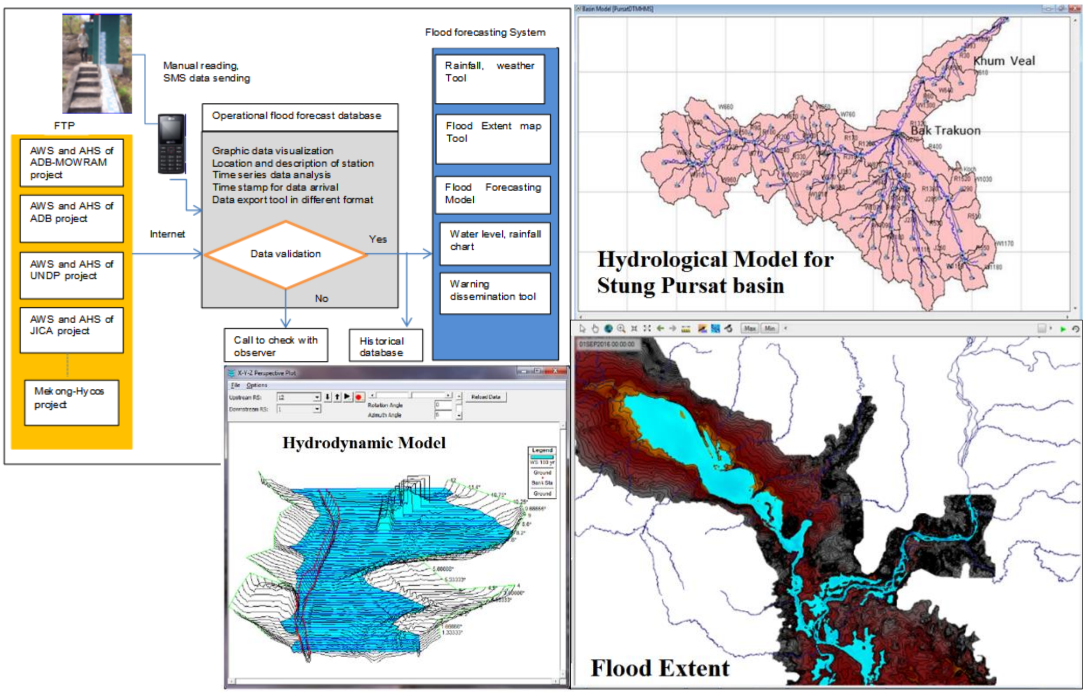
GREATER MEKONG SUB-REGION FLOOD AND DROUGHT RISK MANAGEMENT AND MITIGATION PROJECT

Consulting Services for Support to the National Flood Forecasting Centre and to Improve Hydraulic Design Standards

Contract Number: GMS-FDRMMP-CS-003

CONCEPTUAL DESIGN REPORT – FORECAST PRODUCTION AND DISSEMINATION



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July 2016

Document History

Version	Remarks	Date
Draft	Distributed among team for improvement	10 June 2016
Draft Report	Draft submitted for review	28 July 2016
Final Draft	Final Draft submitted for review	
Final	Incorporated all final comments from CPMU, PIU/DHRW, PIC and ADB	

Executive Summary

This report presents the Conceptual Design for a comprehensive "end to end" system with an objective to improve flood forecasts and drought predictions for Cambodia. The report focuses on key issues and provides a future vision for improving NFFC's analytical and modelling capability. The conceptual design considers flood and drought forecasting tools such as hydrological and hydraulic models as well as rainfall forecast models that support regional storm tracking and satellite based rainfall estimates.

The report highlights the flood and drought context within Cambodia and provides an overview of the physical features of the study area. The report presents a review and assessment of current weather and flood forecasting models as well as forecasting procedures and systems used by DOM and DHRW as well as those used at the regional level by the Mekong River Commission (MRC-FMMP). The review also includes an assessment of the current human resource capacity and available computer applications and hardware.

The conceptual design provides a plan for improvements to weather forecast operations including the selection of appropriate weather forecast models and seasonal climate prediction models. As well, the conceptual design proposes procedures for forecasting rainfall including satellite based rainfall estimates and appropriate hydrological and hydrodynamic models to forecast flood level, extent, and duration.

The conceptual design considers regional available weather products and forecast services based on Operational Numerical Weather Prediction Models and WMO's network of regional centres, such as the Japanese Meteorological Agency as well as regional storm tracking services available from the Regional Typhoon Centre.

The hydrological and hydrodynamic modelling needs consider the HEC Suite, developed by the US Army Corp of Engineers, as well as regional models used by MRC-FMMP. The conceptual design details the required staff, expertise, and training as well as operational budgets to operate, maintain, and enhance the forecast systems.

The report details the necessary investment in training and capacity strengthening within MOWRAM to operate and sustain the proposed design. The required investment in training and capacity strengthening for the project is estimated at US$ 200,000.

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List of Acronyms and Abbreviations

ADB	Asian Development Bank
AusAID	Australian Agency for International Development
AWS	Automatic Weather Station
BDP	Basin Development Plan
CBDRM	Community Based Disaster Risk Management
CBOs	Community-Based Organization
CNMC	Cambodian National Mekong Committee
CRC	Cambodian Red Cross
DEM	Digital Elevation Model
DIS	Database and Information System
DHRW	Department of Hydrology and River Works
DOM	Department of Meteorology
DSF	Decision Support Framework of MRC
DTM	Digital Terrain Model
EIA	Environmental Impact Assessment
EWS	Early Warning System
GFDRR	Global Facility for Disaster Reduction and Recovery
GMS	Greater Mekong Sub-Region
RGC	Royal Government of Cambodia
GTZ	German Technical Cooperation
ICT	Information and Communications Technology
IDPs	International Development Partners
IRBM	Integrated River Basin Management
IWRM	Integrated Water Resources Management
M-IWRMP	Mekong Integrated Water Resources Management Project

MOWRAM	Ministry of Water Resources and Meteorology
M&E	Monitoring and Evaluation
MRC	Mekong River Commission
MRC-RFMMC	MRC Regional Flood Management and Mitigation Centre
NFFC	National Flood Forecasting Centre
O&M	Operation and Maintenance
PEMSEA	The Partnership in Environmental Management for the Seas of East Asia
PIO	Project Implementation Office
RB	River Basin
RBO	River Basin Organization
RBU	River Basin Unit
SEA and SSA	Strategic Environmental and Social Assessment
SOP	Standard Operating Procedures
TA	Technical Assistance
TSA	Tonle Sap Authority
WB	World Bank
WBS	Work Breakdown Structure
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting
WUAs	Water User Associations

1. Introduction

1. The Royal Government of Cambodia (RGC) has received financial support from the Asian Development Bank to implement the Greater Mekong Sub-Region Flood and Drought Risk Management and Mitigation Project (GMS-FDRMMP), which is comprised of three components. The objective of Component 1.0 is to improve the National Flood Forecasting Centre (NFFC) and to propose climate resilient design guidelines for structural flood and drought mitigation.

2. The focus of the NFFC project is to support the RGC undertake structural and non-structural measures to forecast floods and droughts and to better mitigate the effect that these disasters cause. The objective is to strengthen the National Flood Forecasting Centre (NFFC) and to enhance regional data, information, and knowledge for the improved management of risks associated with floods and droughts. A complementary objective of the project is to propose climate resilient design guidelines for structural flood and drought control measures in Cambodia.

3. The Ministry of Water Resources and Meteorology (MOWRAM) is the Executing Agency (EA) and the Department of Hydrology and River Works is the Implementing Agency (IA) for the project. The Department of Meteorology is a key stakeholder and is actively engaged in the project.

4. This report presents a conceptual design for the conduct of flood and drought forecasting and for the issuing of early warnings by MOWRAM The conceptual design considers flood and drought forecasting tools such as hydrological and hydraulic models as well as rainfall forecast models that support regional storm tracking and satellite based rainfall estimates.

5. The report details the necessary investment in training and capacity strengthening to operate and sustain the proposed design. Recommendations on the institutional setup of NFFC and within the Department of Hydrology and River Works (DHRW) and the Department of Meteorology (DOM) are noted. The conceptual design considers improved coordination and the sharing of national forecast data in support of regional forecasting and vice-versa.

2. Flood and Drought Context

6. Cambodia (**Figure 1**) is situated in the south-western part of Indochinese peninsula, bordered by Thailand and Lao PDR to the North, Vietnam to the East and South, and the Gulf of Thailand to the West. The area of Cambodia is 181,035 km^2. About 75% of the country is located at elevations of less than 100 metres above mean sea level, and its topography can be grouped into three types:

(i) the low swampy region around Tonle Sap Great Lake and the rivers valleys of Mekong and Bassac River;

(ii) the mountainous and highland area including a plateau region in the northeast and east of the Mekong River; and

(iii) the coastal zone in the west covering the Kompot, Koh Kong, and Preah Sihanouk Provinces.

7. Cambodia's population is predominantly rural based and most of the population is subsistence farmers or fishers. As a result natural hazards have drastic effects on its population and pose a serious challenge for water resources management and poverty alleviation in the country.

Figure 1: Location Map - Cambodia

8. Floods, droughts, and extreme weather are the dominant hazards in Cambodia and cause loss of life, damage agricultural production, and threaten livelihoods.

9. The occurrence of significant flood events and periods of droughts has increased in recent years. The increase in these severe events tends to support climatic change predictions which suggest that there will be increased variability in the climate as the earth warms with an increase in the occurrence of more extreme weather events. The effect of any increase in extreme flood and drought events will directly affect vulnerable populations, exacerbate food insecurity, and result in an increase in related damages.

10. The monsoon season for the Mekong River basin typical begins in June and persists to late October. Rainfall during this period accounts for 80 to 90% of the total annual flow of the Mekong River (MRC 2010).

11. While annual floods have significant benefits, severe flooding can cause significant damage to communities, infrastructure, and agriculture crops; disrupt economic activities; endanger human health; and result in loss of life. Examples are Typhoon Ketsana in 2009, and Typhoons Haima and Nok Teng in 2011. The average annual cost of floods in the Lower Mekong basin is estimated to be US$60 to US$70 million.

12. An important consideration of floods in Cambodia is the transboundary nature of the Mekong River basin. Much of the floodwaters in Cambodia are derived from upstream countries, including Vietnam and Thailand, and in some provinces, floods and droughts occur simultaneously. Therefore, effective flood management hinges on regional cooperation, information sharing, and the development of region-specific solutions.

13. Unlike floods, droughts have less apparent benefits. Droughts can result in food and water shortages, loss of income, and higher levels of disease. Droughts are damaging to agriculture, especially rice, and can result in a total loss of crops, livestock, and fisheries. Given the relatively high frequency of severe drought in the Lower Mekong basin, the cost of droughts dwarf the cost of flooding while providing no apparent benefit. It is expected that the cost of droughts will continue to be greater than those of flooding as the climate warms.

14. MOWRAM, in its sub-decree on river basin management, has defined 39 river basins (**Figure 2, A**) which were grouped into 5 main major basin groups (**Figure 2, B**) under CDTA-7610, April 2014. The basin areas for each of these 39 sub-basins are summarized in **Table 1**.

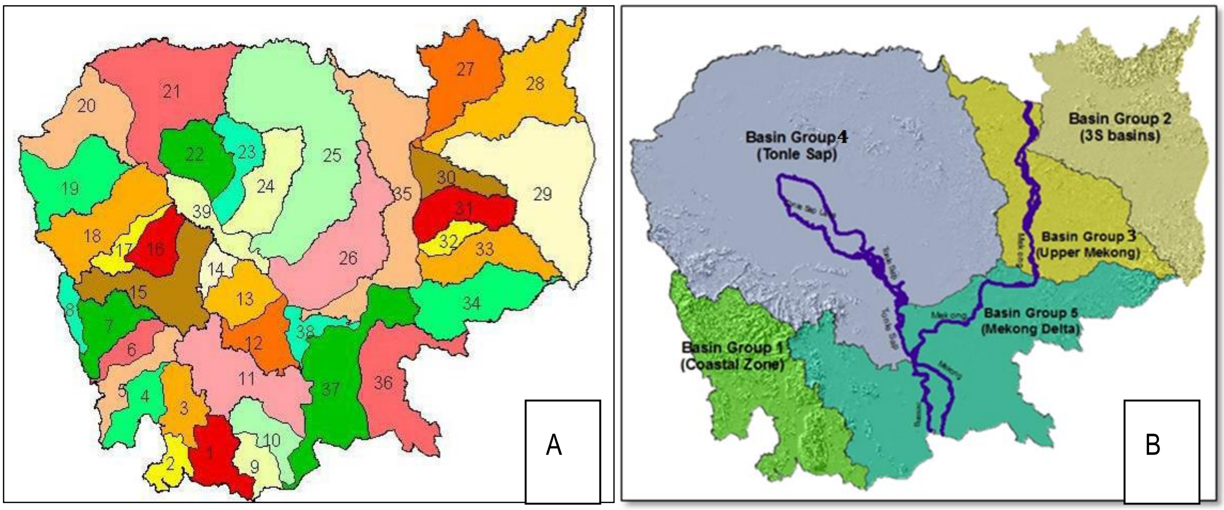


Figure 2: River Basins and Basin Groups in Cambodia

Table 1: Surface Area [km^2] by River Basin

Basin Group	Code	River basin	Area (km²)	Basin Group	Code	River basin	Area (km²)
I	1	Prek Kampong Bay	3,018	III	30	Prek Preah	2,399
	2	Prek Toek Sap	1,529		31	Prek Krieng	3,331
	3	Prek Sre Ambel	2,653		32	Prek Kampi	1,142
	4	Prek Andong Toek	2,460		33	Prek Te	4,363
	5	Prek Trapang Rung	2,615		35A	Mekong Riverine (Downstream)	8,287
	6	Prek Tatai	1,619			**Sub-Total III**	**19,522**
	7	Prek Koh Pao	3,109	IV	12	Stung Krang Ponley	3,033
	8	Stung Me Toek	1,043		13	Stung Baribour	3,003
		Sub-Total I	**18,046**		14	Stung Bamnak	1,116
II	27	Tonle Se Kong	5,564		15	Stung Pursat	5,964
	28	Tonle Se San	8,021		16	Stung Svay Don Keo	2,228
	29	Tonle Srepok	12,380		17	Stung Moung Russei (Dauntry)	1,468
		Sub-Total II	**25,965**		18	Stung Sangker	6,052
V	9	Stung Toan Han	1,765		19	Stung Mongkol Borey	5,264
	10	Stung Slakou	2,485		20	Stung Sisophon	5,593
	11	Stung Prek Thnot	7,055		21	Stung Sreng	9,931
	34	Prek Chhlong	5,599		22	Stung Siem Reap	3,619
	35B	Mekong Riverine (Upstream)	2,086		23	Stung Chikreng	2,714
	37	Mekong Delta Cambodia	8,723		24	Stung Staung	4,357
	38	Mekong TS flood plain (Spean Troas)	1,508		25	Stung Sen	16,342
	36	Tonle Vaico	6,618		26	Stung Chinit	8,236
		Sub-Total V	**35,839**		39	Boeng Tonle Sap	2,743
						Sub-Total IV	**81,663**
TOTAL = 181,035 km²							

2.1. Study Area

15. As requested by MOWRAM, the study area for improved flood modelling in support of forecasting and early warnings will be one tributary basin as well as the mainstream Mekong. This approach will enable the flood

modelling and drought prediction approach to be expanded in the future to all major tributaries in Cambodia, as resources permit. As well, the scope of the study area was discussed during the ADB Review Mission of April 05 to 11, 2016. The Aide Memoir of the mission notes that a hydrodynamic simulation model with a reasonable level of accuracy will be developed for the entire reach of the Mekong Tonle Sap and Bassac Rivers in Cambodia, and a pilot basin - Pursat River.

2.1.1. Pursat River basin

16. The Pursat River basin is located in the Pursat province in the southern part of the Tonle Sap Great Lake basin, and drains an area of 5,964 km^2 (**Figure 3**).

17. The Pursat River originates in the drier eastern slopes of the Cardamom Mountain Ranges and flows for approximately 150 km, ultimately draining into the Tonle Sap Great Lake. The basin ranges in elevation from 6 m to 1,717 m above masl (**Figure 3A**). More than 75% of the basin consists of hilly terrain with an elevation above 30 m masl. Two main tributaries, the Stung Peam and Stung Santre (Prey Khlong), flow in a northerly direction, and meet the Pursat River just above Bac Trakuon gauging station. The drainage area at Bac Trakuon, just below the confluence of the two tributaries with the Pursat River is 4,245 km^2. The drainage area increases to 4,596 km^2 farther downstream at the Khum Veal gauging station, located near the town of Pursat.

18. Forest covers some 74% of the area and agriculture production utilizes some 13% of the land area.

19. The Pursat River basin is affected by both a rain shadow and flood threat from the Cardamom Mountainous range. The Pursat River basin has a history of being a severely affected basin by both floods and droughts. The basin receives a mean annual rainfall of 1,390 mm. The maximum annual rainfall observed was 2,080 mm and the minimum was 870 mm. Rainfall amounts increase with basin elevation. The mean annual flow is 2,130 million cubic metres.

20. A number of dams and diversion (**Figure 3B**) have been constructed in the basin to support irrigated rice protection as well as to provide flood protection. The main diversion structures are Damnak Chheukrom and Damnak Ampil schemes, which capture excess water and surface runoff are divert these waters toward the Stung Kambot and Svay Donkeo rivers, which are located outside the Pursat River basin. During the high flood period, the flood affected area is larger than 5,964 km^2 i.e. it extends to Stung Kambot and some parts of Stung Svay Donkeo basins. From Bak Trakuon to Khum Veal, the Pursat River losses some 60% of its peak flood: partly through a diversion canal on the left bank (Damnak Ampil), channel storages and under natural conditions. The overbank flood passes through Stung Kambot, O Ta Poang, and Stung Svay Donkeo, which later flow to the Stung Dauntry before discharging into the Tonle Sap Great Lake.

21. During the raining season (south-west monsoon), from late May to November, the floods caused by runoff from the Cardamom range and rising water levels in the Great Lake frequently inundate the Pursat Town (e.g. in 1996, 2000, 2006 and 2011). During flood events, the water level in the river rises quickly and affects the riparian agricultural land, villages, infrastructure, and most significantly, Pursat Town. Moreover, during the wet season, the regular occurrence of severe drought spells between July and August also affects the basin. Severe droughts damage agricultural yields if they are over one month in duration. More details for floods and droughts are found in the **Appendix 1** - the Pursat River basin profile.

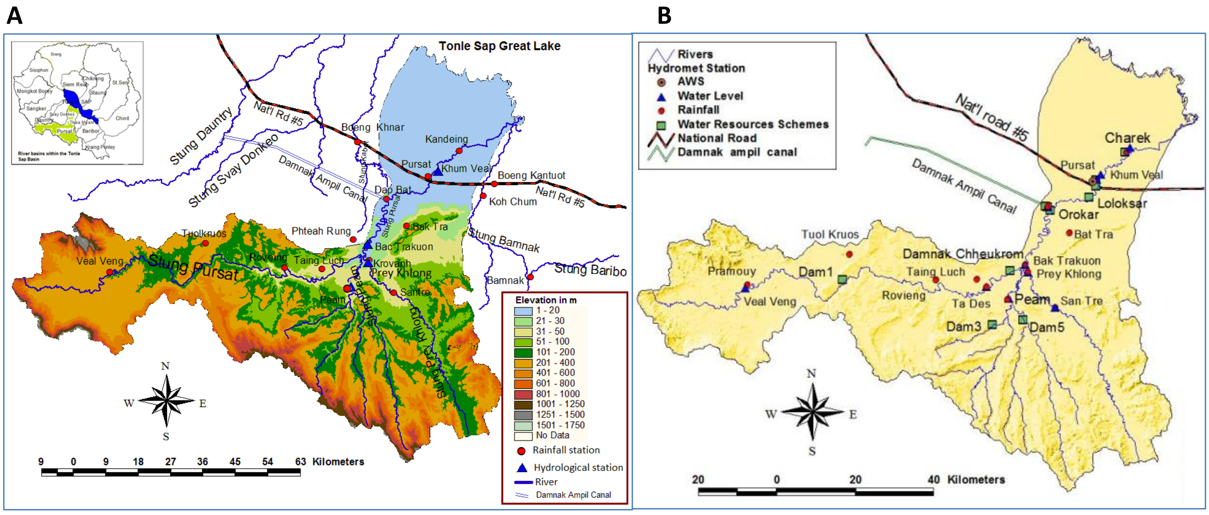


Figure 3: Location Map, Topography, Hydromet Network and Water Resources Development - Pursat River basin

2.1.2. Mainstream Mekong

22. The Mekong River flows through Cambodia for a total length of about 500 km before discharging into the Vietnamese Mekong delta. At the Phnom Penh-Chaktomuk junction (Quatre Bras), the Mekong River is hydraulically connected to the Tonle Sap Great Lake by the 120 km long Tonle Sap River. Downstream of Phnom Penh, the Mekong splits into two rivers, namely the Lower Mekong River, which flows into the South China Sea after crossing the Vietnamese Mekong delta, and the Bassac River, which also flows to the South China Sea. About 86% of Cambodia's land surface area is within the Mekong River basin (Figure 4), including the basins of the Bassac River, the Tonle Sap River, the Tonle Sap Great Lake, and the tributaries to the Great Lake.

23. The Mekong River can be divided into a number mainstream reaches (**Figure 4**):

24. **Reach 1** is the Mekong River from the Laos-Cambodian border to the town of Kratie. The major flow contributions to the Mekong mainstream in this reach come from the transboundary Se Kong, Se San, and Sre Pok basins, which discharge at Stung Treng. In total, over 25% of the mean annual flow volume of the mainstream Mekong River at Kratie comes from these three transboundary basins. There are two river gauging stations in this reach, one at Stung Treng and the other at Kratie.

25. **Reach 2** is the Mekong River from Kratie to Chroy Changvar (Phnom Penh), just upstream of the Chaktomuk Junction, where the Tonle Sap River joins the Mekong and the Bassac Rivers. The flow pattern in this reach is very complex during the flood season as hydraulic conditions define the flow distribution. The complexity includes downstream backwater effects that reverse the flow system of the Tonle Sap River, overbank and overland flow, temporary water storage on the floodplain, colmatage systems, and infrastructure controls. There are two river gauging stations in this reach, one at Kampong Cham and the other at Phnom Penh-Chroy Changvar.

26. **Reach 3** is defined as the Mekong River from Phnom Penh to the border of Cambodia and Viet Nam, with river gauging stations at Koh Norea and Neak Luong.

27. **Reach 4** includes the Bassac River from Chaktomuk Junction to the Cambodia–Viet Nam border with a river length of about 94 km. Downstream of the Chaktomuk junction, at about 9 km, the Bassac River receives water from the Prek Thnot basin. River gauging stations are located at Chaktomuk and Koh Khel.

28. **Reach 5** is defined by the Tonle Sap River and the Tonle Sap Great Lake. A river gauging station is located at Prek Kdam. At the beginning of the flood season, in late May, Mekong floodwater flows into the Great Lake via the Tonle Sap River. This reverse flow into the Great Lake from the Mekong River continues to early October until the water level in the Great Lake measured at Kampong Luong exceeds the level at Phnom Penh. At that time,

the flow in the Tonle Sap River changes direction and discharges water from the Great Lake to the Mekong and Bassac Rivers.

29. The Stung Treng, Kratie, Kampong Cham, and Phnom Penh are the key river gauging stations, which monitor upstream flows before the Mekong River is join by the Tonle Sap River.

30. Upstream of Kratie (Reach 1), the Mekong River generally flows within the well-defined mainstream channel. In all but the most extreme flood years, the channel has the capacity to contain the full discharge with only limited local over-bank flow to natural storage areas.

31. From Kratie to the sea (Reach 2 and onward), the Mekong River is affected by downstream hydraulic conditions during the flood season. During the dry season, tidal effects up to Kampong Cham influence the Mekong River. Seasonal natural floodplain storage dominates the annual flow regime. There is significant redistribution of water between channels, as the result of overland flooding and natural storage, the seasonal refilling of the Great Lake, and the flow reversal in the Tonle Sap River. Hence, water levels and hydraulic conditions determine the movement of water in these lower reaches of the Mekong basin and over the landscape.

32. During the flood season, floodwaters of the Mekong or the Bassac Rivers are diverted naturally at upper locations by a number of overflow branches, which return floodwaters to the Mekong or the Bassac Rivers further downstream. In Reach 2, at about 15 km downstream of Kampong Cham on the left bank, part of the Mekong flow is diverted into the Tonle Toch river, which then discharges back into the Mekong downstream at 4 km north of Neal Leung in Reach 3.

33. During the flood season when the flow of the Mekong River at Kampong Cham exceeds about 25,000 m^3/s, water spills over the banks of the Mekong River between Kampong Cham and Phnom Penh. Part of the spill on the right bank reaches the Tonle Sap Great Lake as overland flow and as such is not measured at Prek Kdam. The overland flow component contributing to the Tonle Sap Lake inflow varies from year to year depending on the flood magnitude. DHRW estimates that the overland flow varies from 2 % to 12 % of the total Tonle Sap Lake inflow volume.

34. The two main branches on the eastern part of the Mekong floodplain in Reach 3 are the Stung Slot and Prek Kampong Trabaek. These two branches divert flow from the Mekong River via the floodplain and discharge into the Soha-Caico River in Viet Nam, which later flows back to the Mekong River or is further diverted to the Plain of Reeds in Viet Nam. Flow measurements on these two branches are made along National Road #1, at the Stung Slot and Kampong Trabaek gauging stations.

35. The main tributaries in Reach 4 are the Prek Thnot and the Stung Slakou (Stung Takeo). The Prek Ambel branch on the right bank near Koh Khel of the Bassac River diverts flow from the Bassac River, which is later returned to the Bassac River upstream of the Stung Takeo river confluence near the Cambodian-Vietnamese border. Flow measurements on the Prek Ambel branch are made at Angkor Borey. Flow measurements on the Stung Takeo are taken at Kampong Ampil (Borey Chulsar).

36. The Tonle Sap River and the Tonle Sap Great Lake System functions as a natural storage reservoir for Mekong floodwaters. The area of the Great Lake increases from a dry season area of 2,500 km^2 to a typical flood season area of 15,000 km^2. During a typical flood season that average depth of the lake increases from 1 m to 6 – 9 metres. The volume of water held in the Great Lake is between 60 to 70 km^3 during the wet season and may be reduced to 1.5 km^3 during the dry season.

