁷ Source: De Groeve et al. (2013)

2.8. Examples from the region

2.8.1. Thailand

Department of Disaster Prevention and Mitigation (DDPM)

The Department of Disaster Prevention and Mitigation (DDPM) has developed a disaster report system available at www.ddpm.go.th. Users can search for any type of disaster, time period and area. It is very useful to look back at the history of natural disasters especially floods that occurred in the country.



Department of Water Resources (DWR)

The Department of Water Resources (DWR) was established under the Bureaucratic Reform Act 2002 under the Ministry of Natural Resources and Environment and defines standards and transfers technology of water resources both at national and at basin level so as to achieve sustainable water resources management. One of the important missions of the Department of Water Resources is to further develop knowledge base of floods and landslide disasters in order to enhance the readiness of communities in disaster prone areas to cope with floods. For that reason, DWR has installed an early warning system (EWS). The early warning for the flood plain areas is under the supervision of the Water Crisis Prevention Centre within DWR and is divided into 2 parts:

- Part 1: Establishment of a telemetry system that is able to monitor current states in remote areas by analysing rainfall, water levels, geological conditions and other governing

factors by means of modelling and to present results thereof at www.mekhala.dwr.go.th/. The purpose is to forecast and detect critical situations to enhance lead time and response actions.

Part 2: Installation of a closed-circuit television (CCTV) and remote-control system for monitoring of flood related states. Data received from the system could be used to support decision-making forecasts.

A) Early Warning System (EWS) for mountainous area

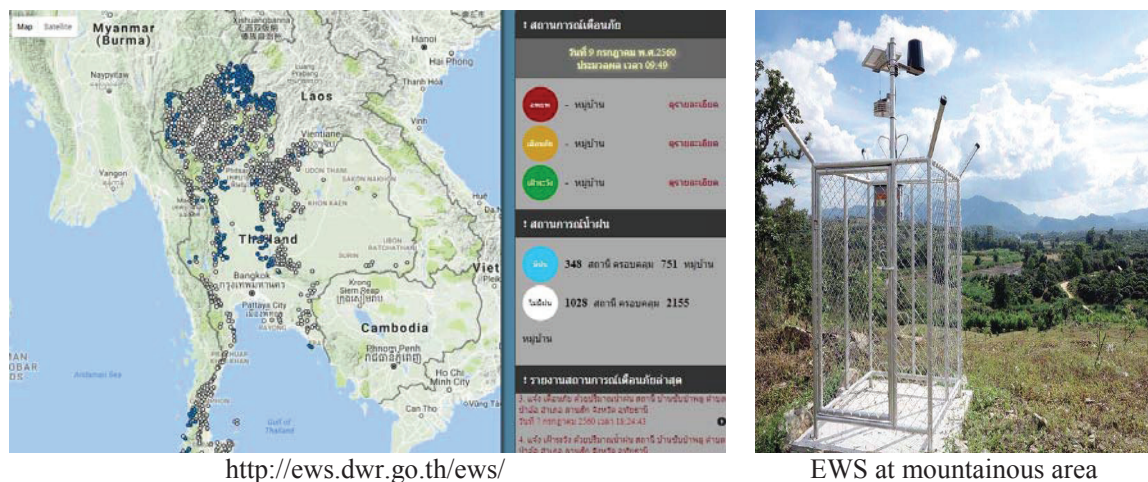


Figure 28: Early Warning System's website and key station in the field (source: DWR)

B) Telemetry System for flood plain areas



Source: Department of Water Resources (DWR) <http://tele-khongchemun.dwr.go.th/>

Figure 29: Telemetry System's website for flood plain areas (source: DWR)

Information on the Khong-Chi-Mun river basin, which is a part of Lower Mekong Basin (LMB) can be accessed at <http://tele-khongchemun.dwr.go.th/>.

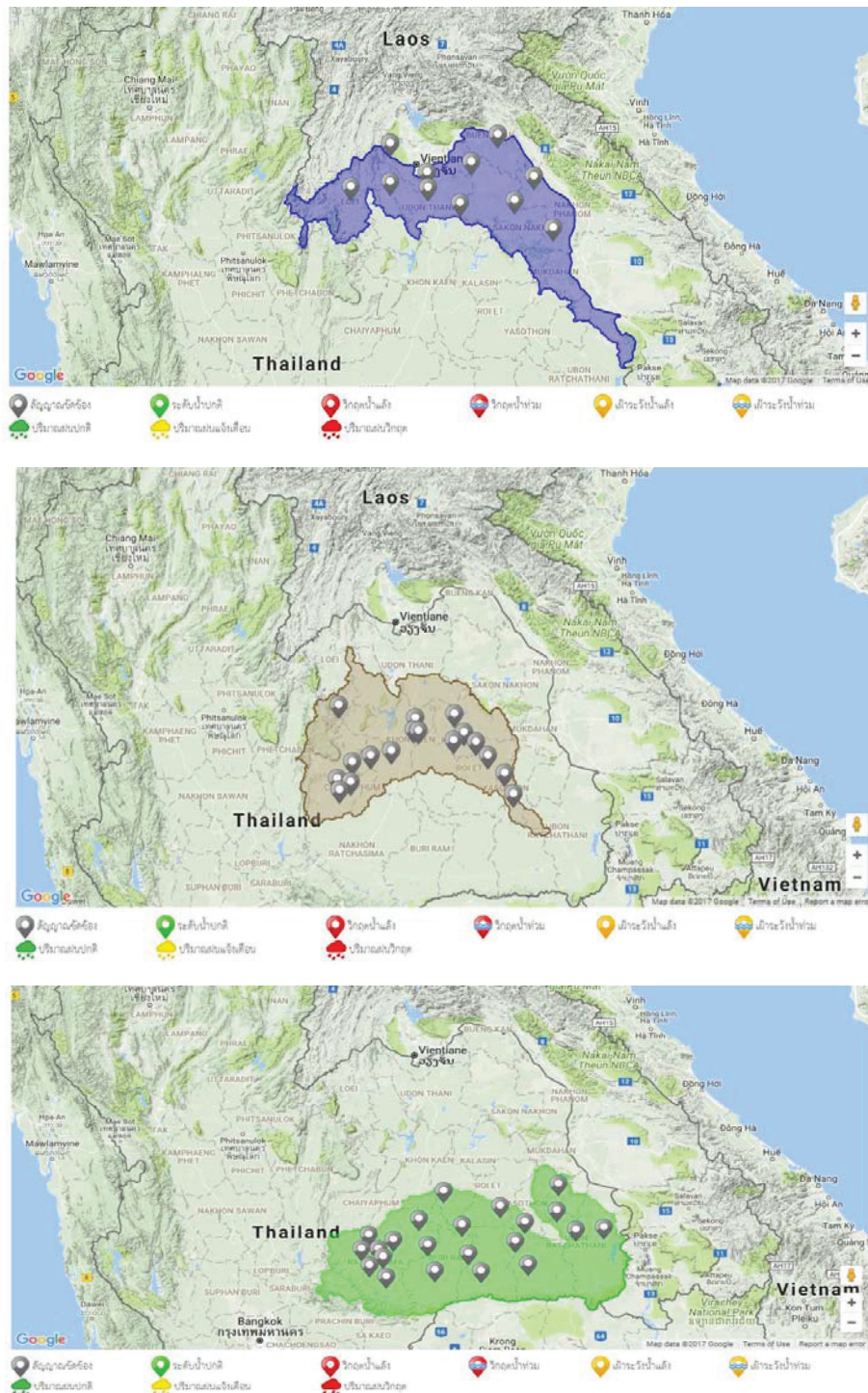


Figure 30: Telemetry System for Khong-Chi-Mun basins

The Royal Irrigation Department (RID)

Duties and responsibilities of the Royal Irrigation Department according to the Ministerial Regulation Organizing the Royal Irrigation Department, Ministry of Agriculture and Cooperative include:

Implementation of activities aimed at achieving, collecting, storing, controlling, distributing, draining or allocating water for agricultural, energy, household consumption or industrial purposes under irrigation laws, ditch and dike laws and other related laws.

Implementation of activities related to prevention of damages from water; safety of dams and appurtenant structures; safety of navigation in commanded areas and other related activities that may not be specified in annual plan.

Implementation of land consolidation for agriculture under the Agricultural Land Consolidation Act.

Implementation of other activities designated by laws or properly assigned by Cabinet or Minister.

RID objectives and framework consist of; (1) Water resources development and increase of irrigated area (2) Integrated water management and (3) Water hazards prevention and mitigation as the department's mission.

Therefore, RID has also developed a telemetry and early warning system for location under the responsibility of RID.

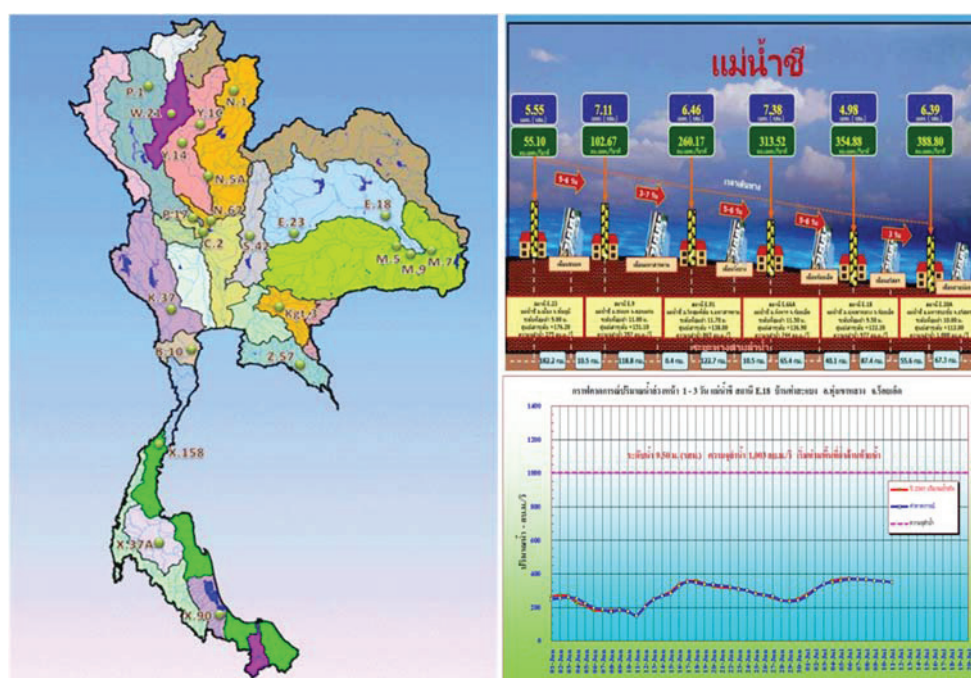
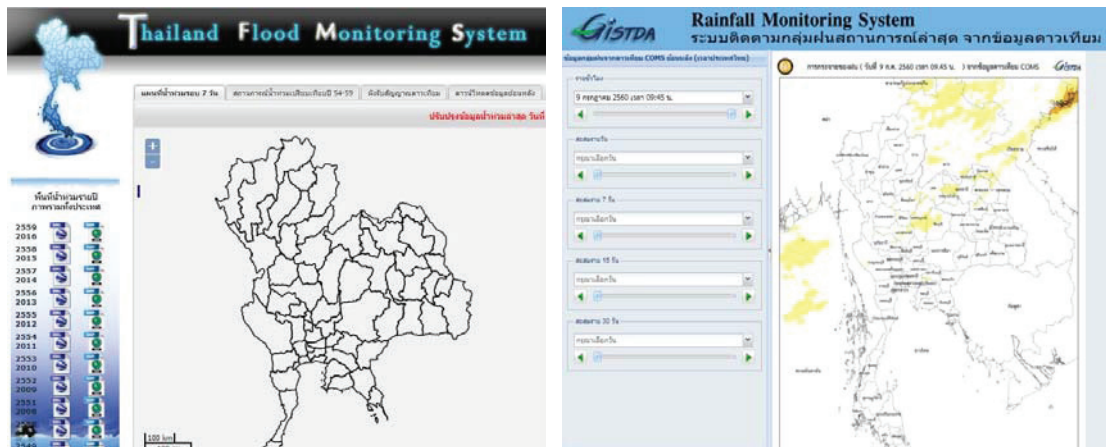


Figure 31: RID telemetry System (source: Royal Irrigation Department (RID))

Geo-Informatics and Space Technology Development Agency (GISTDA)

The Geo-Informatics and Space Technology Development Agency (GISTDA) is a Thai space agency and space research organization. It is responsible for remote sensing and technology development satellites. It is led by Thailand's Minister of Science and Technology. GISTDA has established the Thailand Flood, Drought and Rainfall Monitoring System providing both real time data and historic data of flood and drought illustrated in Figure 32.



Flood Monitoring System
(<http://flood.gistda.or.th/>)

Flood Monitoring System
(http://flood.gistda.or.th/rainfall_monitoring/)

Figure 32: Thailand Flood and Rainfall Monitoring System by GISTDA

Hydro and Agro Informatics Institute, Ministry of Science and Technology (HAI)

The Hydro and Agro Informatics Institute (HAI) is a public organization under the Ministry of Science and Technology focusing on developing and applying sciences and information technology to better support agricultural and water resource management (<https://www.haii.or.th/>).



Source:
<http://www.thaiwater.net/web/index.php/archive.html>

Figure 33: HAI Rainfall and Telemetry system

Another field of work HAI is involved in is Community Water-Related Disaster Risk Reduction. HAI develops and provides best practices guidelines for communities on how to use science and technology to address disaster risks, natural resource management and sustainable agriculture. The practices and case studies present an integrated approach that aims at building resilience and sustainable livelihoods. The case studies also demonstrate how the Sendai Framework, the 2030 Agenda for Sustainable Development (or Sustainable Development Goals) and Climate Change Agreement can be implemented coherently at a local level.

Electricity Generating Authority of Thailand (EGAT)

The Electricity Generating Authority of Thailand (EGAT) is Thailand's leading state-owned power utility under the ministry of energy, which is responsible for electric power generation and transmission for the whole country. As the largest power producer in Thailand, EGAT operates 25 hydropower plants located across the country.

EGAT has developed and established a telemetry system to monitor all hydropower plants. The telemetry system is important for water management, including water quality and stream gauging and regulating functions. Monitoring data is published at EGAT's website at <http://watertele.egat.co.th/PakMun/> as shown below for the Mun River, a tributary of the Mekong.

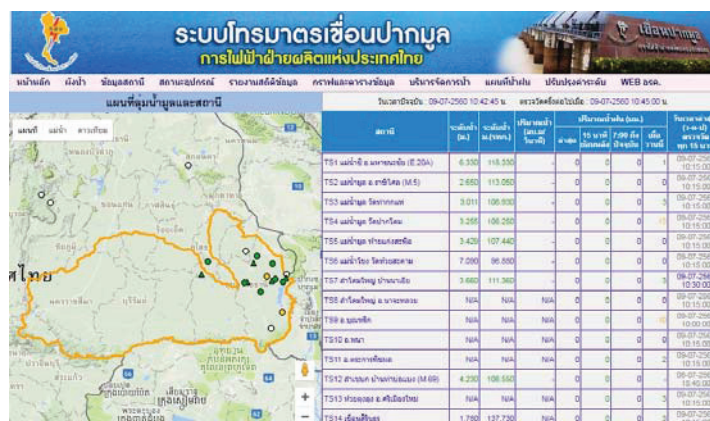


Figure 34: EGAT Telemetry systems (source: <http://watertele.egat.co.th/PakMun/>)

3. THE REGIONAL FLOOD SITUATION 2016

3.1. Tropical storms and cyclones

14 typhoons or tropical storms were counted in 2016 of which 5 struck the LMB. A list of tropical storms and cyclones with wind speed level is provided in Table 1.

