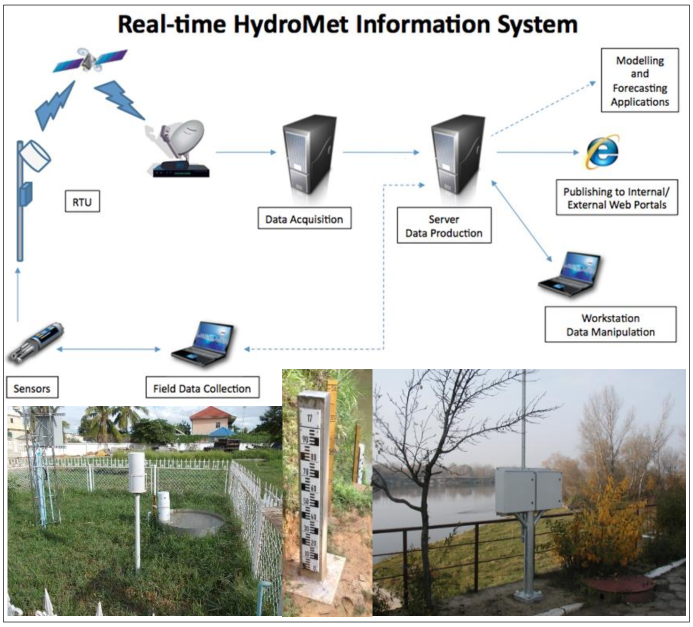
GREATER MEKONG SUB-REGION FLOOD AND DROUGHT RISK MANAGEMENT AND MITIGATION PROJECT

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 – HYDROMETEOROLOGICAL NETWORK AND DATA MANAGEMENT SYSTEM



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Document History

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Executive Summary

This report presents the conceptual design for an “end-to-end” system complete with a description of the system’s structure and technical specifications. The report discusses station network characteristics, data management, communications and IT systems, integrated information platforms, and data governance from a national hydrometeorological perspective.

A focus for the conceptual design is to ensure the integration of various components and activities of the project with other initiatives and modernization efforts. The objective is a unified hydrometeorological observing, data management, and delivery system that effectively utilizes the available human resource and financial capacity to sustain and maintain the system.

The report identifies and discusses a number of cross-cutting themes that must be considered for the successfully development and implementation of the proposed hydrometeorological architecture

An outline of a capacity building plan has been prepared. The capacity building plan will enable staff to carry out data observation, data processing, data analysis, information generation, and maintain the proposed national hydrometeorological system.

The report presents technical specifications for each of the elements that make up the ‘end-to-end’ system.

Of the twenty-one (21) stations in the Pursat basin ten (10) are rainfall only, eight (8) are water level only, two (2) are combined water level and rainfall, and one (1) is an Automatic Weather Stations (AWS). Four (4) of the rainfall and one (1) water level station are non-operational.

It is proposed that all eight (8) manual water level stations be upgraded to automatic stations with telemetry. The water level stations will be equipped with tipping bucket and manual rain gauges, therefore only six (6) of the ten (10) rainfall only stations are proposed to be upgraded to automatic stations with telemetry

Upgrading of the two (2) combined water level and rainfall stations and the one (1) AWS is not proposed, as these sites were operational with telemetry at the time of the field visit.

As well as the automation of stations with telemetry, staff gauges and manual rain gauges will be installed to support the taking of manual observations. The on-site gauge observers will be equipment with mobile phones to SMS observations. The combine manual system and automatic system will ensure redundancy at the site.

At the time of preparing this report the upgrading or installation of new sites for the Mekong Mainstream has not been identified, as many of the Mekong stations are being addressed under other modernization programs. However, the Mekong River Commission has been consulted and asked to identify additional priority stations for consideration by the NFFC project.

The initial financial investment to upgraded the eight (8) manual water level stations and six (6) rainfall stations to automatic stations with telemetry in the Pursat basin is estimated to be US$ 240,000 for the procurement of equipment, instrumentation, and related civil works at the field sites including installation and commissioning of the field network.

An additional US$ 140,000 is required to upgrade the data acquisition, data management, and information production systems at MOWRAM headquarters. It is important to note that this investment at MOWRAM headquarters will support the data acquisition, data management, and information production for the countywide hydrometric and rainfall network operated by MOWRAM.

An additional US$ 25,000 will be required to provide computers and computer related equipment, transport, and hydrometric related equipment to the provincial office in Pursat in order to service and maintenance the hydrometeorological network.

The required initial investment in training and capacity strengthening for the project is estimated at US$ 115,000.

The ongoing operating and maintenance requirements are estimated to be US$ 30,000 per year for field network operations in Pursat and an additional US$ 30,000 per year for the countywide data management system at MOWRAM headquarters. To life cycle manage the equipment and infrastructure installation in the Pursat basin as well as at MOWRAM headquarters an additional US$ 25,000 would be required per year.

Table of Contents

List of Tables

List of Figures

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
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
WUAs	Water User Associations

1. Introduction

1. The Asian Development Bank (ADB) is assisting the Royal Government of Cambodia (RGC) to improve the National Flood Forecasting Centre and to develop structural design guidelines for flood protection. The assistance is being provided under the umbrella of the Greater Mekong Sub-Region Flood and Drought Risk Management and Mitigation Project.

2. The Greater Mekong Sub-Region (GMS) Flood and Drought Management and Mitigation Project is assisting the Royal Government of Cambodia to undertake structural and non-structural measures to prepare for and manage disaster risks linked to floods and droughts. The GMS project goals are:

i. enhanced regional data and knowledge for the management of floods and droughts;

ii. upgraded or new water management infrastructure; and

iii. better prepared communities to manage disasters, such as flood and drought, and to adapt to climate change.

3. The focus of the 'Support to the National Flood Forecasting Centre' project is to help the RGC undertake structural and non-structural measures to forecast floods and droughts and to better mitigate the effect that these disasters cause.

4. The NFFC project 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 NFFC project is to propose climate resilient design guidelines for structural flood and drought control measures in Cambodia.

5. 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.

6. This report presents the conceptual design for an "end-to-end" hydrometeorological system complete with a description of the system's structure and technical specifications. The report discusses station network needs as well as field instrumentation, data management, communications, and IT requirements. It presents the technical specifications for each of these elements.

7. Preliminary estimates of operating and maintenance budget requirements, which will be necessary to sustain the proposed modernized hydrometeorological observing and data management system, have been developed,

8. The report details the necessary investment in training and capacity strengthening for MOWRAM to operate and sustain the proposed design. Recommendations on adjustments to the institutional setup of NFFC and within the Department of Hydrology and River Works (DHRW) and the Department of Meteorology (DOM) are noted.

9. The conceptual design of the system considers a national perspective that will support the requirements of an early warning system. The approach enables the integration of other sub-systems and considers new proven technologies.

10. A critical consideration of the proposed hydrometeorological system is the sustainability of the "end-to-end" architecture including further development and upgrading of the architecture's sub-systems.

11. A significant focus of the conceptual design is to ensure the integration of various project components and activities into a unified observing, forecasting, and delivery system and to build the necessary capacity for the effective functioning of the system. As well, the observing, forecasting, and delivery system must be functionally compatible with regional and global modernized meteorological and hydrological systems as recognized by WMO.

2. Hydrometeorological Context

12. 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 Sihanuk Provinces.

Figure 1: Location Map - Cambodia

13. Cambodia's population is predominantly rural based and most of the population is subsistence farmers or fishers.

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

15. 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).