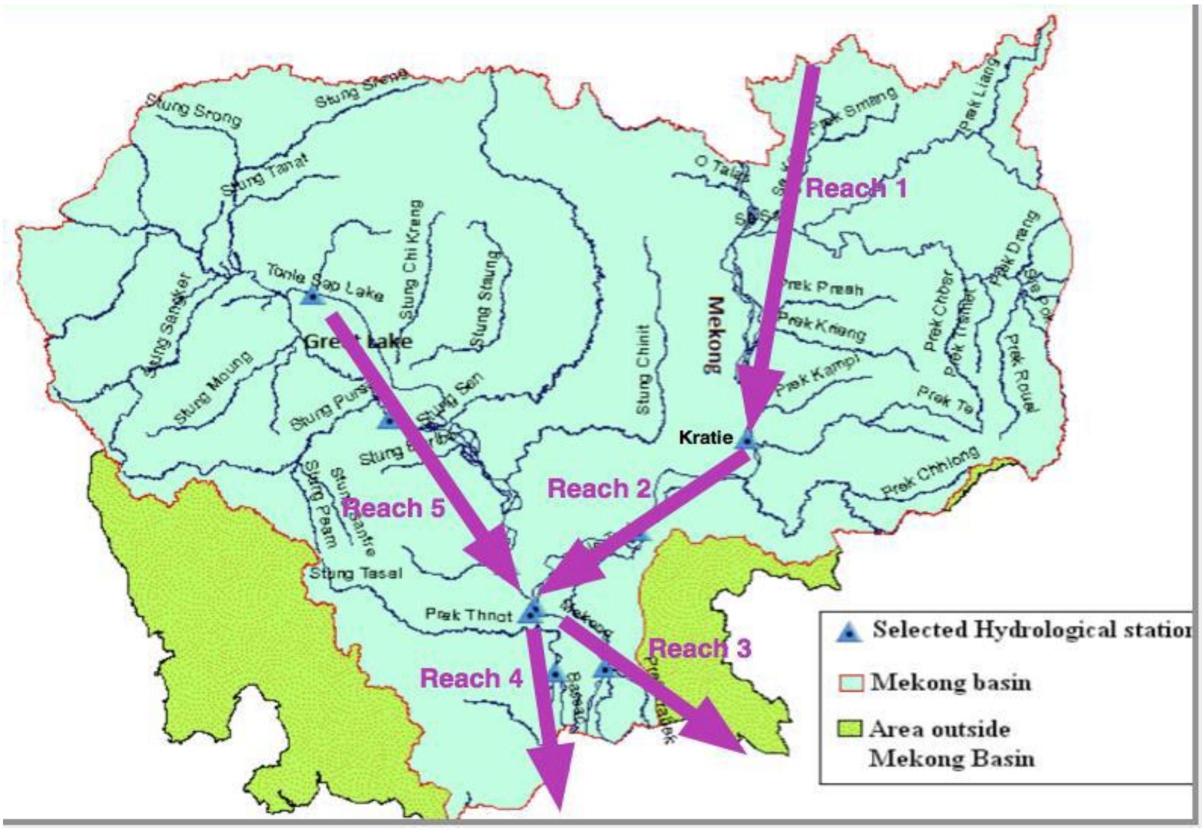


Figure 4: Mainstream Mekong, Bassac, and Tonle Sap Rivers in Cambodia. Source: ADB CDTA 2014

3. Institutional Setting

3.1 National Level

37. The Ministry of Water Resources and Meteorology (MOWRAM) was established in 1999 based on proclamation NS/RKM/0699108, dated June 23, 1999. MOWRAM is responsible for monitoring and managing all activities related to water resources and meteorology, and plays a key role in the mitigation of water-related hazards. It has the lead role for the implementation of the Law on Water Resources Management, 2007.

38. Article 26 of the proclamation requires MOWRAM, in the event of floods and droughts, to serve as Headquarters for the RGC in the execution of required actions in close collaboration with the Ministries concerned and local authorities.

39. In the Rectangular Strategy III 2009-2013 (2nd angle: water resources management and irrigation schemes), the RGC continued to strengthen and expand the mechanisms for observation/monitoring as well as for forecasting and disseminating of real-time hydrological and meteorological information, aim at ensuring crop safety and mitigating natural disaster event, especially from serious floods and droughts.

- Under sub-decree N58 dated June 30 1999, the Ministry of Water Resources and Meteorology was established with nine departments, which has grown to twelve. Two authorities report to the MOWRAM Minister, the Cambodian National Mekong Committee (CNMC) and the Tonle Sap Authority (TSA):The CNMC is a government body with members from 17 line ministries and committees and is chaired by the Minister of MOWRAM, assisted by a Secretariat. CNMC plays a crucial role in coordinating activities for the effective implementation of the 1995 Mekong Agreement, and the preparation and implementation of other related projects and programmes of Mekong River Commission (MRC) in the Sustainable Development Framework of Water and related resources in the Mekong River basin.
- The TSA's role coordinates the management, conservation, and sustainable development of the Tonle Sap region and relevant area, which includes Tonle Lake and the surrounding flooded forests and floodplains. Specific tasks are: to facilitate research on ecological systems, fisheries and irrigation potential; to develop policies, strategic plans, programs and projects; to facilitate the implementation of activities of all agencies; to monitor and evaluate the implementation of projects; to collect, analyze and update date and information; and to educate stakeholders.

40. MOWRAM's technical functions are within the Technical Affairs Directorate. In the Technical Affairs Directorate there are seven operational departments all supported by the Department of Administration and Human Resources (DAHR). The mandates of these seven departments are summarized as follows:

- Department of Water Resource Management and Conservation (DWRMC) – whose mandate covers laws and policies, strategic planning for multi-purpose use of water, basin planning, water allocation, efficiency of water use, regulations and standards, and research;
- Department of Hydrology and River Works (DHRW) – whose mandate covers all aspects of hydrological measurement and assessment, assessment of surface water and groundwater potential, river level and sediment monitoring, water quality monitoring, river bank protection, modelling, forecasting and warning, reporting, GIS system, and research;
- Department of Meteorology (DOM) – whose mandate covers all aspects of meteorological monitoring and assessment, atmospheric monitoring, forecasting and warning, reporting, international liaison, and research;
- Department of Irrigation and Agriculture (DIA) – whose mandate covers developing and restoring irrigation schemes, O&M of schemes and drainage works, assessing groundwater for irrigation development, saline intrusion in coastal areas, operating pumping stations, leading interventions for water related disasters, and support to FWUCs;

- Department of Engineering (DoE) – whose mandate covers design of works such as irrigation and drainage schemes and flood protection, management of equipment for construction, soil quality assessment for construction, and technological research;
- Department of Water Supply and Sanitation (DWSS) – whose mandate covers surface and groundwater source identification, planning for potable water source developments, planning for sewerage scheme development, and research; and
- Department of Farmers Water Users Committees (DFWUC) – whose mandate covers policy and legal documents, FWUC policy and strategy, irrigation system information, standards for O&M, support to establish FWUC and their operation, training, and technology development.

41. Two key departments involved with this component of the Greater Mekong Sub-Region Flood and Drought Risk Management and Mitigation Project are DHRW and the DOM.

42. DOM and DHRW within the MOWRAM manage the hydro-meteorological services in Cambodia. These two departments are responsible for collecting and disseminating hydro-meteorological information and are mandated to provide early warning to a range of stakeholders. The National Flood Forecasting Centre reports under DHRW.

43. DHRW was established in 1999. DHRW has 60 staff, who work in five different offices (**Figure 5**): Office of Administration, Office of Research and Flood Forecasting, Office of Water Quality Analyses, Office of Hydrological Works, and Office of River Bank Management.

44. The responsibilities of DHRW include:

- To prepare plans for the installation of hydrological stations for the operation of water related structures and water resource development;
- To prepare short, medium, and long-term strategic plans for erosion protection of riverbanks and the control of sedimentation;
- To conduct research and monitor surface and groundwater regimes by operating and managing a hydrological station network for the collection of water level, water discharge, and sediment data and information;
- To conduct water quality monitoring at key hydrological stations;
- To conduct studies related to hydrological phenomena and on surface and ground water potential;
- To manage the generation and exchange of hydrological information;
- To issue forecasts and early warnings of flood and drought events as per a national early warning strategy; and
- To maintain a geographical information system (GIS) of river basin features, hydrological networks, and the locations of water resources development infrastructure.

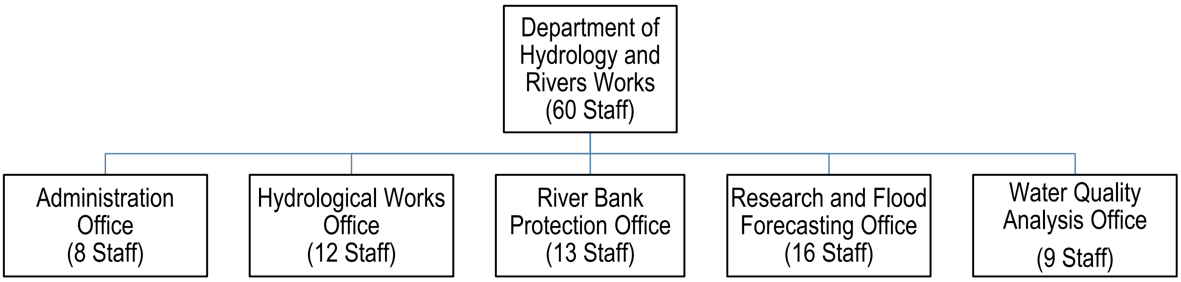


Figure 5: Organizational Chart for the DHRW.

45. DOM's mandate is to prepare short, medium, and long term plans for rehabilitation and development of meteorology capabilities within the country. Specific responsibilities include:

- To establish and operate the Cambodian meteorological observing network;
- To prepare annual reports on meteorology events and conditions in the Kingdom of Cambodia;
- To provide daily and seasonal weather forecast for all sectors dependent on weather;
- To predict severe and extreme meteorological events and to issue alerts and warnings;
- To raise awareness and knowledge of weather phenomena; and
- To strengthen and broaden the Cambodian cooperation with regional meteorological organizations, United Nation agencies, and the World Meteorological Organization.

46. To fulfil this mandate, DOM collects, processes, catalogues, and disseminates meteorological data and information as well as issues weather forecasts and seasonal predictions, including severe and extreme weather warnings and alerts.

47. There are 41 staff working in five offices within DOM (**Figure 6**): Office of Administration, Office of Research and Forecasting, Office of Climate, Office of Observation, and Office of Equipment Management.

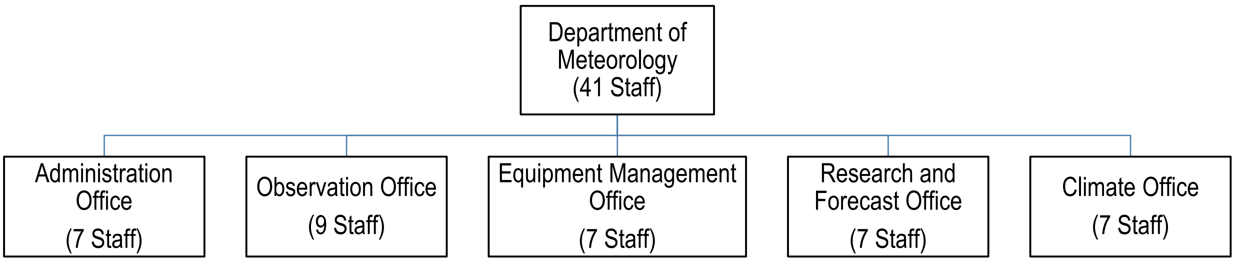


Figure 6: Organizational Chart for the DOM

48. MOWRAM has Departments in each Province known as Provincial Department of Water Resources and Meteorology (PDOWRAM). The functions of the Provincial Departments are:

- Planning and organizing the development program of the Ministry at province level;
- Operation and maintenance of major irrigation works;
- Management of FWUCs and other farmer bodies with responsibility for supporting irrigation scheme operation and maintenance;
- Management of the collection of ISF (by FWUCs) and control of expenditure from the ISF account;
- Oversight for construction of irrigation and flood protection works at the provincial level; and
- Minor procurement and disbursements associated with construction projects.

49. A June 2012 staff survey reported that the Ministry had 1,258 staff, of which 633 were in the central office departments, and 625 were in the PDOWRAM offices.

3.2 Regional Level

50. With much of its land being within the Mekong River Basin (MRB), water governance in Cambodia must take place in the context of the 1995 Mekong Agreement. This defines the scope of activities and cooperation related

to coordinated and joint planning for balanced and socially just development in the MRB, while protecting the environment and maintaining the ecological balance. The Mekong River Commission (MRC) is therefore a key player in the management of water resources in the MRB parts of Cambodia.

51. The MRC has a long and successful history. Its regional cooperation continues to reduce the risks of regular flooding and to promote the beneficial effects of the annual flood pulse. The mandate and role of the MRC under its Flood Management and Mitigation Program (MRC FMMP) provides a regional context for the activities to strengthen the National Flood Forecasting Centre.

52. The 1995 Mekong Agreement sets a framework for the achievement of IWRM strategic objectives, recognizes that development decisions by sector agencies in the sovereign riparian countries of the MRB may have transboundary consequences, and that the MRC as an inter-governmental river basin organization is reliant on the endorsement by the Member Countries of its activities.

53. Article 1 of the Agreement calls for "cooperation in all fields of development, utilization, management and conservation of water and related resources to optimize the multiple use and mutual benefits and minimize the harmful effects".

54. Ultimately, the objective of cooperation among Member Countries is to promote an optimal and well-balanced development of the Mekong River Basin, while ensuring the equitable sharing of benefits among all users of basin water and related resources, and preventing any harmful effects from hindering the continued functioning of the Mekong River systems and so ensuring the continuation of the multi-generational benefits that the Mekong River Basin brings to all its people (Article 1).

55. To ensure the cooperation among the MRC member countries for the sustainable development of the Mekong River Basin, and to support the implementation of the 1995 Mekong Agreement, the MRC Council adopted five core procedures, which are linked. The core procedures are:

- Procedures for Data and Information Exchange and Sharing (PDIES);
- Procedures for Notification, Prior Consultation and Agreement (PNPCA);
- Procedures for Water Use Monitoring (PWUM);
- Procedures for Maintenance of Flows on the Mainstream (PMFM); and
- Procedures for Water Quality (PWQ).

4. Current Status of Existing Flood and Weather Forecast Systems

4.1 National Level

56. In Cambodia, there are two departments under MOWRAM who take responsibility for the flood and weather forecast system (FWFS) at the national level. These are DHRW, which is the main agency responsible for flood forecasting, and DOM, which is responsible for public weather forecasts and provides alerts for extreme weather events.

4.1.1 Weather Information, Forecasts, and Dissemination

4.1.1.1 National Meteorological Services

57. DOM is responsible for monitoring weather conditions in the country and region and issuing weather forecasts and Tropical Cyclone Warnings to inform the public of impending hazards.

58. At DOM, there are 41 staff in total working in five offices namely: i) Administration Office; ii) Meteorological Observation Offices; iii) Meteorological Equipment Management Office; iv) Weather Forecasting Office and v) Office of Climatology. The educational qualification of the staff varies from Master to non-technical support: there are 5 staff holding the Master degree; 6 engineers (B.Sc. In Engineer); 16 BSc. in Techniques (B.ST); 9 preliminary technicians and 5 support staffs. Among those staff only 28 claimed to be meteorologists (4 masters; 15 BST and 9 preliminary technician) and the rest 13 staff do not have a meteorological education. Seven staff of the Weather Forecasting Office (WFO) are work on the monitoring and forecasting tasks.

59. At provincial level, meteorological services are operated within the PDOWRAM. Each PDOWRAM has one Hydromet unit, which is in charge of the provincial synoptic station located within the compound of each PDOWRAM and a rainfall station within the province.

60. DOM continuously monitors the meteorological observation network, satellite images, and weather charts in support of a forecast of daily weather and the tracking of cyclones.

61. The public telephone, facsimile, and e-mail are used for delivering the weather forecast and Tropical Cyclone Warnings to government and private sectors. DOM issues a weather bulletin to MOWRAM, who releases the weather bulletin to the public through TV, radio, and newspapers. In the case of urgent warnings, DOM provides an announcement to MOWRAM, and MOWRAM advises the Prime Minister. The Minister of MOWRAM and/or the Director of DOM makes live announcements of warnings on television and radio. As well, DOM sends warnings to the National Committee for Disaster Management (NCDM), Cambodian Red Cross (CRC), and the mass media.

4.1.1.2 Meteorological Data Networks

62. DOM reported[1] that its observing network is composed of 35 weather stations providing coverage for all 25 provinces of Cambodia. Of the 35 stations, 26 are Manual Weather Stations (MWS) installed in the main towns of each province including Phnom Penh. As well, 26 Automatic Weather Stations (AWS) have been installed: 17 AWSs are located with the MWSs and the remaining 9 AWSs are installed in the main district centres located in the Tonle Sap Great Lake basin. The manual stations observe meteorological parameters twice per day at 07:00 and 19:00. Most stations report data on mean, maximum, and minimum air temperature and rainfall. In 2015 there were some

[1] Confirmed by Mr. Sam Oeun Soknara, Chief Administrative Office of DOM through communication on 07 April 2016

193 manual rainfall stations managed by DOM. However, many of the rain gauges lack maintenance and are non-operational. Cambodia has no upper air stations.

63. In February 2012, a Doppler radar station "Doppler Weather Radar Meteo 650C" was installed in Phnom Penh at MOWRAM headquarters. The Doppler radar is equipped with 3 ranges: 80 km, 240 km and 450 km, which covers all of Cambodian. The radar improves DOM's ability to observe the spatial development of storms for improved severe weather forecasts. The Doppler radar rainfall estimate has not been verified with ground rainfall observations, hence limiting its reliability for now-casting rainfall.

64. DOM has a ground satellite receiving system and is connected to Bangkok through GTS. DOM receives and transmits meteorological data according to WMO requirements.

4.1.1.3 Data Transmission and Management

65. Data collection and transmission from the synoptic stations is reliant on HF radio communication and telephone calls from DOM to observers. Weather observations for synoptic stations are sent to DOM once per day after the 07:00 AM observation and in paper form at the end of the year.

66. With the support of MRC, under its flood management program, rainfall data for 30 stations are sent daily to DOM via the mobile SMS network.

67. Data from the DOM's AWS are received by the MRC's Regional Flood and Mitigation Centre using the HYDMET software. These data are then made available to DOM through Centre's 'FTP' server. DOM does not have a structured database and uses MS Excel for their data storage, which limits further data checking, processing, and collating.

4.1.1.4 Weather Models and Modelling Environment

68. DOM doesn't run a Numerical Weather Prediction (NWP) model[2] but the department receives a suite of forecast products from different Global and Regional forecasting centres. By using licensed software, such as Synergie and Rainbow, the DOM Office of Research and Forecasting has customized some products and has made them available to the public and stakeholders. DOM also makes use of satellite images, which they receive from the Japan Meteorological Satellite 'Himawari', to prepare their forecast. DOM uses information from the Radar for now-casting (<6hours), which was commissioned at Phnom Penh in 2012.

69. The following sections highlight major model outputs from various centres, which is available to DOM. Of those NWP outputs, some are freely downloadable and others are provided exclusively to DOM by the corresponding forecast generation agency.

City specific NWP Products from Hong Kong Observatory

70. Location specific NWP products based on the model output of the Hong Kong Observatory Non Hydrostatic Model (NHM) system is being provided for 22 cities in Cambodia. The horizontal resolution of the model is 10 km and the forecast for the city uses the model grid nearest to the corresponding city location. The graphs are available for time series and for time cross-sections. The meteorological parameters provided in the city specific forecast time series are MSLP, surface air temperature, surface dew point temperature, surface relative humidity, surface wind speed and direction, total cloud cover, and 1 hour accumulated rainfall. Meteorological elements shown by the forecast time series charts are given in hourly intervals from 1 to 72 hours.

[2] Confirmed by Mr. OUM Ryna, DOM Director, on 04 May 2016.

71. Those shown by the forecast time cross-section are given in 3-hourly intervals from 3 to 72 hours. The NWP products are updated twice daily at 0530 UTC and 1730 UTC based on the model initial time at 0000 UTC and 1200 UTC respectively. By analysing the NWP product from HKO, DOM forecasters generate specific location forecasts for a short-range scale. A sample of the forecast time series graph for Bantey Meanchey is provided in **Figure 7**.

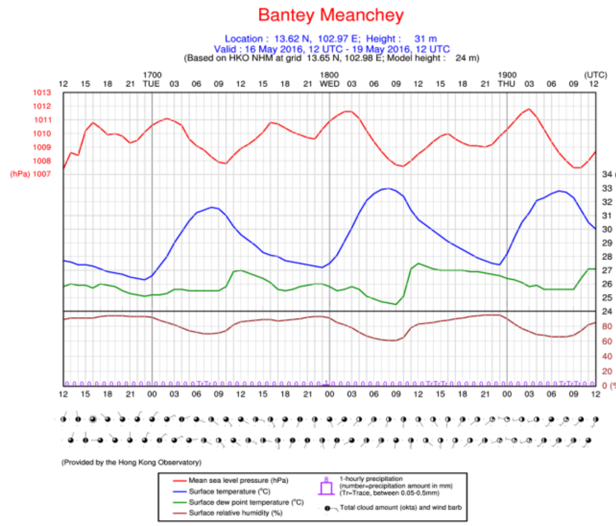


Figure 7: NWP Products from Hong Kong Observatory

Global Forecasting System (GFS) output from the National Center for Environment Prediction (NCEP), USA

72. The GFS forecast is available to the public and can be downloaded from their website http://www.ftp.ncep.noaa.gov/data/nccf/com/gfs/prod. The product is available with a lead time of 16 days (0.5º lat/lon and 4 time cycles per day) at an interval of 3 hours for the next 10 days and every 12 hours from day 11 to day 16. The products are available for three horizontal resolutions; 0.25º lat/lon, 0.5º lat/lon, 1.0º lat/lon and 2.5º lat/lon. Currently 0.5º lat/lon output for 7 days is integrated with the Synergie system of DOM.

Meteo France (ARPEGE)

73. The Meteo France global forecast model output is not available to the public. However, DOM can access the ARPEGE global products. Currently, 72-hour forecast with a horizontal resolution of 1.5º lat/lon has been integrated with the Synergie system. The following meteorological variables are available to the forecasters: pressure, height, potential velocity, cloud cover, temperature, geo-potential, mean sea level pressure, total precipitation, wind speed, and Key Index (KI).

Regional Forecasting Support Centre (RFSC), Hanoi

74. As part of WMO's Severe Weather Demonstration Project (SWDP) to strengthen the capacity of National Meteorological and Hydrological Services to deliver improved forecasts and warnings, Cambodia receives a number of forecast products through 'login access' from RFSC, Hanoi. The forecast products available are:

- Guidance products for short and medium range information;
- Satellite based products such as images, rainfall (Gsmap), storm track etc.;
- Global and regional NWP products (GSM, GFS, NAVGEM, ICON, COSMO, WRF);
- Global EPS products; and
- Regional EPS products.

European Centre for Medium Range Weather Forecasts (ECMWF)

75. As a WMO member country, Cambodia can access (through login) a suite of weather products from ECMWF. The products cover short range to seasonal forecasts. All products are available in chart form. ECMWF forecast products are considered to be one of the best in the world. The products available to DOM are as follows:

- **Medium-Range Forecasts -** ECMWF uses an ensemble of 52 individual ensemble members and integrates them twice a day. One ensemble is at a higher spatial resolution than the others (HRES). Its initial state is the most accurate estimate of current conditions and the ensemble uses the best model physics.
- **High Resolution Model forecast charts (HRES) (10 days) -** The HRES model outputs (medium range forecast) available to DOM from ECMWF web site are mean sea level pressure, wind, geopotential height, temperature, relative humidity, vorticity, divergence, wave period, wave height, ocean wave height, etc. These products function as forecast guidance when preparing forecast bulletins and warning messages. These products are provided as charts and an examples is provided in the **Figure 8** (significant wave height and mean direction over the ocean). Similarly, one can down load other parameters. These forecast products are updated twice daily at 0000UTC and 1200 UTC.

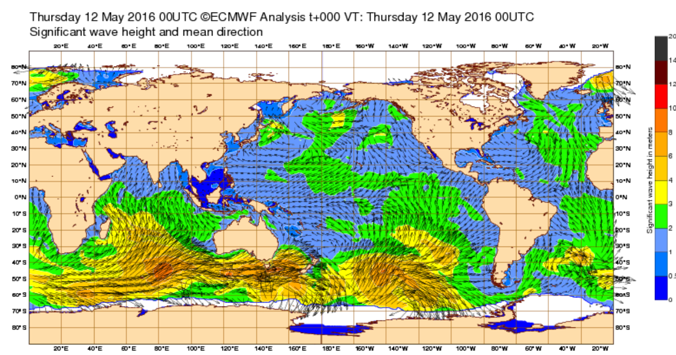


Figure 8: ECMWF High Resolution Model forecast charts

- **Extreme Forecast Index (EFI) -** The Extreme Forecast Index is an integral measure of the difference between the ENS (ensemble) forecast distribution and the model climate distribution. The model climate is constructed by re-running the current model version on past dates. These measures of extreme information is available to DOM. EFI allows the abnormality of the forecast weather situation to be assessed without defining specific (space- and time-dependent) thresholds. The EFI takes values from -1 to +1. If all the ENS members forecast values above the model climate maximum, EFI = +1; if they all forecast values below the model climate minimum, EFI = -1.
- Experience suggests that EFI magnitudes of 0.5 - 0.8 (irrespective of sign) can be generally regarded as signifying that "unusual" weather is likely, while magnitudes above 0.8 usually signify that "very unusual" or extreme weather is likely. Although larger EFI values indicate that an extreme event is more likely, the values do not represent probabilities as such. The EFI products are available for the parameters temperature (2m), wind and wind guests at 10 m height, and for precipitation (**Figure 9**). This product is extremely useful information for forecasters to develop a EWS and is updated twice per day and is valid for upto 5 days.

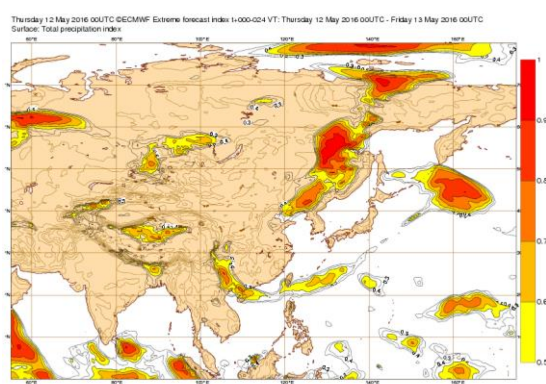


Figure 9: ECMWF EFI - precipitation

- **Significant Wave height Probabilities -** This statistical product from the ECMWF (**Figure 10**) is a useful tool for the forecaster to warn the coastal region in terms of wave height probability. The probabilities are based on the number of forecast ensemble members which meet the criteria (each member is assigned an equal probability of 1/50). The probability product is valid for 24 hours and is updated daily twice by ECMWF. This product can be used to warn people living in the coastal belt of Cambodia particularly during the monsoon period (during the monsoon period, coastal areas of Cambodia experiences strong westerly to south westerly wind) and during cyclonic activities in the gulf of Thailand.