Table 1: List of tropical storms and cyclones during 2016 (source: National Centre of Hydrology and Meteorology Forecasting, Viet Nam, 2016)

Sea region	Date of Occurrence	Storm name	Wind speed level
North West Ocean	21/12/2016	Nock-ten	Level 15-16 (185 km/h)
East Sea	11/12/2016	Tropical depression	Level 6 (39 - 49 km/h)
North West Ocean	23/11/2016	Tokage	Level 10 (110 km/h)
East Sea	3/11/2016	Tropical depression	Level 6 (39 - 49 km/h)
North West Ocean	13/10/2016	Haima	Level 17 (215 km/h)
North West Ocean	11/10/2016	Sarika	Level 15 (175 km/h)
North West Ocean	4/10/2016	Aere	Level 10 (110 km/h)
North West Ocean	8/9/2016	Meranti	Level 15 (200 - 220 km/h)
Middle East Sea	11/9/2016	Rai	Level 8 (65 km/h)
East Sea	24/8/2016	Tropical depression	Level 6 (39 - 49 km/h)
North East Sea	16/8/2016	Tropical depression	Level 6 (39 - 49 km/h)
North East Sea	15/8/2016	Dianmu	Level 9 (75 - 83 km/h)
North West Ocean	29/7/2016	Nida	Level 13 (110 - 139 km/h)
East Sea	25/7/2016	Mirinae	Level 9-10 (83-100 km/h)

The coloured rows show the storms or typhoons which affected one or more member countries.

Tropical Storm Mirinae (July 2016)



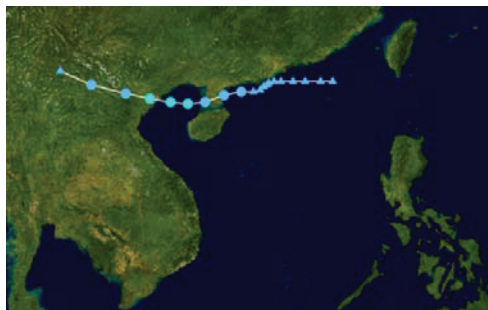
Severe Tropical Storm Mirinae was a strong tropical cyclone that struck Hainan Island, China and Northern Vietnam in late July 2016. The third named storm of the annual typhoon season, Mirinae formed on July 25, 2016 as a tropical depression in the west of Luzon, Philippines. On July 26, it moved west-northwestwards, became a tropical storm and made landfall in Hainan Island, China.

During July 27, it intensified into a severe tropical storm and made landfall over Red River Delta in Northern Viet Nam late on July 27 and dissipated during the next day (source: Wikipedia).

During the passage of Tropical Storm Mirinae, strong south-western wind prevailed over the central and southern Lao PDR and brought heavy rainfall, flash floods and landslides in some provinces. Also Thailand was indirectly affected and experienced increased rainfall.

Mirinae hit Viet Nam first in the Bac Go Gulf and then moved along Nam Định – Ninh Binh province's shore.

Tropical Storm Dianmu (August 2016)



On August 15, a tropical depression developed about 305 km to the southeast of Hong Kong. During the course of August 17, enhanced satellite imagery showed that Dianmu was rapidly organising. Dianmu made landfall in Haiphong and Thái Bình Province in northern Viet Nam. While overland, the system gradually weakened into a tropical depression, before it degenerated into an area of low pressure during August 20 while over Myanmar (source: Wikipedia).

Under the influence of Dianmu, Thailand faced higher rainfall in the middle of August.

Tropical Cyclone Rai (September 2016)



On September 11, a tropical depression formed about 860 km to the northeast of Ho Chi Minh City, Viet Nam. Tropical Storm Rai was a weak and short-lived tropical cyclone, which affected Indochina in September 2016. Formed from a tropical disturbance on September 11, the system developed into a tropical storm and reached its peak intensity on September 12, before making landfall in Viet Nam and affecting Laos, Thailand and Cambodia (source: Wikipedia).

Rai affected 4 provinces in central and southern Lao PDR.

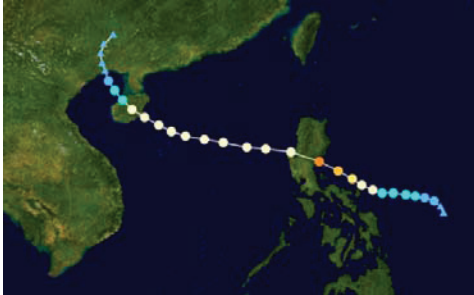
Tropical Storm Aere (October 2016)



Severe Tropical Storm Aere was a long-lived tropical cyclone that struck Central Vietnam in October 2016. Aere formed on October 4, 2016 as a tropical depression to the east of Luzon, Philippines. On the next day, the system had become a tropical storm and it moved into the South China Sea. During October 7, it intensified into a severe tropical storm and reached peak intensity with 10-minute winds of 110 km/h.

Shortly thereafter, due to remaining in almost the same area for hours, Aere began to weaken to a tropical storm and on October 10, it weakened to a tropical depression, before weakening to a low-pressure area late on October 11. On October 13, Aere re-generated into a tropical depression and made landfall in Huế, Viet Nam late that day. The system moved towards Lao PDR and Thailand before it fully dissipated late October. Aere affected parts of Southeast Asia in October 2016, but its impact was most severe in Vietnam. Heavy flooding was triggered by the remnants of Aere from October 13 to October 17, 2016 in North-Central Vietnam (source: Wikipedia).

Tropical Cyclone Sarika (October 2016)



Typhoon Sarika, known in the Philippines as Typhoon Karen, was a powerful tropical cyclone which affected the Philippines, China and Vietnam in mid October 2016.

By October 13, Sarika or Karen was located in an area of high sea surface temperatures of 31 °C. Sarika was upgraded into a severe tropical storm by the Japanese Meteorological Agency (JMA).

Shortly after, Sarika started to form an eye feature and the JMA upgraded Sarika to a typhoon. After imagery had depicted a significant organisation of convection around the system, the storm was upgraded to a Category 1 typhoon.

By October 15, Sarika had expanded and deepened and was upgraded into a Category 2 typhoon. Within their next advisory, JMA reported that Sarika had strengthened into a Category 3 typhoon. Sarika reached its peak intensity as a Category 4 typhoon with 1-minute sustained winds of 215 km/h and a minimum barometric pressure of 935 mbar. Weakening occurred as Sarika traversed the islands, by the time the storm entered the South China Sea. After moving westward rapidly for two days, Sarika weakened to a severe tropical storm as it made landfall over Hainan. By October 19, imagery depicted that Sarika was rapidly deteriorating as it made its final landfall over the coastline and border of Vietnam and China (source: Wikipedia).

One characteristic of the storms in 2016 was their relatively short lifetime of about 2- 3 days, except for Dianmu which sustained itself for 5 days. Only one event made landfall in Viet Nam's central region, whereas all other headed towards North Viet Nam or China's shoreline.

3.2. The regional climate 2016

As in previous years, 2016 confirmed and continued the tendency of warming and ranks amongst the warmest years in history. After 2015 and 2007, 2016 ranks third in the list of warmest recorded years in Asia.

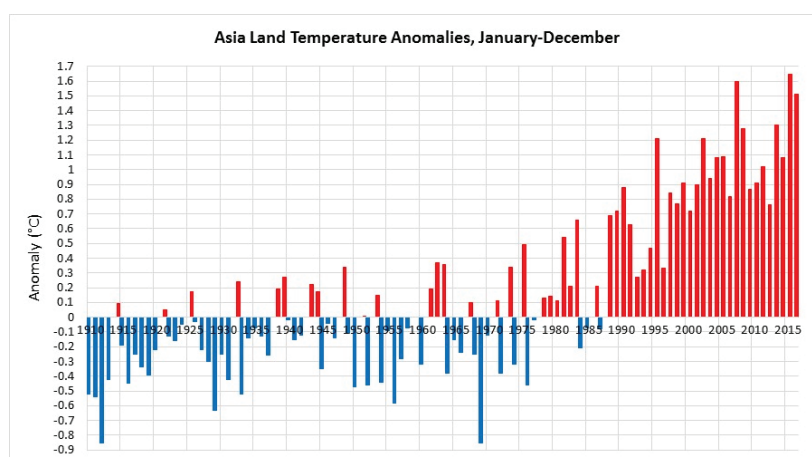


Figure 35: Asia land temperature anomalies, Jan-Dec 1910-2016 (source: NOAA)

The World Bank data portal provides monthly means of rainfall for all four member countries from 1910 up to 2015. This data was used and compared with the mean monthly rainfall of 2016. The data for 2016 was derived from 169 rainfall stations. The available number of stations for each country differs: 40 stations were available from Cambodia, 10 from Lao PDR and 2 from Thailand and Viet Nam. The number of stations must be kept in mind when analysing the charts but what can be derived due to the overall tendency from all stations is the shifting of the precipitation pattern in 2016 with a late onset of the monsoon and almost zero precipitation in May but higher rainfall in October to November.



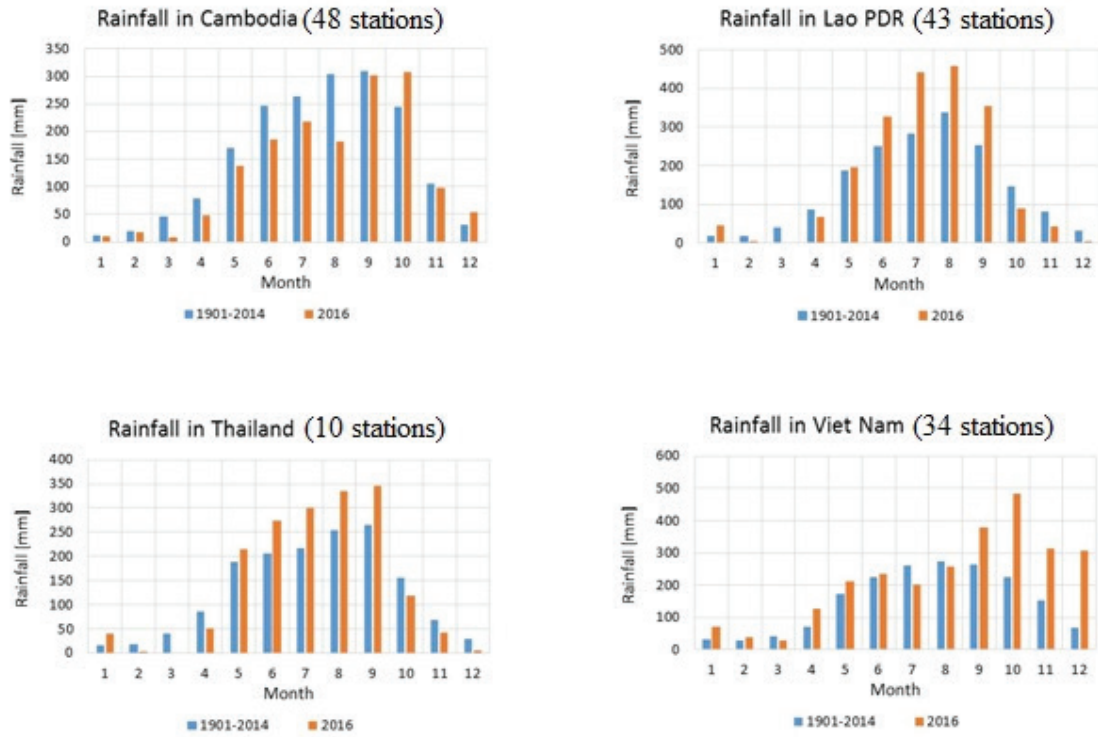


Figure 36: Monthly mean rainfall data 2006-2010 compared with 2016 from 169 stations located within the LMB

Cumulative rainfall and anomaly thereof for the year 2016 are illustrated in Figure 37. The anomaly for 2016 was calculated with mean values from 2006 to 2014. The Mekong Delta and parts of southern Lao PDR show below average conditions. The picture is not homogeneous and demonstrates arbitrary impacts of rainfall distribution.

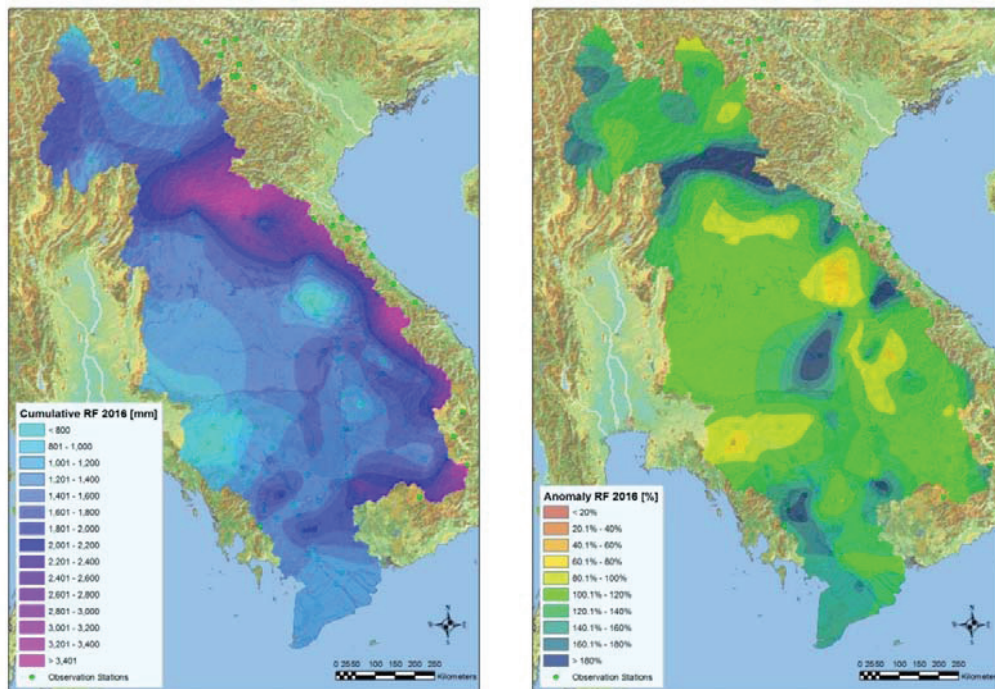


Figure 37: Cumulative rainfall and anomaly for the year 2016

The Global Precipitation Climatology Centre (GPCC) operated by the German Weather Service DWD under the auspices of the World Meteorological Organization (WMO), provides global precipitation analyses for monitoring and research of the earth's climate. Data for the year 2016 in a 1° degree resolution was used for the following analysis.

The analysis with the 169 stations using the same grid as GPCC shows a more stratified picture because of the larger number of underlying stations.