16. An important consideration in Cambodia is the transboundary nature of the Mekong River basin.

17. MOWRAM has further defined thirty-nine (39) river basins in its Sub-decree on river basin management. The following map (**Figure 2A**) shows the delineation of the thirty-nine basins.

18. **Figure 2B** shows the major basin groups in Cambodia defined under CDTA-7610, April 2014.

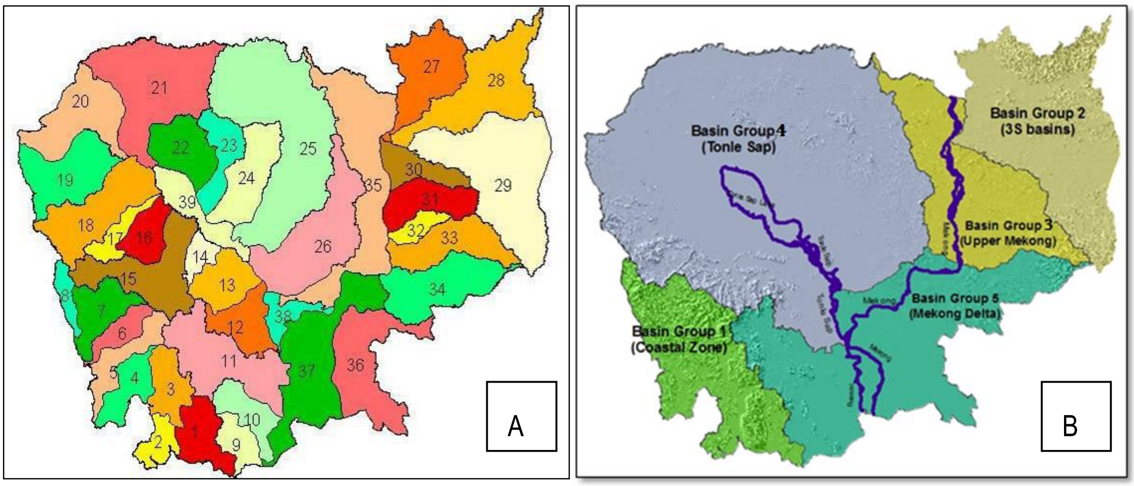

Figure 2: River Basins and Basin Groups in Cambodia

19. The basin areas for each of these thirty-nine (39) basins are summarized in the **Table 1**.

Table 1: Surface Area [km²] 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							

3. Institutional Setting

20. 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. The organizational structure of MOWRAM is shown in **Figure 3**.

21. The following are MOWRAM's main duties and responsibilities:

- To define policy and strategy development for water resources – including business development and protection of water resources.
- To develop regulations, legislation, and other measures to ensure sustainable management.
- To research potential water resources including groundwater and weather.
- To develop plans for water development and protection of water resources that ensures alternative livelihoods for urban and rural people.
- To regulate and control the use of water resources directly and indirectly and to minimize natural disasters.
- To collect and record information on meteorology and hydrology, and to use this information to serve national and international needs.
- To prepare a plan for flood control.
- To provide support and technical advice to stakeholders such as the private sector, NGOs, and the community for sustainable water resources decision-making.
- To introduce modern technology through training and propagation.
- To lead all activities related to the Mekong River Basin, and to strengthen and promote national and international cooperation.
- To prioritize water resources management activities to the areas of most need.
- To manage river basins, sub-basins, and groundwater aquifers to protect water use areas and region.
- To organize the farmer community for more effective participation.

22. 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 and to work in close collaboration with the other concerned Ministries and local authorities.

23. 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 the dissemination of real-time hydrological and meteorological information. These activities are designed to ensure crop safety and to mitigate natural disaster events, especially from serious floods and droughts.

24. 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's Minister, the Cambodian National Mekong Committee (CNMC) and the Tonle Sap Authority (TSA).

25. 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 the Mekong River Commission (MRC) under the Sustainable Development Framework of Water and related resources in the Mekong River basin.

26. The Tonle Sap Authority's role is to coordinate 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.

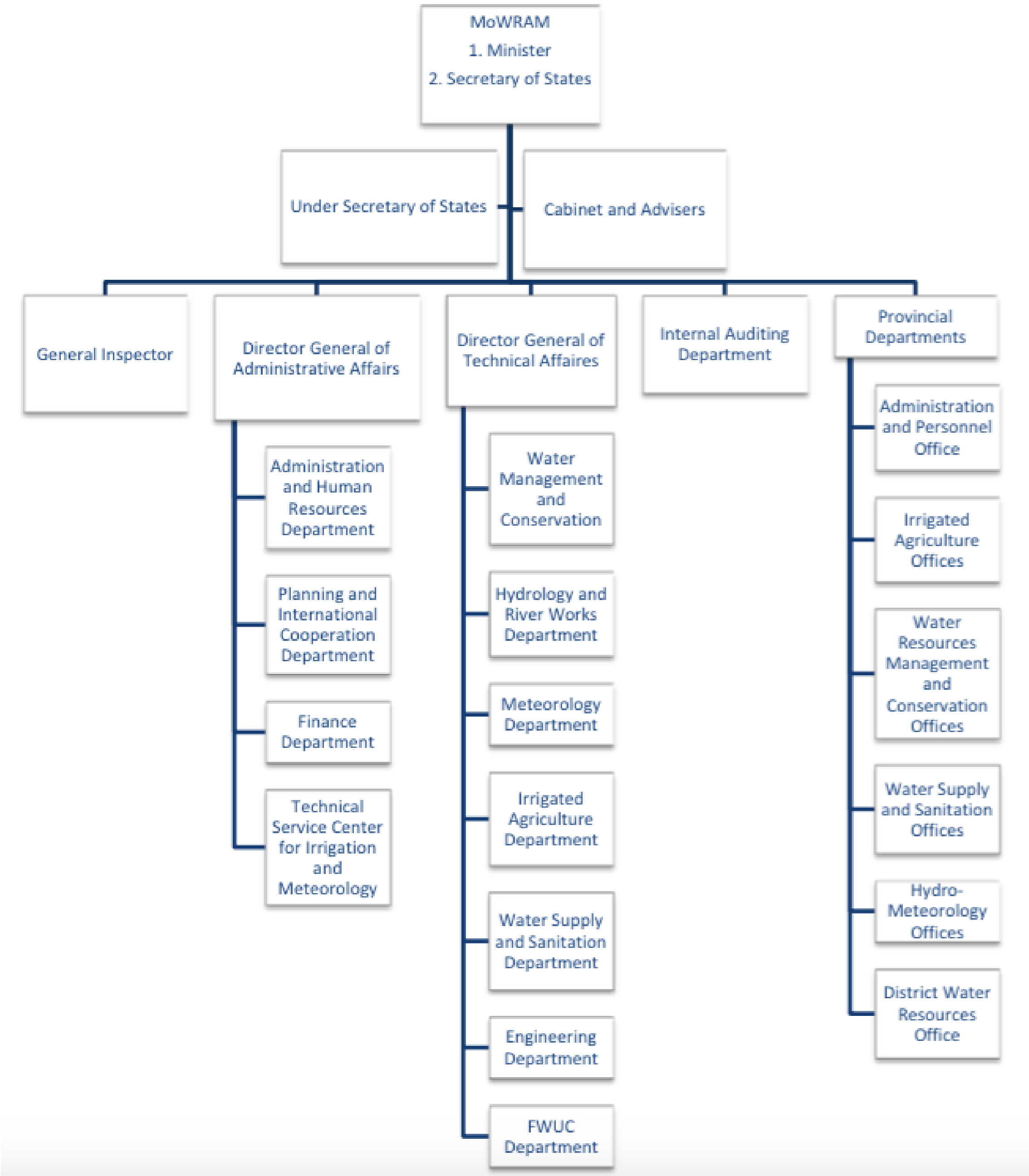

Figure 3: Organizational Structure - MOWRAM

27. MOWRAM's technical functions are located 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, catchment 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.
- 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.