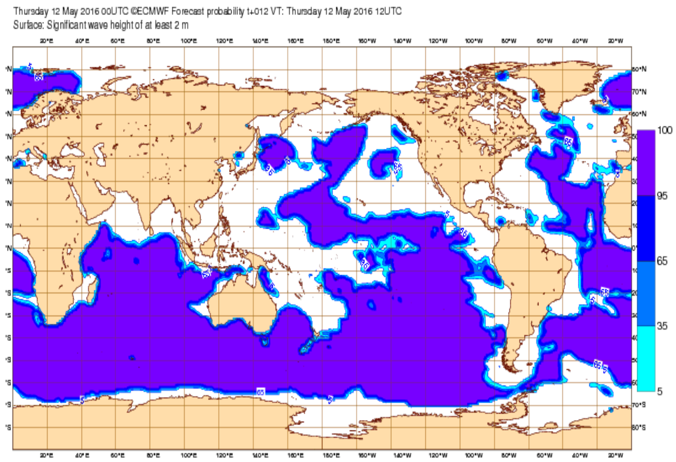


Figure 10: ECMWF Significant Wave height Probabilities product

- **Ensemble Mean and Spread -** These charts (**Figure 11**) are updated once every 12 hours at 0000 UTC and 1200 UTC. Each chart header is labelled with the date and time when the ensemble forecasts were initiated (D0), which will be 00UTC for the 08:30 UTC update, and 12UTC for the 20:30 UTC update. Each map is valid for a date between D0 + 1 and D0 + 10 days, which is indicated in the chart header by VT (=Valid Time) and which can be adjusted using drop down menus above the plot (grey boxes). Additional drop down menus enable the user to change parameter and geographical region. The charts are available for mean sea level pressure,850 hPa temperature,850 hPa wind speed, and 500 hPa geopotential height. One 'ensemble forecast' consists of 51 separate forecasts made by the same computer model, all with the same starting time. The starting conditions for each member of the ensemble are slightly different, and physical parameter values used also slightly differ. The differences between these ensemble members tend to grow as the forecasts progress, that is as the forecast lead time increases. This chart are a very useful tool for a forecaster to develop confidence in preparing forecast bulletins.

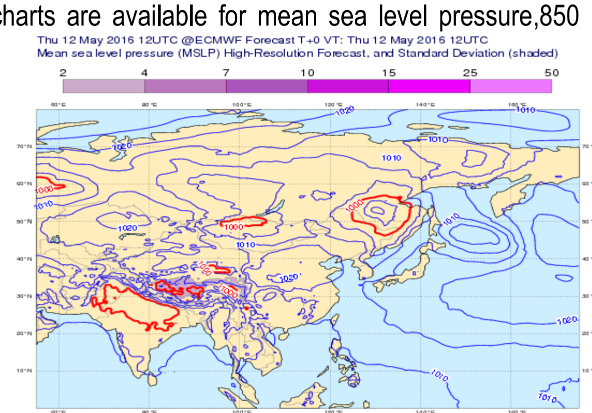
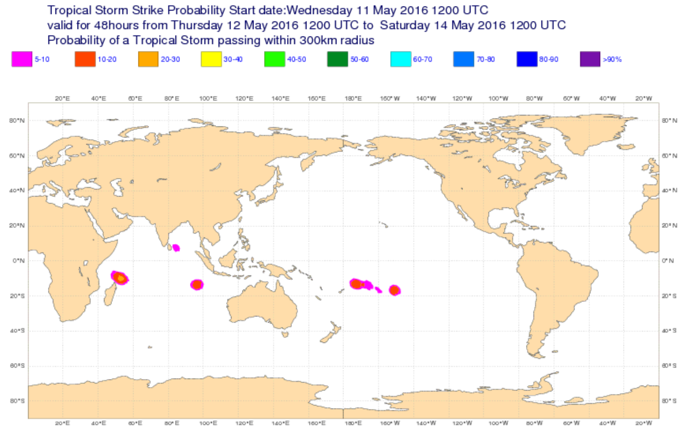


Figure 11: Ensemble Mean and Spread Charts

- **Tropical Cyclone Activities (including Genesis) -** This product shows the potential tropical cyclone activity at different time ranges during the forecast. It includes both tropical cyclones that are present at analysis time and those which may develop during the forecast. The maps (**Figure 12**) show the "strike probability" based on the number of ENS members that predict a tropical cyclone, each member having equal weight. The strike probability is the probability that a tropical cyclone will pass within a 300 km radius from a given location and within a time window of 48 hours.



This information provides DOM a quick assessment of high-risk areas allowing for some uncertainty in the exact timing or position. The strike probabilities are generated for three storm categories; tropical cyclones (> 8 m/s), tropical storms (> 17 m/s) and hurricanes/typhoons (> 32m/s). This product is updated twice per day and is available to Cambodia.

Figure 12: Map of potential tropical cyclone activity

- **ENS Meteograms -** The Ensemble (ENS) Meteogram (**Figure13**) provides weather parameter time evolution for high resolution (HRES), and ensemble (ENS) forecasts for a given location. The ensemble mean of the parametes are also provided in the meteogram. The 10-day meteograms provide forecast distributions at 6-hour intervals up to day 10 for 4 parameters namely cloud cover, precipitation, wind speed, and temperature. These meteogram charts are available for 11 stations in Cambodia. The locations are Bantey Meanchey, Kandal, Koh Kong, Kompomg Cham, Kompong Speu, Kompong Thom, Kompot, Phnom Penh, Preh Vihear, Prey Veng and Sihanouk Ville.

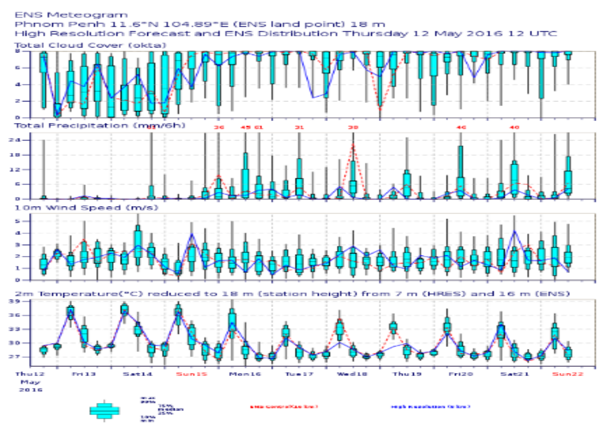


Figure 13: ENS Meteograms

- **Seasonal Products –** In addition to short to medium **r**ange products, ECMWF provides extended range products such as monthly and seasonal products. Such products can be used as an excellent tool to forecast the weather in the coming season. This product is updated monthly. **Figure 14** provided aside is the average rainfall for the months of September, October, and November 2016 and is predicted in May. This ensemble forecast can be used to predict the coming season in a probabilistic format. Other types of seasonal forecasts are avaiable in the form of climograms and Nino plumes.

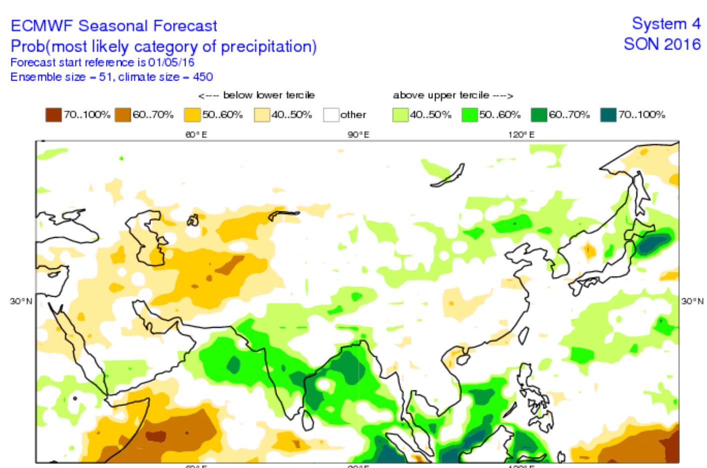


Figure 14: ECMWF seasonal forecast products

76. Although a number of seasonal and medium range forecast products are generated by ECMWF, not all of them are available to DOM. However, the above-mentioned ECMWF forecast products are available to DOM and are integrated into the Synergie system.

Japan Meteorological Agency (JMA)

77. A suite of forecast information is available from JMA ranging from 0.25 degrees to 1.25 degree resolution for up to 10 days. Some meteorological parameters are integrated into the Synergie system

4.1.1.5 Dissemination

78. DOM issues a daily weather forecast bulletin, which is sent to relevant agencies including NCDM and CRC and the national television and radio media. The bulletin is comprised of two parts - a general weather outlook for three relief zones and a 3-day forecast for cities and provincial towns. The forecasted elements are rainfall, air temperature, wind direction, and wind speed. For the coastal cities and provinces, sea wave and water temperature information is also included.

79. The DOM Director or the Officer-in-Charge approves the daily bulletin, while warnings for severe events are approved and signed by the MOWRAM Minister, who briefs the Prime Minister. The Prime Minister announces the warning on national television. National and municipal radio stations frequently broadcasting the warnings several times throughout the day.

80. Weather forecasts and warnings are also disseminated via the DOM website: http://www.cambodiameteo.com. The website provides the 3-day weather forecasts for each city and provincial town, 3-day outlook warnings, radar and satellite images, and forecast products for fisheries, roads, and tourism.

4.1.2 Flood Monitoring, Forecasting, and Dissemination

4.1.2.1 National Hydrological Service

81. DHRW is the agency responsibility for flood monitoring and forecasting. DHRW is organized in to five offices under a Department Director: 1) Administration Office; 2) Hydrological Works Office; 3) River Works Office; 4) Research and Flood Forecasting Office and; 5) Water Quality Analysis Office.

82. In total there are 60 staff working at the DHRW Phnom Penh office. Six staff in the Office for Research and Flood Forecasting (ORFF) perform the flood monitoring, forecasting, and disseminating activities. At the provincial level, hydrological services are operated within PDOWRAM.

83. Flood forecasting is done only in the flood season from 1st June to 30th November. During the flood season, 1 to 3 forecasts are issued daily for seven mainstream stations along the Mekong, Tonle Sap, and Bassac rivers. There are four stations on the Mekong river: Stung Treng, Kratie, Kampong Cham and Neak Luong, two stations on the Bassac river: Phnom Penh (Chank Tomuk) and Koh Khel, and one station on the Tonle Sap river: Prek Kdam. DHRW does not provide a flood forecast for the tributaries, which can experience flash floods caused by tropical storms such as Pabuk in 2007, Ketsana in 2009, a tropical depression in 2011, and recently Wutip in October of 2013.

84. DHRW issues two hydrological products: a water level bulletin containing observations, which is issued daily to the senior ministry officials just after 07:00 am, and a flood bulletin, containing the 07:00 AM observations and 07:00 AM forecasts for the next 3-days, which is issued by 08:30 AM.

85. The flood bulletin is disseminated to about 40 to 50 addressees, including senior ministry officials, media, provincial agencies, and NGOs. The provincial departments of MOWRAM are asked to provide reports of flood occurrence and impacts. The information is exchanged via radio, facsimile, and mobile phone.

4.1.2.2 Hydromet Data Networks

86. DHRW operates the hydrometric network with support from the government budget and the MRC. DHRW reports that due to insufficient operational budgets about 40[3] of the 123 hydrometric stations are operational. Most of the hydrometric stations provide only water level observations. Some discharge measurements are made at stations on the mainstreams and on few tributaries.

87. As reported by DHRW, twelve of the 40 operational hydrometric stations are equipped with automatic data recorders with real-time data transmission under the Mekong HYCOS project. Of the twelve auto-stations, four stations are located on the Mekong mainstream and Tonle Sap Rivers. The remaining eight stations are located on the main tributaries of the Mekong River and Tonle Sap Great Lake.

88. With support under the MRC Flood Management and Mitigation Program (MRC FMMP), improvements to data collection at 15 hydrometric stations have been made. Observations are made at 07:00 and 19:00 and the data are transmitted by 07:00 AM to the HYDMET data system at DHRW in Phnom Penh and shared with the Mekong River Commission riparian countries. Rainfall data is collected once per day for the past 24 hours at 07:00 AM.

4.1.2.3 Data Transmission and Management

89. Data collection and transmission are reliant on telephone calls from DHRW in Phnom Penh to observers, except for the telemetry equipped HYCOS stations. Staff of the Office of River Flood Forecast (ORFF) telephone observers at 07:00 AM. In total fifteen observers along the mainstream and main tributaries are called. Rainfall data is collected once per day. As well, DHRW in Phnom Penh receives water level data for upstream stations from the Mekong River Commission.

90. In 2015, JICA supported the installation of six hydrometric auto-stations with telemetry under the River Basin Water Resources Utilization Study Project of Tonle Sap Great Lake. The project also established a number of manual hydrometric stations, where data is sent using SMS messaging. The six JICA supported stations are at Bak Trakuon, Andeuk Haeb, Bassac Reservoir, Prek Am, and Ta Des.

91. Parallel to the manual data collection from the noted 15 stations, real-time water level data from 18 telemetry stations, twelve under HYCOS and six under the JICA's River Basin Water Resources Utilization Study Project on Tonle Sap Great Lake are received.

92. All water level data for the fifteen manual stations, seven on the mainstream, six stations on the Tonle Sap River and Tonle Sap tributaries, and two stations on the Se San and Sre Pok, are entry into an Excel spreadsheet, DHRW's flood forecasting model interface, and at the same time these data are stored in the operational flood forecasting database, called HYDMET. The data is then sent via 'FTP' to the Regional Flood Management and Mitigation Centre (RFMMC) of the Mekong River Commission. The data is used by MRC's flood forecasting system.

93. HYDMET is custom designed database software for operational flood forecasting at MRC RFMMC. It is used to collect and distribute rainfall and water level data from the involved national line agencies in all Mekong riparian countries. HYDMET has tools to manage data transmission from stations as well retransmit data to the national line

[3] Confirmed by officers of ORFF of DHRW on 12 May 2016

agencies by SMS, to access data using a graphical interface, and the ability to export data in a number of formats to MRC's flood forecasting system.

94. Hydrological data observed from other stations are sent to DHRW at year end or every six months in a hard copy paper format. All daily data are later archived to the HYMOS database several times per week by staff of ORFF.

4.1.2.4 Flood Models and Modelling Environment

95. Multi and single-regression models have been applied by DHRW to determine the water level forecast at the seven mainstream stations. The model is based on Excel and uses only water level data as input. The effect of local rainfall is subjectively considered and the model output adjusted based on experience.

96. The mainstream model calibration used a long period of record. However, the regression equations used in the model haven't been updated with data since 2009. The model verification is a manual process and is carried out at the end of the flooding season.

97. The rainfall-runoff model, "URBS - Unified River Basin Simulator", developed in Australia, has been introduced to DHRW by the MRC RFMMC as a tributary flood forecasting tool. Several ORFF staff have been trained in the use of the model. However, DHRW has not made use of the model to extend the flood forecasts to the tributaries.

98. As well, a Flash Flood Guidance System (FFGS - called MRC-FFGS) can be accessed by DHRW to obtain real-time information on flash flood guidance (FFG), flash flood threats (FFT), mean areal precipitation (MAP), and average soil moisture (ASM) for 1, 3, 6, and 24 hours for small basins in Cambodia. The Flash Flood Guidance System was developed by the U.S. Hydrological Research Centre (HRC). DHRW has received training and support from MRC under a USAID/OFDA funded program. The FFGS has not been used operationally by DHRW for warnings as further testing and verification is required.

4.1.2.5 Dissemination

99. A daily flood bulletin is disseminated to senior ministry officials, media, provincial agencies, and NGOs. The bulletin is sent by faxed to 40-50 recipients and by email to about 20 recipients. The flood bulletin presents water levels for the issuing date, a 3-day water level forecast, and an overview of the flood situation. The DHRW Director or the Officer-in-Charge approves the daily bulletin, while warnings for severe flood events are approved and signed by the MOWRAM Minister.

100. Information on flood forecasts and warnings are also disseminated via the DHRW website: http://www.dhrw-cam.org.

101. The website provides the 3-day flood forecast, hydrographs, and observed daily water level data for the seven stations along the Mekong, Bassac, and Tonle Sap rivers. Moreover, maps, and metadata of both observed water level and water quality can also be accessed using the DHRW website.

4.2 Regional Level

102. MRC's Regional Flood Management and Mitigation Centre (RFMMC) provides a flood forecasting service for 21 mainstream locations from Chiang Saen near the border with China to Chau Doc and Tan Chau at the upstream end of the Mekong delta. Among those 21 stations, eight stations are located in Cambodia along the Mekong, Bassac, and Tonle Sap rivers.

103. The forecast made by RFMMC provides 5-days lead-time. The flood forecast provides water level, discharge, and potential flood extent information in relation to the water levels.

104. MRC RFMMC uses the Flood Early Warning System (FEWS), which has a FEWS engine, models, post-processing tools, and database. Three models are used in FEWS: URBS (hydrological), ISIS (Hydrodynamic), and Multi-regression models. FEWS was developed by Delft University in the Netherlands. It is a fully scalable system that can be run as a self-contained manually driven forecasting system, operating on a normal desktop computer, but can also be deployed as a fully automated distributed client-server application.

105. Rainfall and water level data are collected by email from the member countries as well as from the HYMET data communication system. The data is automatically processed and placed into FEWS.

106. The URBS model covers all tributaries of the Mekong Basin and the Tonle Sap Great Lake, however flood forecasts are only produced for the mainstream Mekong, Tonle Sap, and Bassac rivers. As well, the MRC Flash Flood Guidance System (MRC-FFGS) is used by RFMMC to assess the potential of flash floods.

107. The Flood Bulletin, produced by 10 AM each morning during the wet season (1st June to 30th November), is issued by fax and email to 70 recipients.

108. However, RFMMC does not have a flood-warning role but plays an essential role in providing flood forecasts and advice to assist flood-warning centres in the member countries. In addition to flood forecasting, RFMMC monitors and provides a forecast of low flow conditions in the mainstream Mekong. During the low flow period, a 7-days lead-time forecast is made weekly by the RFMMC.

109. All flood and low flow forecasts can be obtained from the MRC website: http://ffw.mrcmekong.org.

4.3 Gaps in Flood and Weather Forecast Systems

110. One of the paramount functions of a National Hydrological and Meteorological Services (NHMS) is to generate accurate and dependable forecasts and warnings at various time scales and to make them available to the public and stakeholders. Warnings should be clear and simple so that stakeholders can understand them without ambiguity and use the information for disaster risk reduction. In order for a NHMS to produce such skilful weather, climate, and hydrological information, it is necessary to have good in-house capacity to forecast and analyse meteorological and hydrological parameters. As well, in-house infrastructure is required which includes robust models and software to predict and analyse the weather and hydrological parameters, sufficient computational power to integrate numerical models, and good internet connectivity to exchange data sets. A basic requirement for skilful forecast generation is the availability of quality observational data with wide coverage and technically skilled personnel to handle, analyze, and interpret pre-processed and processed data sets.

111. From the middle of the month of May to the end of September every year, Cambodia will receive copious rainfall from the West (South West Monsoon). It is very common during this wet season that Cambodia will experience both riverine and flash floods. By having the knowledge of occurrence of flood events in advance, sufficient risk reduction measures could be taken by concerned authorities. However, for such a forecast system capable of predicting the parameters with sufficient lead time to be in place, availability of good weather forecast system is needed apart from robust flood forecast models.

112. During the monsoon season itself, there will be ‘breaks’ for few days or even for weeks in rainfall resumption and due to this gaps in precipitation events, farmers experience difficulties in their farming pattern. By knowing the periods of such dry spells in the wet season in advance, the farmers can take ample precautionary measures to reduce the damages. Medium range (up to 10 days of lead time) and extended range (beyond 10 days) weather forecast can provide information on such intra-seasonal variability within in the monsoon season.

113. Though Cambodia is surrounded by land on three sides, its proximity to the South China Sea is not far. It is well known that a good portion of the typhoons formed over the West Pacific Ocean, travels westward and fall in the Vietnam

coast. In some cases, they cross Vietnam, Lao PDR and reach Cambodia as well (e.g. Typhoon Ketsana, 2009). Such typhoons will have immense potential to damage life and property in Cambodia as well. Similarly, at times, storms formed over the Gulf of Thailand will take a north to north-east directional course and occur land fall in Cambodia. These cyclones are also possesses huge destructive potential due to its strong wind, heavy precipitation and storm surge over the coast. State-of-art Numerical Weather Prediction (NWP) models can simulate the severity and location of those storms in advance and mitigation measures can be taken well ahead of its destruction over the land if the forecast products are available with sufficient lead time.

114. To prepare against those natural calamities, a good forecasting system and proper warning system is the requirement and DOM has to take the responsibility to provide those information as accurately as possible.

115. There is some forecast capacity in Cambodia to predict severe weather and floods, however the capacity is limited in design and function. These limitations directly influence the quality and timeliness of the forecast information and may place communities at risk.

116. In terms of weather and flood monitoring, forecast generation, issuing warnings, and information dissemination, gaps are apparent due to aging and insufficient hydromet observational networks, insufficient data communication facilities, limited data sharing/dissemination among agencies, lack of human resources in both number of staff and their level of training, and the need for modern numerical weather prediction models, flood forecasting models, and data analysis and presentation applications to produce reliable information and next generated forecast products.

117. The need for robust forecast and warning systems is further supported by the unpredictability and increasing severity of extreme weather events as a result of a changing climate.

4.3.1 Weather Forecast System

118. The demand for accurate weather and climate information of all time scales from various sectors like agriculture, disaster management, water management, power, defence, police etc. are increasing day by day. It is the duty of DOM to meet these demands for weather and climate information. From data collection to warning formulation, the forecasting centres have to carry out a series of processes. Various infrastructures such as software, hardware, human resources, data sets will function as links in the forecast chain and the reliability of the forecast is directly associated with the strength of the weakest link.

119. In order to generate skilful and timely weather and climate information by DOM, it is necessary to have sufficient in-house capacity to forecast and analyse meteorological parameters. In-house infrastructure includes robust models and software to predict and analyse weather parameters, sufficient computational power to integrate numerical models, reliable internet connectivity to access and exchange data sets. The other mandatory requirements for skilful forecast generation are the availability of reliably observational data with wide coverage and technically skilled personnel to handle, analyze, and interpret those pre-processed and processed data sets.

120. As provided in the earlier section of 4.1.1.4, DOM is receiving or capable to receive a wide range of weather information from various global and regional centres. Those products and the information from satellite and Radar can be used to generate various time scales of information such as now-casts (up to 6 hours), short-range forecasts (6 hrs to 3 days), medium-range weather forecasts (3 days to 10 days), and extended and seasonal forecasts (beyond 10 days). Although DOM is providing a range of forecasts, their main focus is on the 3-day forecast. From the agricultural perspective, which include drought monitoring and mitigation and water resources management. It is very important to provide medium and seasonal forecasts. The consultants learned during discussions with other stakeholders that there is a lack of information availability for taking appropriate actions.

121. Many global agencies involved in Weather Prediction are closely monitoring typhoons and cyclones formed in various basins. However, their focus is until land fall occurs. Some of the Tropical Cyclones travel thousands of

kilometres inland with destructive potential hours after land fall. Once the storm makes land fall localized information may not be available from cyclone/typhoon prediction centres. Radar can track the storm but is not useful for forecasting. Similarly, satellite information can be used to track the storm but has limited use for forecasting. Once the storm reaches land fall DOM requires a high resolution NWP model to predict the track and intensity of cyclones and typhoons.

122. It is expected that high resolution meteorological information may be required for the tributary basin under the NFFC project. Rainfall and wind information in the basin area are required as initial and forecast conditions to drive the hydrological model. At this time the forecast products available to DOM are of a coarse resolution and many are graphical in nature. Higher resolution meteorological data, if required, will require DOM to run a high resolution NWP model.

4.3.2 Flood Forecast System

123. As provided in the earlier section of 4.1.2.4, it is clearly recognized that the current practice is generally limited to short term forecasting for selected locations along the main streams. The model is outdated and the current practice of using observed water levels for forecasting is inadequate for medium and long -term forecasts as well as for defining flood extent and duration.

124. The gauge-to-gauge correlation procedure does not incorporate any addition of flow between the stretches from the base station to the forecasting station. In a conventional hydrological modelling approach such additional flow through the intervening basin is considered and thus provides the opportunity or improving the forecast.

125. The present system is capable of forecasting the water level at the designated downstream site with the assumption that there is no breach in the embankments between the stations. Another major limitation to correlation method is the availability of prediction only at selected sites and not for other sites along the river. Other information such as the area likely to submerge, as well as time, depth, and duration of submergence are also not provided, but are needed for effective flood management.

126. The focus for the flood forecasting system must be on improving the lead time, forecasting river flow at any site along the river, especially in the floodplain, mapping the inundation for the forecasted flood, and generating early warning alerts at the community level for effective flood response.

127. Medium-term forecasts will need to be based on observed rainfall and forecasted rainfalls. Therefore, the introduction and development of rain-based hydrological and hydraulic forecasting models is required to improve reliability, accuracy, and forecast lead times as well as defining flood extent and duration

128. However, it should also be acknowledged that this will result in more uncertainty in the forecasts and will also require more complex systems in order to deliver the forecast. It is clear that the largest single constraint to moving from the current practice of short-term forecasting to the desired practice of medium-term forecasting is the availability of a hydro-meteorological database within DHRW and DOM.

129. The development of short to medium and further to long-term forecasts will require a staged approached to improve each component in the flood forecasting process. The outcomes of the process should be to produce a user-friendly system, which matches the available inputs, the skills of the users, and produces results, which are accepted and used by clients for decision making.

130. Given this situation, it is proposed that the development of long-term forecasts be placed on hold until the systems are in place for producing medium-term forecasts.

4.3.3 Warning Dissemination

131. In general, weather and flood forecast and warning information do not reach stakeholders, especially at the community level. The reasons include:

i. Themechanism for disseminating information from the central to the community level requires improvements. A dissemination strategy., EWS Standard Operation Procedure (EWS SOP), details the process for issuing of warnings however there has been limited awareness buildign at the local and community level.

ii. Lack of communication equipment. Communications between the concerned stakeholders from one level to another has not been well established due to lack of equipment and support.

iii. Information dissemination on TV and radio channels doesreach the affected population, however the broadcasts are limited to once or twice per day.

5. Conceptual Design

132. The objective of this section is to present a conceptual framework for a comprehensive “end to end” system outlining a future vision for:

1. Improving weather forecast in support of flood and drought predictions,
2. improving NFFC’s analytical and modelling capability, and
3. improving flood forecasts and drought predictions.

133. The purpose of the conceptual design is to provide a plan for improvements to weather forecast operations including the selection of appropriate weather forecast models and seasonal climate prediction models. As well, it will propose an approach for forecasting rainfall considering satellite based rainfall estimates and identify appropriate hydrological and hydrodynamic models to forecast river flood levels, river flow at any site along the river, especially in the floodplain, and mapping likely inundation from the forecast flood.

134. The conceptual design considers available Global and regional weather products and forecast services based on various Operational Numerical Weather Prediction Models and WMO’s network of regional centres, such as the Japanese Meteorological Agency as well as regional storm tracking services (RSMC’s) available from the Regional Typhoon Centre. The selection of models and modelling approach considers the models used and applicable in the Mekong region including the modelling system used by the MRC-FMMP.

5.1 Forecast System Components

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

136. **Figure 15** presents the general model layout for an operational water level and flood forecast system. However, it is expected that the flood forecasting system for the NFFC will be a less elaborate system, but the structure will lay a solid foundation for the evolution to a fully operational flood forecasting system using more sophisticated and powerful weather prediction products and data assimilation techniques.

137. It is important to note that the flood forecast 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 Digital Elevation Model (DEM) or Digital Terrain Model (DTM), to route and simulate water levels over a large flood plain and produce useful flood inundation and duration maps.