GPCC Monitoring Product Version 5 Gauge-Based Analysis 1.0 degree
precipitation percentage of normals 1951/2000 for year (Jan - Dec) 2016
(grid based)

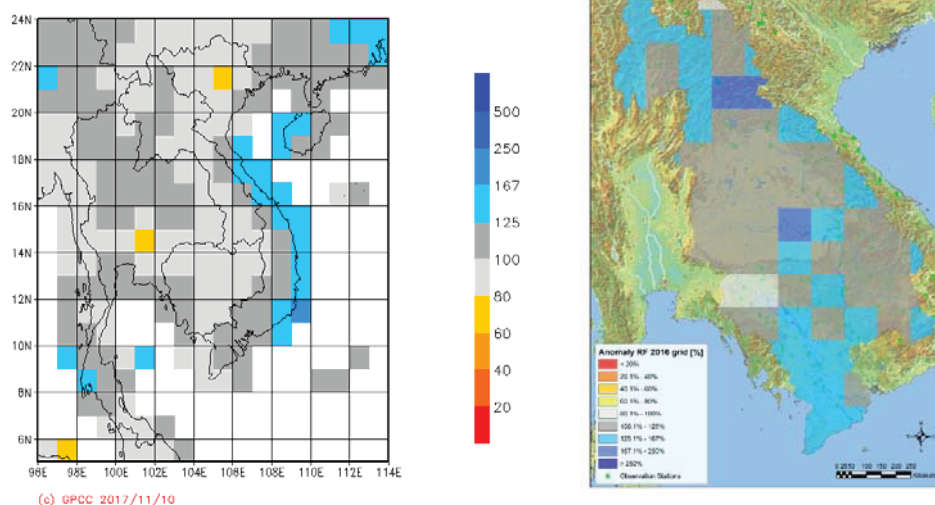


Figure 38: Precipitation percentage of normal 2016 (source: GPCC)

Rainfall intensities are shown in Figure 39 and compared with long-term averages shown in blue. Long-term is defined as values from 1980 to 2015. The approach used is simple. All days with rain between 1980 and 2015 were sorted for each year separately and subsequently mean values were calculated for each day 1 to day 365. For example, the day with the highest rainfall in each year obtains the index 365. The mean value for index 365 is then calculated with all days with index 365. The second largest rainfall day obtains the index 364 and the mean value is calculated based on all days with index 364 and so on. By sorting all rainfall days for each year the time reference when the rainfall occurred within a year is lost. Illustrated are the largest 100 days of precipitation. If the red line, which represents 2016, lies above blue (average), daily rainfall intensity in 2016 is higher than average or vice versa. Although the cumulative rainfall was remarkably lower than average, Stung Treng and Kratie had a few days with higher intensities than usual.

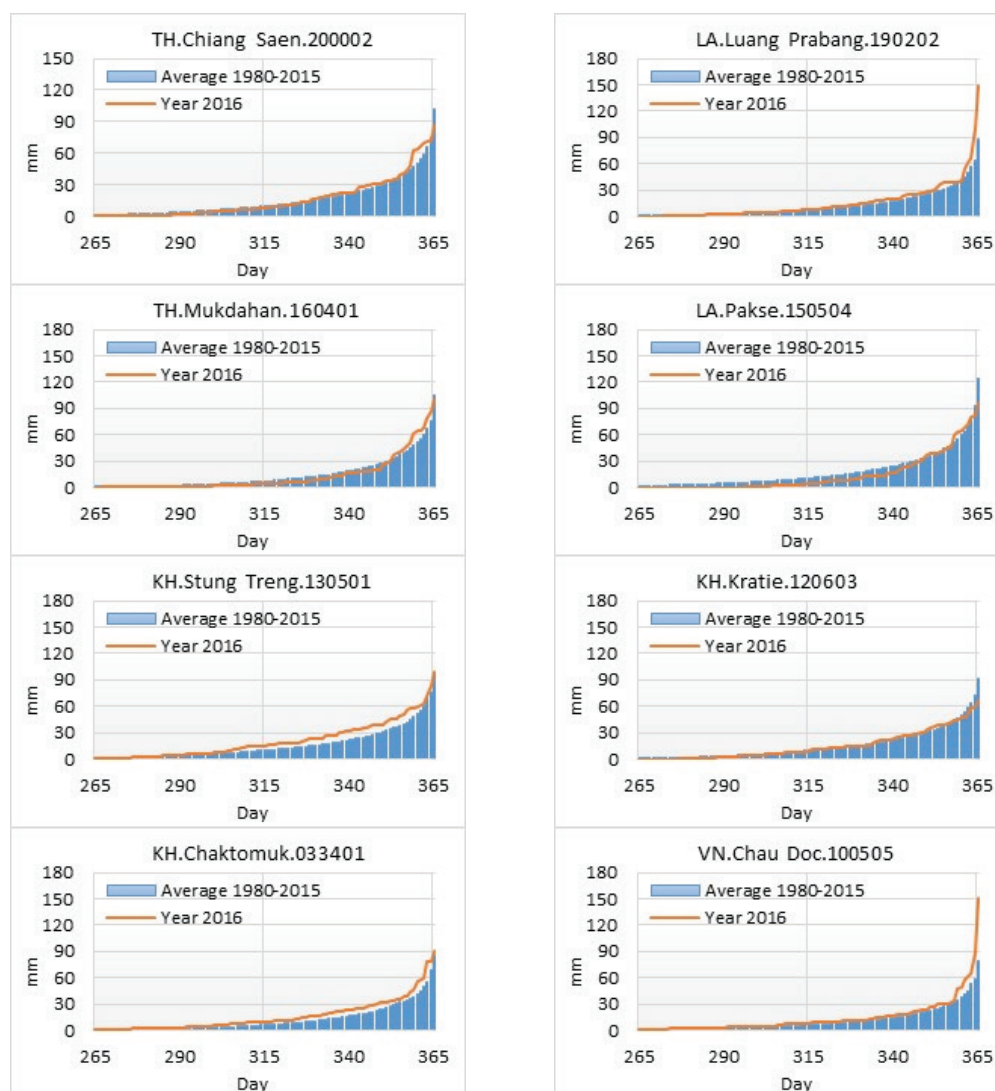


Figure 39: Rainfall intensities 2016 at selected stations

Two stations indicate maximum intensities above the normal range. Luang Prabang and Chau Doc had at least one day with 150 mm. A monthly analysis of intensities shows more details and provides information about the date when the events occurred.

The cumulative rainfall at the main stations along mainstream Mekong outlines the inhomogeneous situation. Chiang Saen was very close to a normal year, while Luang Prabang lies above average with a sharp rise in August due to the high intensities.

In contrast to the rather close distance between Pakse and Stung Treng of approximately 180 km, the difference in rainfall is considerably high. Pakse is permanently below normal and ends up with 75% of the annual rainfall, while Stung Treng was just above 125% of the average.

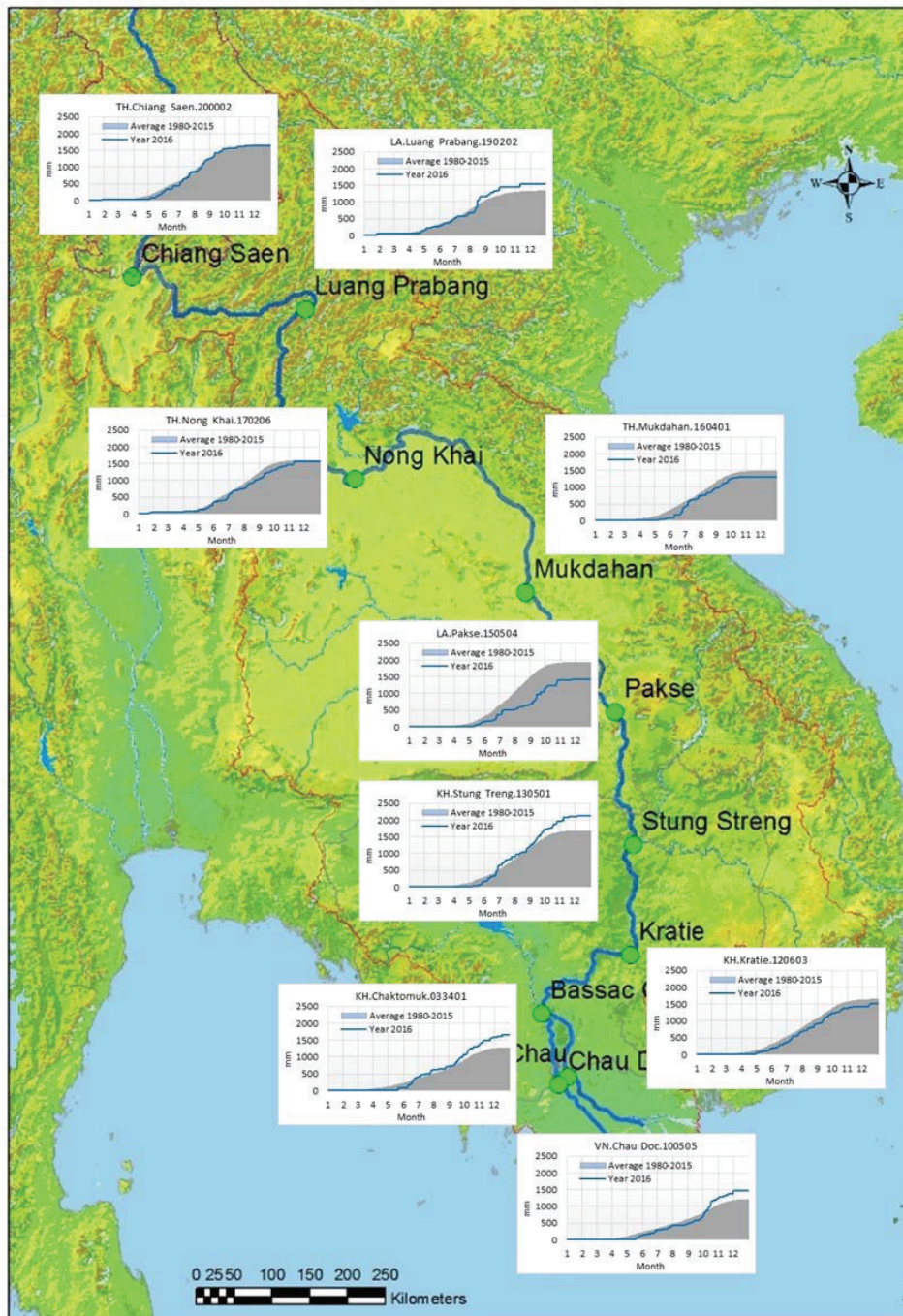


Figure 40: Cumulative rainfall 2016 and long-term average at selected stations

3.3. The flood hydrology of 2016

The flood season 2016 started with a delay. From north to south up to Kratie, hydrographs started slowly and reached their maximum just before the flow recedes again with a typical falling limb. The Mekong Delta and the contribution from the Cambodian plain and Great Lake, however, were below average. The peak discharge at Phnom Penh Port was 25% less than average. No warning levels were reached along the main reporting stations.

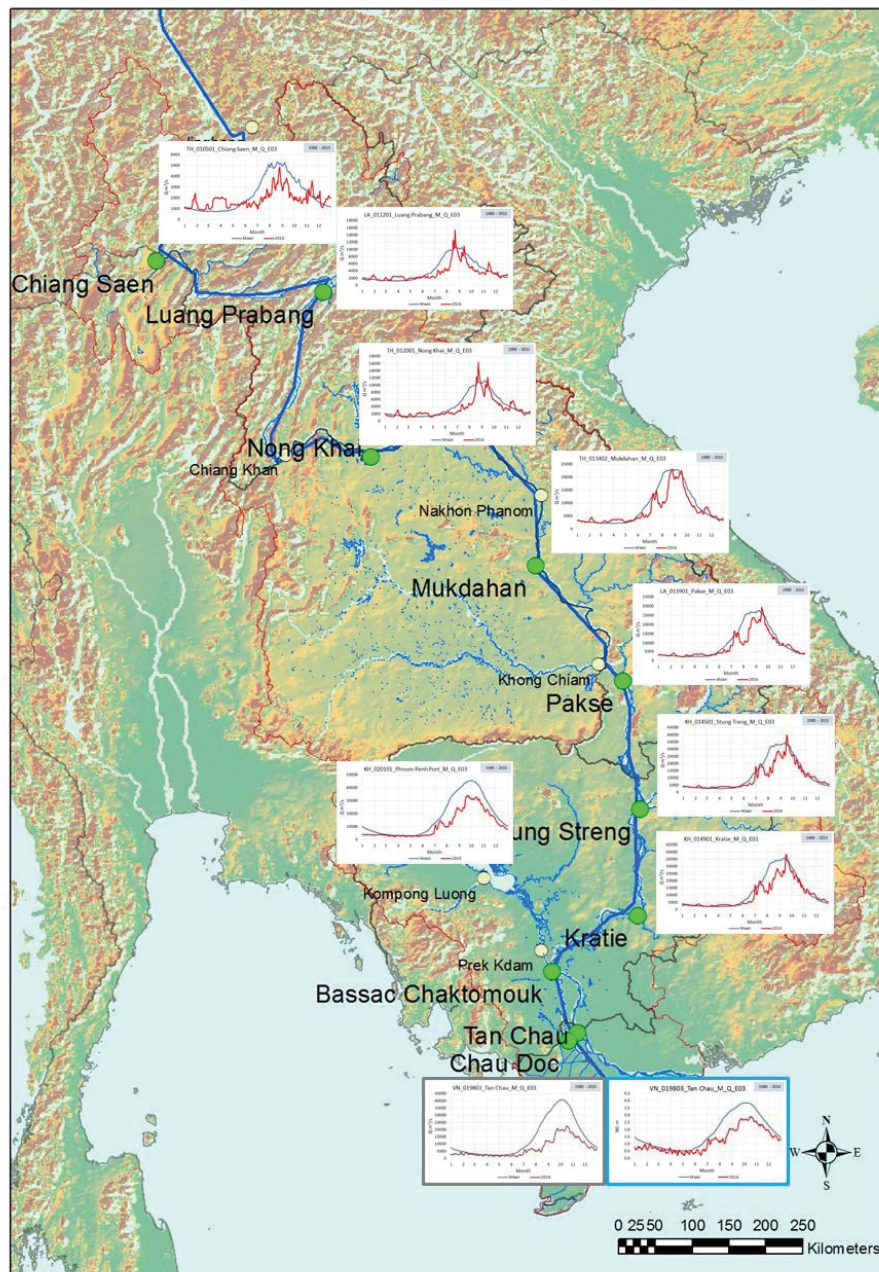


Figure 41: Hydrographs comparing mean with 2016 at selected stations

In contrast to mainstream Mekong, some tributaries reached or exceeded defined warning or dangerous water levels.

Table 2: Peak water levels at main tributaries exceeding warning levels in 2016

Name of Station	Warning Level (m)	Dangerous Level (m)	Peak Water Level in 2016 (m)	Country
Nam Khan at Xiengngeun	11.00	10.00	12.20 (20/08/16)	Lao PDR
Nam Song at Vangvieng	3.50	4.50	3.88 (20/08/16)	Lao PDR
Nam Sane at Bolikhane	7.00	8.00	8.91 (21/08/16)	Lao PDR
Sebangfai at M.Sebangfai	17.50	18.50	17.50 (16/09/16)	Lao PDR
Sre Pok			174.82 (07/11/16)	Viet Nam

More details about water levels in relation to warning levels for rivers in Viet Nam can be found in 4.4.

Concerning Cambodia, it can be stated that 2016 was the second consecutive year with drought conditions in the Cambodian plain.