28. The key departments involved with this component of the Greater Mekong Sub-Region Flood and Drought Risk Management and Mitigation Project are the Department of Hydrology and River Works and the Department of Meteorology.

29. The Department of Meteorology (DOM) and Department of Hydrology and River Works (DHRW) within the Ministry of Water Resources and Meteorology (MOWRAM) manage the hydrometeorological services in Cambodia. These departments are responsible for collecting and disseminating hydrometeorological information and are mandated to provide early warning to a range of stakeholders. The National Flood Forecasting Centre reports under the Department of Hydrology and River Works.

30. The Department of Hydrology and River Works (DHRW) was established in 1999 under the Ministry of Water Resources and Meteorology. There are 5 offices within the DHRW: Office of Administration, Office of Research and Flood Forecasting, Office of Water Quality Analyses, Office of Hydrological Works, and Office of River Bank Management.

31. 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.

- To maintain a geographical information system (GIS) of river basin features, hydrological networks, and the locations of water resources development infrastructure

31. **Figure 4** shows the organizational chart for DHRW.

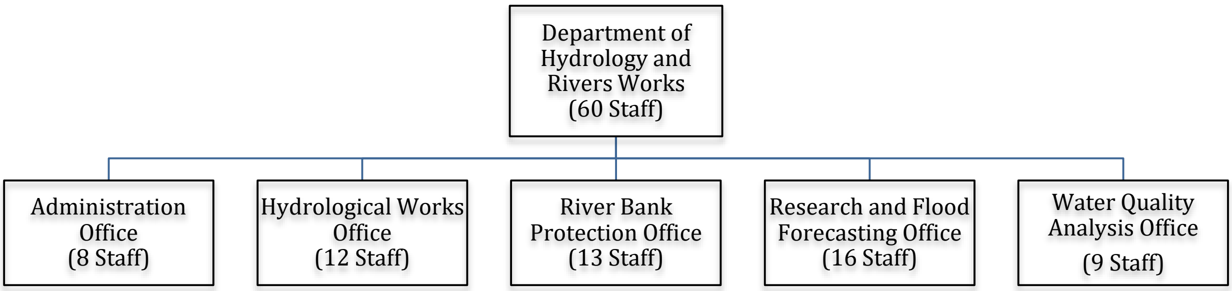

Figure 4: DHRW Organizational Chart

32. The Department of Meteorology'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.
- To strengthen and broaden the Cambodian cooperation with regional meteorological organizations, United Nation agencies, and the World Meteorological Organization.

33. To fulfil this mandate the Department of Meteorology 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.

34. **Figure 5** shows the organizational chart for the Department of Meteorology

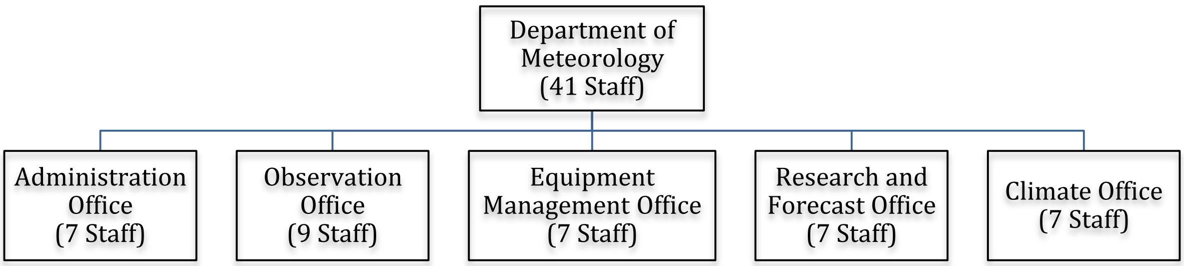

Figure 5: DOM Organizational Chart

35. MOWRAM has Departments in each province (PDOWRAMs). The functions of the Provincial Departments are:

- Planning and organizing the development program of the Ministry at the 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.
- Minor procurement and disbursements associated with construction projects.

36. According to the June 2012 staff survey the Ministry has 1,258 staff, of which 633 are in the central office departments (**Table 2)** and 625 are in the PDOWRAM offices. Four departments have staff numbers between 41 and 60 (DHWR, DAHR, DOM, and DIA), while the rest have much lower staffing levels.

Table 2: Number of MOWRAM Staff within the Central Office Departments

Department	No. Staff	Department	No. Staff
Administration and Human Resource	48	Technical Service Centre	19
FWUCs	38	Meteorology	41
Hydrology and River Works	60	Headquarter	19
Irrigated Agriculture	45	Planning and International Cooperation	30
Water Resource Management and Conservation	29	Finance	22
Engineering	241	Internal Audit	19
Water Supply and Sanitation	22		
TOTAL MOWRAM CENTRAL LEVEL STAFF: 633			

37. The mandate and role of the Mekong River Commission under the Flood Management and Mitigation Program (MRC FMMP) provides a regional context for activities to strengthen the National Flood Forecasting Centre.

38. The 1995 Mekong Agreement defines the scope of activities and cooperation arrangement for coordinated and joint planning of development in the Mekong River Basin, while protecting the environment and maintaining the ecological balance. The 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 Mekong River Basin 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.

39. 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".

40. 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 system and so ensuring the continuation of the multi-generational benefits that the Mekong River Basin brings to all its people (Article 1).

41. The MRC Council adopted five core procedures, which are linked, to ensure 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 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).

42. The MRC has a long and successful history. Its regional cooperation continues to reduce the risks of flooding and to promote the beneficial effects of the annual flood pulse.

4. Conceptual Design

43. The objective of this section is to provide a conceptual framework or national architecture for the hydrometeorological system. The conceptual framework presents the fundamental design principles and conditions for field instrumentation, data processing, and data management. The conceptual framework considers the integration of the existing and planned sub-systems of the Department of Hydrology and River Works and the Department of Meteorology. Also, the framework considers the sustainability of the system as well as the possibility of further development and upgrading of all sub-systems.

44. The followings are recognized as the fundamental requirements of the national hydrometeorological system:

- An effective and properly designed hydrometeorological network, reflecting the hydrologic and climate characteristic of the basins within Cambodia;
- A reliable monitoring system, which supports the information needs of the Department of Hydrology and River Works and the Department of Meteorology. The information needs include long-term information on the hydrology and climate of Cambodia, reliable data and information for operational planning in support of a wide range of economic sectors, and real-time data for warnings and alerts to prevent the disastrous consequences of floods, droughts, and extreme weather;
- An efficient data and information collection, processing, and dissemination system to support decision-making functions of government as well as for effective economic development and increased safety and security of the country's people; and
- An effective and appropriate system to support weather, early warning, and hydrologic forecast activities with the goal of preventing human life and economic loss.

45. The hydrometeorological system must be suited to the environmental conditions of Cambodia. Cambodia is characterized as having a tropical monsoon climate, with a northeast flow of the atmospheric air mass in the dry season and southwest flow during the rainy season. The monsoon or rainy season, normally affects the tributary basins and the Mekong River from May to November and the dry season is generally from early December to April. Temperatures typically range from 25 ^{o}C in the north at higher elevations to 35 ^{o}C at the lower elevations during the year.