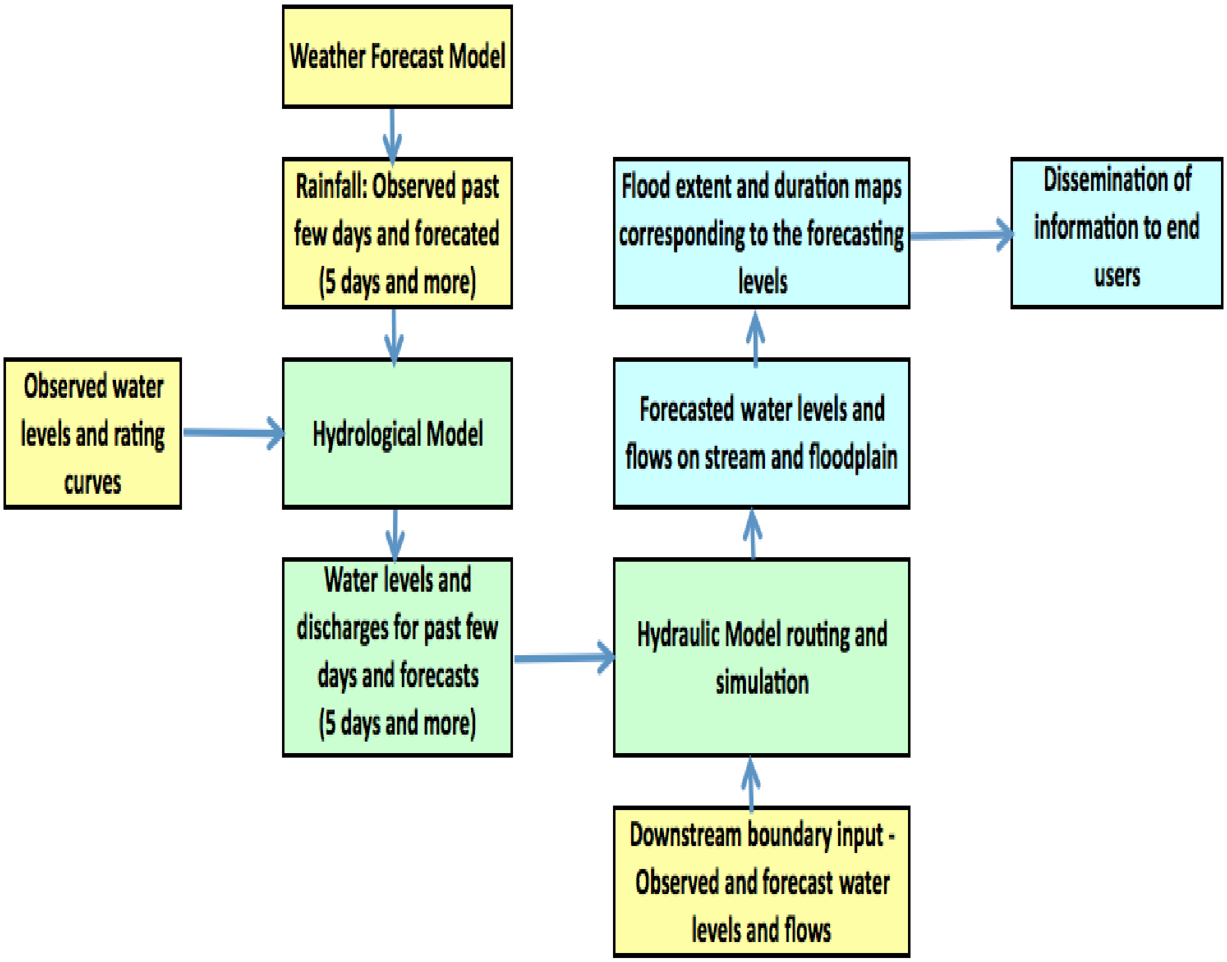


Figure 15: General Model Layout for an Operational Flood Forecast System

5.2 Improvement in Meteorological Observation and Prediction Capabilities

138. DOM's ability to provide reliable and timely rainfall forecasts at scales adequate for large to small watersheds is critical to the flood and drought prediction system. Improvement to the rainfall forecast requires reliable observed data in near real-time from automatic weather stations (AWS) at crucial locations in Cambodia. The real-time data are important for assimilation by GCMs operated by Global Prediction Centres and future in house Numerical Weather Prediction systems of Cambodia. As well, observed meteorological data is needed to verify the forecast skill of various weather forecast models and recalibrate the now-casting algorithms of the weather radar. Past observed data sets over a period of time are required for climate change assessment.

139. More use of the Doppler Weather Radar to provide now-casting of rainfall events and severe weather events is needed as there are some uncertainties in every NWP model outputs. The current radar system configuration commissioned at DOM is state-of-the-art and fully operational. Only the skill level of the staff needs more strengthening in analysing the outputs through more hands-on training. As well, verification of the rainfall algorithms is necessary, using observed rainfall data as supplied by the AWS network.

140. The data management system of DOM requires strengthening to manage the observed AWS and manual meteorological data in a structured SQL database. As well, the data management system must be able to store radar

images over a longer period. Database management tools and applications are required for the QC/QA of the data and for the generation of reports and meteorological information.

141. The generation of rainfall forecasts for 7-days, 15-days, monthly, and seasonal scales are required. DOM staff have access via the Synergie system to a broad range of Global Numerical Weather Prediction products from a number NWP regional and global centres. As mentioned, only the skill level of the staff needs strengthening through more hands-on training for customization of the global products considering local conditions. As the staff's skill level is strengthened, the implementation of a Numerical Prediction Model at DOM will be necessary to provide higher resolution forecasts.

142. The drought prediction capacity of DOM needs strengthening to provide a medium and seasonal drought prediction service. The methodology for the drought prediction service will be developed under the NFFC project.

143. Training and capacity strengthening of the DOM staff is a key focus to ensure improvements in the observational network and radar operations as well as for improved forecast and prediction services are made and are sustained over long-term.

144. Institutional arrangements between DOM and the DHRW/NFFC are required to ensure forecast support and information sharing protocols are in place and functional.

145. To address the above mentioned gaps and enhance the capacity of DOM to support an Early Warning Service, the following actions are required

5.2.1 Adequate and Reliable Meteorological Data

- Upgrade and modernization of DOM synoptic and rain gauge stations / instruments with data communication network for real-time data transmission from the field stations to the DOM Centre in Phnom Penh;
- Improve the use of the Doppler radar for now-casting of rainfall;
- Improve the quality of observations and equipment maintenance through training; and
- Implement a data management system at the DOM Centre in Phnom Penh for the management of real-time data, data quality control, and data presentation and reporting.

5.2.2 Rainfall Forecast and Drought Prediction

- Train DOM staff on the interpretation and customization of available Global Numerical Weather Prediction Products;
- Develop a standardized methodology for 7-days, 15-days, monthly, and seasonal rainfall forecasts and implement with training;
- Develop a standardized methodology for medium to seasonal drought prediction and implement with training; and
- Select and implement with training an appropriate model for generating quantitative precipitation forecasts in support of the flood-forecasting model and drought prediction system.

5.2.3 Human Resources and Institutional Arrangement

- Develop the institutional arrangements and protocols between DOM and DHRW/NFFC for the open and timely exchange of data and forecast in support of flood forecasting and drought prediction; and

- Identify capacity strengthening opportunities for DOM staff through advance studies and technical training of the professional and sub-professional staff.

5.3 Improvement of Flood Monitoring and Forecasting Capabilities

146. In parallel with the improvements in meteorological observation capacities, the existing hydrometric network needs to be enhanced for DHRW to provide an effective Flood Early Warning service. As well, the upgrade and rehabilitation of existing hydrometric stations with expansion to cover ungauged sub-basins is required. Real-time reporting of hydrometric data is mandatory to support forecasting and efficient network operations.

147. Flood Forecasting Systems (FFS) are generally composed of four components:

i. Access to real-time or near real-time rainfall, water level, and streamflow data;

ii. Access to reliable and timely rainfall forecasts for short to medium term;

iii. Hydrological and hydraulic models; and

iv. Forecasting and presentation systems.

148. The development of medium to long-term forecasts will require a staged approached with improvements to each component of the flood forecasting process.

148. The objective is to produce a user-friendly system, which matches the available inputs, the skills of the users, and produces results, which are accepted and used by clients for decision-making and disaster response.

5.3.1 Real-time Data Collection

150. A Flood Forecasting System requires access to reliable real-time rainfall and hydrometric data via a database.

151. There are few real-time or near real-time stations in Cambodia, however this is being addressed under WBS 200 and some 17 sites in the Pursat basins are scheduled for upgrading to real-time reporting of water level and rainfall data. For the mainstream Mekong the existing MRC network and real-time reporting system will be used. Additional real-time stations will be considered for the mainstream Mekong as the models are developed and verification gaps are identified.

152. The access to real-time rainfall data has been previously discussed under Section 5.2.

5.3.2 Rainfall Forecast

153. The access to reliable and timely rainfall forecasts for short to medium term has been previously discussed under Section 5.2.

5.3.3 Hydrological and Hydraulic Models

154. The review of the forecasting system revealed that the existing multi-regression models are not suitable for medium term forecasting nor can they provide the required scope of information for flood duration and extent in their current form. The reason for this is due to model configuration being fixed and limited by the travel time between mainstream stations. In addition, the model will only generate 3-day forecasts.

155. In this regard the following section reviews a number of models that have been used in Cambodia.

5.3.3.1 Hydrological (Rainfall-Runoff) Models

156. Rainfall-runoff models are used to simulate runoff from a watershed for a give rainfall amount. The model inputs are characteristics of the watershed being modelled, such as drainage area and channel network geometry (size and length), topography, soil and land use characteristics and a time series of rainfall. The output is a time series of stream flow at an outlet location.

157. Hydrological or rainfall-runoff models can be used to forecast discharge as an upstream boundary condition for a flood prone area. As well hydrological models can be used to transfer statistical information on rainfall to statistical information on river discharge.

158. There are numerous hydrological models applied in the Mekong region and a number of those models are suitable for flood forecasting. The models are Hydrologic Engineering Centre-Hydrologic Modelling System (HEC-HMS), Unified River Basin Simulator (URBS), the Soil and Water Assessment Tools (SWAT), TANK, and VMod.

159. The following is a brief description for each of the hydrological models noted.

HEC-HMS

160. The Hydrological Modelling System (HEC-HMS) was developed by the Hydrologic Engineering Centre of the United States Army Corps of Engineer. The model is designed to simulate the rainfall-runoff processes of dendritic watershed systems. It is applicable to a broad range of geographic areas. The model can be used to support large river basin water supply and flood hydrology investigations as well as small urban or natural watershed runoff. Hydrographs produced by the program can be used directly, or in conjunction with other software for a range of studies including water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation.

161. HEC-HMS features a completely integrated work environment including a database, data entry utilities, computation engine, and results reporting tools. A graphical user interface allows the seamless movement between the different parts of the program. Program functionality and appearance are the same across all supported platforms. As well, the power and speed of the program make it possible to represent watersheds with hundreds of hydrological elements.

162. HEC-HMS is available at no costs and is supported by the United States Army Corp of Engineers (USACE). Downloads of the software and related HEC modules can be done online from the USACE website. The USACE also offers training courses and full documentation for the HEC software suite.

163. HEC-HMS has been applied by the EPTISA in Lao PDR as a flood forecasting model for a project similar to the NFFC project. As well, EPTISA has extensive knowledge and significant experience in applying the model in a number of similar projects worldwide.

URBS

164. The Unified River Basin Simulator (URBS) model was developed by Don Carroll, a senior modeller from Australia. URBS is a commercial software application, but royalty free within the Mekong Basin through an arrangement with MRC. URBS is a semi-distributed non-linear network model. The model combines rainfall-runoff and runoff-routing components and allows users to configure the model to match the characteristics of individual catchments. URBS is supported with a GIS package, known as CatchmentSIM.

165. URBS catchment runoff is described by flow through a series of non-linear reservoirs representing sub-catchments. Each sub-catchment has a non-linear routing parameter defined as a function of sub-catchment slope, reach length and reach length factor, roughness, urbanization and forest fractions of the sub-catchment, scaled finally

by a storage lag parameter. URBS catchments are combined through a channel routing component based upon a non-linear Muskingum method. The model can be applied both as an event model and as a continuous model. It uses rainfall data as a minimum required input, however a DEM and river network delineation are required for model schematization.

166. The URBS model was adopted and developed for flood forecasting by the MRC and it has been calibrated for the Lower Mekong Basin including the Tonle Sap Great Lake tributary basins in Cambodia. Moreover, DHRW/NFFC staff have received training from the MRC on using the model as a flood-forecasting tool. A formal protocol request to MRC for permission to use the URBS model is needed.

SWAT

167. SWAT is a free rainfall-runoff model jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research, part of the Texas A&M University System. SWAT is a small watershed to river basin-scale model to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds.

168. SWAT models have been calibrated for the Lower Mekong Basin including the Tonle Sap Great Lake tributary basins as part of the development of the MRC Decision Support Frameworks (DSF). However, the model does not have a flood forecasting facility.

VMod

169. VMod is a modelling system part of the suite of modelling support tools developed by Environmental Impact Assessment Centre of Finland Ltd (EIA Ltd.). VMod is a physically based spatially distributed model, which uses a series of grid cells to simulate runoff from rainfall. The model is based on a rectangular grid, where each grid cell is individually computed and has its own set of parameters such as ground slope and aspect, vegetation type, and soil type. The grid values are obtained from a digital elevation model (DEM), land use data, and soil type data. In each of the grid cells hydrological processes such as interception, infiltration, surface runoff, evapotranspiration, interflow, percolation, and ground-water exchange with neighbouring cells are computed. Typical grid cell sizes range from 0.01 to 1 km^2. However, computational time increases with increasing number of grid cells.

170. The model has been applied to a number of basins in the Lower Mekong Basin, but has not been used for flood forecasting. VMod is freely available software.

TANK Model

171. The TANK model is a lumped model and was developed by Dr. M Sugawara, Japan. The TANK model uses a conceptual design of one or more tanks to represent the hydrological response of a watershed. The TANK model uses rainfall as input and generates surface runoff, subsurface flow, intermediate flow, sub-base flow, and base flow as output. As well, the model can explain the phenomenon of infiltration, percolation, deep percolation, and water storages. The calibration of the TANK model is done by comparing the historical discharge (observed discharges) with simulated discharge from the TANK model (Sugawara, 1961).

172. The TANK model is capable in modelling the hydrological response from a wide range of watersheds. The model was applied by JICA in 2011 to simulate the Pursat River basin for a water balance study.

5.3.3.2 Hydrodynamic Models

173. There are several hydrodynamic models currently in use in the Lower Mekong Basin. These include HEC-RAS, InfoWorks ICM, ISIS, EIA 3D, MIKE 11, and SOBEK.

174. The following is a summary for each of the hydrodynamic models noted.

HEC-RAS

175. HEC-RAS V5.0.1 (1D and 2D) with the GIS extension GeoRAS is an internationally recognized freeware modelling system developed by the Hydrological Engineering Centre of the US Army Corps of Engineers. The model is designed to perform one and two-dimensional hydraulic calculations for a network of natural and constructed channels. It is based upon an implicit numerical solution of the de Saint Venant equations. As well, HEC-RAS has a Graphical User Interface for easy access to a series of HEC support components, such as Hydraulic Analysis, Data Storage and Management, Graphics and Reporting, and RAS Mapper. The Hydraulic Analysis component can conduct steady flow surface profile computations, one- and two-dimensional unsteady flow simulations, movable boundary sediment transport computations, and water quality analysis.

176. HEC-RAS is available as freeware and is supported by the United States Army Corp of Engineers (USACE). Downloads of the software and related HEC modules can be done online from the USACE website. The USACE also offers training courses and full documentation for the HEC software suite.

177. HEC-RAS has been used by EPTISA in Lao PDR as a flood forecasting model for a similar project. As well, EPTISA has extensive knowledge and significant experience in applying the model in a number of similar projects worldwide.

178. HEC-RAS is linked to the HEC-DSS, which is a database system designed to efficiently store and retrieve scientific data that is typically sequential. Such data types include, but are not limited to, time series data, curve data, spatial-oriented gridded data, and others. The system was designed to make it easy for users and application programs to retrieve and store data. HEC-DSS is incorporated into most of HEC's major application programs.

179. Data in HEC-DSS database files can be graphed, tabulated, edited and manipulated with HEC-DSSVue, a Java-based visual utilities program. HEC-DSS Utility programs provide "batch" type data entry capabilities from a variety of formats, report generation with HEC-DSS data, as well as legacy applications whose functionality has been superseded by HEC-DSSVue. Additional information on HEC-DSS software can be found in http://www.hec.usace.army.mil/.

InfoWorks ICM

180. InfoWorks ICM (Integrated Catchment Modelling) is commercially available software developed by Innovyze, USA. It is an integrated modelling platform and incorporates both urban and river watersheds. InfoWorks ICM uses 1D and 2D hydrodynamic simulation techniques to model the surface and subsurface flow in a watershed. InfoWorks ICM can account for hydraulic features such as small inlets, bridges, sluices, weirs, and pumping stations and model the influence on flow patterns. The Real-Time Control function allows control structures to be programmed to respond to conditions during a simulation. This function supports the optimization of storage and operation rules.

181. InfoWorks ICM supports the presentation of data as geographical views, sections, longitudinal profiles, temporary tables, and graphs. Data can be presented in an animated form using geographic, longitudinal, or transverse views, including full dynamic flood maps.

182. Water quality and sedimentation studies can be carried using InfoWorks 2D simulations. These simulations enable the fate of pollutants from non-point and point sources to be analysed.

183. EPTISA has extensive knowledge and significant experience in applying the InfoWorks ICM model in a number of similar projects worldwide.

ISIS

184. ISIS is commercially available software developed jointly by Halcrow and Wallingford Software in the United Kingdom. ISIS is a hydrodynamic modelling system providing an implicit numerical solver for the de Saint Venant equations. The model can be applied for a wide range of hydraulic problems, such as flood propagation, tidal flow and channel drainage. At selected intervals the model computes water levels and discharges on a non-staggered grid.

185. Recently, the commercial rights to ISIS was acquired by the CH2M HILL, USA, and rebranded the software under their "Flood Modeller" application. Flood Modeller is a flexible and comprehensive package of tools for deriving flood maps, flood forecasting, designing flood management schemes, developing basin strategies, and other flood and non-flood applications including modelling low flows, sediment, and water quality.

186. ISIS is an integral component of the Decision Support Framework (DSF) developed by Halcrow Group Ltd for the MRC's Water Utilization Program (WUP). The surface scheme used in MRC's ISIS model was built using GIS software to process data from existing digital models of the terrain and from existing bathymetry. The ISIS model was calibrated for the 2000 flood and verified using the 2001 and 1998 events. The ISIS model is available to the various MRC line agencies, including DHRW. In 2009, the model was recalibrated by MRC's RFMMC for flood forecasting.

187. MRC has some experience with the ISIS model. The schematization for the MRC ISIS model was performed using available topography data, which was supplemented with a field data collection program. The model has been validated. The software is available to DHRW/NFFC, however a formal protocol arrangement with MRC's permission for the model application is needed.

EIA 3D

188. The EIA 3D modelling system has been developed and maintained since 30 years ago by EIA Ltd in Finland by Jorma Koponen et al.

189. EIA 3D is a three-dimensional modelling system and can be used in a 2D mode. The model is based upon the simplified Navier Stokes equations and can use a variety of turbulence formulations. The equations are solved using a finite volume technique, which allows for the spatial variation of rectangular grid cells. Unlike other numerical models, flow velocities are combined in the centre of cells. This facilitates flow around bends, which is important for bank erosion applications and the simulation of morphological processes.

190. EIA 3D has been tested in over 200 applications worldwide. It has been used in the detailed hydrodynamic and water quality modelling of Tonle Sap Lake. The EIA 3D model of the Tonle Sap Lake covers an area of 261 km by 196 km (51,000 km^2) using a 1 by 1 km grid. The modelled area includes the main tributaries and the Tonle Sap River from Prek Dam to Tonle Sap Lake. During the high flood levels about 15,000 km^2 of this area is flooded.

191. The application of EIA 3D in the Mekong region is expanding with the start of IKMP project. The EIA 3D model is free from the developer upon request.

MIKE 11

192. Mike 11 is commercially available software developed by the Danish Hydraulic Institute (DHI) in Denmark and is used worldwide. MIKE 11 has recently been rebranded as MIKE HYDRO River with an improved user interface and workflow as well as performance enhancements. The model application is map-based with an intuitive graphical user interface for river modelling.

193. Mike 11 was used by MRC under the WUP-JICA project, which focussed on the Cambodian floodplain. The Mike 11 model used under the project covered the area downstream of Kratie to the border with Vietnam, including the complete area of the Tonle Sap. The model was developed on the basis of additional field surveying, which improved

significantly the knowledge on the hydraulic behaviour of the Cambodian floodplain. The model is no longer operational at MRC.

SOBEK

194. SOBEK is a licensed product of Deltares. It is a generic modelling system that can be applied tostudy river floods, urban and rural drainage systems, as well as to study river, channel and lake water quality, and river morphology. A particular strong feature of SOBEK is its ability to model floods over floodplains through implicitly connected 1D and 2D schematizations.

195. The schematization for the model uses GIS layers with a 1D schematization layer for the channel network and a 2D schematization layer for the floodplain.

196. SOBEK has been used in the Mekong Delta under the MRC Roads and Floods Project to study the interaction of 1D and 2D flow processes around hydraulic structures, roads, and embankments.

5.3.3.3 Empirical Models

197. Both DHRW and MRC use regression models for flood forecasting. The regression model could be used to provide a check on the sophisticated physically approaches, however the regression model requires updating using recent flood data.

5.3.4 Flood Forecasting and Presentation Systems

198. The challenges to developing a modern flood forecasting and warning system are found in the integration of large data sets, easy access to specialized modules to process data, and open interfaces to allow easy existing modelling capacities. The Flood Forecasting System is the shell the enables access to a variety of data sets and the integration of hydrological and hydrodynamic models. It supports connectivity between the various components of the forecasting system and provides a platform for running models, for storing and managing results, and for issuing information to users via a variety of methods.

199. The Flood Forecasting System may adopt an open architecture where users can incorporate their own models, while others restrict the users to in-built models.

200. There are number of integrating platforms available. The more popular systems are Delft-FEWS and FloodWorks, which are discussed briefly in the following sections.

Delft-FEWS

201. The Deltares' Flood Early Warning System (Delft-FEWS) provides a state of the art flood forecasting and warning system. The FEWS system is a sophisticated collection of modules designed for building a flood forecasting system, which is customized to the specific requirements of an individual flood-forecasting agency.

202. The philosophy of the system is to provide an open shell system for managing the forecasting process. The shell incorporates a wide range of general data handling utilities, while providing an open interface to a wide range of forecasting models. Also, Delft-FEWS provides advanced graphical and map-based displays. Forecast results can be disseminated through configurable HTML formatted reports, allowing communication to relevant authorities and public through intranet and internet. Standard output formats such as HTML formatted reports are available, and can be customized to specific user requirements

203. The modular and configurable nature of the FEWS system allows it to be used effectively both in rudimentary forecasting systems and in highly complex systems. Delft-FEWS can either be deployed in a stand-alone, manually driven environment, or as a fully automated distributed client server application.

204. MRC uses Delft-FEWS as part of its flood forecasting system. A series of training sessions on FEWS as well as on the URBS and ISIS model applications has been provided to the DHRW staff by MRC.

205. Delft-FEWS is free software supported by Deltares with large users community for demonstration and research purposes. Consultants who want to use Delft-FEWS commercially or end-users must contact DELTARES for a license agreement. Additional information on Delft-FEWS can be found: http://www.wldelft.nl/soft/fews/int/index.html.

FLOODWORKS

206. FloodWorks is a commercially available software application developed by Innovyze, USA. It is a modular software package for real-time simulation and forecasting of extreme hydrological and hydraulic conditions within river basins. Designed for operational use, FloodWorks is suitable for real-time flood forecasting, warning, and management for river basins. It links real-time hydrological and meteorological time-series data sources with detailed hydrological-hydrodynamic models, such as InfoWorks ICM, to provide forecasts of water level and flood depth.

207. Additional information on FloodWorks software can be found in: http://www.innovyze.com/products/floodworks/.

5.3.5. Model Output and Products

208. The first output from hydrological and Hydrodynamic models will provide water level and flow forecasting hydrographs at featured locations of the pilot river basins to define flood peaks, timing and duration of flood. This information will support the generation of flood bulletins for warning purposes.

209. The model output will support flood hazard mapping, which is derived from results of hydrodynamic models with assistance of the mapping tools. The hazard maps display information on flood characteristics, such as water depth and flow velocity, flood extent and duration for a certain flood event (probability).

210. **Figure 16** shows the scheme of process and data requirement applying the HEC suite to generate the required model output and products.

5.3.6. Human Resources and Institutional Arrangement

211. The DHRW will need to strengthen its human resources capacity through advanced studies and technical trainings of the professional and sub-professional staffs.

- Develop the institutional arrangements and protocols between DHRW/NFFC and DOM for the open and timely exchange of data and forecasts in support of flood forecasting and drought prediction; and
- Identify capacity strengthening opportunities for DHRW/NFFC staff through advance studies and technical training of the professional and sub-professional staff

212. The technical training should focus on hydrological equipment installation and maintenance, data analysis, hydrological and hydrodynamic modelling, operation of a forecasting system as well as on GIS flood mapping application.

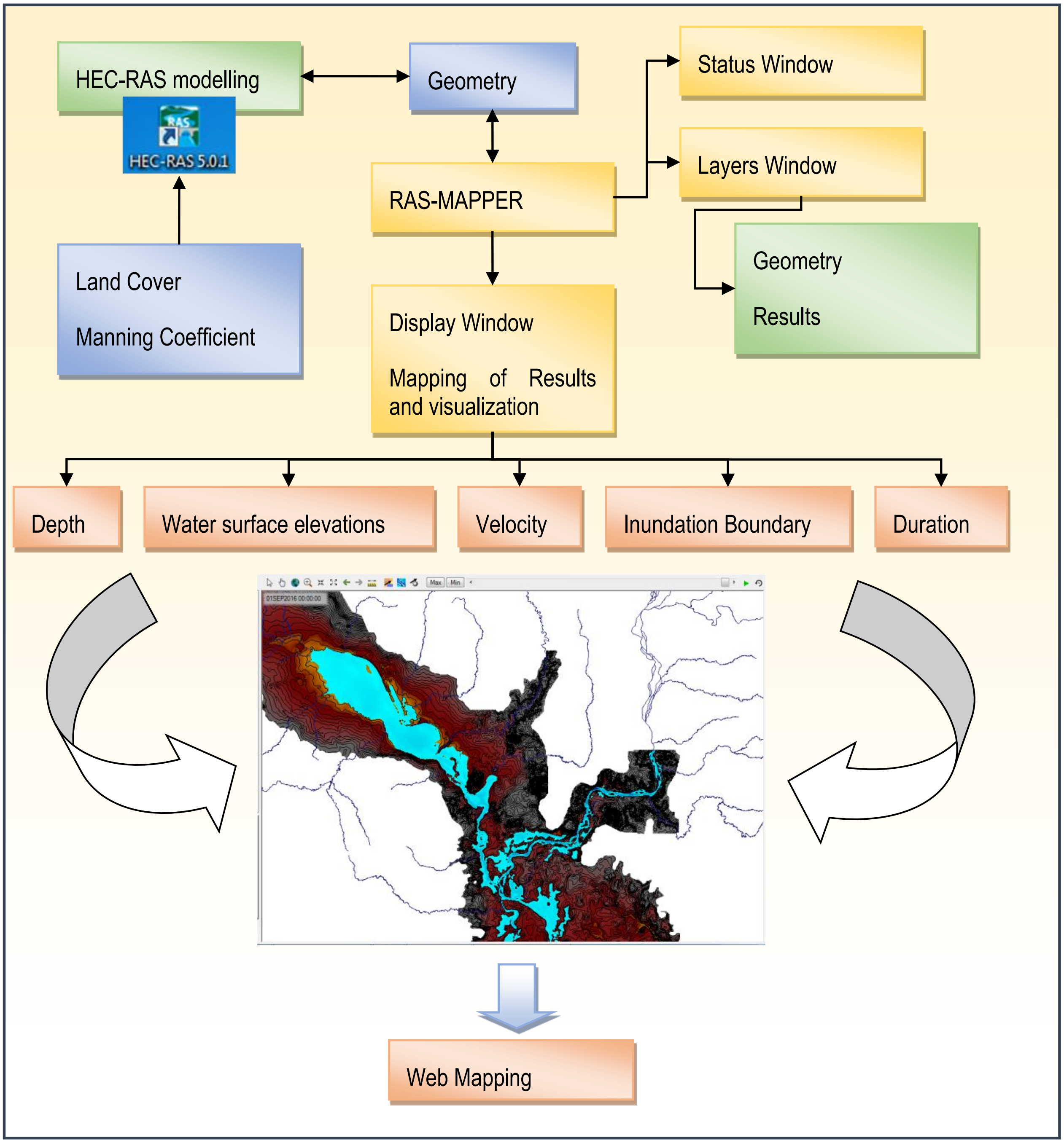


Figure 16: Detailed scheme for flood hazard mapping - HEC RAS MAPPER Scheme

5.4. Development of Long and Medium Term Drought Prediction

213. As a result of significant negative anomalies of seasonal rainfall, Cambodia has been subject to recurrent droughts with negative consequences in almost all sectors of the economy, especially in agriculture. However, Cambodia's drought strategy has been oriented more on "relief" rather than preparedness. Drought preparedness promotes a more

preventive, risk management approach to droughts reducing vulnerability to drought and dependence on emergency assistance from government and international organizations.