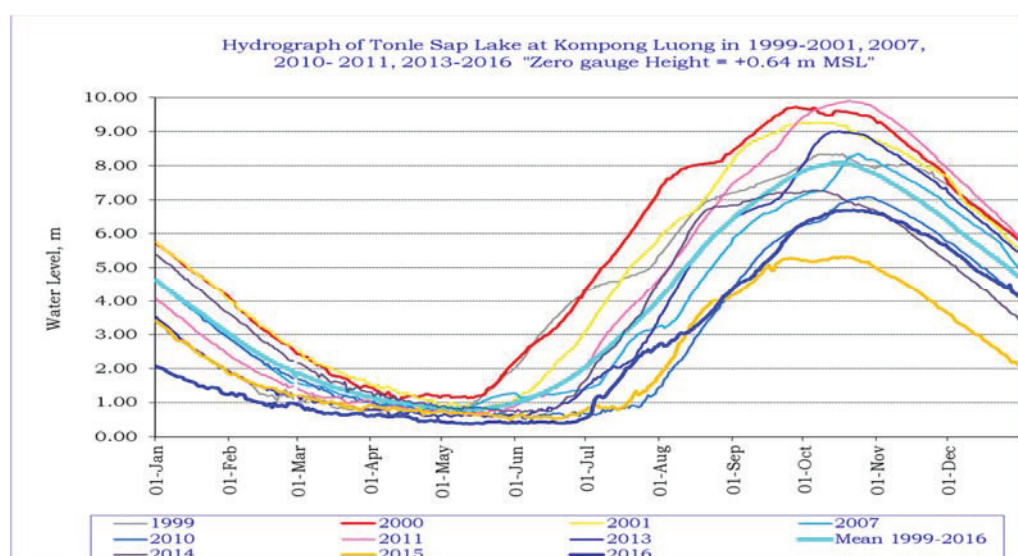


Figure 42: Hydrograph of Tonle Sap Lake at Kampong Luong in 1999-2001, 2007, 2010-2011, 2013-2016

The water level at the Tonle Sap Lake at Kampong Luong did not increase until the first week of July and was close to the lowest records observed in 2015. The values fell short of the long term average by about 0.5m to 2.0m. The highest water level ever recorded in Kampong Chhnang, which is located at the Tonle Sap River downstream of the Tonle Sap Lake, reached 11.8m during the flood 2011.

Figure 43 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 delta flow volume between adjacent up- and downstream stations. Losses are indicated as yellow arrows. A loss occurs if the downstream station from two adjacent stations had 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 in tidally influenced areas. The contribution of the Cambodian Plain is very low but exceeds the value of 2015. Nevertheless, annual flow volume at Phnom Penh Port reaches 65% of the average 55% further in the Delta (Tan Chau + Chau Doc).

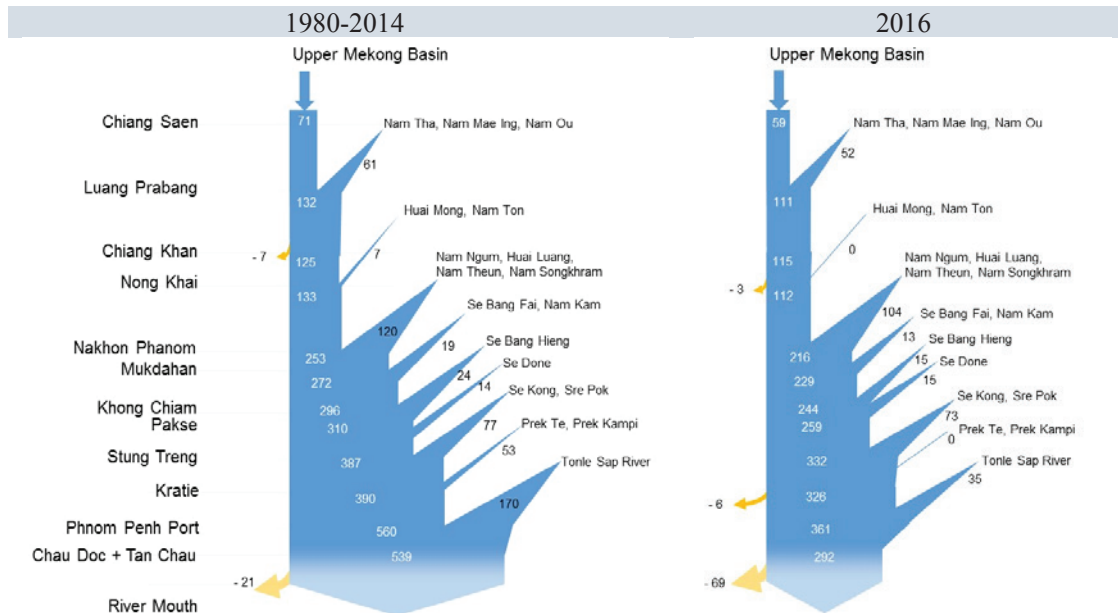
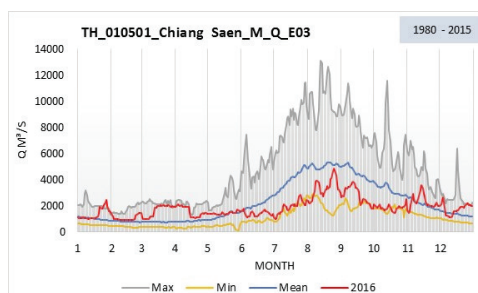


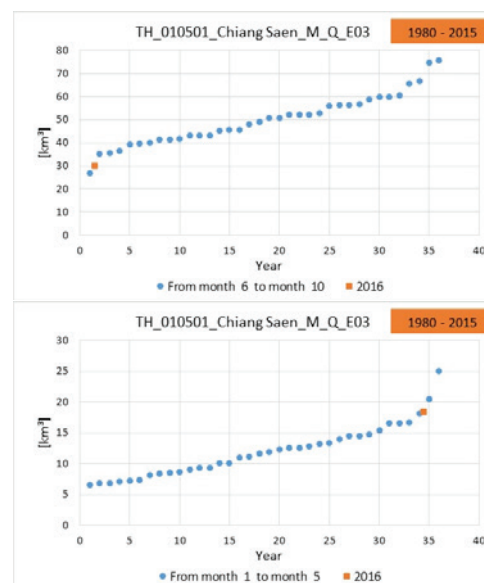
Figure 43: Comparison of annual discharge volume in km³ (1980-2015) with 2016

The flood season 2016 can be characterised as follows:

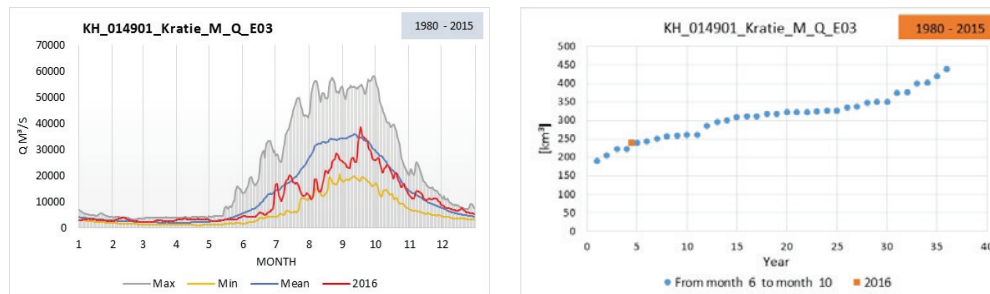
- Flood discharge volume in 2016 at Chiang Saen ranked amongst the lowest recorded values ever. Releases from the Lancang reservoir system augmented flow conditions during March, April and May. This is the second consecutive year with extremely low flood season flow volumes.



However, the flow volume from January to May results in a different picture. 2016 ranks 3 highest



- Kratie's flood season volume ranks 5 lowest in the history going back to 1980.



- Flood volume at Phnom Penh Port was the third lowest since 1980.

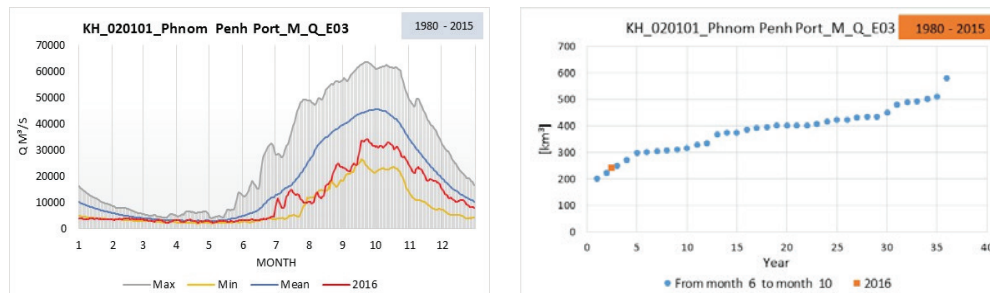
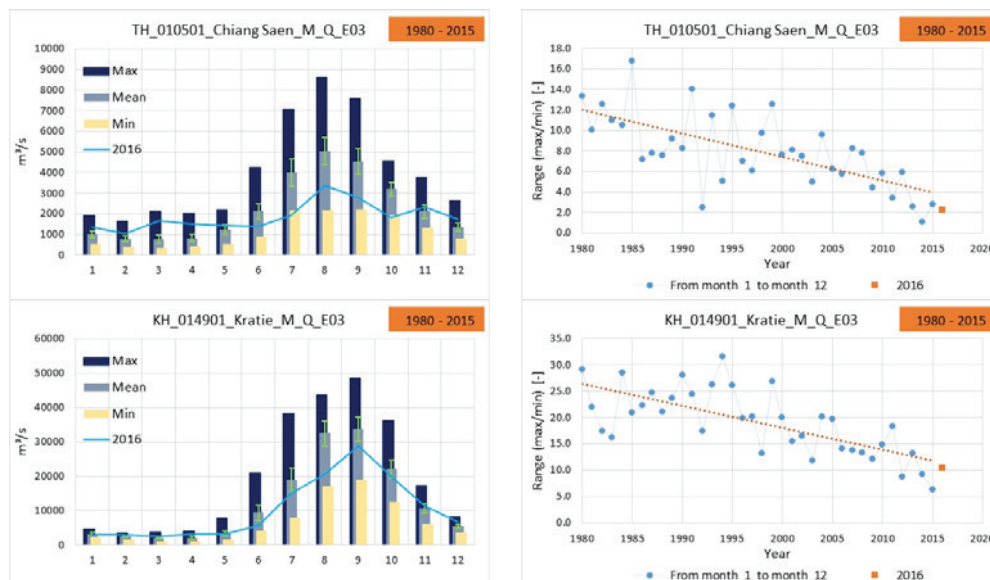


Figure 44: Hydrograph 2016 and list of flood volumes at selected stations

- The range between maximum and minimum discharge throughout the year along main-stream Mekong, in particular at Chiang Saen, was amongst the lowest ratios ever with a clear downward trend. This is true for Kratie and Phnom Penh Port as well and for the other stations not illustrated here.



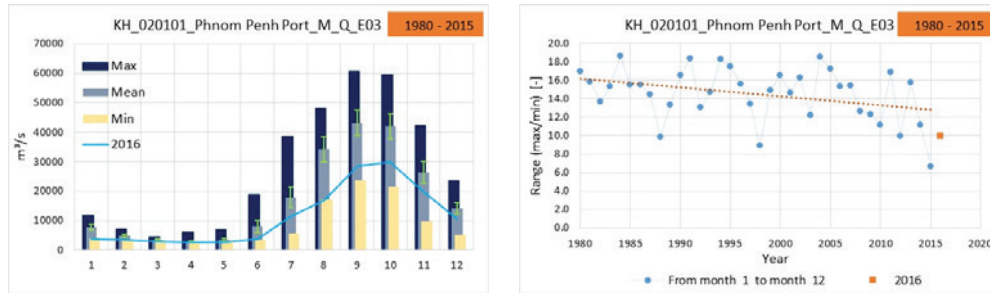


Figure 45: Range of maximum to minimum discharge per year at selected stations

Discharge at Phnom Penh Port was at minimum level over a number of months.

- In 2016, Phnom Penh Port had both a very low flood volume and a low peak discharge. Only 2014 and 1998 were lower. The drop in the peak discharge and flood volume is common to all stations but worsened further south.

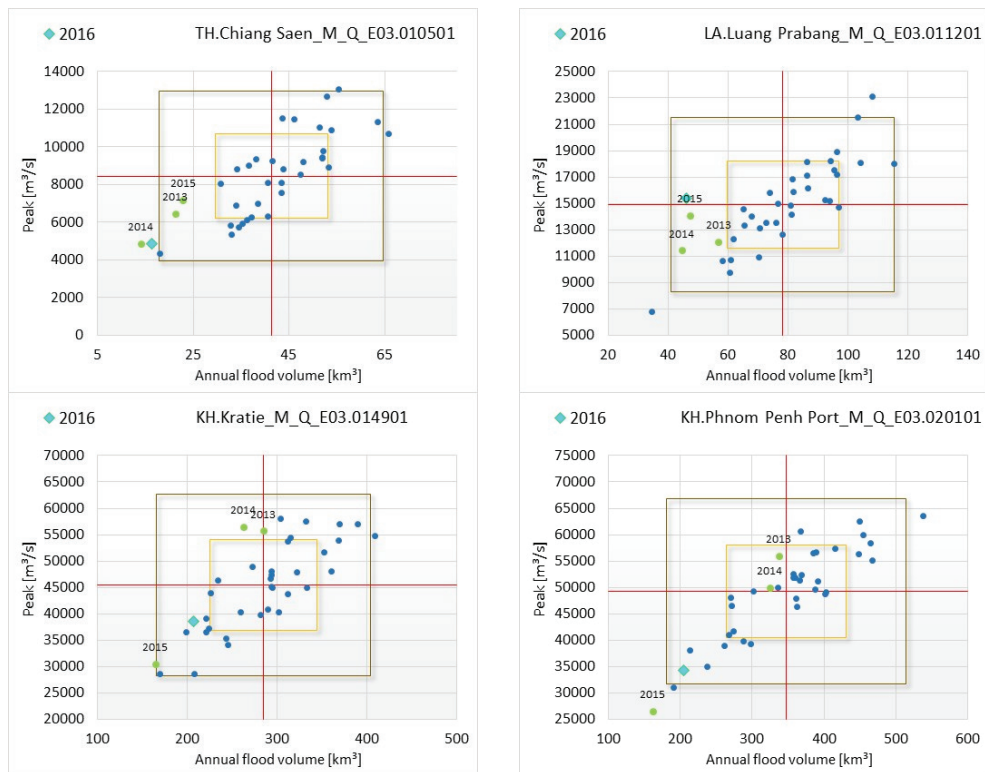


Figure 46: Flood volume / peak discharge relationship at selected stations 2016

The inner rectangle in the chart indicates derivation in the magnitude of the standard deviation for both peak discharge and annual flood volume. The outer rectangle simply doubles the standard deviation.

3.4. Regional flash floods 2016

The maximum daily precipitation is illustrated in Figure 47. The rivers which caused floods and water levels above warning levels are also depicted.