46. The flow regime of the Mekong River and its tributary basins is significantly influenced by the two distinct seasons. During the flood season, from June to November, some 85 to 90% of total annual flow is realized while the remaining 10 to 15% of total annual flow occurs during the dry season, from December to May.

4.1 HydroMeteorological System Components

47. The main components of the national hydrometeorological system, which would support a forecast and early warning service, are:

- an observing station network for rainfall, climate, water level, streamflow, and weather,
- a near real-time field data transmission system,
- a centralized data reception and processing centre at MOWRAM, Phnom Penh,
- a centralize data management and data archiving system,
- a communications system linking Regional Centres and other concerned institutions,
- a production centre to support the generation of information products and services, and
- a web based dissemination system for data and information.

48. These components can be linked using a high-level data model for the hydrometeorological system, which identifies functions and activities specifically required to support each element of the data model. The high-level data model is shown in **Figure 6**.

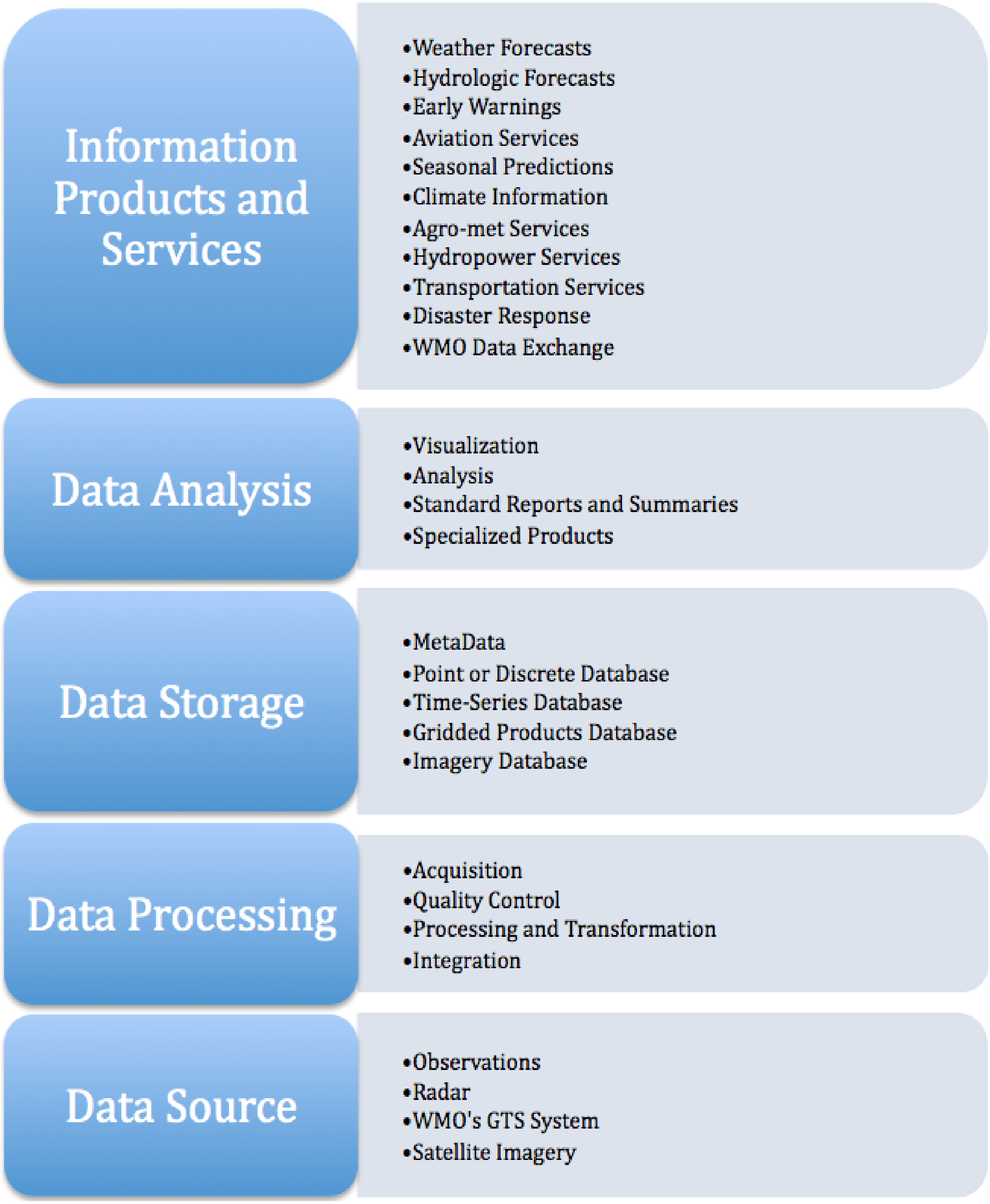

Figure 6: High-level data model

49. A conceptual overview of the physical components of a national hydrometeorological system is shown in **Figure 7**. The schematic incorporates the above data model and physical elements of a hydrometeorological observing network into an "end-to-end" system that supports the forecast and an early warning needs of Cambodia.

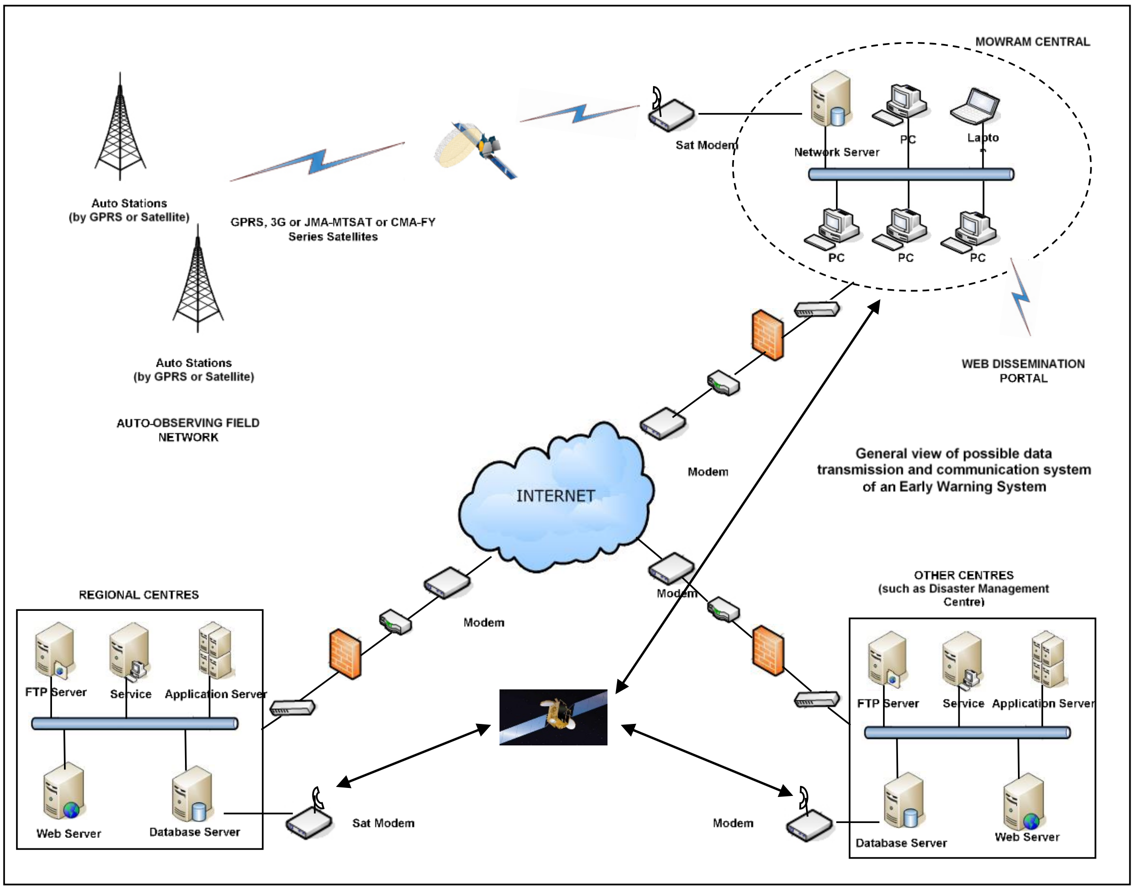

Figure 7: A conceptual overview of the physical components of a national hydrometeorological system