214. Droughts can be classified into three broad categories as follows:

i. Meteorological drought - occurs when rainfall over a prescribed period is significantly less than the long-term average.

ii. Hydrological drought - occurs when water resources are significantly depleted because of meteorological drought, which results in stream flows over a prescribed period being significantly less than the long-term average.

iii. Agricultural drought - occurs when meteorological and hydrological droughts reduce crop yields and livestock and fisheries production. An agricultural drought occurs when soil moisture is insufficient to meet crop water requirements for food and fodder.

215. Having a capability to accurately predict the onset, persistence and cessation of drought conditions will enable more effective drought mitigation strategies to be developed for Cambodia. Therefore, warnings should not only flag when drought might/is occurring but also provide an indication of how long drought conditions will last so that proper planning and mitigation strategies can be put into place. These warnings will need to meet the following criteria:

1. where and when the drought will occur and where in case of an ongoing drought,
2. indication of duration and severity of event,
3. be issued at least three months in advance (or ahead of the start of the planting season) and updated in real time.

216. Rainfall observations and predictions will need to be compared to long term mean measures of rainfall in order to establish the scale of the rainfall deficit during a drought period. This will require the collation and an analysis of historical rainfall data as well as the establishment of an appropriate index (e.g. Standardized Precipitation Index, SPI) or measure for quantifying drought. The index will need to be flexible enough for application at a range of temporal scales. Operational thresholds will need to be also established, using case-studies based on a selected number of past drought events for calibration, and linked to on-the-ground impacts and a methodology for dissemination of the warnings developed.

217. To achieve these, the following specific tasks are foreseen:

1. Evaluation and enhancement of meteorological network for drought monitoring including provision of training in system maintenance;
2. Establishment of appropriate forecast dataset, design, and provision of a system for manipulating this data:
   a. Identify candidate forecast datasets as already mentioned in 5.2.2. Some products that might be free available for consideration:
      - the US National Centers for Environmental Prediction (NCEP) CFSV2 Climate Forecast System, which is a long range (out to 9 month) 56km resolution ensemble Numerical Weather Prediction (NWP) which used 16 different ensembles,
      - A shorter range ensemble (the Global Ensemble Forecasting System, GEFS - also run by NCEP), which provides 33km horizontal resolution for the first 168 hours (7 days) of model integration, and 70km resolution output out to 16 days.
   b. Prepare evaluation criteria for the forecast dataset. This will investigate the quality, consistency, robustness of the forecast data, reliability, ease of obtaining/processing the data. Evaluation/ground truthing of the forecast measurements against local data has to be performed.

c. Provide a system/software for streaming, manipulating, and storing the selected forecast data.

d. Set up and testlocal downscaling models for Cambodia linked to the boundaries supplied from the global models.

3. Recommendation a drought severity indices, and developf a system for calculating the index from forecast and observed rainfall as well as consider the recession flows. The work will invove the stablishment of operational thresholds.

   The aim is to provide a method for quantifying the magnitude of a drought, and for establishing the operational thresholds (such as drought profile identified by NCDM) that will trigger a drought warning to be issued. The main activities are as follows:

   a. Research report documenting all candidate methods for quantifying drought, focusing on those methods that quantify the precipitation contribution, or lack thereof, towards drought conditions. Recommendations will be made regarding a preferred approach for Cambodia, the candidate indices (e.g. Standardized Precipitation Index, SPI) will be based on criteria such as robustness, tractability, transparency, sophistication, extendibility and dimensionality.

   b. Identify historical datasets from which long term mean monthly rainfall values can be determined across Cambodia. These data are required to furnish drought index values for current or forecast rainfall, which is achieved by comparing observed or forecast rainfall for a particular interval to the normalised mean value over the same interval during the period of record.

   c. Using the 2002, 2004-05, and 2012 droughts as case-studies to determine SPI values that are commensurate with the onset of droughts effects. It is expected that it will be necessary to define different thresholds for different communes/provinces, and that thresholds will vary depending on the time of year (potentially aligned with the rice planting cycle) and duration considered.

4. Design and develop anf operating system for combining outputs from tacks 1 to 3 including training in use of the system.

   a. Design and implement a processing system that will estimate drought index values (e.g. SPI) on a gridded basis for Cambodia. This will use forecast data to provide 6-month index estimates with a lead time of 6, 3, 2, 1 months, 2 weeks and 1 week. Real time rainfall data will be used to provide the real-time corrections to predicted values and to help establish the accuracy of future values. The same system will be used to provide point estimates for those areas deemed to have the highest vulnerability to drought.

   b. Design and implement a processing system to compare calculated drought index values to the established drought trigger thresholds, leading to issue of advance-time arid real time drought warnings.

   c. Prepare a comprehensive operational instructions for the entire process. An in-depth and hands on training course will also be produced and delivered.

5. Provision of a pilot system for dissemination of warnings.

6. Technical Design

6.1. Weather Forecast Modelling

218. The proposed technical design to enhance DOM's forecast capacity follows two approaches. The first involves the use of and customization of available products from global and regional centres described in section 4.1.1.1. The second involves the implementation of a high resolution NWP model at the EWC. The schematic description of the approach is shown by **Figure 17**. The details for the approaches are provided in subsections 6.1.1 and 6.1.2, respectively.

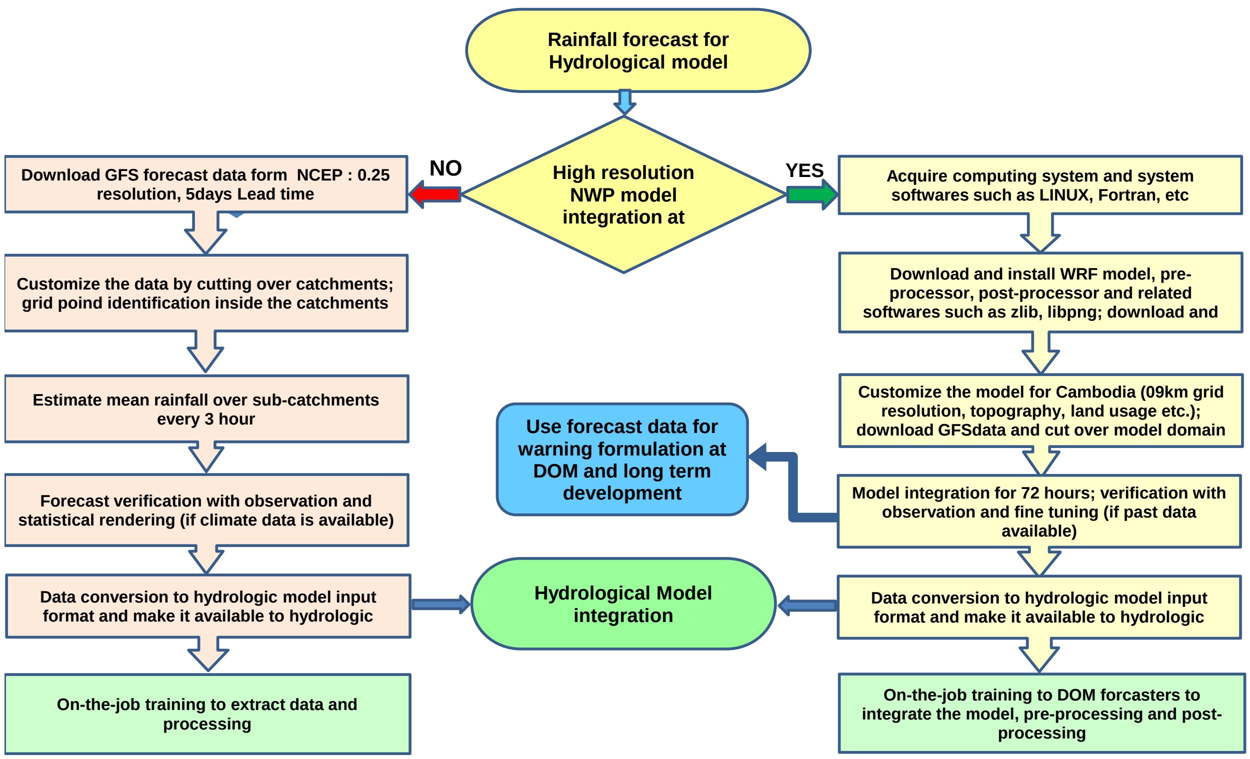


Figure 17: Design Options for Weather Forecasting improvement

6.1.1 Customization of Various Global and Regional Products

219. The objective of the project is to develop an 'end-to-end' flood forecast warning system with sufficient lead time to warn communities at risk. Digital rainfall forecast data is needed to drive the hydrological model. One approach to provide the required digital precipitation data is to download forecast data from GFS systems. These global forecast data are available for up to 10-days of lead time with a resolution of 0.25 degrees (about 30 km) on a 3-hour time step. From the downloaded NCEP rainfall forecast data, pre-defined grid points over the river catchment will be extracted and the average rainfall for different sub-catchments can be computed. If necessary, proper statistical rendering can be performed on the forecast data to achieve greater accuracy. Computer programs will be required to extract and statistically rendered rainfall data, which will be passed on to the hydrological model for further processing.

220. As presented in the section 4.1.1.4, relevant information can be extracted from the products received by DOM in addition to those currently used. For example, the ENS meteogram from ECMWF details information on rainfall,

temperature, wind, cloud percentage for the next 10 days for a 6-hour time step. This ensemble forecasting system product is available for eleven locations in Cambodia. With training the box and whisker type forecast representation can be used by DOM to generate location specific forecast with a high confidence level.. As well, with training DOM forecasters can customize seasonal forecast products from ECMWF to generate seasonal forecasts.

221. Other products from ECMWF and other GFS centres, as presented in section 4.1.1.4, may be customized by DOM forecasters to generate products for short range to medium range to seasonal range time scales. The details of customization and training plan are presented in section 7.1.

6.1.2 Integration of High Resolution NWP Models

222. Forecast generation using numerical methods is the most reliable method of forecasting and predicting weather related events. Most of the Weather Forecasting Centres around the globe employ Numerical Weather Prediction (NWP) models to generate weather information at different time scales. The requirements are access to NWP models, computing systems, and observed data sets.

223. The Weather Research and Forecasting (WRF) Model is a non-hydrostatic, limited area model used widely around the world for operational and research purposes and is freely available. The WRF model can be customized for specific purposes and for specific location by providing appropriate local information. The model may require tuning in terms of grid spacing, constants involved in the model such as topography, land usage, and physical parameterization schemes over the domain of interest.

224. As presented in section 2.1.1, the National Centre for Environment Prediction (NCEP) generates global medium-range forecasts at different resolutions and uploads this information to their website 4 times per day at 00 UTC, 06 UTC, 12 UTC and 18 UTC. The initial and boundary condition data sets required by the high resolution NWP model at DOM can be drawn from the above mentioned Global Forecasting System (GFS) of NCEP, which is freely downloadable.

225. The computational requirements will vary according to the grid spacing and integration period. Based on the consultant's experience in WRF modelling and the GFS data availability, it is proposed to run the WRF model to generate a forecast for 120 hours (5-days) twice per day (00 UTC and 12 UTC). An overview of the model is provided in **Table 2** and the schematic diagram of the model domain is shown in **Figure 18**. While the outer domain covers most of Asia, the inner domain will cover South-East Asia and surrounding areas to ensure that areas, which influence weather and climate of Cambodia, are included. The outer mother domain of the model is planned to have a 27 km horizontal resolution, while the inner child domain will be a resolution of 9 km.

226. The Department of Hydrology and River Works can receive these high resolution (9 km) numerical forecast values as input to the hydrological models.

227. The estimated CPU requirements for that model configuration are calculated and provided in **Table 3**. The output of the numerical model can also be used for flash flood warning, cyclone warning and for the preparation of daily weather forecast bulletins. The modelling system can also be used to address future needs of DOM.

228. The detailed activities under developments of NWP modelling system can be found in the **Appendix 2**.

Table 2: Overview of the Numerical Weather Prediction system for Cambodia

Core of the model	WRF ARW
Number of domains	Two (with one nest)
Outer domain	15°S-50°N; 65°E-150°E with 27km horizontal grid spacing
Inner domain	0°N-30°N; 90°E-125°E with 9km hor. grid spacing
Number of Vertical levels	40
Time step	120 Seconds for the outer domain & 45 Seconds for the inner domain (estimated)
Initial and boundary conditions	NCEP (GFS) (other data sets can also be used if they are available to DOM)
Integration period	120 hours (5 days)
Model integration frequency	2 cycles/day (00UTC and 12 UTC)

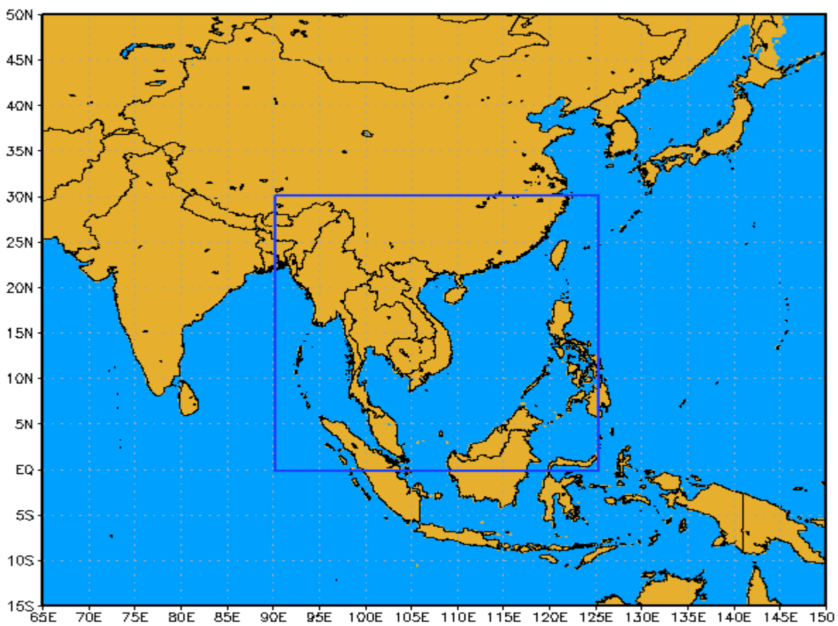


Figure 18: Model domain (Outer domain covers South-East, East and South Asia and the inner domain within the blue box covers Cambodia and its neighbourhood)

Table 3: Computational requirements to generate weather forecast in Cambodia

Model configuration (a)	No. of grid points in horizontal and vertical directions (b)	Time step and total integration period (c)	Total iterations involved (Integration period/time step) (d)	Floating point operations required per grid point (2800 x no.of iterations) (e=2800 xd)	Time frame to get the output (in seconds) (f) (one hour in sec)	Floating point operations per second per grid point (g=e/f)	FLOPS required for the whole domain (h=g x b)
Outer domain 65°E-150°E; 15°S-50°N; Hor. Res: 27km	347 X 265 X 40	120 sec; 120 hours	3600	10080000	1X60X60	2800	0.010298 TF
Inner Domain 90°E-125°E; 0°N-30°N Hor.Res:09km	428 X 367 X 40	45 sec; 120 hours	9600	26880000	1X60X60	7467	0.04692TF
Required computational power to integrate both the outer and inner models (in Tera Flops)							0.057218TF
Preparation of IC &BC, calculation of physical parameterization processes and post processing and graphics will take about 50% additional floating point operations.							0.028609TF
Total Peak computational capacity required for short range prediction system (in TF)							0.085827TF

6.2. Flood Forecast Modelling

229. The flood forecasting modelling will cover a pilot basin - Pursat River and mainstream Mekong, Bassac and Tonle Sap Rivers in Cambodia.

230. Typical flow chart for flood forecast modelling system is shown in **Figure 19** that starting from data collection and transmission, to the central database for data checking and analysing before imputing to the flood forecast model to produce forecast outputs.

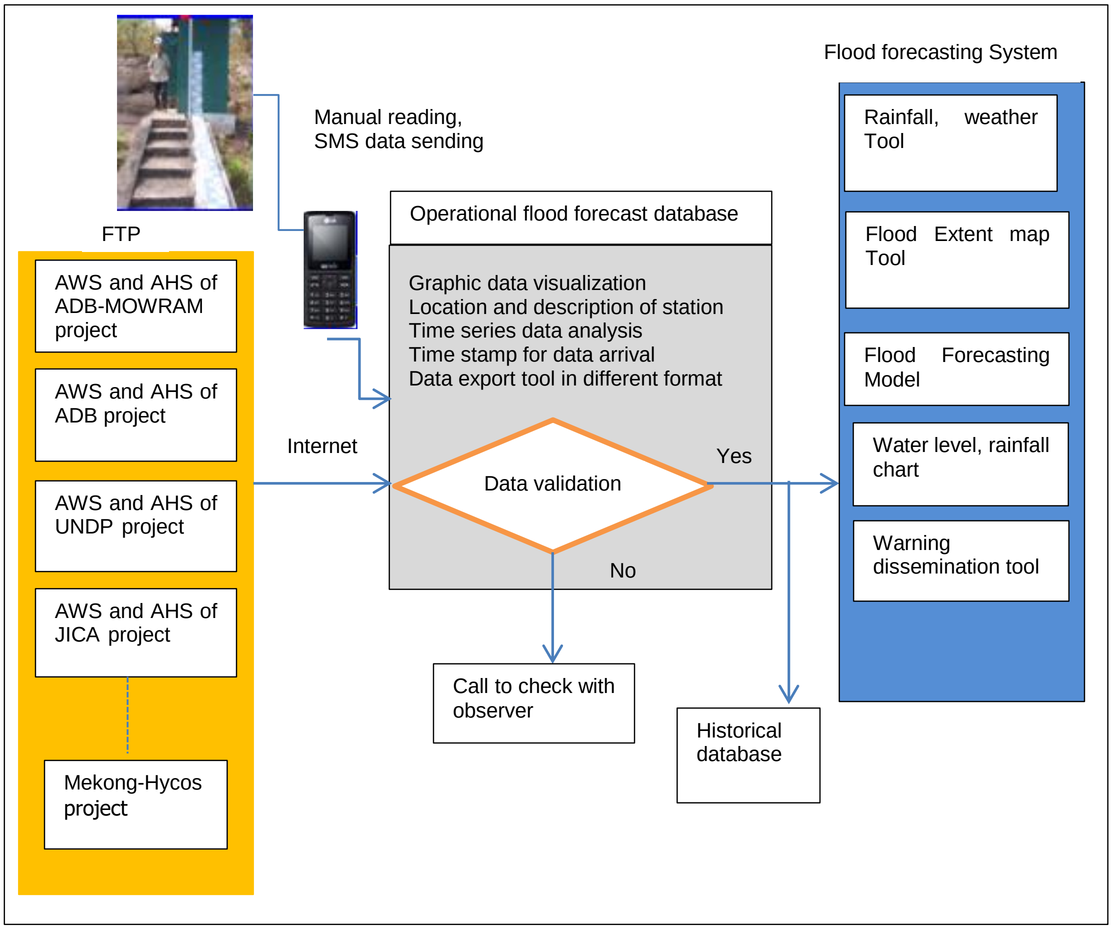


Figure 19: Typical flow chart for flood forecast modelling system in Cambodia

6.2.1. Pursat River basin

231. In the upstream parts of the basin (upstream of the Bak Trakuon station), runoff of rainfall is important and local hydrological processes (**Figure 20 A**) will be very relevant. The gradient of the river is often steep. The river is confined by and below the surrounding land level. In this case flooding is most often limited to the areas close to the river.

232. Downstream of Bak Trakuon station, the flow will propagate and attenuate (**Figure 20 A**) due to some water structures across the river, such as, Damnak Ampil gates, Kbal Hong (upstream Khum Veal station), and Charek (downstream Khum Veal station).

233. From Bak Trakuon to Khum Veal, the Pursat River losses about 60% of its peak flood: through exiting via the intake canal on the left bank (Damnak Ampil), channel storages and under natural conditions. The overbank flood flow passes through Stung Kambot, O Ta Poang, and Stung Svay Donkeo, which later flow to the Stung Dauntry before discharging into the Tonle Sap Great Lake.

234. In downstream areas below the National Road 5, where the Pursat Town is located, the land elevation is often below the high water levels in the river. The areas are hydraulically dominant,

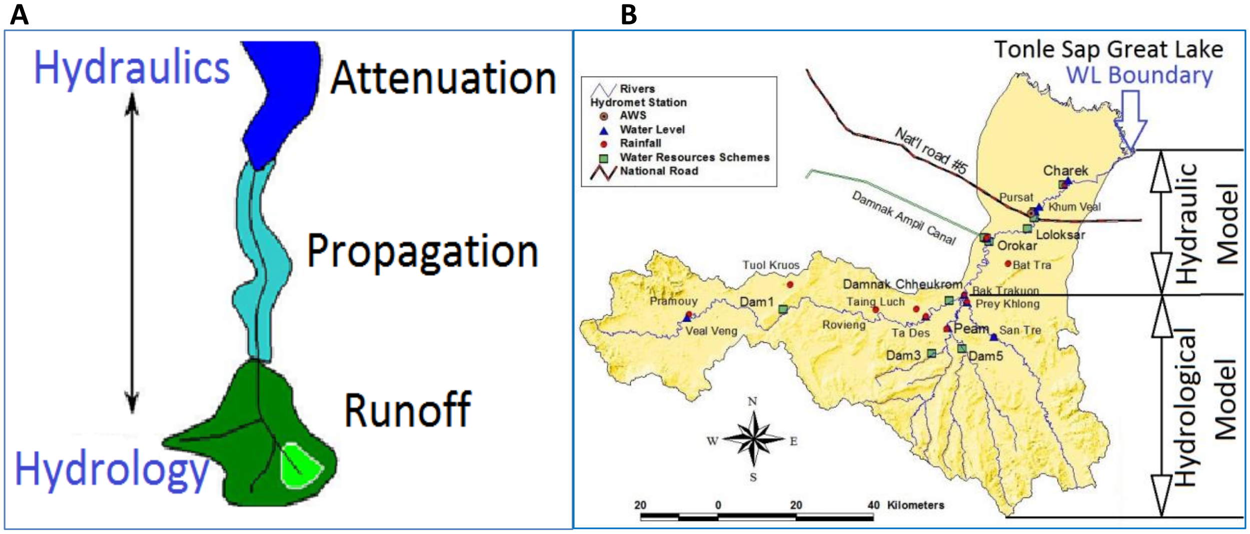


Figure 20: Processes in a river basin and typical model application to the Pursat River

235. Therefore, the development of flood forecast modelling for the Pursat River will consider a combination of both hydrological and Hydrodynamic models as shown in **Figure 20 B**:

1. Rainfall-Runoff modelling for the whole Pursat River basin

2. Hydraulic (Hydrodynamic) model for the lower part from Bak Trakuon station downward to Tonle Sap Great Lake.

236. The hydrological model will be developed taking into account 2 dam reservoirs (Dam 3 and 5), the being-constructed gates at Damnak Chheukrom and Damnak Ampil gates and others, as diversion elements. The model will use all available rainfall data recorded since 1996 onwards and will be calibrated again the observed flows at Peam for Stung Peam river, at Prey Khlong for Stung Prey Khlong river and finally at Bak Trakuon, where all three rivers meet. The results from the hydrological model are flows at Bak Trakuon, which will be used as boundary inputs to the hydrodynamic model. Example of hydrological model development using HEC-HMS 4.1 for the Pursat River basin was shown in **Figure 21**.

237. The hydrodynamic model development will be calibrated again the observed flows at Khum Veal considering the Damnak Ampil gate operation and all lower irrigation schemes. The model will use the flow hydrograph at Bak Trakuon and water level of Tonle Sap Great Lake as upstream and downstream boundary inputs, respectively. However, the cross section data along the Pursat River are not available. The cross section survey campaign will need to be conducted.

238. For flood forecast, the models will use the observed rainfall from the new rehabilitated stations (WBS 200) together with forecast rainfall as discussed in Section 6.2.