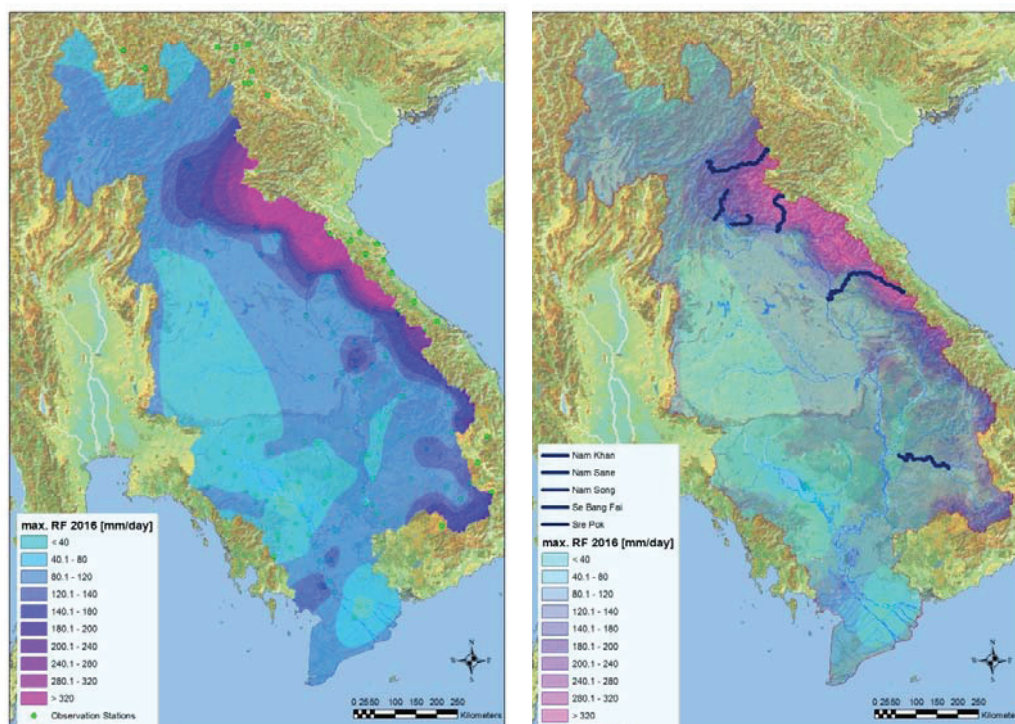
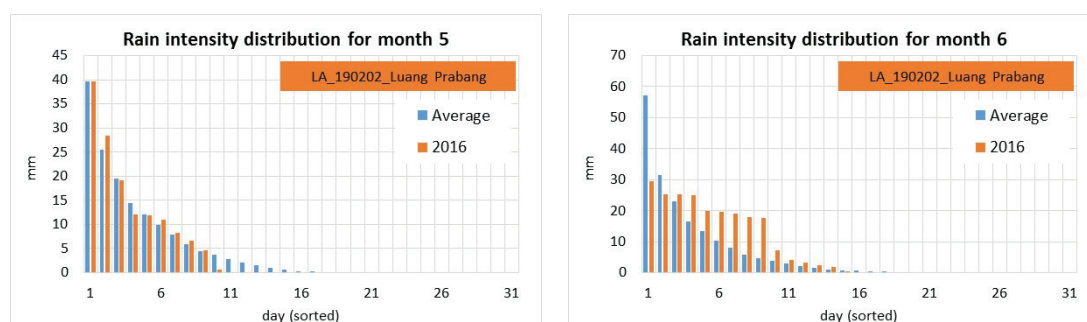


Figure 47: Maximum daily rainfall over the LMB in 2016

From the viewpoint of flash floods, cumulative precipitation over weeks, months or a year are not relevant. One single day with extreme rainfall in a dry year is enough to cause unwanted flooding. Figure 48 shows daily rainfall intensities for May until October for Luang Prabang. The values show rainfall sorted in a descending order compared with long-term averages of rainfall intensities from 1980 to 2014.

The typhoon Sarika in October 2016 is the cause for the high rainfall intensity.

Luang Prabang had a number of high daily rainfall occurrences exceeding the usual range. The largest rainfall depth amounts to 150 mm within 24h. During 11 to 16 August, Luang Prabang had consecutive days of high rainfall with the peak on August 16 as a consequence of tropical storm Dianmu.



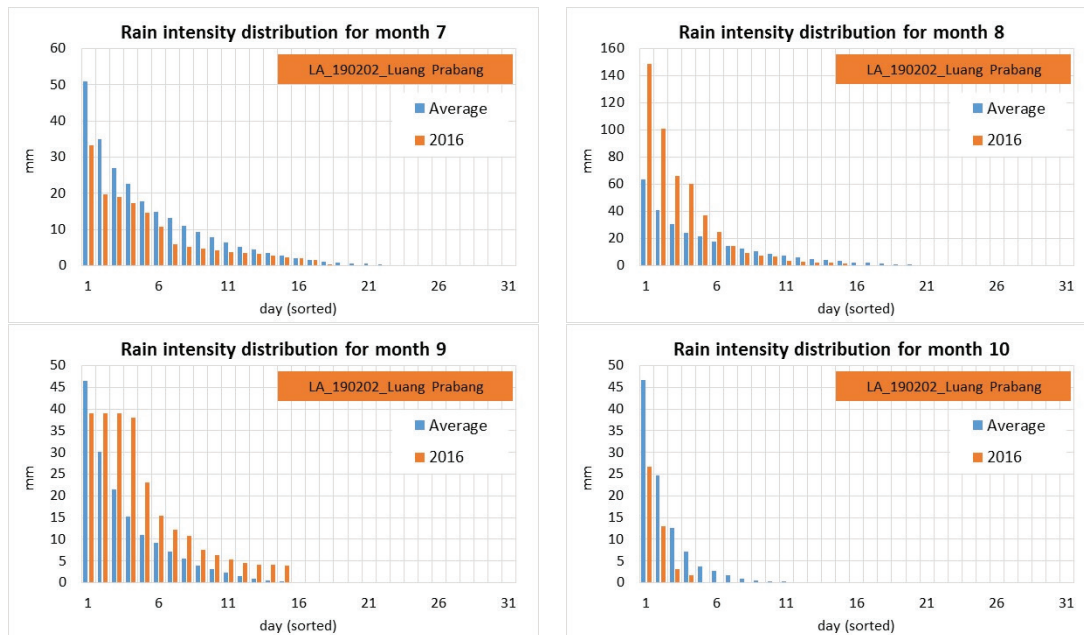


Figure 48: Rainfall intensities for each month at Luang Prabang

The maximum daily rainfall at Luang Prabang can be rated as a 50 year recurrence interval based on the time series from 1980.

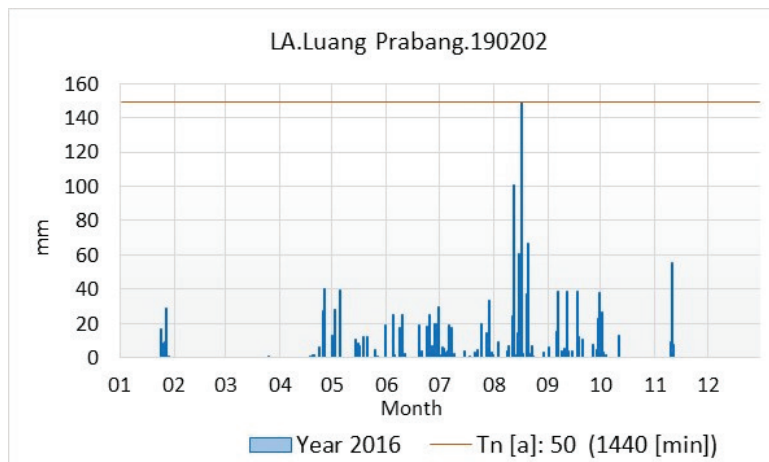


Figure 49: Time series of daily rainfall for Luang Prabang in 2016

Maximum intensities of precipitation are difficult to measure as they occur locally and are mostly very confined in terms of time and space. Ground stations observe maximum intensities only if the rain cell is located exactly above. The longer an observation station exists, the higher the chance that such a coincidence happens. If records are kept as daily sums, the inner-daily distribution is unknown and maximum intensities are levelled out. As a consequence in terms of flash flood observation and prediction, techniques are required which allow for areal observation and records with a high temporal resolution.

Radar or satellite observations can provide both. In contrast to point measurements of ground stations, both techniques observe precipitation over an area and have the potential to generate a high temporal resolution. But as always, there is substantial effort needed to make full use of these techniques. The applications require calibration and that, in turn, requires ground stations. To arrive at predicting flash floods, additional tools are needed as flash floods follow a complex formation process. Flash floods arise due to high rainfall intensities, exceedance of infiltration capacity of the soil and conditions which favour fast runoff like steep slopes, impermeable surfaces, no plant canopy, etc. These factors are accounted for in the Flash Flood Guidance Systems (FFGS) which is in operation at MRC. The system is described in (MRC, 2014).

4. COUNTRY REPORTS

4.1. Cambodia

4.1.1. Introduction

In Cambodia, the flood season is commonly seen as a source of profit rather than a source of disaster. In the floodplain of Cambodia, people live with the annual flood and even if the flood is severe, they are accustomed to managing the situation year after year. The water level must be high enough to allow inundation of large areas, bringing sediment for soil and nutrients for fish, as well as to kill rats and other undesirable vermin. However, beyond a certain limit, the flood may be disastrous for people, infrastructure and agriculture.

4.1.2. The flood season 2016

Availability of Data

Rainfall data was collected from 1985 to 2016 and hydrological data from 1991 to 2016 from MOWRAM. Information about flood impacts and damages could be gathered from 2009 to 2016 from the National Committee for Cambodia Disaster Management. Some information about floods and droughts were taken from newspapers and websites including graphs and maps.

Meteorological and hydrological conditions

Rainfall in Cambodia is distributed according to the geographical characteristics with high amounts in coastal and mountainous areas and less rain in the central flood plain. September and October are the wettest months and April and May are driest.

In recent years, provinces in the Cambodian plain have been facing drought conditions with less than 1000 mm per year such as Battambang, Banteay Meanchey and Kompong Speu. According to the record of annual rainfall, average rainfall from 2000-2016 was lowest in Pailin with 1,072 mm and highest in Koh Kong with 4,140 mm while the average was around 1700 mm.

The rainfall in 2016 at Stung Treng started with a sharp increase end of June due to the impact of the south west monsoon. The annual rainfall in 2016 along the 7 main hydrological stations with an average of approx. 1,700 mm ranged from 1,289 mm at Prek Kdam to 2,120 mm at Stung Treng.

Table 3: Annual rainfall in Cambodia from 2000-2016

No.	Station Name	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average 2000-2016
1	Battambang	1424	1141	1387	1058	994	1237	1219	1322	1390	1398	1332	1707	1339	1394	881	1095	954	1251
2	Bantey Meanchey	1489	1122	1297	998	1092	1209	1246	1273	1345	1050	1108	1476	1319	1471	619	857	861	1166
3	Kompong Cham	1506	1324	1133	1415	1183	1446	1591	1576	1503	1767	1208	1381	1694	1467	1322	1384	1525	1437
4	Kompong Chhnang	1645	1310	1160	1114	1262	1349	1459	1759	1449	1651	1335	1929	1831	1583	1436	1210	1383	1463
5	Kompong Thom	1755	1602	1484	1299	1206	1375	1945	1423	1677	1558	1419	2094	1395	1644	1174	4800	1471	1725
6	Kompong Speu	1817	1723	937	883	950	1114	1178	1650	1444	1405	1215	1378	1444	1465	993	1052	1430	1299
7	Koh Kong	3791	3359	2310	2953	3548	3661	5202	3860	4439	4771	3969	3073	4914	5253	5830	4466	4990	4140
8	Kompot	2417	2309	1613	2225	1573	2079	2454	1879	1269	2240	1413	1949	1819	1999	1784	1569	1802	1905
9	Kandal	1780	1430	1217	1066	910	1092	952	1095	1500	1180	1711	1248	1465	1318	1194	961	1638	1280
10	Kratie	2155	1907	1829	1573	1619	1468	1663	1864	1565	1849	1392	1986	2278	1984	1697	1185	1880	1758
11	Modulkiri								1537	1503	1108						1628	1851	1526
12	Prey Veng	1782	1532	1378	1619	1152	1259	1188	1365	1692	1178	1887	1370	1772	1371	1674	1309	2136	1510
13	Pochentong	2096	1599	1231	1257	1153	1386	1208	1374	1886	1456	1512	1555	1336	1420	1462	1065	1869	1462
14	Palin			633	1011	453	969	821	1134	1317	1330	1923	1076	1105	1464	844	961	1034	1072
15	Preh Vihear			1512	1470	1346	1452	1525	2035	1542	2070	1439	1947	1645	2051	1647	1429	1679	1652
16	Pursat	1740	1297	1409	1485	1056	1252	1393	1496	1962	1156	1360	1488	1640	1584	1285	1226	1773	1447
17	Ratanakiri			1826	2291	2126	2500	2792	1659	1411	1356	759	1947	2502	2630	1919	1818	1776	1954
18	Stung Treng	2652	1872	1433	1469	1491	1389	1597	1776	1778	1698	1159	2318	1783	2241	2359	1401	2148	1798
19	Svay Rieng	2206	1568	1578	1603	1379	1712	1616	1603	1440	1476	1980	1879	1731	1467	1430	1370	2190	1660
20	Siem Reap	1637	1753	1141	1271	1610	1496	1415	1356	1716	1480	1301	1686	1466	1861	1490	1249	1696	1507
21	Sihanoukville	3399	3397	3187	2833	3353	2956	4065	3314	2893	2307	2176	2347	2758	2682	2726	2504	2654	2915
22	Takeo	1553	1597	1283	1384	1016	1202	1135	1501	1017	1017	1428	1487	1370	1258	1383	1284	1329	1308
23	Odor Meanchey											1321	1190	1231	1696	1360	1096	1323	1317
Minimum (mm)		1424	1122	633	883	453	969	821	1095	1017	1017	759	1076	1105	1258	619	857	861	1072
Average (mm)		2047	1769	1475	1537	1451	1600	1793	1720	1715	1659	1561	1751	1811	1877	1659	1605	1799	1676
Maximum (mm)		3791	3397	3187	2953	3548	3661	5202	3860	4439	4771	3969	3073	4914	5253	5830	4800	4990	4140

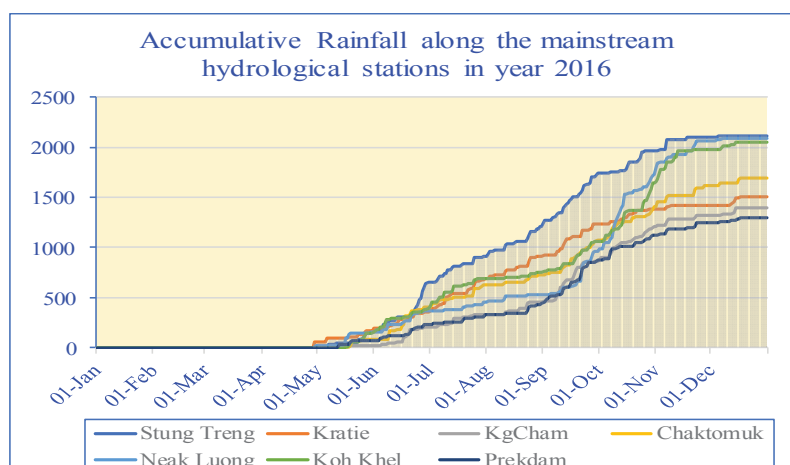
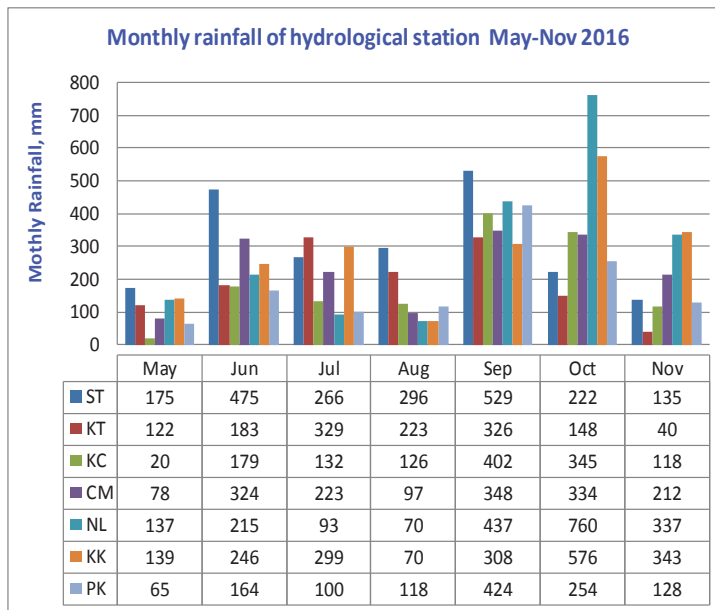


Figure 50: Cumulative rainfall along the mainstream hydrological station in [mm]



Monthly Rainfall observed on the main hydrological stations along the Mekong and Bassac river were slightly below or similar to normal. However, high temperatures caused more evaporation so that the amount of available water in the soil was insufficient for agriculture in 2016.