4.2 System Design Criteria

50. In order to design a comprehensive “end-to-end” system, which will satisfy the forecast and early warning as well as the information and service requirements, a series of principle design objectives have been developed. The design principles are based on international and WMO guidelines for the development of national hydrometeorological networks and programs and are as follows:

- Technical solutions must be supported by capacity building and strengthening, must limit the need for specialized support once the project is closed, and must build upon the existing knowledge and capacity of the Department of Hydrology and River Works and the Department of Meteorology.
- The meteorological forecast and prediction approach must be supportive of regionally collaborative needs and must build upon MRC and WMO’s initiatives for the region, but be nationally independent.
- The hydrological forecast and prediction approach must build upon a regionally common system that is river basin specific and conforms to the Mekong River Commission requirements. The modelling capability must be based on internationally available and supported model applications, with a limited requirement for annual licensing and support fees.
- The hydrometeorological data management approach must include data acquisition, data processing, data visualization, data archive, and the generation of data and information reports and products. The data management approach must handle the required range of hydrometeorological parameters, be SQL compliant, and be able to operate in near real-time.

The approach must be based on internationally available and supported commercial data management applications, with a limited requirement for annual licensing and support fees.

- Communications between the hydrometeorological field sites and national data centres must support near real-time data acquisition and be reliable in the event of extreme events. The communication system must be internationally available and must be a proven commercial system, with a limited requirement for annual licensing and support fees.
- Communications from MOWRAM's data centre must support a Web Portal for information dissemination and moderate levels of data, image, file, and information exchange. Internet service providers must be national in scope and have a reliable service history. Ongoing service costs must be sustainable.
- The upgrading and modernization of the hydrometeorological network must focus on key meteorological and hydrological sites and must take a parallel approach of upgrading the manual instrumentation with the installation of automatic instrumentation at each site. The automatic instrumentation must operate in a tropical environment, have a very low power requirement, be easy to service and maintain, be internationally available, and must satisfy internationally recognized standards and specifications.
- Regional cooperation, collaboration, and coordination is seen as a key strategy for the development and sustainability of the MOWRAM's capacity to provide reliable weather and hydrological forecast and for the support of systems with the ability to offer regional access to data. Data exchange within the region as well as the need for ongoing capacity strengthening and training is a must. As such, a common regional approach to specifications and standards must be used for field instrumentation, field to data centre communications, data management, and weather and hydrological forecasting.

51. The primary guide for the design of hydrometeorological systems is the specifications of the World Meteorological Organization (WMO). WMO provides a basic level of standardization for hydrometeorological observation, data management, and forecasting functions and services worldwide. Hence, the conceptual design and technical design are guided by a number of WMO Standards. These include:

- WMO No. 8 "Guide to Meteorological Instruments and Methods of Observation" - while WMO No. 8 is primarily for conventional stations, its guidelines also apply to automatic weather stations.
- WMO No. 49 "Technical Regulations – Volumes I, II, III, and IV"
- WMO No. 168 "Hydrological Practices" - covers precipitation and evaporation as well as stream gauging.
- WMO No. 386 "Manual on Global Telecommunications System"
- WMO No. 485 "Manual on Global Data Processing and Forecast Systems"
- WMO No. 544 "Manual on Global Observing System"
- WMO No. 1004 "Manual on Stream Gauging – Volume 1 – Field Work"
- WMO No. 1004 "Manual on Stream Gauging - Volume II – Computation of Discharge"
- WMO No. 1060 "Manual on the WMO Information System"
- WMO No. 1083 "Manual on the Implementation of Education and Training Standards in Meteorology and Hydrology"
- Guide No. 8 "Meteorological Instruments and Methods of Observations"
- Guide No. 100 "Guide to Climatological Practices"
- Guide No. 134 "Guide to Agricultural Meteorological Practices"
- Guide No. 168 "Guide to Hydrological Practices

- Guide No. 305 “Guide to Global Data-Processing Systems (GDPS)”
- Guide No. 488 “Guide to Global Observing System”
- Guide No. 636 “Guide to the Automation of Data-Processing Centres”
- Guide No. 834 “Guide to Public Weather Services Practices”
- Guide No. 1061 “Guide to WMO Information System”

4.3 Network Design

52. MOWRAM has selected the Stung Pursat basin as one of the priority basins. The Mekong Mainstream system was select by MOWRAM as the other priority area.

53. **The Stung Pursat basin** (**Figure 8**) is 5,964 km^2 in area and 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 increases with basin elevation. The mean annul flow is 2,130 million cubic metres.

54. The Stung Pursat basin flows into the Tonle Sap Great Lake. The basin ranges in elevation from 1,717 m to 6 m above masl. More than 75% of the sub-basin consists of hilly terrain with an elevation above 30 m masl. There are three upper branches, Stung Pursat, Stung Pam, and Stung Santre. Forest covers some 74% of the area and agriculture production utilizes some 13% of the land area.

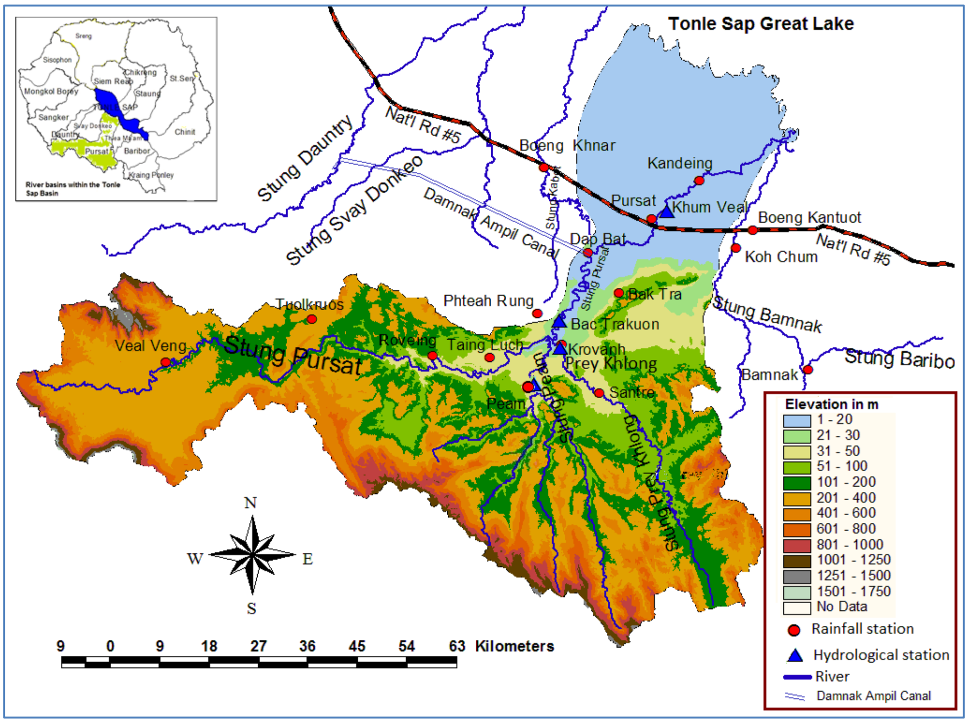

Figure 8: Location Map, Topography, and Hydromet Network - Pursat River Basin

55. **The Mekong Mainstream** system flows through Cambodia for a total length of about 500 km before flowing 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 flows to the Gulf of Thailand. About 86% of Cambodian territory is within the Mekong River basin, including the catchments of the Bassac river, the Tonle Sap river, the Tonle Sap Great Lake, and the tributaries to the lake.