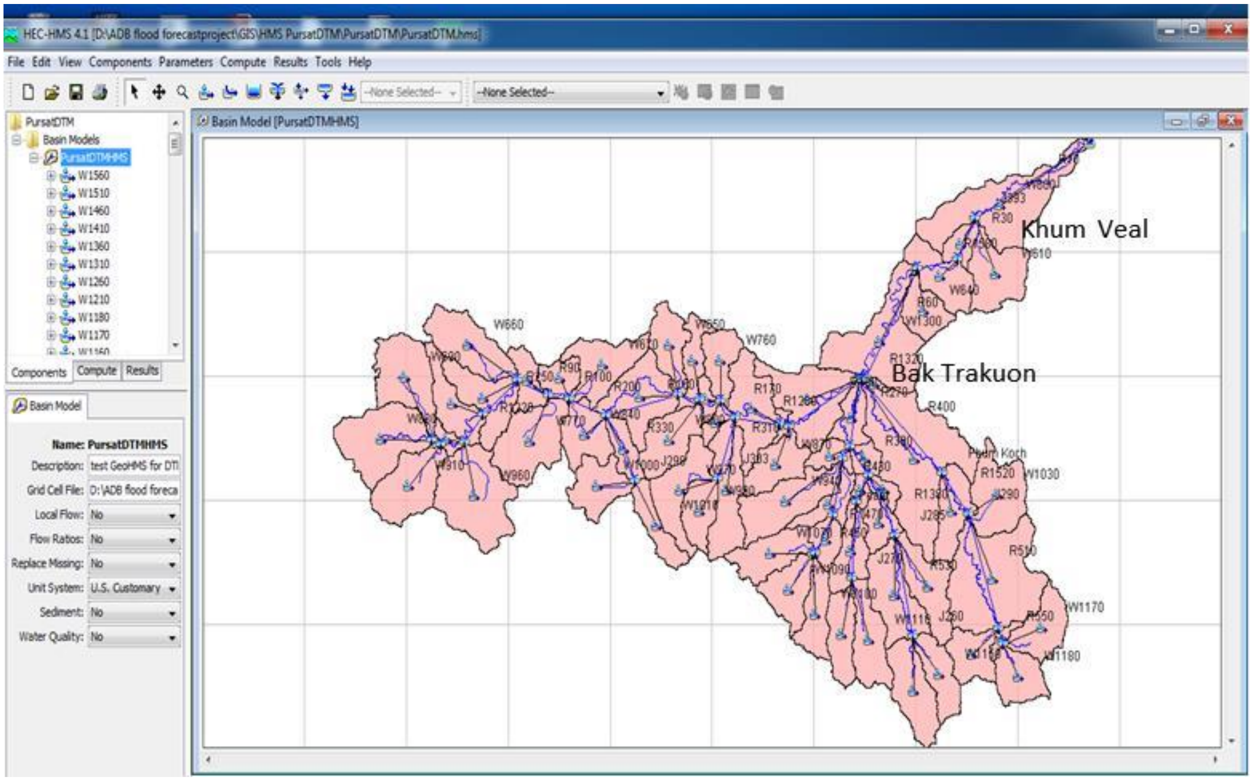


Figure 21: Hydrological Model - HEC-HMS 4.1 for the Pursat River basin

6.2.2. Mainstream Mekong

239. For the mainstream Mekong, combined hydrological and hydrodynamic models will be developed to forecast both flood levels and flows at the main focal stations as well as at location of interest in floodplain.

240. The hydrological model will be developed for the tributaries and the upper parts of the mainstream from Cambodia - Lao PDR down to Kratie station. Results from the hydrological models are water flow hydrographs at the outlet of each tributary, and for the mainstream Mekong at Stung Treng and Kratie. The rainfall input will be forecast rainfall as discussed in Section 6.2.

241. Then, from Kratie downwards including the Tonle Sap Great Lake, the Hydrodynamic model is applied. The hydrodynamic model will use the flows (water levels) at Kratie and from the tributaries' outlets as the upper boundary inputs. The lower boundary inputs will be the water levels at Tan Chau and Chau Doc or from new proposed stations at Cambodia-Vietnam border on the Mekong and Bassac rivers.

242. The regression model will be updated and used to provide a check at the existing forecast stations (shown in **Figure 22** by the red triangles) on the results of physically modelled approaches as well as to assist in generating water levels/flows as the upper boundary input (at Kratie) and forecast water levels at Tan Chau (on the Mekong river) and Chau Doc (on the Bassac river) as the lower boundary inputs.

243. Both the hydrological and hydrodynamic model development will consider data information of regional models used by MRC-FMMP such as the existing DTM with scale 1:50,000, cross section from the MRC ISIS model with a 4 km spacing, topo map (JICA 2004), SRTM from USGS and other related available maps. Hydromet data available within DHRW and DOM, especially from the Cambodia Operational Hydrological Database (CamOHDB) compiled by CDTA-CAM 7610 will be used for model calibration and verification.

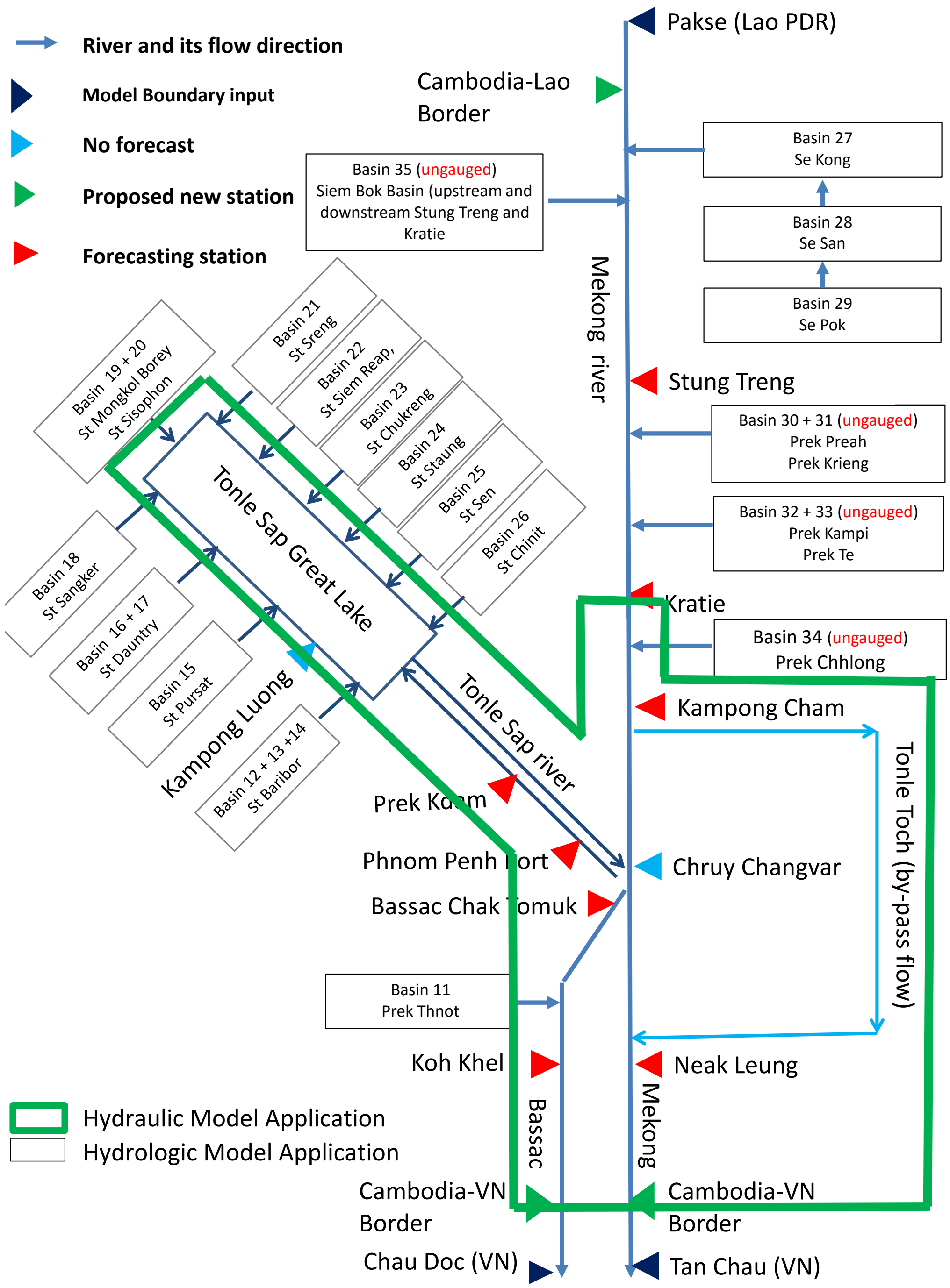


Figure 22: Scheme for the Mainstream Mekong

6.2.3. Model Selection

244. The proposed modelling strategy is based on the United States Army Corp of Engineers HEC suite of models. It is believed that using the HEC suite of models will build additional modelling capacity in Cambodia and provide future options for modelling of hydrological and hydraulic events.

245. The following features make the HEC suite of models a good choice for this activity:

- The models are available free of charge and are actively maintained, supported, and under regular development by the U.S. Army Corps of Engineers' Hydrological Engineering Center (HEC) in Davis, California.
- The models are widely used in the engineering community, including applications around the world by consultants and counterpart teams. Software support, including regularly scheduled training courses, is readily accessible.
- The models facilitate processing of geospatial data within a GIS framework, simplifying model development.
- The models provide map-based representations of drainage basins and stream networks.
- The models offer a user-friendly graphical interface, which makes model updating, scenario testing, sensitivity analysis, and reporting more efficient.
- The HEC models read and write hydrometric data stored in a common and easily accessible database format such as HEC-DSS. HEC-DSS is the Corps of Engineers' data storage system for hydrometric data. However the read-write functionality and database interface format can be easily configured for other database structures.

6.2.3.1. Hydrological modelling

246. Regarding hydrological modelling, **HEC-HMS model** version 4.1 will be applies for the purpose. **Figure 23** shows a scheme of the HEC-HMS hydrological modelling methodology.

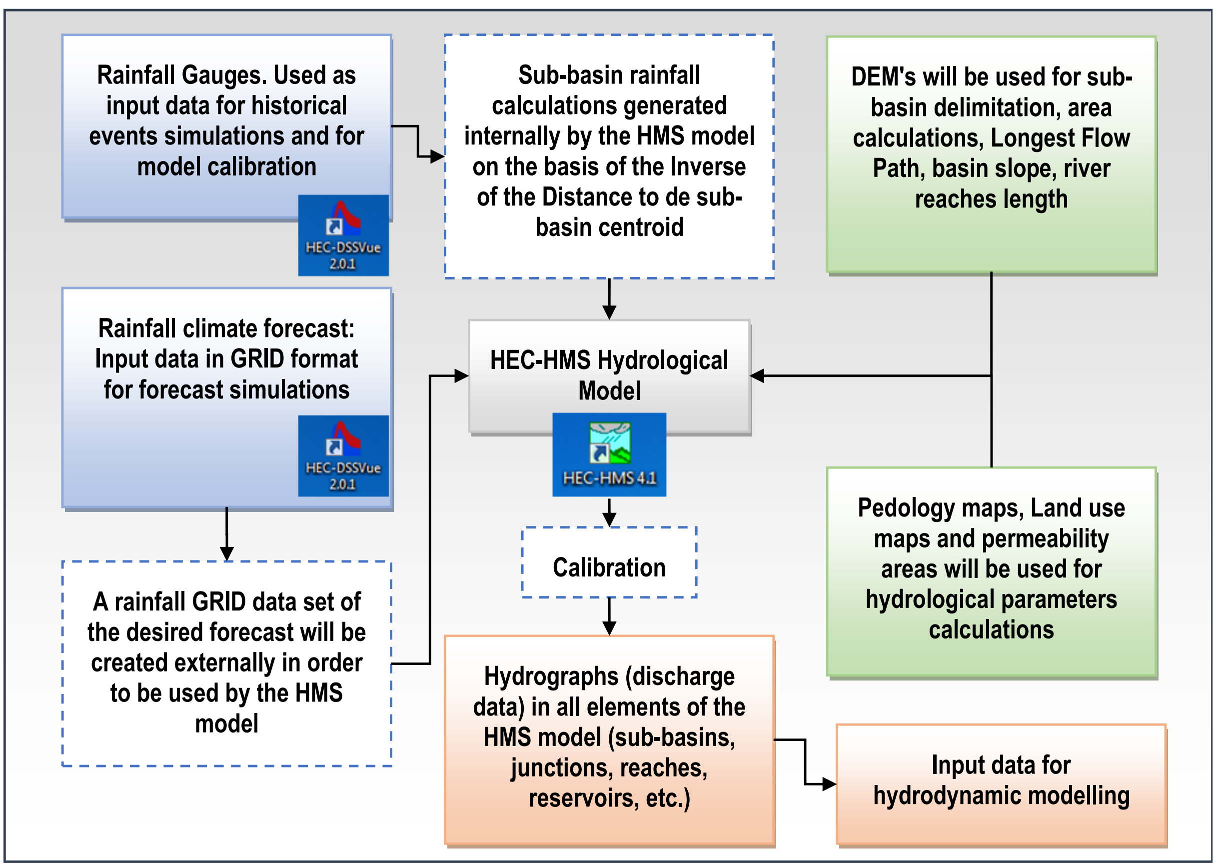


Figure 23: HEC-HMS hydrological modelling methodology scheme

6.2.3.2. Hydrodynamic modelling

247. Regarding hydrodynamic modelling, HEC-RAS model version 5.0.1 will be applies for the purpose. **Figure 24** shows a scheme of the HEC-RAS hydrodynamic modelling methodology. Mapping and visualization of flood extent and duration of flood events will be carried out with the use of the RAS-MAPPER interface, which is accessed from the HEC-RAS program. The methodology to apply the RAS-MAPPER for determining mapping, and visualizing flood extent and duration for flood events is already shown in **Figures 16**.

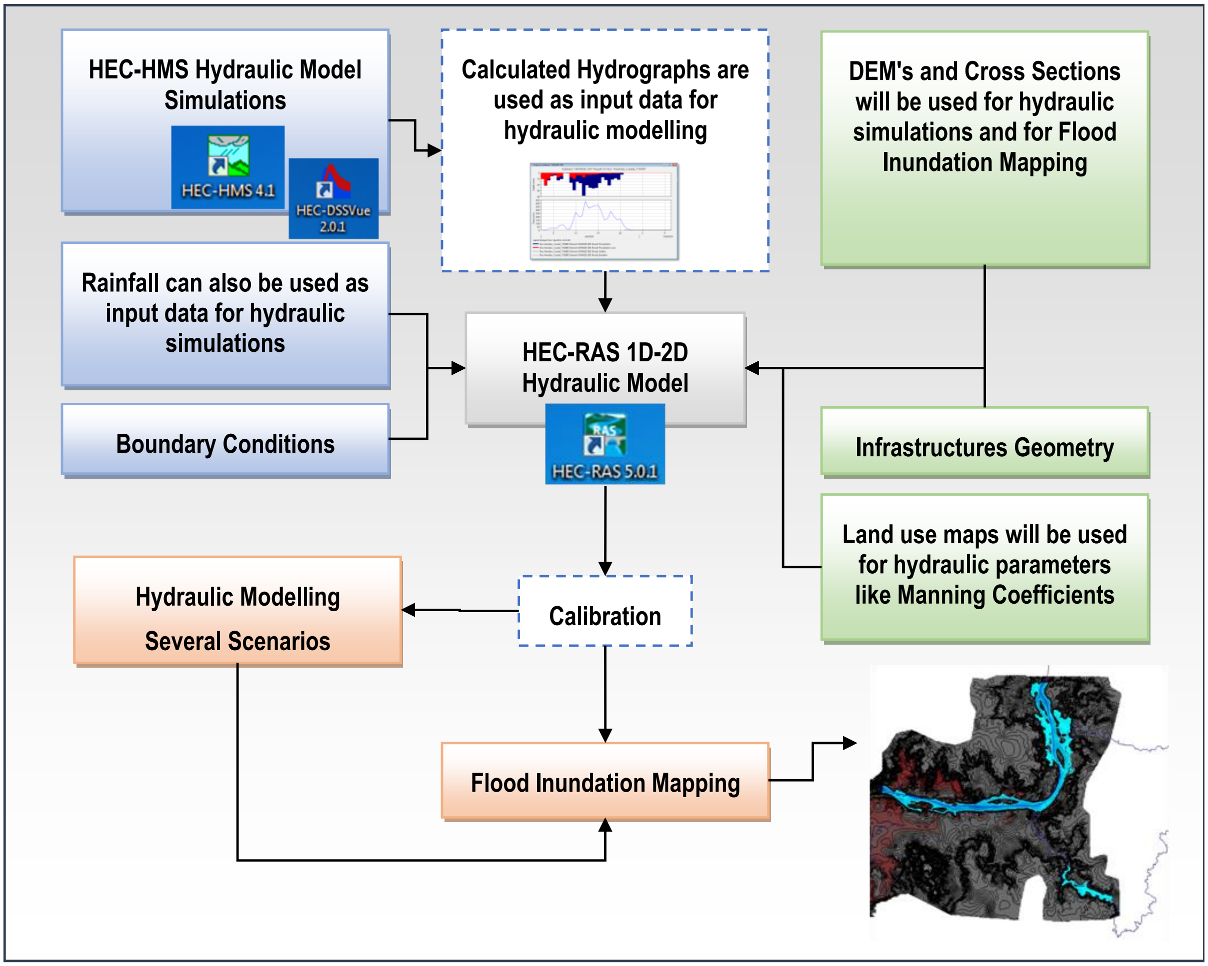


Figure 24: HEC-RAS hydrodynamic modelling methodology scheme

6.2.3.3. Flood Forecasting and Presentation Systems

248. The project considers to apply the Deltares' Flood Early Warning System (Delft-FEWS) as it is an open data handling platform with sophisticated collection of modules designed for building a hydrological forecasting system customised to the specific requirements of any individual organisation. Essentially, Delft-FEWS is already available within the MRC as part of its flood forecasting system and a series of training sessions on FEWS has been provided to the DHRW staff by the MRC.

249. The database system is the one that will be procured and developed under the WBS 200 and 400.

7. Capacity Strengthening and Training

7.1. Weather Forecast Modelling

250. The proposed capacity building and training plan to achieve greater customization of the available GFS products and for the development of capacity within DOM to run a NWP model are outlined in the following sub-sections.

7.1.1 Capacity building and Training plan to use customized products of other centres

251. As provided in the section 2.1.1, and 6.1, many types of forecast information can be extracted from the currently available products received by DOM. The training schedule includes hands-on customization of the selected products and lectures on product details and the analysis of the products considering Cambodian requirements. The lectures are to be in-house and with on-the-job mentoring. The proposed period of training is as follows:

- Short range weather products from ECMWF, ARP, GFS and SWDP: 12 working days
- Medium Range weather products (ECMWF, GFS, JMA): 12 working days
- Long range weather and seasonal products (ECMWF, IRI, APCC): 12 working days

7.1.2 Capacity building training for Integration of high resolution NWP models

252. A series of steps are required to implement a NWP model, which include the installation of various software applications, compiling the model, and setting up the initial conditions for the NWP model. These initial steps will involve DOM staff

253. The time required to complete the noted steps, after the installation of system software is summarize below. All developmental work will be carried out in-house with the DOM forecasting staff to ensure that DOM staff receive exposure to the processes involved in NWP modelling.

- Installation of WRF system: 5 working days
- Installtiaon of WRF pre-rocessing and post-processing packages: 2 working days
- Installation of associated software such as libpng, japer, zlib, perl etc.: 3 working days
- Installation and compilation of graphic software: 2 working days
- Compilation of all the softwares and model components: 5 working days
- Sample integration and verification with observed data: 5 working days
- On-job-training to the participants: 20 working days

254. Total training provided in all the activities: **40 working days**

7.2. Flood Forecast Modelling

255. The capacity development for the NFFC staff in flood forecast modelling would be through technical trainings in the following themes:

- Hydrological equipment installation and maintenance;
- Data analysis and management;

- Hydrological and hydrodynamic modelling: model setting-up, calibration, validation, operation, and maintenance and upgrading;
- Forecasting system operations, model refinements, presentation and dissemination; and
- GIS flood mapping applications ranging fromsimple GIS functions to more complex spatial functions required to generatee flood maps

256. The trainings will use formal and on-the-job training approaches during project implementation from July 2016 to October 2017.

257. The formal training, will be conducted as the modelling work progresses. On-the-job training will be conducted. A self-study approach is also encouraged and the consultant team will prepare self-study modules and user guides for the NFFC staff to use.

8. Budget Requirements

8.1 Weather Forecast modelling component

258. An estimate of the financial requirements to complete the weather forecast modelling component is provided below. The hardware components of the computational system for weather forecasting component will consume the major portion of budget and a small part will be used for software such as LINUX OS (4 Licenses) and PGI Compilers (FORTRAN 95 and C++). Though freely downloadable compilers are available, past experience pointing towards purchasing them as some of the FORTRAN and C++ language built-in functions are missing in the freely available compilers. It may create problem while integrating the WRF model. Other modelling software components such as WRF model, Pre-Processing and Post-Processing programs, graphics, and libraries for the WRF model are open source. Variations in price may be expected between manufacturers and from country to country. An estimated budget is provided in **Table 4** below.

Table 4: Estimated budget for weather forecast modelling component

No.	Item List	Price in USD
1	CPU with (96 GHZ; 48 GB RAM,):	20,000
2	Storage (50 TB):	10,000
3	Graphic Card (1.28 GB):	5,000
4	LED Monitor (dual monitor; 24”):	5,000
5	Operating System:	5,000
6	Compilors (Fortran 95, C++; 4 Licenses):	5,000
Total cost:		50,000

8.2 Flood Forecast modelling component

259. An estimate of the financial requirements to complete the flood forecast modelling component is provided below. Variations in price of hardware and software may be expected between manufacturers and from country to country. An estimated budget is provided in **Table 5** below.

Table 5: Estimated budget for Flood forecast modelling component

No	Item	Quantity	Unit Price	Total Price
			USD	
1	PC (CPU core i7 - Processor 4,2 GHz; 32 GB RAM, 6 - 8 GB Graphics card, 2 TB Solid State Drive Hard Disk, LED 24" - 27" dual screen, NVIDIA® GeForce® GTX 960 2GB DDR5, Windows 10 Pro)	4	5000	20,000
2	Formal Trainings Organization for both weather and flood modelling	Lumped SUM		120,000
3	Training Materials, Translation, Reports	Lumped SUM		10,000
Total Cost				150,000

9. Conclusions and Recommendations

260. This report presents a Conceptual Design for a comprehensive "end to end" system, outlining key issues, and provides a future vision for improving NFFC's analytical and modelling capability to provide improved flood forecasts and drought predictions for Cambodia. The model selection for the flood forecasting system has been defined.

261. An outline of a capacity building plan has been prepared. The capacity building plan was developed to support the hydrological equipment installation and maintenance, data analysis, hydrological and hydrodynamic modelling, forecasting system as well as on GIS flood mapping application as implemented under the proposed Flood forecasting and Drought predicting systems.

10. References

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Appendix 1 - Pursat River Basin Profile.

Physiography

262. The Pursat River basin is located in the Pursat province in the southern part of the Tonle Sap Great Lake basin, and drains an area of 5,964 km^2 (**Figure i**).

263. The Pursat River originates in the drier eastern slopes of the Cardamom mountain and flows for approximately 150 km, ultimately draining into the Tonle Sap Great Lake. Two main tributaries, the Stung Peam and Stung Santre (Prey Khlong) rivers, flow in a northerly direction, and meet the Pursat River just above Bac Trakuon gauging station. The drainage area at Bac Trakuon, just below the confluence of the Pursat River and the two tributaries is 4,245 km^2, and 4,596 km^2 farther downstream at the Khum Veal gauging station, located near the Pursat town.

264. Elevations in the Pursat River basin range between six and 1,717 m above sea level (masl)[4]. More than 75% of the basin encompasses terrain of hilly topography with an elevation greater than 30 masl, and is covered by forested land of varying densities. The remaining low-lying land is occupied by agriculture (**Figure ii**).

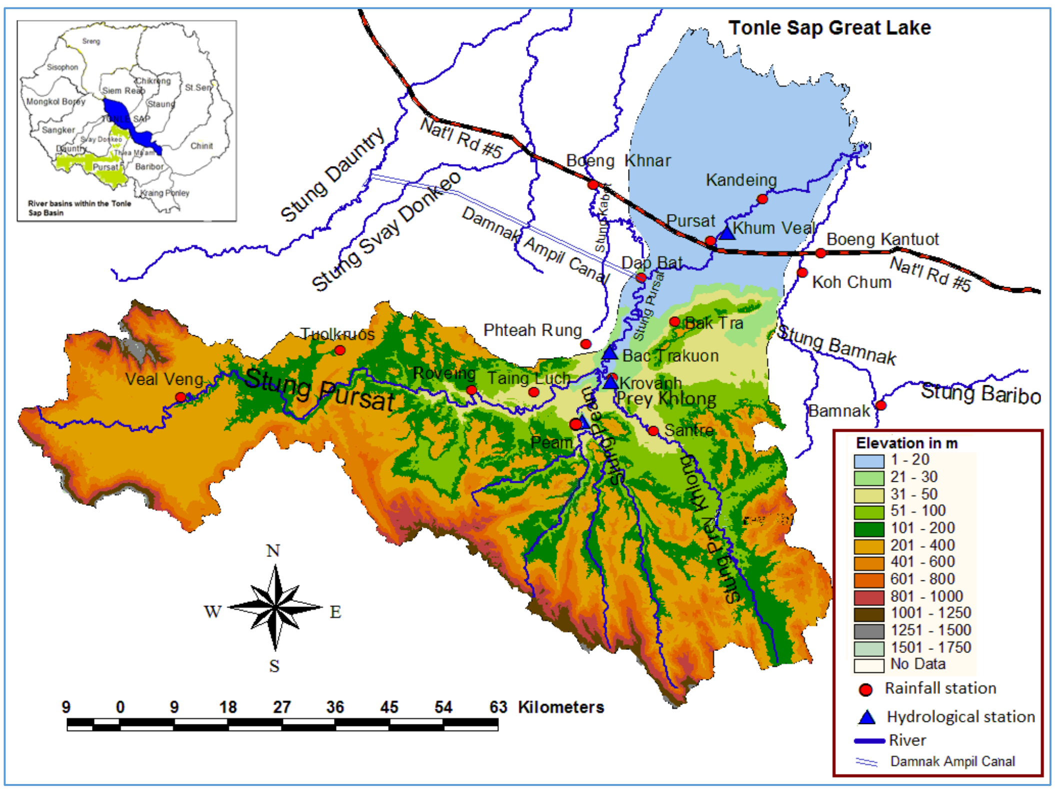


Figure i: Map of location of the Pursat River basin, elevation and hydromet monitoring stations

265. Major soil types in the Pursat River basin are: Dystric Leptosol, and Cambisol in the upper reaches; Gleyic, and Plintic Acrisols in the mid-elevation reaches and; Dystric Fluvisol, and Dystric Gleysol in the lower elevation reaches (**Figure iii**).

[4] Elevations referenced to mean sea level based on the Ha Tien datum, Viet Nam

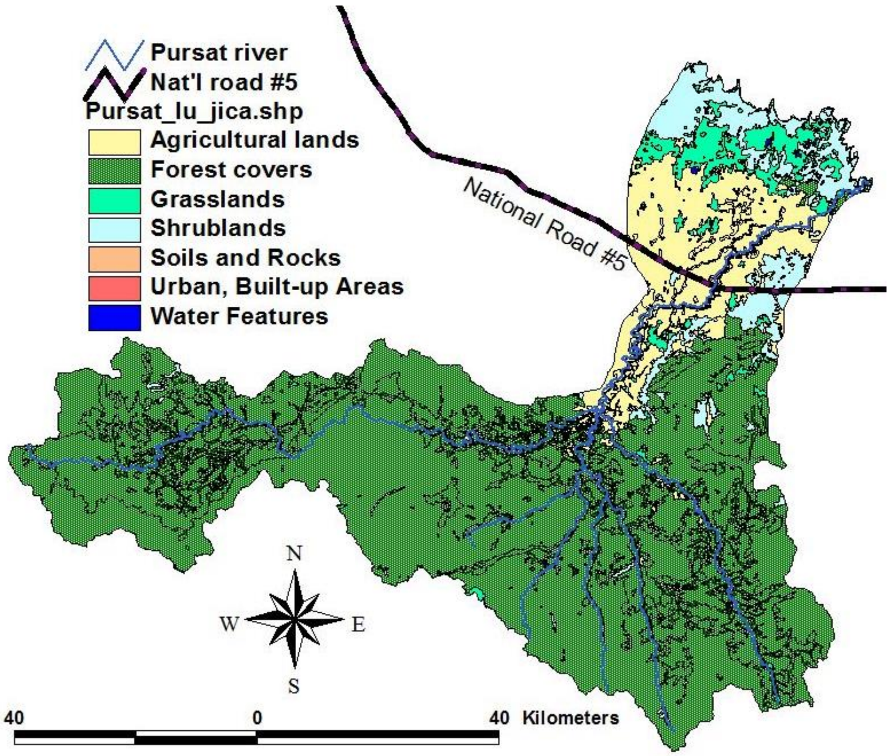


Figure ii: Map of Forest Cover of the Pursat River basin (source: JICA Map 2005).