Flood hydrology of 2015

In 2016, the monsoon season led to maximum water levels which were higher than 2015 but still below the long-term average. Troughs of tropical storm Aere are regarded as responsible for the flash floods in 2016 in Kompong Speu with heavy rainfall up to 200–350 mm with subsequent floods in Srok Thpong and Udon. The flooding occurred mid of October. The Ministry of Water Resources and Meteorology (MOWRAM) took action to dam and divert the water through the canal system further downstream.

The highest water levels observed in 2016 on the mainstream stations were roughly 12% lower than the long-term average of maximum, except for Prek Kdam station which reached 81% of the average.

Table 4: Maximum water level in 2016 and long-term average in Cambodia

Station name	River name	Period of Record	Annual maximum water level, m		
			Historical average, m	2016, m	2016 as % long term average
Stung Treng	Mekong	1991-2015	10.45	9.56	92
Kratie	Mekong	1991-2015	21.22	19.98	94
Kompong Cham	Mekong	1991-2015	14.91	13.31	89
Chaktomuk	Bassac	1991-2015	9.75	8.13	83.4
Neak Loeung	Mekong	1991-2015	7.05	5.87	83
Koh Khel	Bassac	1991-2015	7.35	6.87	93
Prek Kdam	Tonle Sap	1991-2015	8.81	7.12	81

4.1.3. Impact of floods 2016

Vulnerabilities are accumulating in Cambodia. As the population in the Mekong floodplain of Cambodia continues to increase rapidly due to migration from ru-

ral to urban areas and inadequate land-use planning in cities such as Phnom Penh and Siam Reap, the impacts of flooding are high. Inappropriate drainage systems were identified as one main reason which has become a focal point of intervention in cooperation with international partners like JICA or ADB.

Table 5: Impacts of floods and droughts compiled for Cambodia from 1996 to 2016

Year	Disasters	Affected/ Damages
1996	Severe flood	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.
1999	Flood and Typhoon	37,527 people in 10 provinces were affected, 17,732ha of rice crop and 491 houses were destroyed
2000	Severe flood	3,448,629 people were affected, 768 houses were damaged and 347 deaths occurred
2001	Severe flood	429,698 families, equivalent to 2,121,952 people were affected. People killed: 62 (70% were children), houses destroyed: 2,251
2002	Flood and Drought	Drought: People affected: 442,419 families (2,017,340 individuals), Flood: People affected: 1,439,964 , 1,082 houses destroyed, deaths: 29
2009	Typhoon Ketsana	14 provinces affected, 43 deaths, 67 severely injured, destroyed homes and livelihoods of some 49,000 families or 180,000 people, the equivalent of 14 percent, and 80% of total land area.
2010	Flash flood	14 provinces affected, 22,746 families affected, 6,301 houses affected, 86 houses damaged, 11 deaths, 7 injured, 272 schools affected, affected nurseries: 77,629 ha and crop damages across 6,942 ha
2011	Severe flood	18 provinces affected, 354,217 families affected, 268,631 houses affected, 1297 houses damaged, 250 deaths, 23 injured, 1,360 schools affected, 491 pagodas, 115 health centers, seeding 431,476 ha, crops 21,929 ha, national roads 956,638m, laterite roads 5,594,119 m, ..etc.
2012	Flash flood	7 provinces affected, 23,691 families affected, 22,863 houses affected, 2 houses damaged, 27 deaths, 122 schools affected, 7 pagodas, 4 health centers, seeding 57,432 ha, crops 3,585 ha, laterite roads 25,4287 m, ..etc.
2013	Severe flood	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, ..etc.
2014	Flash flood	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, ..etc.
2015	Flash flood/ Drought	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
2016	Flash flood	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

The most affected places were:

Thousands of homes in Phnom Penh and Kampong Speu were flooded after three dams were seriously damaged following two weeks of torrential rain.

The homes of 1,637 families in nine different Dangkor district communes were flooded following severe damage to three dams. An additional 1,367 homes were flooded in Kampong Speu.

Prek Thnout dam was seriously damaged as a section of concrete wall collapsed on 17 October 2016 according to Dangkor District Governor Nut Putdara as well as Roland Chrey dam in Kampong Speu and Svay dam. The damage of the Roland Chrey and Svay dam was a direct consequence of the damage of the upstream Prek Thnout dam. Countermeasures with sandbags and earth work organised by authorities were unsuccessful.

Three schools in Phnom Penh's Dangkor district failed to open for the first day of the school year due to residual flooding from the Prek Thnout River. The affected schools were Wat Hear Primary School in Prey Sar commune, Spean Thma Primary School in Spean Thma commune and Prek Kompoes Secondary School in Prek Kompoes commune.



The impact of the failure of Prek Thnout dam was captured by satellite images.

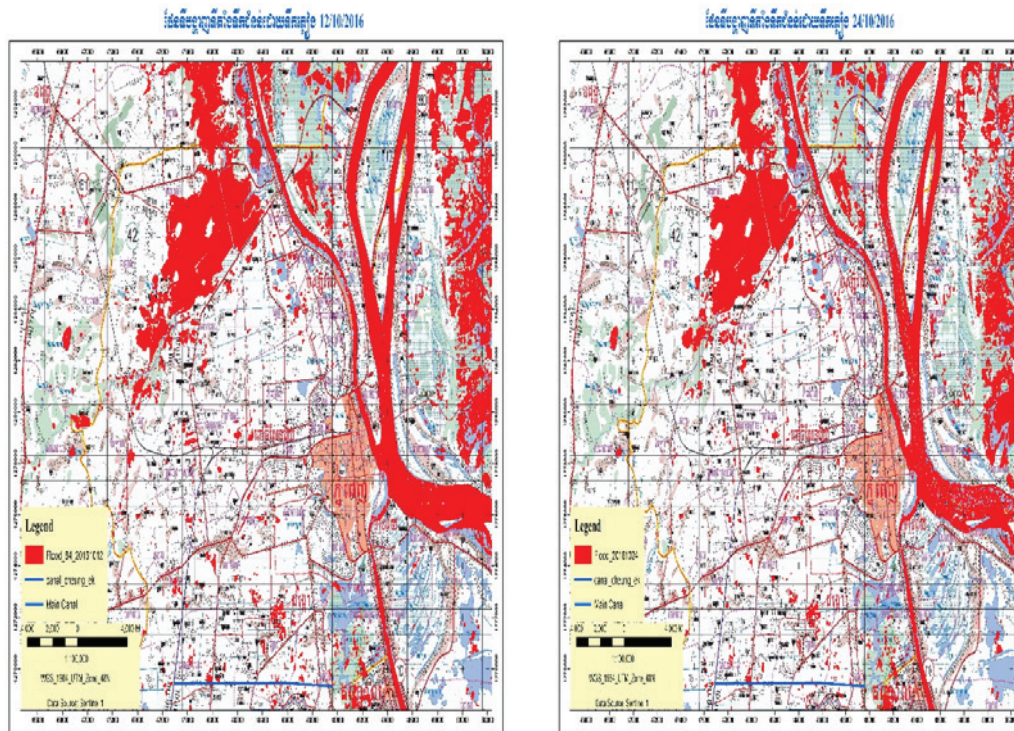


Figure 51: Flood map from Sentinel 1 on 12/10/2016 and 24/10/2016, upper part of Phnom Penh

In 2016, drought conditions were considered even more serious than floods. Water resources still had not yet fully recovered from the shortage in 2015, extreme high temperatures up to 41 °C with correspondingly high evaporation diminished the water resources even further. The Phnom Penh Post reported that Kampong Thom province, Staung and Prasat Balaing districts faced water shortages. The worst shortage happened in seven communes in Kampong Thom's Staung district, affecting even the domestic water supply so that drinking water had to be delivered by trucks.



Figure 52: Depleted West Baray reservoir in Siem Reap and empty Banteay Meanchey's Sisophon River (photo left: Thik Kaliyann, photo right: Alessandro Marazzi Sassoon; Phnom Penh Post, accessed November 2017)

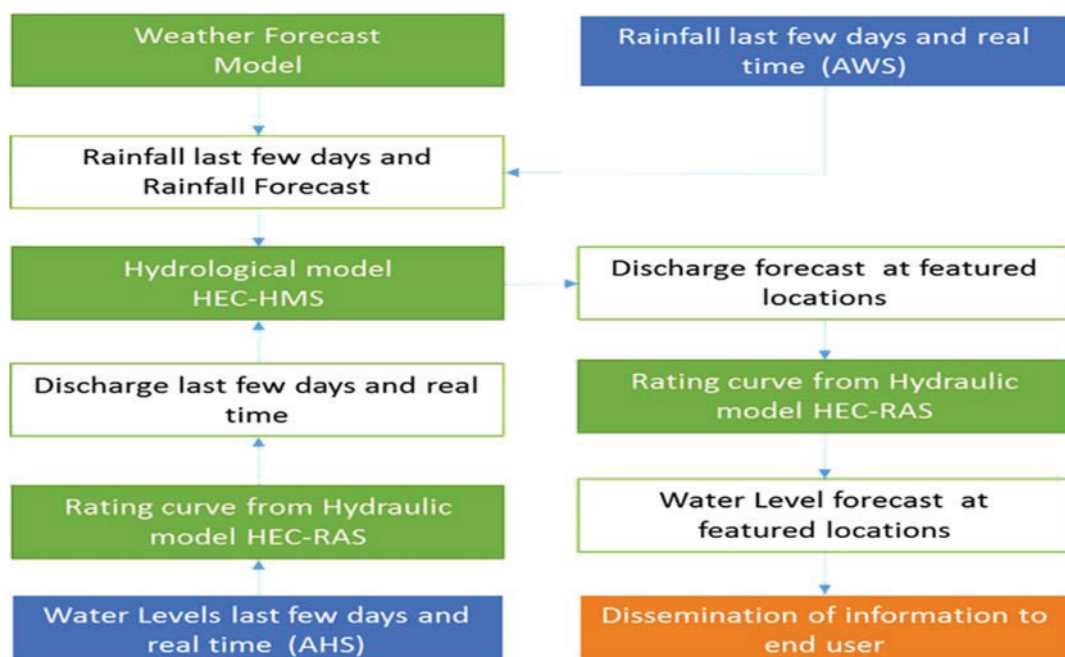
4.1.4. Flood management and response

A Flood Forecasting Tool for Cambodia (FFT) is being developed by the National Flood Forecasting Centre (NFFC) and the Department of Hydrology and River Works (DHRW). The FFT application developed in Visual Basic uses a multi-regression method for quickly computing flood level forecasts for 5 days at 8 Main-stream stations in Cambodia and 2 stations in Vietnam. For the flood forecasting as pilot in Pursat Basin HEC-HMS and HEC-RAS is used. The models and FFT are under development and testing until 2017.

A successful flood forecasting system has a number of key requirements. The first is access to reliable and timely weather forecasts, especially for severe weather events. The second is reliable and timely data on current hydrological conditions in the basin. The third is the availability of calibrated hydrologic and hydrodynamic operational models for the priority basin.

The following schematic presents the general model layout for an operational water level and flood forecast system. Though it is expected that the flood forecasting system for the NFFC will be a less elaborate system, the structure will lay a solid foundation for an evolution to a fully operational flood forecasting system using more sophisticated and powerful weather prediction and data assimilation techniques.

It is important to note that the flood forecasting system must provide a projection of the area that will be inundated, given the predominance of large flood plains in the lower Mekong region occupied by Cambodia. Therefore the flood forecasting system must be coupled with a hydraulic model, supported by a reliable DEM, to route and simulate water levels over a large flood plain and produce useful flood inundation maps.



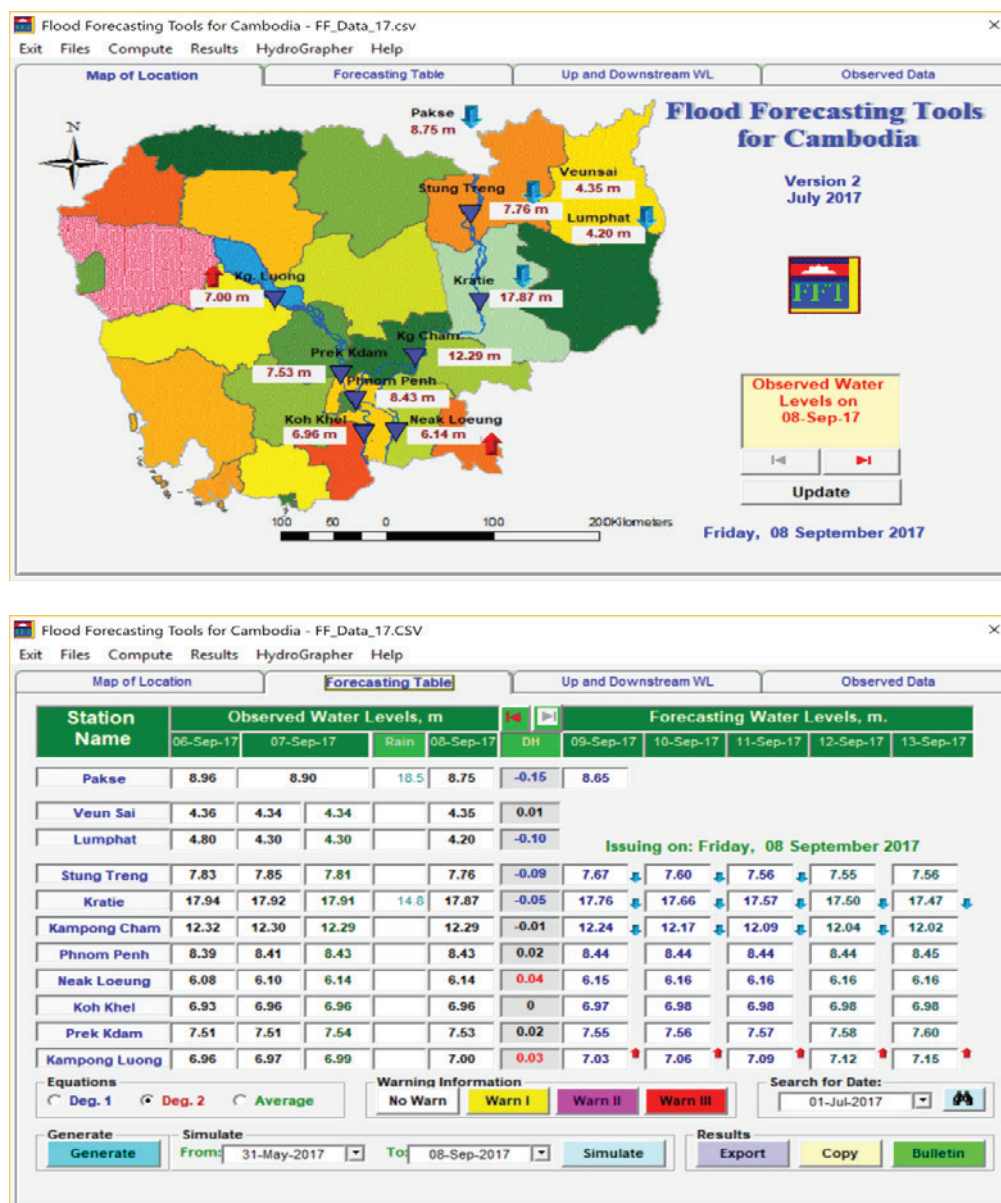


Figure 53: Development of the Flood Forecasting Tool for Cambodia (NFFC and DHRW)

4.1.5. References used

Annual Mekong Flood Report 2012, Flood Management and Mitigation Programme, MRC

Annual Mekong Flood Report 2013, Flood Management and Mitigation Programme, MRC

Conceptual Design Report-Forecast Production and Dissemination (Final Report)_NFFFC Consulting Team of EPTISA and KCC , September 2016_GMS-ADB Flood and Drought Risk Management and Mitigation Project

MOWRAM/ADB CDTA 7610-CAM “Cambodia Water Resources Profile”, April 2014

Hydro-meteorological data from Ministry of Water Resources and Meteorology (www.mowram.go.org, www.cambodiameteo.com, www.dhrw-cam.org)

Data and information from National Cambodia for Disaster Management (NCDM) website: (www.camdi.ncdm.gov.kh)

Thai Meteorological Department Website (www.tmd.go.th)

4.2. Lao PDR

4.2.1. The flood season 2016

Availability of Data

Data was provided by the Department of Meteorology and Hydrology. In addition, flood damage and impact data and information were supplied by the Department of Climate Change Management.