56. The Mekong river can be divided into a number mainstream reaches (**Figure 9**). Reach 1 is the Mekong river from the Laos-Cambodian border to Kratie town. The major flow contributions to the Mekong mainstream in this reach come from the Se Kong, Se San, and Sre Pok catchments discharging at Stung Treng Town. In total, over 25 % of the mean annual flow volume of the mainstream Mekong river at Kratie comes from these three river sub-basins. There are only two stream gauging station in this reach, one at Stung Treng and the other at Kratie.

57. 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 in this reach is very complex during the flood season as hydraulic conditions define the flow distribution. The complexity includes downstream backwater effects that reverses the flow of the Tone Sap river, overbank and overland flow, temporary water storage on the floodplain, colmatage systems, and infrastructure controls.

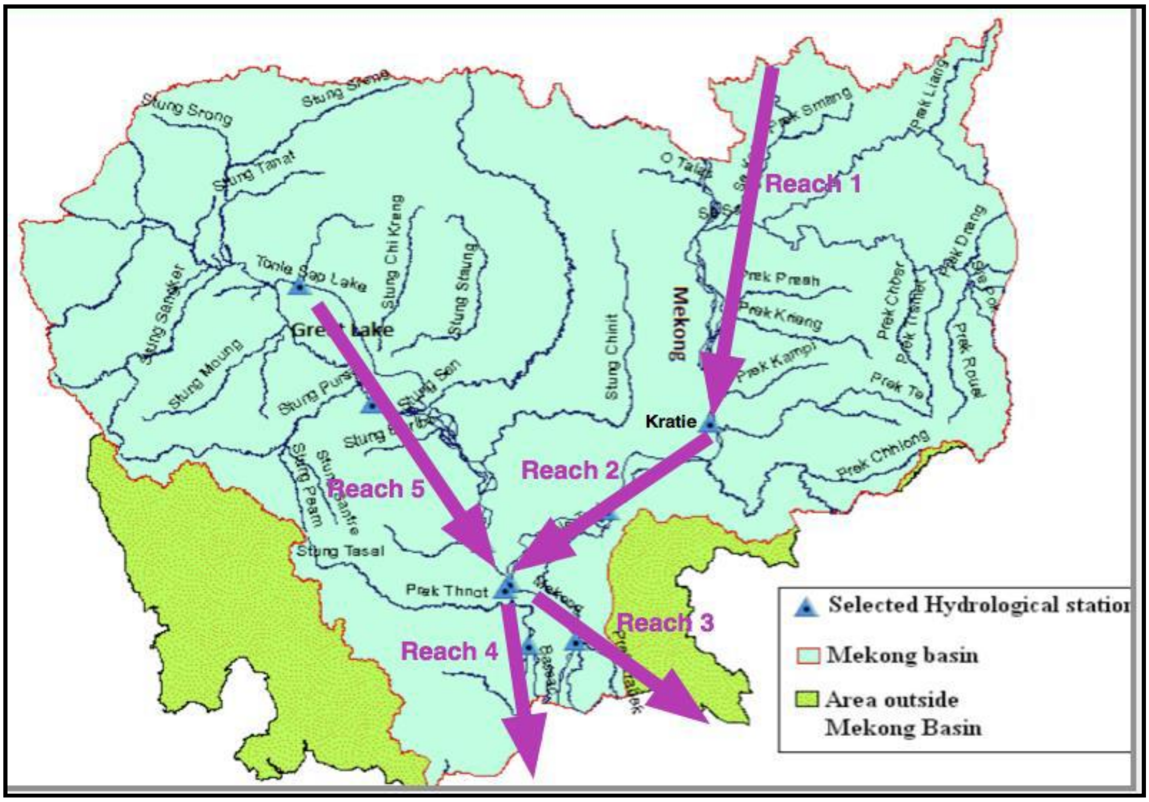

Figure 9: Mainstream Mekong, Bassac, and Tonle Sap Rivers in Cambodia. Source: ADB CDTA 2014

58. Reach 3 defines the Mekong river from Phnom Penh to the border of Cambodia with Viet Nam, with discharge stations at Koh Norea and Neak Luong.

59. 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 river. Stream gauging stations are located at Chaktomuk and Koh Khel.

60. The Tonle Sap river and the Tonle Sap Great Lake define reach 5 with a discharge station 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. The flow into the Great Lake from the Mekong river continues to about early October when the water level in the Great Lake measured at Kampong Luong exceeds the level at Phnom Penh. At that time, the flow changes its direction with the Great Lake water discharging to the Mekong and Bassac rivers.

61. The two main river branches on the eastern part of the Mekong floodplain in Reach 3 are the Stung Slot and Prek Kampong Trabaek rivers. These two rivers 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. The flow measurements of those two rivers have been made along the National Road #1, at the Stung Slot and Kampong Trabaek hydrological stations.

62. The main tributary located in Reach 4, beside the Prek Thnot river, is the Stung Slakou (Stung Takeo) river. The Prek Ambel is a branch of the Bassac river and it diverts flow from the Bassac river, on the right bank near Koh Khel, and discharges the flow back at its confluence located upstream of the Stung Takeo river confluence near the Cambodian-Vietnamese border. Flow measurements on the Prek Ambel river have been made at Angkor Borey. As well, flow measurements on the Stung Takeo river have been taken at Kampong Ampil (Borey Chulsar).

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

64. A field trip was conducted in February 2016 to complete an initial field site surveys for the hydrometeorological stations in Stung Pursat basin. Representatives from MOWRAM's Phnom Penh and Pursat offices were involved in the field visits. During the field trip the following key activities were conducted:

- Checked the status of each visited station (operation and non-operation);
- Checked the sources of project funding for station installation and maintenance;
- Checked surrounding environment, which can affect the data observed at the station;
- Consultation with PDOWRAM on station status and data availability for each station; and
- Checked dimension of control gate and canal.

65. **Table 3** shows the hydrometeorological network and proposed upgrade requirements for the Pursat basin. Typical hydrometeorological stations are shown in **Figure 10**.