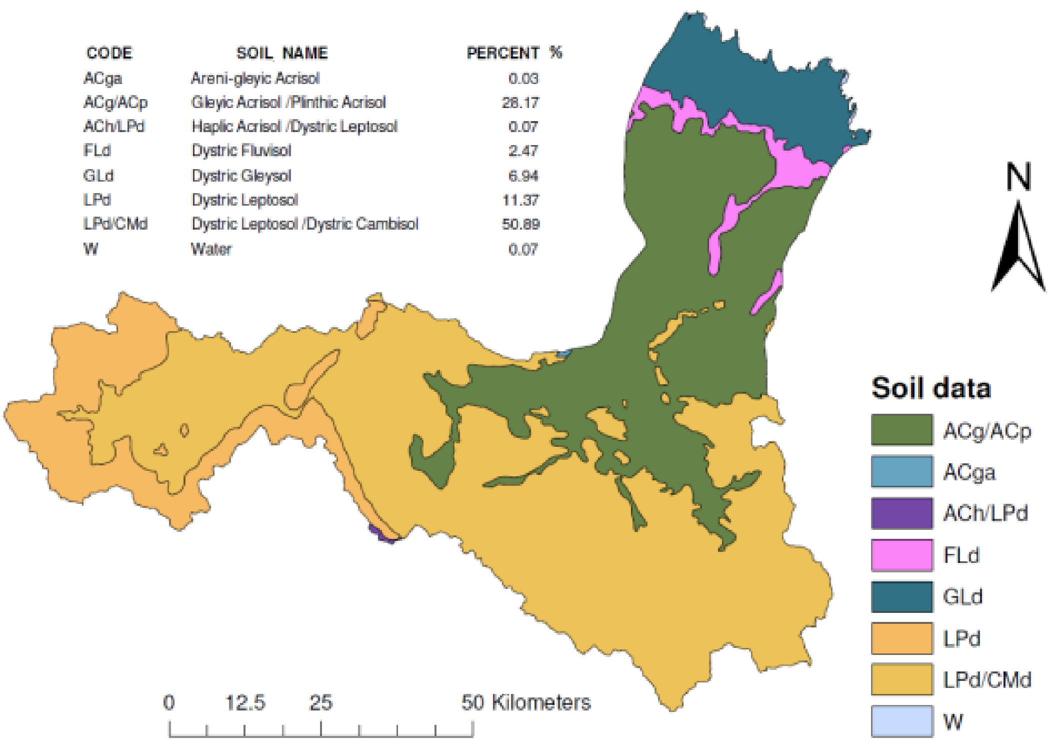


Figure iii: Soil map of the Pursat River basin (source: MRC 2002).

266. Based on the General Population Census of Cambodia 2008 (**Figure iv**), the population in the Pursat River basin is 203,522 persons (CNMC 2012: "Profile of Sub-area Tonle Sap"). The basin is shared by six districts: Veal Veng, Kravanh, Sampov Meas, Krakor, Bakan, and Kandieng. People living close to the lake earn their livelihood from fishing, while those further away depend on rice cultivation.

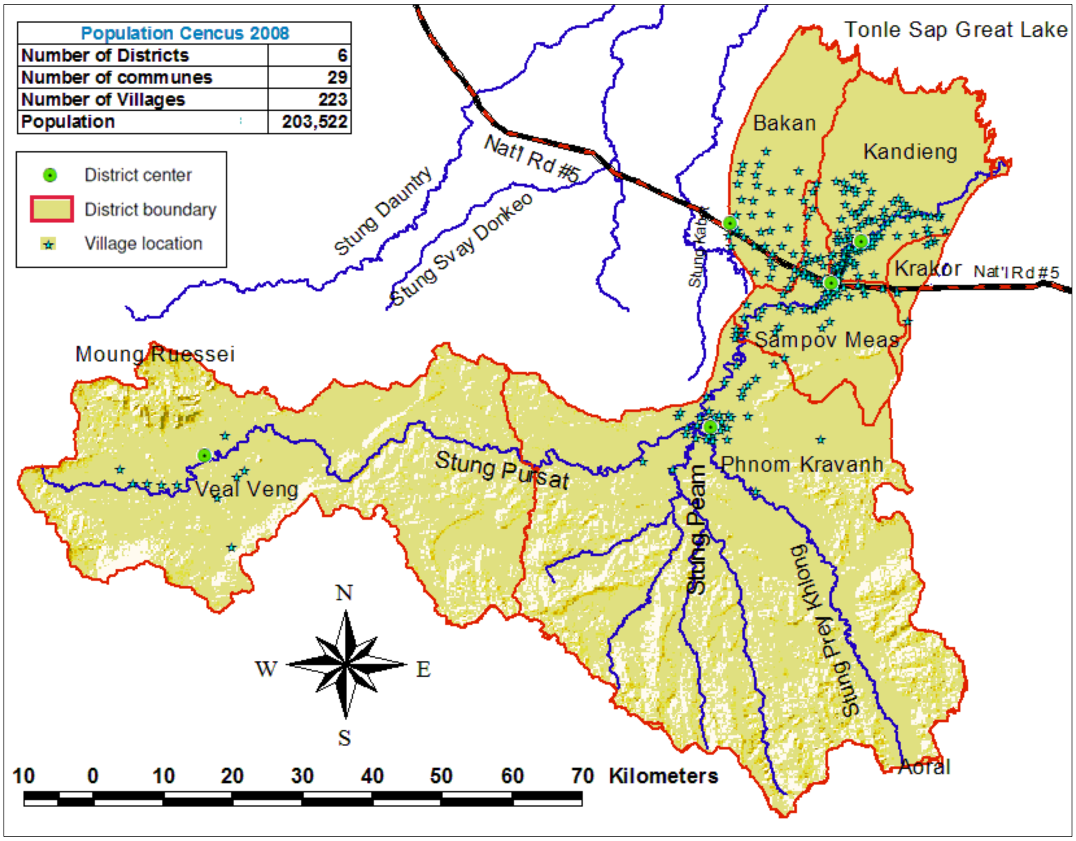


Figure iv: Map of Districts and village location share the Pursat River basin (CNMC 2012)

Existing and Planned Water Development Structures

267. Similar to other basin of the Tonle Sap Basin, the basin water resources is increasingly under stress with some irrigation projects already under construction and planning and hydropower projects. Those projects are mainly conceived and planned based on existing demised Pol Pot infrastructure. Recent focus on rice production export has put extra stress on water resources of this basin while knowledge gaps are growing in all development sectors including capacity for planning and management.

268. Irrigation system distribution is very complicated since there are 17 large and medium size existing and planned irrigation areas including 3 in the Svay Donkeo river basin (**Figure vi**). The location of all existing and planned water development structures in the Pursat River basin is shown in **Figure vii** with the total command area of 55,509 ha (**Table i**)

269. At present, two dam projects (Dam No. 3 and No. 5) for creating two reservoirs by the development partners (China) have been implemented since 2010. Dam No. 3 has storage capacity of 25.5 MCM and Dam No. 5 of 24.5

MCM. According to the Feasibility Study report on those dams, these two dams would realize double cropping of paddy for 6,200 ha and supply to the Damnak Ampil irrigation schemes.

Table i: Total irrigation area of Existing and planned irrigation systems

Irrigation Scheme	Command Area [HA]
Damnak Chheukrom	16,000
Damnak Ampil	24,629
Lolok Sar	580
Kbal Hong (RB + LB)	3,200
Charek	11,000
Total Irrigation areas in the Pursat River Basin	55,409

270. Another water resource development project is Dam No. 1 (**Figure v**) under Ministry on Industry, Mines and Energy (MIME) and supported by Korean government, though it is still in pre-Feasibility Study stage. Dam No. 1 would have storage capacity of more than 1,000 MCM and aimed mainly at hydro-power generation.

Hydropower dam #1 Characteristics	
RATED GROSS HEAD, M	122
INSTALLED CAPACITY, MW	40
OVERALL EFFICIENCY AT GROSS HEAD	0.9
FULL SUPPLY LEVEL, MAMSL	195
LOW SUPPLY LEVEL, MAMSL	170
TAILWATER LEVEL, MAMSL	65
DESIGN DISCHARGE, M^3/S	38.8
LIVE STORAGE, MCM	1014
DEAD STORAGE, MCM	306

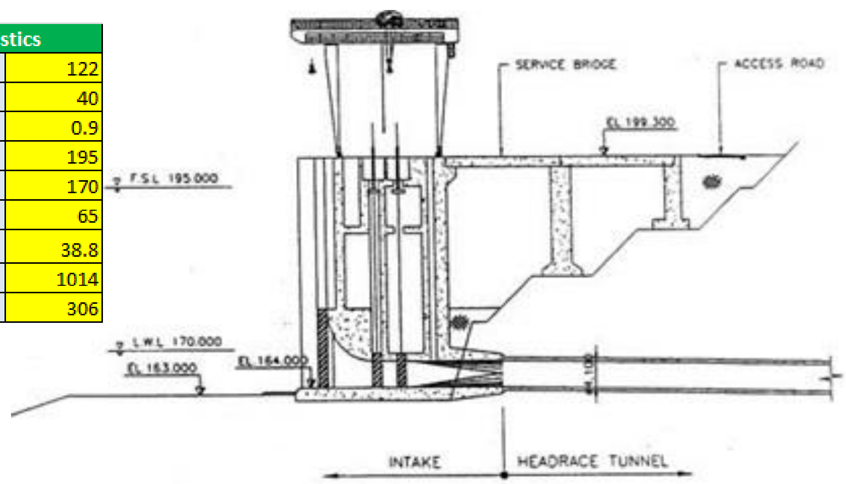


Figure v: Hydropower Dam No. 1 characteristics (MIME 2010)

271. Expecting the augmented river flow by the Dam No.1, the **Damnak Chheukrom** irrigation project has been studied with assistance of ADB and the construction has commenced in 2015. That project is expected to provide irrigation water for 16,100 ha on the left bank of the Pursat River.

272. **The Damnak Ampil Diversion Weir:** A diversion weir with automatic gates (rehabilitated in 2006) at Damnak Ampil was built during Khmer Rouge era across the Pursat River to divert water to feed the canal, which links between Stung Dauntry and Pursat River (**Figures vi**). Part of it has been rehabilitated. The structure will also provide water to irrigation systems on the right bank of Pursat River. In total, the Damnak Ampil headworks will provide water to irrigation systems of 24,629 hectares covering sub-projects: Damnak Ampil extension of 15,000 ha, Damnak Ampil of 2519 ha, Wat Loung 2410 ha and O Rokar of 4700 ha. The canal cross section is trapezoidal with the bed width of 7 m and side slope of 2:3, and the longitudinal slope is about 0.0002. Water is distributed by a network of new and old second order gates and canals. No recorded data for the canal or its diversion structure on the Pursat River was available. With reference to the information provided by the Pursat PDWRAM staff, the gates will automatically fall down (fully open) and let the water in Pursat River freely flows downstream the weir when the water level in the river reaches 17.0 m (local datum).

273. The downstream of the Damnak Ampil irrigation schemes are Lolok Sar, Kbal Hong and Charek. The last two schemes are located inside ring of the National Road 5. The Charek scheme has automatic gates constructed across the river and the gates automatically fall down in similar way to the gates at Damnak Ampil.

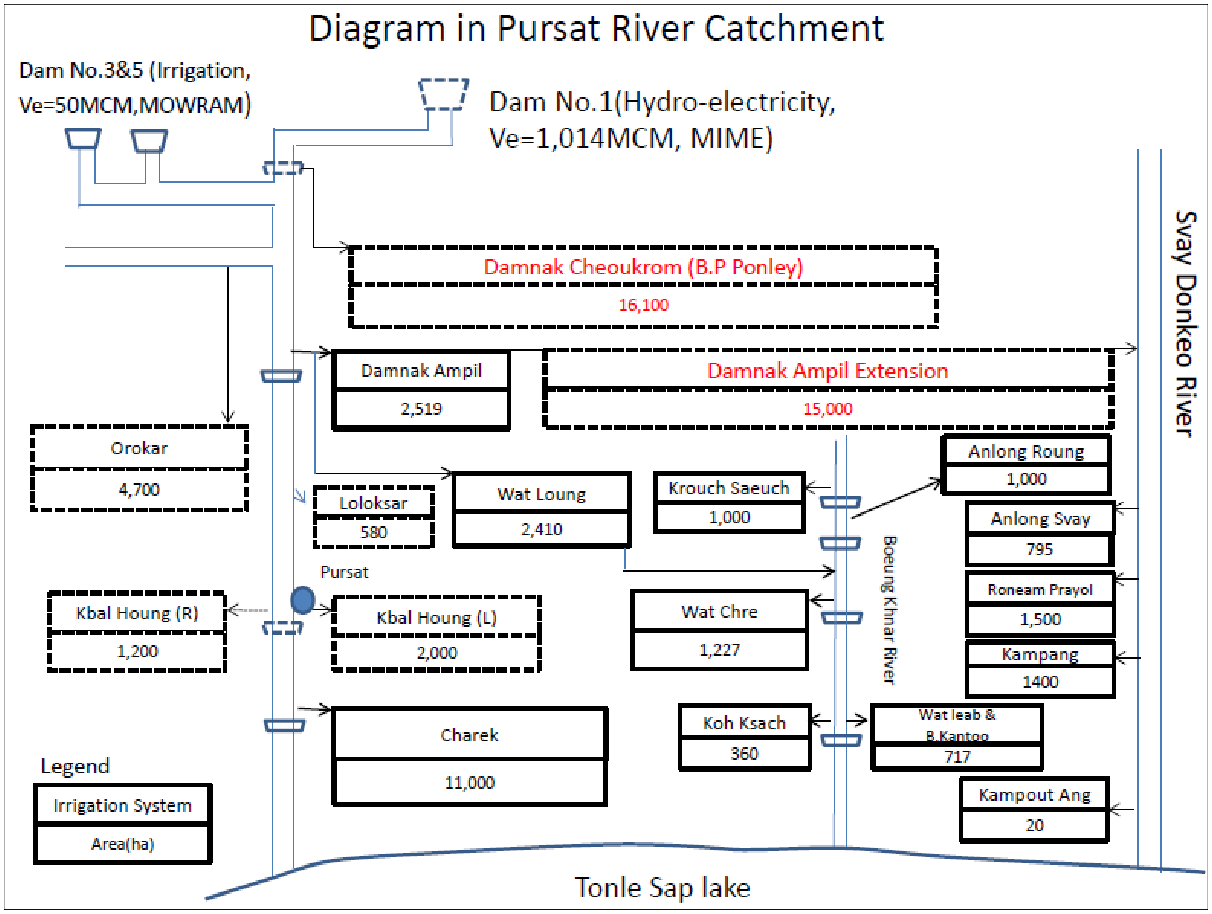


Figure vi: Water resources development in the Pursat River basin (SAPI, JICA 2011)

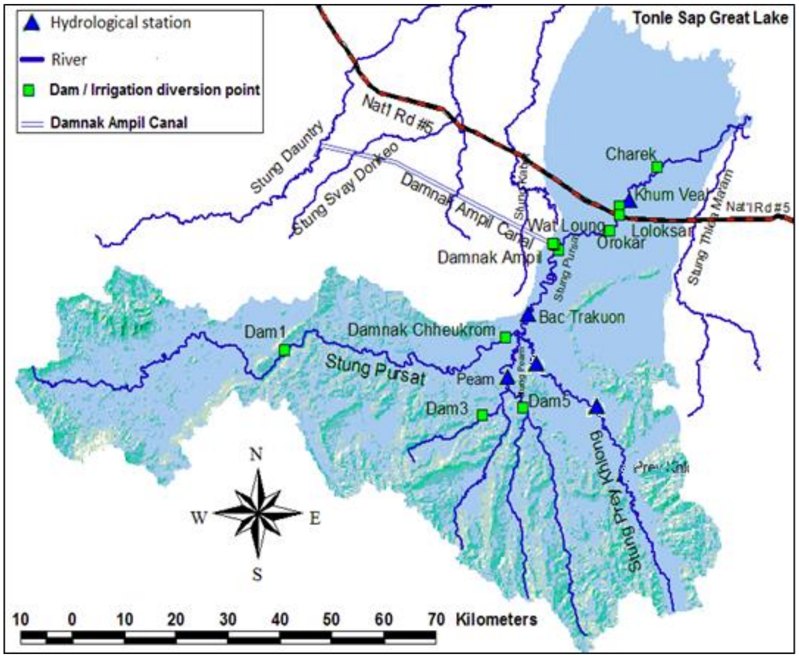


Figure vii: Location of Water resources development in the Pursat River basin (JICA 2013)

Climate

274. The Pursat River basin climate is dominated by tropical monsoons with pronounced wet and dry seasons. In the wet season, the southwest monsoon, extends from May to November when occurs about 90% of the annual rainfall. The remaining months are influenced by the northeast monsoon, characterized by hot and relatively dry air with particularly high potential transpiration demands during March and April. The chain of the Elephant and the Cardamom mountain ranges to the west and southwest of the country modify the rainfall observed in the lowland area to the east that lies in their rain shadow. The strong influence of the Cardamom and other mountain areas exerts are factors in the much lower 900 to 1,800 mm of rain over most of the low land areas during normal years. This is because of the rain shadow effect. Several areas around the Great Lake suffer from persistent rain-shadow effects, which reduce the rainfall over the same area to the range from 800 to 1,500mm in dry year. During these dry years, the area suffering from rain-shadow effects broadens from small areas either side of the Great Lake, to extend over the whole Lake and peripheral low land areas.

275. Rainfall around the Pursat River basin area increases with elevation. The annual average rainfall spatially distributed over the study area ranges from 1200 mm to 1700 mm (**Figure viii**), but the annual amount varies considerably from year to year.

276. The maximum 24-hour rainfall is about 150 mm throughout the region. This is mostly convective rainfall. Occasionally a typhoon from the South China Sea or Gulf of Thailand might cross over land and affect the country. When this happens these storms bring strong wind and torrential rain.

277. Around the Great Lake, on average the monthly rainfall distribution indicates the presence of two peaks periods (**Figures ix** and **x**). The first peak occurs at the beginning of the wet season between May and June as the monsoon rains move north. There is then a period of lower rainfall between June and August whilst the monsoon returns south during August through October and it is at this time that rainfall is usually heaviest and results in widespread flooding occurs.

278. Within this bimodal pattern, substantial rainfall variability often results in serious difficulties for rice farmers during the first few months of the wet season, when rainfall is most erratic, and early season droughts are common. In addition to the main dry season of January to March or April, and prior to the wettest period of end August to end November, there is a small dry season (July and/or early August), when dry spells or only light showers occur. Short droughts typically can last for about 15 days or more, but occasionally last up to 60 days after the first monsoon rains. The cessation of heavy rain at the end of the wet season can also be very abrupt and somewhat unpredictable.

279. The temperature regime is consistently high with little day or seasonal variation. Daily temperature varies between maximum of 36 °C, during the hottest months of April and May, to 17 °C in December-January the coldest months. Daily minimum temperature varies between 8 °C to 12 °C below the daily maximum. The annual average temperature is about 28 °C.

280. The relative humidity is quite different in the wet season compared to the dry season. The average annual relative humidity value is about 70 per cent throughout the country. The climate is consequently warm and humid.

281. **Table ii** below summarizes long-term average climate components observed at the Pursat weather station together with Reference Evapotranspiration (ETo) computed by applying Penman-Monteith method.

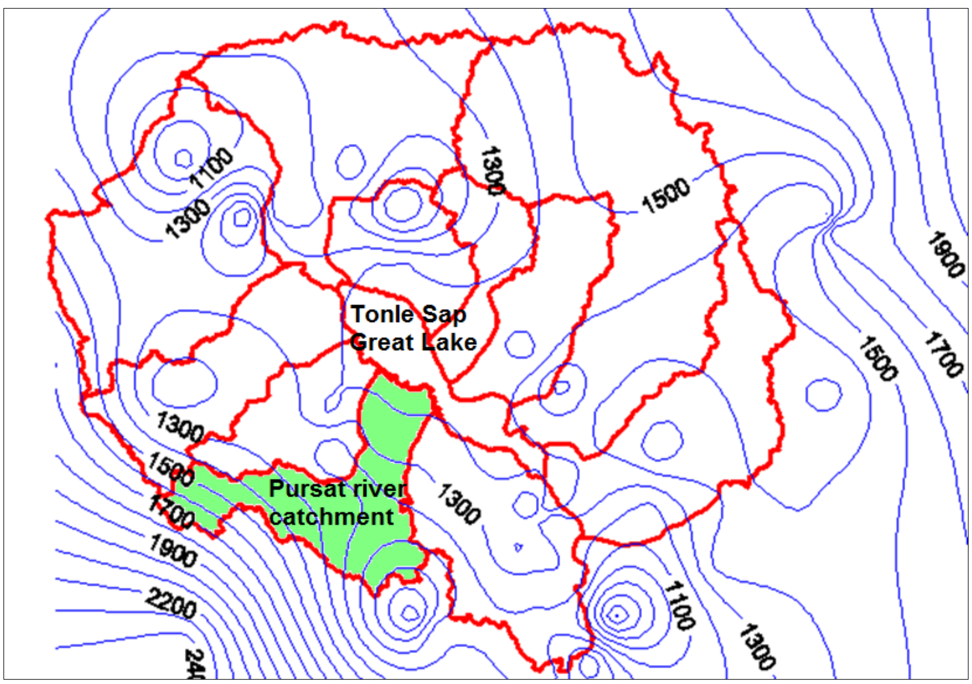


Figure viii: Annual rainfall distribution for the Tonle Sap basin (1990-2011)

Table ii: Climate components at the Pursat meteorological station

Climate Components	Unit	Months of the year												Annual
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Tmax	°C	33.3	34.5	35.7	36.3	36.1	35.3	34.7	34.4	33.2	32.4	32.1	31.6	34.1
Tmin	°C	19.5	20.5	21.8	24.4	24.5	24.7	23.7	24.1	23.4	23.1	21.4	16.9	22.3
Rhmean	%	65.8	63.0	64.6	65.5	67.1	68.0	67.9	71.0	73.9	75.8	74.2	71.0	69.0
U(x)	m/s	0.80	0.78	0.68	0.60	0.48	0.37	0.40	0.37	0.32	0.48	0.50	0.58	0.5
n	hour/day	9.5	9.0	8.8	7.7	7.3	5.6	6.4	5.0	5.5	6.6	7.4	8.5	7.3
Rs	$Mj/m^2.day$	12.2	13.7	16.2	15.6	15.6	14.6	15.4	13.7	12.9	12.7	12.8	13.8	14.1
Pan Evaporation	mm/day	3.7	4.4	4.5	4.6	4.0	4.0	3.4	3.4	3.0	3.1	3.1	3.4	3.7
ETO	mm/day	3.0	3.4	3.8	3.8	3.7	3.4	3.5	3.2	2.9	2.9	2.8	2.8	3.3

Hydrological Characteristics

Data Availability

282. Daily hydro-meteorological (hydromet) data have been collected from the DHRW and Pursat PDOWRAM. An overview of the rainfall, water level and discharge stations (**Figure i)** with data availability in the Pursat River basin are given in Table **iii** to Table **iv**.

283. A total number of 11 rainfall stations exists in the Pursat River basin, or on average 1 station per 540 km^2. The rainfall stations, however, are concentrated in middle and northern (downstream) part of the area, whereas in the upper part of the basin, any rainfall station is not available. The availability of rainfall data is very limited. The records of a number of stations start in the mid-nineties, and almost all have for a few years since 2000.

Table iii: Overview of rainfall stations with daily data availability within and around the Pursat River basin (Source: DWRW, Pursat PDOWRAM)

No.	River Catchment	ID	Station Name	X_COORD	Y_COORD	Daily Data Availability																			
						1990								2000											
						2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	10	11
1	Stung Kambot / Beung Khnar	120426	Beung Khnar	362188.5	1396436.4	F	F	+	+	+	F	F	F	+	+	+	+	+	+	+	+	+	F	F	F
2		120004	Phteah Rung	361016.4	1369770.9	F	F	F	F	F	F	F	F	+	+	+	+	+	+	+	+	+	F	F	F
3	Stung Pursat	120003	Bak Tra	375989.1	1373551.5	F	F	F	F	F	F	F	F	F	F	F	F	F	+	+	+	+	+	+	F
4		120304	Dap Bat	370246.6	1380894.0	F	F	F	F	F	F	F	F	+	+	+	F	+	+	+	+	+	+	+	F
5		120002	Kandeing	390515.1	1394023.5	F	F	F	F	F	F	F	F	F	F	F	F	F	+	+	+	+	F	+	F
6		120312	Kravanh	365457.0	1364266.0	F	F	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	F
7		120313	Peam	360322.6	1356910.4	F	F	F	F	F	F	F	F	+	+	+	+	+	+	+	+	+	+	+	F
8		120302	Pursat	381845.0	1386941.0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
9		120005	Roveing	341975.0	1362273.0	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	+	+	F	+	F
10		120009	Santre	372359.7	1355371.0	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	+	+
11		120006	TaingLuch	352425.1	1361891.5	F	F	F	F	F	F	F	F	F	F	F	F	F	+	+	+	+	+	+	F
12		120301	Tuolkruos	320034.5	1368732.7	F	F	F	F	F	F	F	F	F	+	+	F	F	F	F	F	F	F	+	+
13		120007	VealVeng	293501.2	1361041.1	F	F	F	F	F	F	F	F	F	+	+	F	+	+	+	F	+	+	+	F
14	Stung Bamank / Thlea Ma'am	120406	Bamnak	410323.3	1359592.0	F	+	F	F	F	F	F	+	+	+	+	+	+	+	+	+	+	+	+	F
15		120320	Beung Kantout	400310.1	1384906.1	F	F	+	+	+	F	F	+	+	+	+	+	+	+	+	+	+	F	F	F
16		120001	Koh Chum	397229.9	1381664.0	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	+	+	+	+	F

+	Data available
F	Data obtained from gap filling

284. The Pursat River is the only the Tonle Sap Great Lake basin with more than one hydrological stations benefiting from NGOs direct support for a number of years. Water level data is available for 13 stations on the Pursat River, with 6 are still operational. The record for Bak Trakuon is apparently completed. At the rest stations, their records generally cover a few years either in the mid-nineties or as from the late nineties onward.

285. The discharge records as available cover 4 stations with a few complete years from the mid-nineties. Applying the existing rating curves with water level series available in the DHRW database (**Table v**), more extensive discharges database can be created with the same period as the available water levels. However, the data available for the study

area are limited as there is no any gauge monitoring station at the water resources development places (Hydropower, irrigation diversion).