Meteorological and hydrological conditions

The rainy season of 2016 was close to normal moving from north to south with annual rainfall around the long-term average. Until October 2016, the percentage of annual rainfall for the whole country was already 100 percent. Lao PDR was affected by four tropical storms: Dianmu, Rai, Mirinae and Aere (see section 3.1). The north and centre of Lao PDR with the provinces Oudomxay, Bokeo, Luang Prabang, Sayabouly and Vientiane were affected most.

Flood hydrology of 2015

All observed water levels at all stations along Mekong River remained below warning levels.

Table 6: Peak water and warning levels along Mekong River in 2016, Lao PDR

No	Name of station	Warning Level (m)	Dangerous Level (m)	Peak Water Level in 2016 (m)	Remark
1	Mekong at Houasai	16.50	17.50	6.53 (13/09/16)	
2	Mekong at Pakbeng	29.00	30.00	16.76 (17/08/16)	
3	Mekong at Luangprabang	17.50	18.50	15.76 (20/08/16)	
4	Mekong at Paklay	15.00	16.00	13.20 (21/08/16)	
5	Mekong at Vientiane	11.50	12.50	11.00 (22/08/16)	
6	Mekong at Paksane	13.50	14.50	12.67 (23/08/16)	
7	Mekong at Thakhek	13.00	14.00	11.25 (23/08/16)	
8	Mekong at Savannakhet	12.00	13.00	9.37 (24/08/16)	
9	Mekong at Pakse	11.00	12.00	10.00 (14/09/16)	

Source: DMH, 2016

Tributaries, illustrated below, reached peak water levels that were at or above warning or even emergency levels. The floods occurred end of August and mid of September coinciding with the tropical storm Dianmu and typhoon Rai.

Table 7: Peak water level and warning levels in tributaries in 2016, Lao PDR

Name of Station	Warning Level (m)	Emergency Level (m)	Peak Water Level in 2016 (m)	Remark
Nam Khan at Xiengngeun	11.00	12.00	12.20	Flood

Name of Station	Warning Level (m)	Emergency Level (m)	Peak Water Level in 2016 (m)	Remark
			(20/08/16)	
Nam Song at Vangvieng	3.50	4.50	3.88 (20/08/16)	Flood
Nam Sane at Bolikhane	7.00	8.00	8.91 (21/08/16)	Flood
Xebangfai at M.Xebangfai	17.50	18.50	17.50 (16/09/16)	Flood

The water level in the Xebangfai River at Xebangfai Bridge Station had three distinct peaks of which two reached the warning level: Beginning of July can be related to the storm Mirinae, the second peak is probably a direct consequence of storm Dianmu (August).

4.2.2. Impact of floods 2016

There was no serious event due to flood or inundation along the Mekong River. When flood related damages occurred they took place at tributaries and small rivers due to local storms. Summarizing the incidents in Lao PDR, damages in relation to floods were reported in 55 districts, 1,142 villages, causing 10 fatalities. Costs and losses totalled about 60,901,627,678 Kips (7,612,703 US Dollar).

Table 8: Summary of flood and flash flood related damages in 2016, Lao PDR

Provinces affected	12 provinces: Khammuan, Champasack, Bokeo, Huayphanh, Oudomxay, Luangprabang, Oudomxay, Xekong, Xayabouly, Vientiane, Xiengkhuang and Phongsaly
The most seriously affected provinces	Huayphan
Districts affected	55
Villages affected	1,142
Killed People	10
Injured people	2
Households affected	647
People affected	403
Agriculture	
Hectares of rice paddy fields affected	1,149 Ha
Hectares of upland rice and crop damaged	1,845 Ha
Livestock	
Cattle and poultry	374 and 2,458
Infrastructure	
Houses affected	10,466 (1,457 damaged)
Schools affected	Not available
Weirs damaged	Not Available
Irrigation systems damaged	Not Available
Total damages	60,901,627,678 Kips (7,612,703 US Dollar)

Source: Department of Disaster Management and Climate Change, 2016



Figure 54: Flash flood events in Xekong Province

The most affected areas were in the Huaphanh Province, including the districts of Hiam, Son, Xiengkhor, Xamtai, Viengsay, Huameuang and Et district.

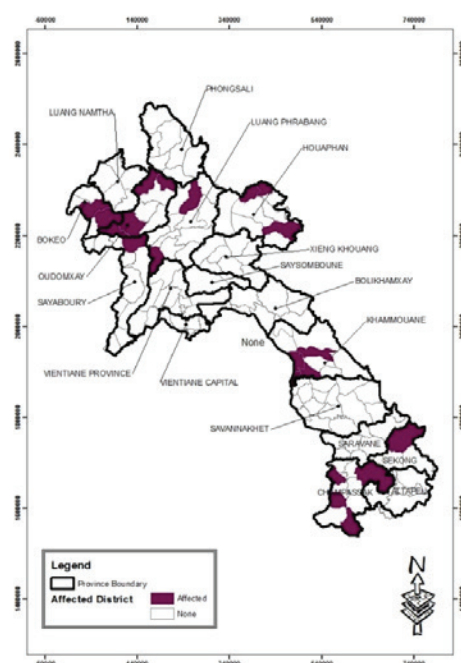


Figure 55: Districts affected by floods and flash floods in 2016, Lao PDR

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4.3. Thailand

4.3.1. Introduction

In 2016, the majority of Thailand was warmer with more rain than usual. Annual rainfall averaged over the country with 1,718 mm was roughly 130 mm (8%) above the 1981-2010 normal while annual mean temperature of 28.0 °C (about 1 °C above normal) was the warmest year in Thailand according to 66 years of records and ranks first together with 1998. The mean temperature was above normal for all months, especially April and May which were 2.2 and 1.8 °C above normal, respectively. The maximum temperature reached the new all-time record in several areas. Precipitation in Thailand was affected by 6 tropical storms or cyclones of which 2 struck Thailand while still classified as storms or tropical depressions, namely the tropical storm RAI that moved into Ubon Ratchathani and Amnat Charoen provinces on 13 September and the tropical storm AERE that moved into Mukdahan and Nakhon Phanom provinces on 14 October. Besides that, rainfall in Thailand was indirectly affected by tropical depressions such as the tropical storm MIRENAE in late July coming from middle Vietnam in late June, DIANMU in middle August and the tropical depression in Cambodia in early November.

4.3.2. The flood season 2016

Availability of Data

Data was collected to identify flood causes, flood areas and flood related damages such as: (1) Storm track history affecting Thailand, (2) Satellite images, (3) Weather maps, (4) Pressure and rainfall maps, (5) Satellite monitoring of floods, (6) Spatial data and photos to show flood extent and impacts.

Flood hydrology of 2015

Significant flood events developed in August due to the influence of DIANMU, a tropical storm which occurred during 12-23 August 2016. These events caused heavy rainfall in the north and north-eastern regions. In the wake of DIANMU, Thailand obtained heavy to very heavy rainfall in some areas in the north and northwest. Maximum daily rainfall of 190 mm was observed at Pua in Nan province on 14 August. Flash floods occurred at Mae Hong Son province on 13 August, at Chiang Rai province on 14 August, at Payao, Nan and Tak provinces on 15 August.

The typhoon RAI in September caused heavy rainfall in the lower part of the North and Northeastern regions during 13-14 September 2016. RAI moved across Laos and was downgraded to a tropical depression before entering Thailand at the adjacent area of Ubon Ratchathani and Amnat Chareon provinces. It moved past Yasothon, Roi Et and Kalasin provinces and was downgraded into an active low pressure cell while located at Roi Et, Kalasin and Mahasarakham provinces before covering middle north-eastern and lower northern parts. These conditions brought abundant rainfall to upper Thailand for almost the whole period. The heaviest daily rainfall was recorded as being 248 millimeters at Phu Kradung National Park in Loei province on September 11. Flash floods occurred at Loei province on September 13, at Mae Hong Son, Chiang Mai, Phayao and Phrae provinces on 18 September.

ber and at Tak province on 19 September. Sukhothai province experienced overtopping river banks on 15 September.

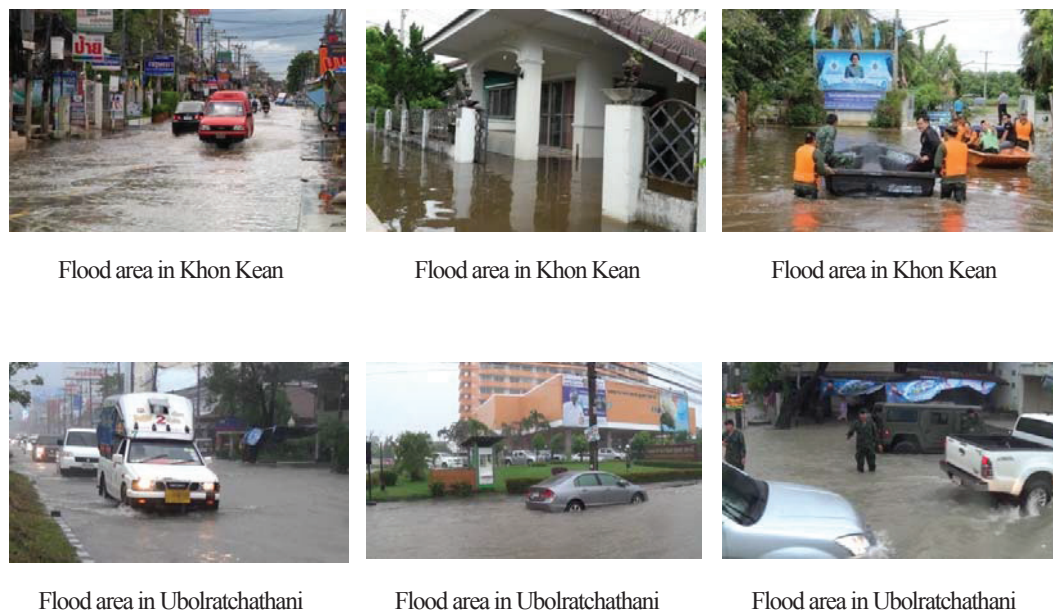
4.3.3. Impacts of floods 2016

The flood event in the wake of tropical storm DIANMU during 14-20 August affected the Nan and Chiang Rai province.



Figure 56: Flood events in Nan and Chiang Rai province (source: Tipaporn Homdee, 2017)

During 13-14 September, the northeast of Thailand, especially in Khon Kean and Ubol Ratchathani provinces, was affected by heavy rainfall exceeding the drainage systems' capacities in the cities.



Source: *Tipaporn Homdee (2017)*

Figure 57: Floods in Khon Kean and Ubolratchathani provinces, September 2016 (source: Tipaporn Homdee, 2017)

In 2016, floods affected or displaced 71,224 people, caused reportedly one fatality and partially damaged 775 houses as well as 125,197 rai (Thai unit) or 20,032 hectares of agricultural land.

The flood situation affected infrastructure such as roads, bridges, drainage systems, schools, and temples. The preliminary estimate of costs amounts to approximately 70.7 million Baht (2.022 million USD).

Table 9: Summary of damages and losses in relation to floods, 2016, Thailand

Description	Damages	Unit
Affected villages	2,708	village
Affected people	71,224	person
Affected families	40,340	household
Evacuated victims	-	person
Evacuated families	-	household
Fatalities	1	person
Missing	-	person
Wounded	7	person
Houses (total damage)	-	each
Houses (partial damage)	775	each
Commercial buildings	-	each
Industrial buildings	-	each
Hotels	-	each
Livestock	834	each
Poultry	2,597	each
Stalls	2	each
Motorcycles	-	each
Cars	-	each
Agricultural buildings	-	each
Fishing boats	-	each
Fishery ponds	718	each
Rice	103,319	rai
Plants	525	rai
Vegetation	21,353	rai
Total agricultural area affected	125,197	rai
Roads	21	line
Bridges	22	each
Dams	-	each
Weirs	7	each
Mining	-	each
Temple	2	each
Schools	6	each
Hospitals	-	each
Government buildings	-	each
Dikes	11	each
Water resources	-	each
Drainage pipes	-	each
Estimated damages	70,771,898.00	Thai Baht

Description	Damages	Unit
Estimated damages	2,022,054.23	USD

Remarks; 1 USD = 35 Thai Baht
 1 ha = 6.25 rai. (area in Thai unit)

4.3.4. Emerging technology to cope with flood

Thailand has embarked on developing Early Warning Systems and Decision Support Systems at various levels and by different organisations.

Currently, the development of a Decision Support System (DSS) is a part of the National Strategy for Thailand's Water Resources Management especially on Administrative Management with purposes as follows:

- Create a national water and infrastructure database that efficiently collects and connects information from all related agencies.
- Create a system for following up, monitoring and predicting normal water situation, and decide, address and mitigate flood and drought in crisis situations integratively
- Create a process for guiding water development, conservation and maintenance systematically and continuously.

The future and ambitious development of the Decision Support Systems includes 4 sub-strategies;

1. **Infrastructure development (I: Infrastructure)**

The existing database about infrastructure development is improved. Information is enhanced, and areas covered are expanded. Information is linked to a central information centre. Information service is improved, and information system standard is set up.

2. **DSS development for normal situation (N: Normal)**

Modelling for analysing and predicting weather is improved both for short-range and seasonal. Modelling for water situation prediction is more efficient, detailed and comprehensive, covering the whole country. Modelling calculation is linked to an information centre to support dam, water allocation and crop planning management and to revise monthly water allocation.

3. **DSS development for crisis situation (C: Crisis)**

Crisis management at district, province and region level is responsive to a situation due to precise and immediate weather and water predictions and scenario simulation of risk and crisis. This helps create options in handling, managing and early warning a crisis in advance as well as helping to improve disaster relief.

4. **DSS support/preservation/maintenance system (D: Development)**

This involves infrastructure exploration, maintenance and improvement of planning, risk and trend evaluation, budget allocation, and monitoring and evaluation of information that disseminates from central agencies to local agencies and vice versa for the sake of analysis and decision.