Table 3: hydrometeorological network and proposed upgrade requirements for the Pursat basin

No.	Station Name	Parameter	River Sub-Catchment	UTM Coordinates		Type	Target	Installed by project/ organisation, year	Status	Proposed Solution	
				Northern	Eastern					Short term	Long Term
1	Bat Tra	Rainfall	Pursat River	376001	1E+06	Data logger		Tokyo Uni	Operational	Install additionally manual rain gauge with SMS	Telemetry and manual with SMS
2	San Tre	Rainfall	Santre/Prey Khlong	372359	1E+06	Data logger		Tokyo Uni	Operational	Install additionally manual rain gauge with SMS	Telemetry and manual with SMS
3	San Tre	Water Level	Santre/Prey Khlong	372389	1E+06	Manual	Check inflow from Santre/Prey Khlong river into Pursat river	PDOWRAM	Operational	SMS	Telemetry
4	Damnak Ampil gate	Water Level	Pursat River	370411	1E+06	Manual	Gate operation, WL =17m gates fall down	PDOWRAM	Operational	SMS, need gate operation info	Telemetry
5	Damnak Ampil (Dap Bat)	Rainfall	Pursat River	370411	1E+06	Data logger and Manual with SMS		DL: Tokyo Uni; M: MRC	DL: Non-operational M: Operational	replace with manual rain gauge with SMS	Telemetry and manual with SMS
6	Peam	Water Level	Arai/Peam	360655	1E+06	Manual	Check inflow from Peam river into Pursat river	PDOWRAM	Operational	SMS	Telemetry
7	Peam	Rainfall	Arai/Peam	360217	1E+06	Data logger and Manual		DL: Tokyo Uni; M: MRC	Non-operational	replace with manual rain gauge with SMS	Telemetry and manual with SMS
8	Taing Luch	Rainfall	Pursat River	352449	1E+06	Data logger		Tokyo Uni, 2005	Non-operational	replace with manual rain gauge with SMS	Telemetry and manual with SMS
9	Prey Khlong	Water level	SantrePrey Khlong	365381	1E+06	manual		PDOWRAM	Operational	Rehabili staff gauge, SMS	Telemetry
10	Bak Trakuon	Water Level; rainfall	Pursat River	364775	1E+06	telem + logger	Sum of river flow after joining all 3 tributaries	JICA RBWRU, 2015	Operational	SMS	
11	Tuol Kruos	Rainfall	Pursat River	320032	1E+06	Data logger		Tokyo Uni, 2009	Non-operational	replace with manual rain gauge with SMS	Telemetry and manual with SMS
12	Kbal Hong	Water Level	Pursat River	382862	1E+06	Manual	Referent flood station for Pursat Town	PDOWRAM	Operational	station relocation	Telemetry
13	Ta Des	Water Level; rainfall	Pursat River	354866	1E+06	telemetry	River flow from the Pursat upstream catchment area and used for Damnak Chheukrom Irr.	JICA RBWRU	operational for rain; non-opertaional for WL	Install additionally manual rain gauge with SMS	
14	Khum Veal	Water Level	Pursat River	384041	1E+06	Manual	Check for Downstream outlte	JICA RBWRU	Operational	SMS	Telemetry
15	Veal Veng	Rainfall	Pursat River	294070	1E+06	Data logger		Tokyo Uni, 2007	Operational	Install additionally manual rain gauge with SMS	Telemetry
16	Veal Veng (Pramouy)	Water level	Pursat River	293515	1E+06	Manual	First upstream station	Tokyo Uni, 2007	Non-operational	Repair staff gage with SMS	Telemetry
17	Pursat	2 AWS	Pursat River	381840	1E+06	AWS		Tokyo Uni (with agromet) 2013 ; MOWRAM 2013	Operational	SMS	
18	Rovieng	Rainfall	Pursat River	341978	1E+06	Data logger		Tokyo Uni, 2006	Non-operational	Install additionally manual rain gauge with SMS	Telemetry
19	Charek	Rainfall	Pursat River	390486	1E+06	Data logger and Manual		JICA RBWRU	Operational	SMS	Telemetry
20	Kravanh	Rainfall	Pursat River	365448	1E+06	Manual		PDOWRAM	Operational	Replace rain gauge with SMS	Telemetry
21	Sya	Water level	Pursat River	391487	1E+06	Manual	Early warning station (NCDM-ADPC project)	NCDM/ADPC 2014	Operational		

Rain gauge at Dap Bat (Damnak Ampil)

Water level Gauge at Stung Peam

Damnak Ampil Diversion Structure

Figure 10: Existing hydrometeorological network

66. In summary, of the twenty-one (21) stations in the Pursat basin ten (10) are rainfall only, eight (8) are water level only, two (2) are combined water level and rainfall, and one (1) is an Automatic Weather Stations (AWS). Four (4) of the rainfall and one (1) water level station are non-operational.

67. It is proposed that all eight (8) manual water level stations be upgraded to automatic stations with telemetry. All of the water level stations will be equipped with tipping bucket auto and manual rain gauges, therefore only six (6) of the ten (10) rainfall only stations are proposed to be upgraded to automatic stations with telemetry

68. Upgrading of the two (2) combined water level and rainfall stations and the one (1) AWS is not proposed, as these sites were operational with telemetry at the time of the field visit.

69. As well as the automation of stations with telemetry, staff gauges and manual rain gauges will be installed to support the taking of manual observations. The on-site gauge observers will be equipment with mobile phones to SMS observations. The combine manual system and automatic system will ensure redundancy at the site.

70. At the time of preparing this report the upgrading or installation of new sites for the Mekong Mainstream has not been identified, as many of the Mekong stations are being addressed under other modernization programs. However, the Mekong River Commission has been consulted and asked to identify additional priority stations for consideration by the NFFC project.

71. It is important to note that there are a number of projects underway or are proposed to improve the hydrometeorological network in Cambodia. The known interventions are:

- The "Uplands Irrigation and Water Resources Management Sector" plans to install 15 hydromet and 15 AWS stations in the upper parts of the Tonle Sap Great Lake basin. As well, 8 synoptic stations will be upgraded as AWS stations.
- It is expected that improvements in the hydrometeorological network will be implemented under the UNDP/GEF-LDCF project (2015 to 2018) - "Strengthening climate information and early warning systems in Cambodia to support climate resilient development and adaptation to climate change". Some 55 hydrological stations and 25 AWS are expected to be installed under the project.
- The Mekong-IWRM APL2, supported by the World Bank, will improve the hydrometeorological network within the 3S River basin in the northeast of the country. Some 10 hydrological stations, 4 AWS, and 10 automatic rain gauges are expected to be either upgraded or installed.

4.4 Standardized Field Instrumentation and Facilities

72. The following section describes the accepted WMO, as well as international, standards and guidelines for the sitting of hydrometeorological stations and the selection of instrumentation and equipment.

4.4.1 Hydrologic Stations

73. The WMO publication for hydrology provides a general discussion on sitting aspects and on equipment and methods to be considered. There are a limited number of prescriptive standards, such as:

- arbitrary gauge datum is to be set to provide small positive numbers. It is desirable to have a permanent gauge datum referenced to a recognized mean sea level datum.
- at least three (3) reference marks or benchmarks are required at each station.
- station should be above the 200-year flood level.

74. The placement of the hydrologic station is not as standardized as the placement of meteorological sensors because each river location is unique. The river cross-section and reach characteristics vary from site to site, as well as the range of stage and bank material. Some river sections are mobile and others may be very stable.

75. Given this range of variability for hydrologic sites, sitting and installation configurations as well as the type of gauging technology will vary from site to site.

76. The following features are required for water level and stream flow stations:

- Each station must have a local datum, and if possible be tied to a national datum.
- The local station datum is maintained by at least (3) benchmarks. One close to the manual gauge, one at the station house or tower, and one protected from possible floods or damage.
- The zero of the local datum is set such that the measured gauge heights will be small numbers but never negative.
- The water level gauging location is upstream of the control section of the stage-discharge relationship. The flow metering location may be elsewhere in the reach.
- Water levels may be a direct water level utilizing a surveying instrument, staff gauges, or by automated means using a pressure sensor placed in the river, a shaft encoder in a stilling well with a float, or a radar unit on a bridge or cantilevered arm over the water.