Table iv: Availability of daily water levels at stations within the Pursat basin (Source: DWRW, Pursat PDOWRAM)

River catchment	River Name	HYMOS ID CODE	Station Name	Area at Gauging Station, km^2	X_COORD	Y_COORD	TYPE of Station run by project /organisation	Status till 2011	Daily Data Availability																	
									1990						2000											
									4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	10	11
Pursat	Pursat	580104	Khum Veal	4,596	363700.7	1346389.3	DHRW	Non-Operational		120	+	306		+	+	+	+	+	+	+	+					
		580103	Bak Trakuon	4,245	364756.9	1365617.7	DHRW	Operational	255	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		580105	Lolok Sar		367847.3	1347660.8	DHRW	Operational	90	+	+	306				+	+	+	+	+	+	+	+	184		
		580106	Phum Kos		378380.2	1351302.1	DHRW	Non-Operational	90	+	+	306														
		580110	Kbal hong(up)		400493.0	1401662.8	DHRW	Operational		120	+	306				+	+	+	+	+	+	+	+	+	+	
		580120	Kbal hong(down)		394894.4	1396798.2	DHRW	Non-Operational		242				+	+	+	+	+	+	+						
	Stung Peam	580201	Peam	1,059	359610.0	1344257.8	DHRW	Operational								+	+	+	+	+	+	+	+	+	+	
	Stung Santre / Prey Khlong	580301	Prey Klong(down)	818	383622.0	1339545.0	DHRW	Operational	90	+	+	306				+	+	+	+	+	+	+	+	+	+	
		580302	Prey Klong(up)		307961.4	1383516.3	DHRW	Non-Operational	243	+	+	306				+										
	Stung Sanlong	580310	Sanlong(up)		371603.2	1410290.0	DHRW	Non-Operational		212	+	306														
		580320	Sanlong(down)		371852.5	1405434.4	DHRW	Non-Operational		212	+	306														
	Stung Svay At	580330	Svay At		371833.1	1401163.8	DHRW	Non-Operational	90	+	+	306														
	Stung Bromauy	580134	Veal Veng		293934.0	1359853.0	DHRW	Operational													364		146			

+ Data available
120 Number of gaps in a year

Table v: Availability of daily water discharges at stations within the Pursat basin (Source: DWRW)

No.	ID	Station Name	River sub-catchment	Computed daily timeseries		Rating Curve used
				Start Date	End Date	
1	580104	Khum Veal	Stung Pursat	01-Jan-99	31-Dec-06	New
2	580103	Bak Trakoun	Stung Pursat	01-Oct-94	31-Dec-11	New
3	580201	Peam	Stung Pursat (Peam)	01-Jan-01	31-Dec-10	New
4	580301	Prey Khlong	Stung Pursat (Santre)	01-Jan-01	31-Dec-10	New

Rating Curve Development

286. Stage-discharge rating curves (rating curves) were used to convert water level data (stage) recorded by the hydrometric monitoring stations into a discharge time-series or hydrograph. Rating curves were derived for the stations Stung Peam at Peam, Stung Santre at Prey Khlong, Stung Pursat (River) at Bak Trakuon, and Stung Pursat at Kum Veal. All those four stations were considered without backwater effects and follow power function::

$$Q = b\,(H - H_0)^c$$

Where: ***Q*** is water discharge in m^3/s;

H is gauge height in meters;

b, ***c*** and H_0 are coefficients

287. It is important to note that the Bak Trakuon station was relocated to the Kravanh bridge about 2 km upstream of the old location since 2010. Thus, two rating curves (**Figure ix**) were developed at this station to compute discharges before and after 2010. The developed rating equations for all stations are shown in **Table vi.**

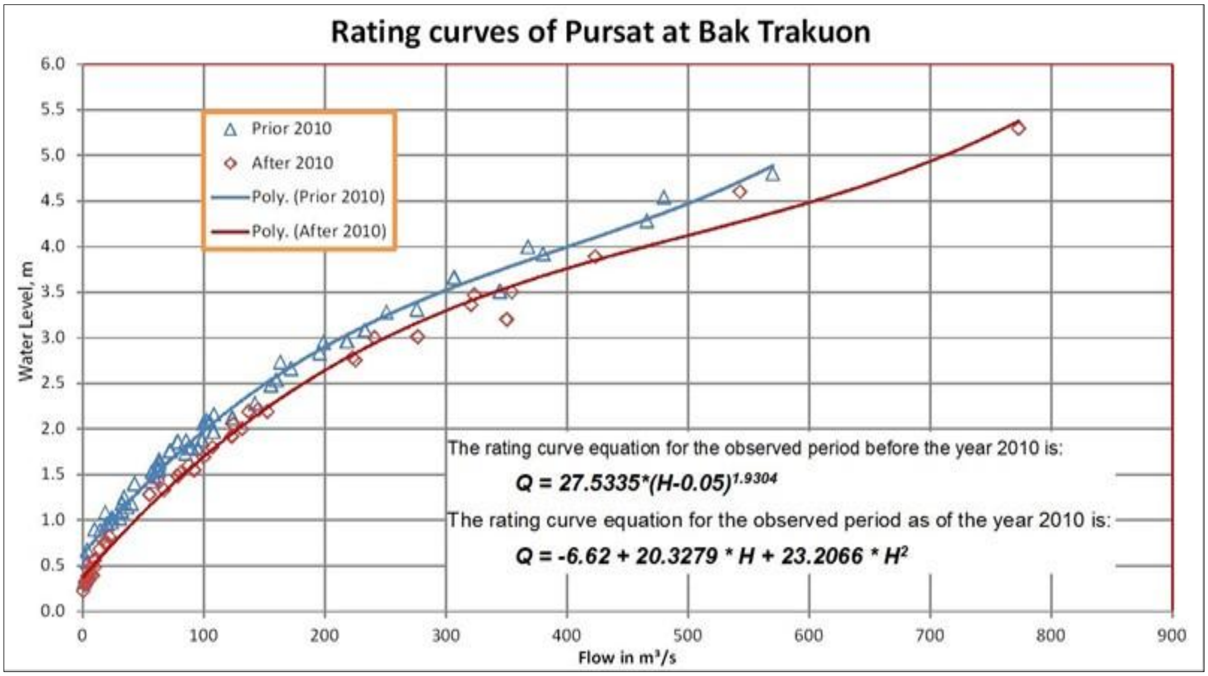


Figure ix: Two rating curve developments at the Bak Trakuon station.

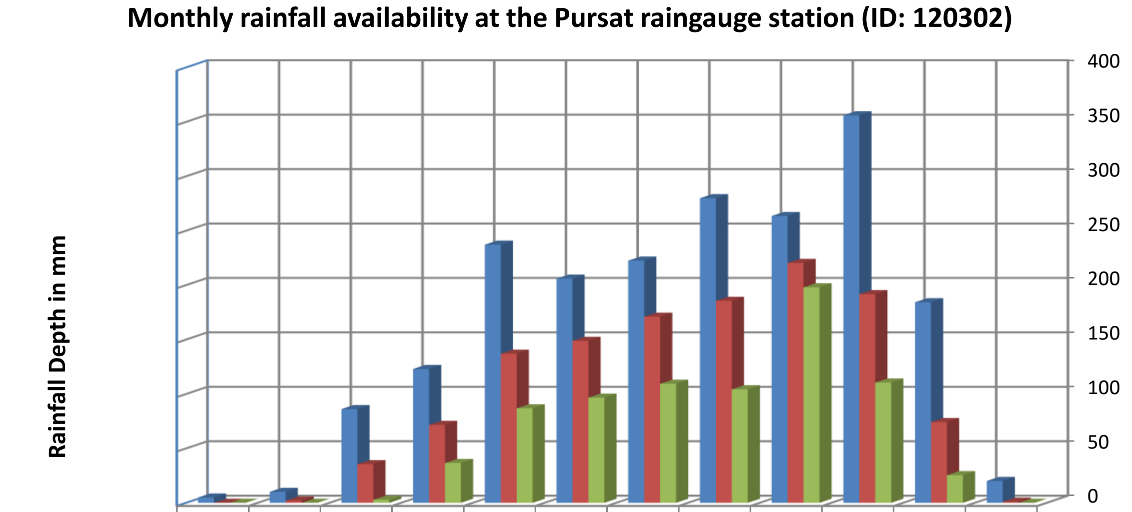
Table vi. Developed rating equations for four hydrometric stations in the Stung Pursat River basin.

Station Name	Station ID	Rating Equation	R^2	Number of points used
Peam	580201	$Q = -0.84 + 6.7952H + 2.713H^2$	0.9848	44 discharges measured between 1999- 2001
Prey Khlong	580301	$Q = 24.3175 \times (H-0.68)^{1.6134}$	0.9917	23 discharges measured in 1994 and 2001
Bak Trakuon	580103	Before 2010: $Q = 27.5335 \times (H-0.05)^{1.9304}$	0.9933	108 discharges measured in 1997 to 1999, 2001, 2005 to 2006, and 2010 to 2012
		After 2010: $Q = -6.62 + 20.3279\ H + 23.2066\ H^2$	0.9946	
Khum Veal	580104	$Q = -42.05 + 52.2099\ H - 8.2745\ H^2 + 2.0294\ H^3$	0.9977	36 discharges measured in 1998, 1999, and 2001

Representative Rainfall Stations for the Pursat River basin

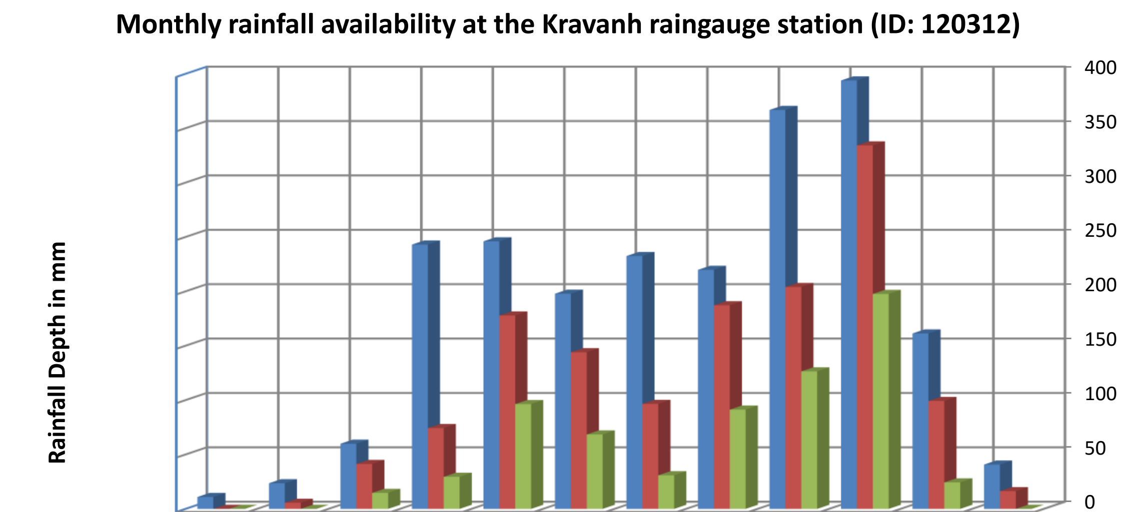
288. The rainfall station at Pursat (ID: 120302) was used as a representative station for the lower part of Pursat River basin as daily data records are available for a period of 29 years (1981-2011). For the upper part of the basin, the rainfall station at Kravanh (ID: 120312) was used as a representative station as daily data records are available for a period of 17 years (1994-2010).

289. The monthly rainfall characteristics of the Pursat and Kravanh stations were shown in **Figures x** and **xi**, respectively. The annual long term average is 1390 mm for Pursat and 1500 mm for Kravanh. The annual variation for both stations ranges between 850 mm and 2100 mm. The month of October appears to be the wettest month.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20% Exceedance	5	10	86	123	237	206	223	280	264	356	184	20
50% Exceedance	0	2	36	72	137	149	171	186	220	192	74	1
80% Exceedance	0	0	3	37	87	97	109	104	198	111	25	0

Figure x: Monthly rainfall distribution at the Pursat station from 1981 to 2011.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20% Exceedance	11	24	60	243	246	198	233	220	367	394	161	41
50% Exceedance	0	6	41	74	178	144	97	187	204	334	99	16
80% Exceedance	0	0	15	30	96	68	31	91	126	198	24	0

Figure xi: Monthly rainfall distribution at the Kravanh station from 1994 to 2010.

Flow Monitoring Stations within the Pursat River basin

290. There are four water level and flow stations with reliably data in the Pursat River basin: the Stung Pursat (River) at Bak Trakuon and Khum Veal, the Stung Peam at Peam and the Stung Santre (Prey Khlong) at Prey Khlong.

291. The flow station at Bak Trakuon (ID: 580103) is used to monitor the upper part of the Pursat River flow, while the station at Khum Veal (ID: 580104) monitors the flow in the lower part of the Pursat River. However, the later station has been non-operational since 2007, but the data are reliable for further model calibration. The average monthly flows at Bak Trakuon and Khum Veal were summarized in **Figures xii** and **xiii**, respectively.

292. It is noted that the downstream flow at Khum Veal is less than the upstream flow at Bak Trakuon due to the fact that water is diverted from the Pursat River at Damnak Ampil weir via the main canal into the Dauntry basin.

Floods and Drought Hazards

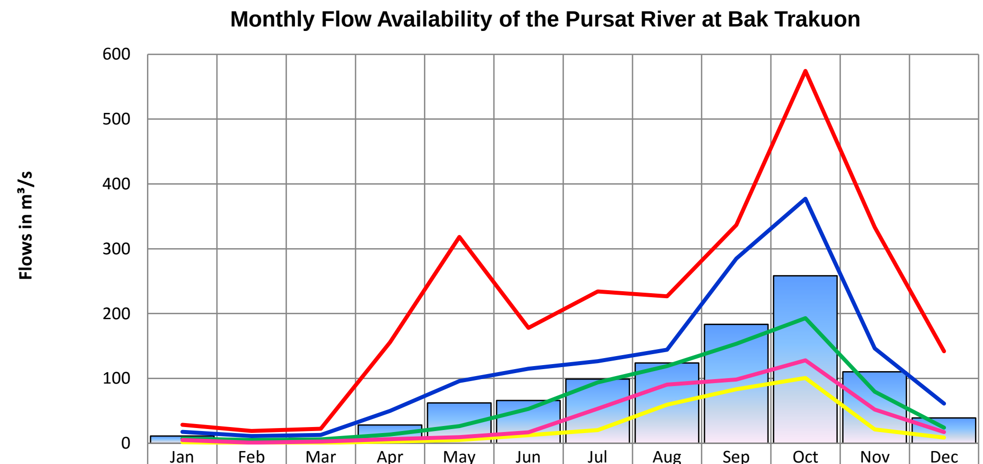
293. Presently the Stung Pursat faces series of water issues, such as:

- Water shortages in downstream parts of the basin;
- Floods and drought in most part of the basin;

293. Drought frequently throughout the basin while flash flood occurs in selected upstream and downstream reaches (**Figure xiv**). The lower parts of the basin, especially in the Kandieng and Bakan districts, are vulnerable to both flash flood and downstream overland floods from the Tonle Sap Great Lake.

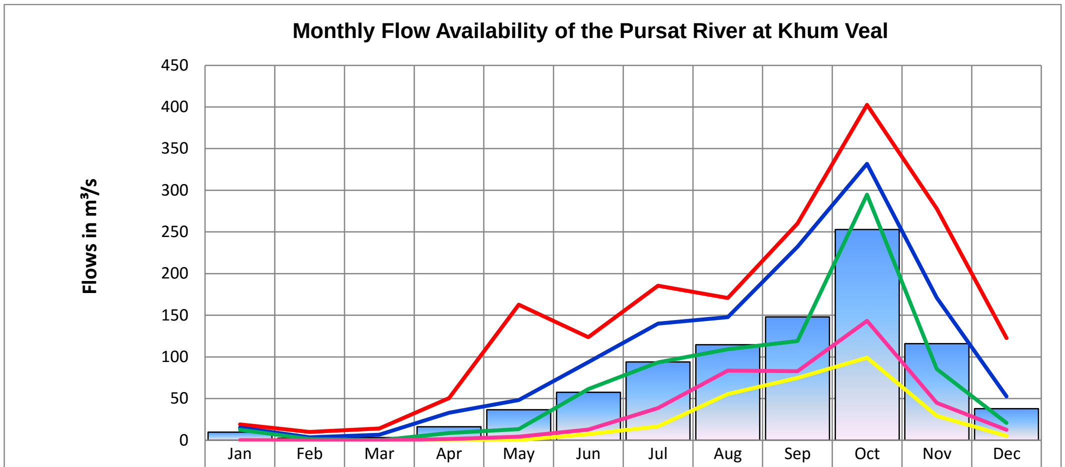
294. In 2013, floods and droughts occurred and damaged areas of all six districts Veal Veng, Kravanh, Krong Pursat (Sampov Meas), Krakor, Bakan, and Kandieng.

295. The major floods, which inundated the Pursat town, occurred in 2000, 2006, 2011 and 2012. **Figure xv** shows the maximum flood hydrograph at Kbal Hong station, which is the focal station for flood monitoring for the Pursat town.



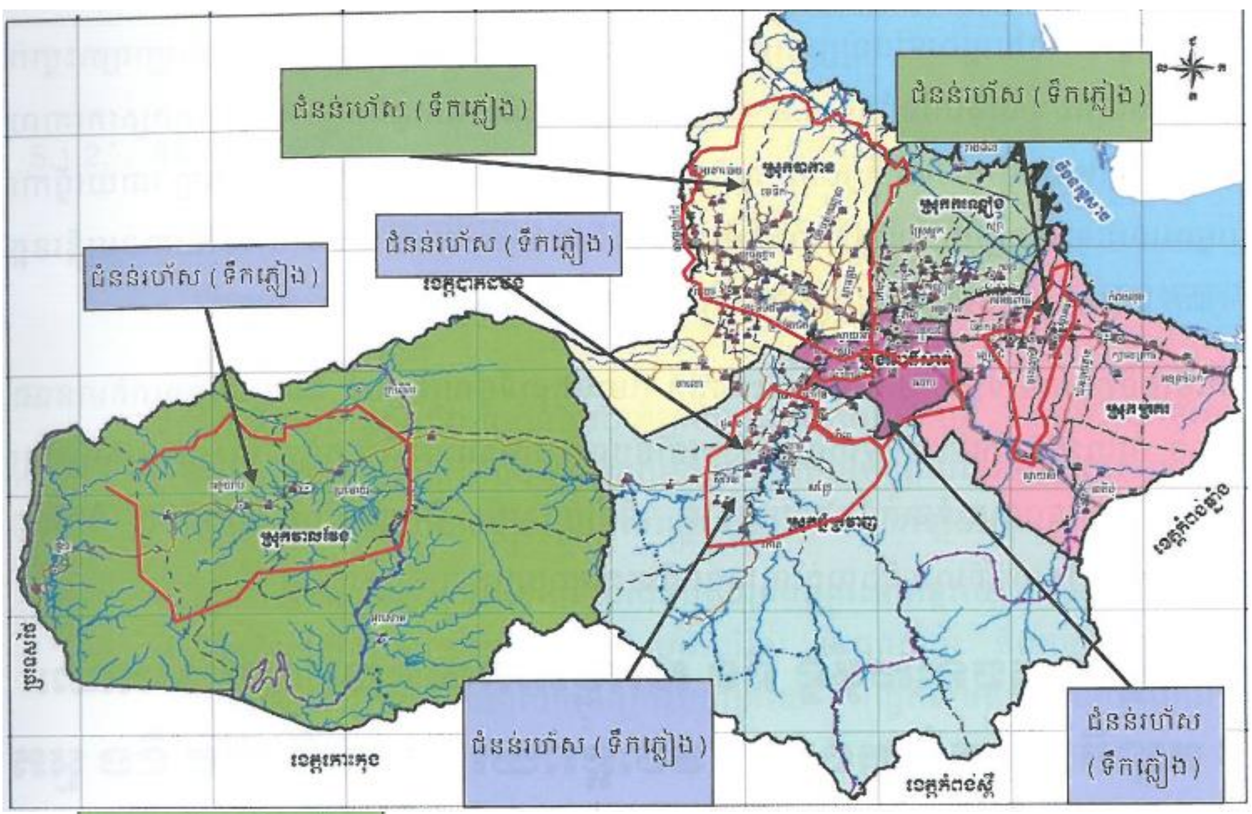
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	11.1	6.3	7.8	28.2	62.2	66.1	99.1	123.8	183.5	258.3	110.1	39.1
Maximum	28.4	19.0	22.3	156.1	318.4	177.9	234.1	226.7	336.7	574.3	333.3	141.8
Minuimum	1.7	0.5	0.5	2.7	5.0	12.5	20.5	59.6	83.4	100.7	21.3	8.8
20% Exceedence	17.8	11.1	12.8	50.0	95.9	115.2	126.7	144.4	285.1	377.1	146.4	61.1
50% Exceedence	7.6	5.2	6.0	13.7	26.6	53.3	94.0	119.3	153.5	193.1	79.7	24.2
80% Exceedence	5.2	1.1	2.6	6.3	9.4	17.1	53.5	90.5	98.2	128.0	52.2	17.2

Figure xii: Monthly flow characteristics of the Pursat River at Bak Trakuon station (1995-2011)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	9.8	2.4	3.2	16.0	36.6	57.5	93.9	114.6	148.0	253.0	115.9	37.9
Maximum	19.1	9.9	14.2	50.5	162.6	123.8	185.5	170.7	260.1	402.5	277.9	122.7
Minuimum	0.0	0.0	0.0	0.0	0.1	7.4	16.7	55.5	74.9	99.1	29.5	5.4
20% Exceedence	15.2	3.5	6.7	33.0	48.1	93.7	139.9	147.8	232.3	331.7	171.0	52.7
50% Exceedence	12.5	1.5	0.0	8.7	13.3	61.4	93.6	109.3	119.2	294.8	85.4	20.9
80% Exceedence	0.2	0.0	0.0	1.5	4.2	12.8	38.7	83.7	82.8	143.4	44.8	12.5

Figure xiii: Monthly flow characteristics of the Pursat river at Khum Veal station (1995-2006)



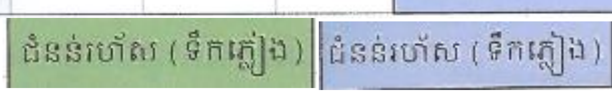
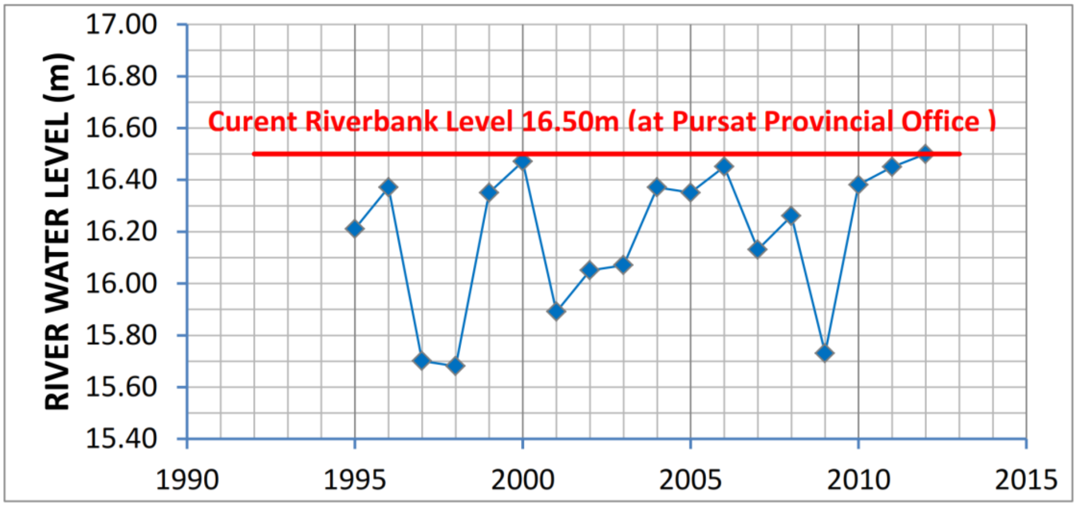
Note:  = Flash flooding

Figure xiv: Areas vulnerable to the flash flooding (Source: Pursat PCDM, 2014)



Source: TA7986-CAM Consultants

Figure xv: Annual Flood Levels of the Pursat River at Pursat (Kbal Hong station)

Appendix 2: Activities Related to NWP Model System Development

296. The following outlines are the various steps required to implement the WRF model:

- Download and installation of libraries like Libpng, Perl, Jasper, zlib etc. which are essential for WRF modelling.
- Download and installation of WRF Model, its pre-processing (WPS), post processing(ARWPOST) and other related software such as graphics package etc.
- Model compilation, IC&BC linking, static data linking, and test integration
- Customization of the model for South East Asia and for Cambodia
- Model validation for past severe weather cases
- Training on model integration and product analyses
- Semi-operationalization of the model

Hardware system configuration for the WRF modelling system

297. In Section 6.2, it is shown that the total peak computational capacity requirement to integrate the WRF nested model for Cambodia is 0.08582 TFLOPS. While converting that speed from floating point operations to cycles per second at a rate of 1.5:1, the required computational power will be about 60 GHz. The matching configuration of the required computational system is as follows:

- Processor speed ~60 GHz
- RAM 48 GB
- Storage[1] 50 TB

[1] Storage has been proposed to 50 TB so that past observed, analyzed and forecasted data sets can be stored for forecast verification, future research and for climate analyses over Cambodia.

Software requirements for the WRF Modelling System

298. Even though most of the software related to the WRF modelling system are open source, a few essential systems related software are licensed ones and need to be purchased. Following are the software to be acquired as part of the capacity development.

- Operating System (RED HAT)[2]: LINUX (licensed)
- Compilers (PORT LAND GROUP)[3] : FORTRAN 95 (Licensed), C++ (Licensed)
- Libraries for WRF model integration : perl , netCDF, JasPer, zlib, libpng (open source)
- Graphics and visualization : GrADS (open source)

299. LINUX OS is available as open source as well as in licensed forms. It is recommended that the licensed version (RED HAT) with multiple (4) licenses to minimize the license and compilation issues while running the NWP model at NFFC/DOM be acquired.

300. It is recommended, from the previous experience of the consultants, to acquire a PGI (Fortran 95 and C++) compiler for compilation and integration of the WRF model.

301. An example the required hardware is NEC Expression 5800/T120f:

(http://www.nec.com/en/global/prod/express/tower/t120f/spec.html)

302. On daily basis, approximately 32 GB of data have to be downloaded from the NCEP web site as initial and boundary condition for integrating the WRF model. The downloading of data should be carried out in about 30-45 minutes so that model integration can be finished in time and timely forecasts can be provided with sufficient lead time. For this to happen, it is ideal to have 5MBPS internet connectivity at the NFFC. The same broadband internet connectivity can be used for other activities.

Time Plan for completing the various weather forecasting components

303. The timeframe to complete the various components of work pertaining to the integration of NWP system detailed above is about two months from the time the computer system is acquired and all the system related software are installed.

304. Capacity building under Sections 6.1 and 6.2 requires the consultants' time of 2 months each and therefore it is only possible to complete only one of the objectives under the current scope of the project. Another two month of consultants' time is needed to accomplish both the tasks.

Capacity building training for Integration of high resolution NWP models

305. Before integrating the model, the LINUX platform should have FORTRAN and C++ compilers in place. Also the library software pertaining to WRF model such as jasper, libpng, zlib, perl, netCDF etc must be installed in the computing system.

306. Once, the system is ready with all software installed, compilation can be carried out for pre-downloaded files of WRF model and its pre and post processing components. Finally a graphics package for visualizing the product has to be installed and compiled. If all the above software are installed and compiled, WRF model can be integrated for a desired time span.