These are important to water resources management which needs precise information, efficient human resources and organisation. Details of the DSS are as follows:

- 1) **Mapping system:** Currently the most precise data is at meter level. This causes ineffective flood management particularly in flood plains. A limitation in a field survey and a real time report constrains quick responsive planning to address a crisis. For effective and continuous operation in a time of crisis, it is necessary to do a survey using Global Navigation Satellite System (GNSS), and a high-resolution version of the Thailand Geoid Model must be developed. All these will support quick effective survey work with a vertical deviation value not exceeding 30 centimetres in all areas. This plan has invested in 80 GNSS stations and renovated 9 old stations of the Department of Public Works and Town Planning from GPS to GNSS. It has improved accuracy and details of baseline map and collection and service of online GPS data.
- 2) **Telemetry station:** A telemetry station project involves the improvement and replacement of old stations with new equipment. Some stations will be equipped with more precise radar technology with ± 2 mm deviation in all ranges. This will reduce frequency and cost of maintenance from 500,000-300,000 Baht per station to approximately 250,000 Baht per station. Moreover, a system for measuring water quality will be installed covering all areas of Thailand. Automatic water quality measuring stations will increase from 116 to 319 stations.
- 3) **Water data inventory:** Data connections will be expanded from 13 agencies to 30 agencies. A full data service responsible by HAIL and related agencies including website, mobile devices, data network, and enhancement of system and maintenance will be developed to become national water database.
- 4) **Modelling system:** The modelling system includes climate, water situation (run-off and flood) and quality prediction.
 - 4.1 Modelling for weather prediction: Consists of investment in a highly efficient computer system for predicting short, seasonal and long term weather. The system can predict precipitation with spatial resolution not less than 3×3 km², which enhances efficiency in monitoring climate and increases period of early climate prediction.
 - 4.2 At present, modelling for forecasting water situation (runoff and flood) and water quality covers all main river basins. The Water Quality Model is still not capable of real-time forecasts. Baseline data should be updated by connecting gauging data and modelling results to the data centre to increase efficiency especially in a crisis which needs forecasting, monitoring and scenarios for decision making support.
- 5) **Analysis and monitoring system:** This emphasises increasing the efficiency of the analysis and monitoring system for reporting water situation of related agencies. A weather prediction centre will be established for 24 hour surveillance and monitoring using international standards. The Bangkok Flood Prevention Centre will be improved and promoted as a model of urban water resources management.
- 6) **Disaster Management System:** The system will be established for crisis management in response to disasters especially flood and drought, preparation and early warning before and when a hazard strikes. This assists in quickly sending a disaster relief team to affected areas. The action plan includes war room establishment and linking all data using similar standards. Disaster warning networks are coordinated for immediate warning. A communication system is used for an early warning system for achieving comprehensive coverage. Area data for disaster is collected to precisely predict urgent

events. The system also helps analyse disaster relief and ICT for necessary relief items and equipment provision.

- 7) **Decision making system:** Currently, decision making of policy makers depends on data from several sub-systems without integration. It is necessary to have an instrument in place which manages data integratively in a form of Business Intelligence and DSS. These systems can classify data according to scenarios, covering all high potential situations, and other baseline data in and around affected areas for efficient and prompt decision making and solution of a crisis.
- 8) **Knowledge system:** The system aims to collect laws and regulations related to water management including baseline data survey to provide systematic and area-based indicators. Other knowledge can also be added to this system with no limits. Research outputs in water management are connected to the system so they can be quickly retrieved and searched for use in budget and socio-economic planning.
- 9) **Research system:** An analysis and research process which creates knowledge in water management especially standard, telemetering, data communication networks and data management system will be set up. The system emphasises the capability of equipment and standards in data collection which enables co-utilization. Reference values have similar standards when evaluating normal and crisis situation.

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4.4. Viet Nam

4.4.1. Introduction

In 2016, the El Nino phenomenon had the tendency to reduce gradually. It seems to have a fuzzy impact on Viet Nam's hydro-meteorological condition. The number of tropical storms and depressions, high temperature, number of floods and flash floods were equal or higher than in average years. However, unusual hydro-meteorological phenomena occurred and were recorded in 2016.

10 tropical storms/typhoons and 7 tropical depressions formed in the East Sea in 2016, more than in average years (5- 6 storms). They included four storms and one tropical depression which directly impacted Viet Nam (made landfall).

As a result of the number of tropical storms and cyclones, total precipitation was generally higher than normal in the highland and southern region with more hazards striking the country than usual. According to the report 2016 of the Central Steering Committee for Flood Prevention and Mitigation floods caused 264 people dead or missing, 431 people injured, and losses and damages amounted to about 175 million USD.

4.4.2. The flood season 2016

Availability of data

Data and information were collected from different sources:

National Center of Hydrology and Meteorology Forecasting (NHMFC);

Southern Center of Flood and Storm Control (SCFSC);

Viet Nam Mekong Committee (VNMC);

Others as the Southern Institute of Water Resource Research (SIWRR); Southern Institute of Water Resource Plan (SIWRP), Institute of Hydrology – Meteorology Science and Climate Change; and the provincial and central newspaper's websites.

Meteorological and hydrological conditions

From January to April 2016, the southern region had almost no rain. Precipitation started in May and by the end of August, rain concentrated mainly on the south west resulting in 10-30% total rainfall above average and increased during September and October to 20-60% more than normal. Figure 58 shows the rainfall distribution for one station in the Mekong Delta and one station in the Central Highlands

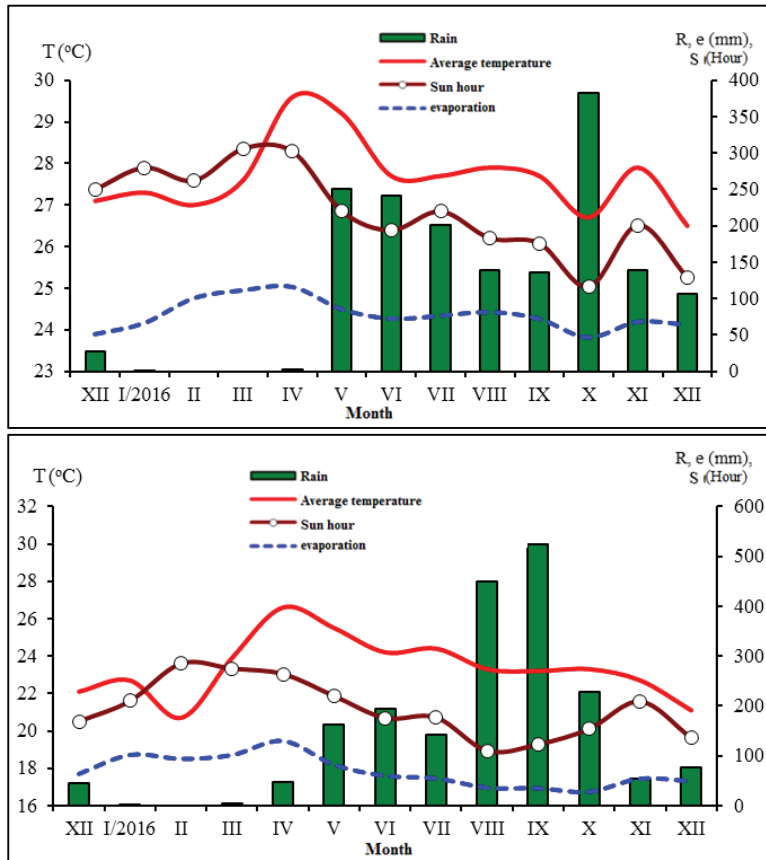


Figure 58: Rainfall and meteorological variables observed in Viet Nam, 2016

Precipitation in the Central Highlands concentrated on a short period from October to December which is remarkably late. Especially rain in December was exceptionally above normal. The three months brought five distinct flood events each causing severe hazards with a total rainfall depth of 1,000 mm within a few days and maximum intensities of 700 mm/day.

Flood hydrology of 2015

Water levels in the Delta at the main hydrological stations were consistently lower compared to average years. Originating from the heavy rainfall due to south-west monsoon wind, the Mekong Delta had to cope with four high flow periods, of which one coincided with high tide and caused the highest water level in 2016 in the upstream part of Viet Nam's Mekong Delta, but still ranked below normal.

In contrast, main stations in the downstream part of the Mekong Delta which is Dong Thap Muoi region, and Tu Giac Long Xuyen region, reached their highest peaks with 0.1-0.5 m above Alarm level No. 3 at the end of October,

4.4.3. Impacts of floods 2016

According to records, mainly from the Northern and Highland's mountain provinces, the impact of floods and flash floods can be summarised as follows:



In July 2016, floods and flash floods happened between 1st and 2nd of July in the Thai Nguyen province – a northern mountain province of Viet Nam. Thai Nguyen town and Dinh Hoa district were hardest hit.

(source: <http://vov.vn/>)



(source: <http://baohangiang.vn/xa-hoi/201607/lu-quet-lam-sat-lo-quoc-lo-4-3-xa-bien-gioi-cua-huyen-vi-xuyen-bi-co-lap-677374>)

In Ha Giang province – also located in the northern mountain province of Viet Nam – access roads and important connecting roads were washed away during storm Mirinae which brought abundant rain from 28 to 29 July. At Na Vang village, Po Ly Ngai commune, a landslide destroyed houses and people lost their lives buried under the mud. Total damage has been estimated at about 26 billion VND (1.15 million USD).



(source: National Center of Hydrology and Meteorology Forecasting, 2016)

Lao Cai province: Bat Xat and Sapa districts were hit by storm rainfall from 28/7 to 5/8 with 130 mm to 240 mm per day, triggering flash floods with severe damages.

Downstream of Dum stream, Bac Cuong ward, Lao Cai town was hit by mudflows up to 1 m depth. Also downstream of Xan stream, Quang Kim commune, a flash flood occurred and intensified rapidly resulting in serious damage to residential areas.

According to the preliminary records of the Central Steering Committee for Flood Prevention and Mitigation, 13 people were killed or are reported as missing, 4 houses collapsed on Bat Xat and Sapa districts; 156 people were isolated at Phin Ngang, Quang Kim, Coc San communes; further 10,000 ha rice were destroyed; around 300 cattle died.



On 20/8/2016, the Van Ban district in the Lao Cai province faced extreme landslides leaving 11 people dead and 7 people missing. Total damage is estimated at 70 billion VND (3.08 million USD).

(source:

<http://muongkhuong.laocai.gov.vn/huyenmuongkhuong/1264/28688/39379/241657/Tin-trong-tinh---Trong-nuoc/Lao-Cai--07-nguoi-chet-va-01-nguoi-mat-tich--thiet-hai-70-ty-dong-do-anh-huong-con-bao-so-3.aspx>)



Son La province: Due to adverse weather at the end of August 200 houses collapsed, 120 ha agricultural land were destroyed, 270 cattle were lost, 14 small bridges were washed away, 140 m length of canal was destroyed.

(source: Son La newspaper)



Thanh Hoa province: The Central Steering committee for Flood Prevention reported an unknown number of fatalities, 43 houses collapsed, 140 ha rice, 16 ha soybean, 8.5 ha sugarcane and 6 ha vegetable destroyed, 2.2 km of roads eroded, 3 dams and ponds failures in the Nhu Thanh district, Hai Long, Mau Lam, Phu Nhuan communes.

(source: <http://congly.vn/xa-hoi/doi-song/thanh-hoa-mua-lon-sat-lo-dat-gay-hau-qua-nghiem-trong-174166.html>)

Table 10: Summary of damages and losses in relation to floods, 2016, Viet Nam

Category	Item damaged	Unit	Total
People	Killed	Person	215
	Injured	Person	431
	Missing	Person	
	Affected	house	
Housing	Houses collapsed, drifted	No	2,636
	Houses submerged and damaged	No	
School	School collapsed	Room	
	School submerged and damaged	Room	
Hospital, clinics	Clinics collapsed	No	
	Clinics submerged and damaged	No	
Agriculture	Rice fields submerged	Ha	807,268
	Farms submerged, damaged	Ha	
	Fruit tree area	Ha	

Category	Item damaged	Unit	Total
	Food (salt) damaged by water	Ton	
Irrigation	Dyke damage	m	
	Small channel, river bank, ... damaged	m	107,186
Transportation	Land drifted	m3	
	Bridge, sewer collapsed	Unit	
	Roads damaged submerged	m	
Aquatic product	Shrimp, fish pool broken	Ha	
	Ships sunk, lost	Unit	
	Ships sunk, damaged	Unit	
	Total damage	10 ⁶ USD	1,737.7

Source: Central Steering committee for flood prevention and Mitigation Losses (2017)

All of the most affected areas are located in the northern mountain provinces (see Figure 59).

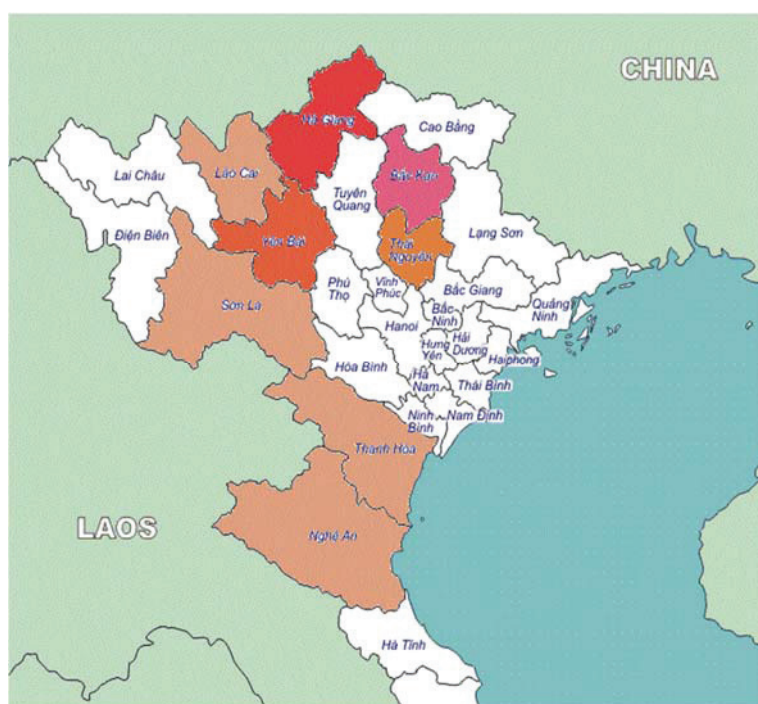


Figure 59: Provinces most affected by floods, Viet Nam, 2016

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5. CONCLUSIONS

2016 confirmed and continued the tendency of warming and ranks amongst the warmest years in history based on a reference period from 1910 to 2000. After 2015 and 2007, 2016 ranks third in the list of warmest recorded years. In contrast to temperature, rainfall turned out to range more or less close to average conditions.

The flood season 2016 started with a delay. From north to south up to Kratie, hydrographs started slowly and reached their maximum mid to end of September, just before the flow recedes again. The Mekong Delta and the contribution from the Cambodian plain and Great Lake, however, were below average, resulting in a peak discharge at Phnom Penh Port 25% less than average.

No warning levels were reached along the main reporting stations. In contrast to mainstream Mekong, some tributaries reached or exceeded defined warning or dangerous water levels.

Regarding flash floods, Luang Prabang observation station recorded high intensities. However, it is obvious that information from ground stations cannot fully cover all events. This is why the Flash Flood Guidance System (FFGS) was established based on satellite information.

The FFGS is a good example how new technology is successfully used for large areas when spatial coverage matters. In addition, it demonstrates the usefulness of satellite information in combination with modelling tools. In this regard, emerging technology has already arrived at MRC.

The theme of this 2016 Report is “Emerging technology to cope with flood”. This topic reflects the world-wide tendency towards internet-based applications and the steadily increasing number of methods and tools designed to capitalise on remote sensing information. It seems as if limits with respect to flood reconnaissance, flood forecast, flood prevention, emergency preparedness and flood recovery are by far not yet reached. Each new satellite program with better spatial and temporal resolution triggers new ideas and entails new hydrological applications.

At the same time, keeping track of all information and new releases is difficult and it is easily possible to get lost in the internet when looking for the right information and data. We can hope that the vast amount of data and tools sooner or later consolidate and the most favourable data sources and methodologies with respect to hydrology and more specifically flood remain at the top.

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