- In cases where river discharge cannot be computed using a stage discharge relationship, an acoustic velocity meter placed in the river channel may be used.

77. All stations will be considered multi-purpose in that water level, rainfall, and water temperature are collected.

78. Although the proposed equipment is fully capable of unattended operation, it should be noted that in some cases it will be necessary for site security and for taking of stream-flow measurements to operate the station as a manned site.

79. The basic station design elements consist of a Real Time Unit (RTU), a power-supply unit, hydrological sensors, and ancillary infrastructure.

80. The measurement of continuous water levels can be achieved using a variety of sensor types. The most straightforward installation is an in-situ pressure transducer mounted on a block in the stream or in a well or other structure. Where stilling well installations exist or can be installed, water levels can be measured using a shaft encoder or pressure transducer. Both types of measurements so far described must be installed with contact to the water.

81. It is suggested that non-contact measurements using downward looking acoustic or radar sensors be used where there is a suitable structure over the water (bridge). Radar sensors are superior to acoustic water level sensors, as acoustic water level sensors are plagued by errors related to air temperature and humidity gradients and these gradients could be significant.

82. Water levels collected by any of the means described can be directly used as the reported water level or can be used to determine flow where a stage discharge relationship has been developed.

83. To support the measurement of water level, reference benchmarks are established at each hydrological station and ancillary staff gauges may be required to take reference water level observations.

84. The measurement of rainfall can be achieved using a single tipping bucket rain gauge mounted on a stand to ensure that the orifice is 1.0 m above grade, or the rain gauge may be placed on an arm off of a tower to achieve good exposure and provide security. The gauge would be connected to a Real Time Unit (RTU). Each station in the proposed network would have an automatic precipitation sensor with supplementary manual rain gauge.

85. A water temperature sensor may be integrated within the pressure sensor or may be a separate probe for sites without a pressure sensor. The sensor would be connected to the RTU.

4.4.2 Meteorological Stations

86. The following synopsis is from Section I of WMO No. 8 and covers a number of meteorological sensors.

87. Air Temperature - Located in open terrain representative of the surrounding area. Sensor shielded from thermal radiation from the sun as well as other heat producing objects and areas with free circulation or forced circulation radiation shields or screens. The air temperature sensor is placed between 1.2 and 2.0 m above the ground.

88. Relative Humidity - Similar to air temperature, separated from moisture producing surfaces such as evaporation pans.

89. Wind - Located 10 m above the ground in open terrain where the distance between any obstruction and the wind sensor is 10 times the height of that obstruction.

90. Net Radiation - The sensor's view is to be free from obstructions, or at least has no obstruction with an angular size greater than 5° in any direction, and to low sun angles at all times during the year. The net radiation sensor is usually placed at a height of 2 m above short homogeneous vegetation within the viewing angle of the downward sensor.

91. Evaporation Pan - Evaporation may be measured in two independent ways. First, the site is equipped with a standard Class A evaporation pan that would be read manually. The pan is to be places at a small height above the ground, in an open level representative area with no obstructions within 5 to 10

times their height. Vegetation near the pan is not to be above the rim. The pan is to be protected from access by animals. As well, evaporation may be calculated by an empirical method such as the Penman method using input parameters of temperature, relative humidity, wind speed, and net solar radiation.

92. Rain Gauge - The tipping bucket rain gauge and/or accumulation gauge is placed at a 1-metre height.

93. Barometric Pressure – Barometers used for meteorological purposes should be graduated in hPa, as one hPa (hectopascal) equals one millibar (mbar), the formerly used unit. The measuring range is 600 – 1080 hPa for both station pressure and mean sea-level pressure. Electronic barometers require a clean, dry atmosphere that is free of corrosive substances. The barometer should also be kept at a constant temperature. The instrument should be mounted in such a manner as to avoid mechanical shock and vibration. It should also be mounted away from electromagnetic sources, where this is not possible, the wires and casing should be shielded.

94. Soil Temperature – The standard depths for soil temperature measurements are 5, 10, 20, 50, and 100 cm below the surface. The site for such measurements should be a level plot of bare ground (about 75 cm^2) and be typical of the surrounding soil for which information is required. If the surface is not representative of the general surroundings, its extent should not be less than 100 m^2.

95. Station layout and Exposure - WMO No. 8 provides a detailed guide for the spatial layout of meteorological sensors.

96. A crucial aspect of any meteorological station is its exposure to the local weather. That is the ability of the sensors to measure what is representative of the area. The ideal station is located in an open level area covered with natural vegetation and without buildings, hills, or trees for hundreds of metres in all directions, except for a low windbreak around the rain gauge.

97. The WMO classifies meteorological stations as Class 1 through 5. The classification is primarily based upon the exposure of the site following specifications in WMO No. 8 Annex 1.B “Sitting Classification for Surface Observing Stations on Land”.

98. The exposure of a meteorological station is to be documented when the station is established and reviewed every three years to update exposure conditions.

4.4.3 Tower Mounting

99. Towers are used quite extensively for meteorological and hydrological applications. The placement and location of sensors on the tower varies based on the use of the data such as for a climate or hydrology network and the degree of security required. Sensor placement on the tower must consider the general exposure of the site to weather and minimize interference between sensors.

100. The placement of sensors should:

- Minimize shadows on the solar panel
- Minimize obstructions around the wind sensor.
- Minimize shadows and thermally reflecting or absorbing objects in the view of the radiation sensor.
- Minimize thermally reflecting surfaces near the temperature sensor.
- Minimize rain shadowing of the rain gauge and likelihood of condensation drops forming above the rain gauge.
- Minimize damage due to vandalism.

101. Solar Panels and Antennas - The solar panel should be placed at a height to reduce theft and to reduce its apparent interference with the radiation sensor. It should be at least 1 or 2 m below the wind sensors. Antennas must be mounted such that they can be aimed in the required direction. If there are several antennas (GPS, cellular, and satellite), they should be separated as much as possible to reduce interference.

102. Wind Sensor - The wind sensor is placed at the top of the tower and aligned with true north. A lightning rod may extend above the sensor.

103. Rain gauge - The rain gauge should be placed on the upwind side of the tower at some distance from the tower to limit splashing from other components. The rain gauge may be placed on a separate post a few metres away from the tower or on a rigid arm extending out from the tower. The arm must be rigid to prevent false bucket tips caused by vibration. It may be mounted at a height to reduce vandalism, commonly at 2.5 or 3 m. If the station does not have a wind sensor, rain gauges have been placed at the top of a shorter tower.

104. Temperature and Relative Humidity - Temperature and relative humidity sensors are mounted on an arm at their standard height of between 1.2 to 2 m a short distance out from the tower to minimize influence from the tower. It may be mounted higher on the tower to reduce vandalism but this must be noted in the station documentation as being non-standard.

105. Solar Radiation - The solar radiation sensor is placed on an arm at least 2 m long extending directly south from the tower at a height of 2 or 3 m. By placing the sensor directly south of the tower, data anomalies at solar noon are known to be artefacts and are consistent from one installation to another. For a net radiation sensor, the ground viewed by the sensor must be short vegetation or bare-ground, whichever is representative of the area.

106. Evaporation - Evaporation may be calculated using the Penman Method using input parameters of rainfall, temperature, relative humidity, wind speed, and net solar radiation.

107. Data logger enclosure - The data logger enclosure is normally mounted at eye height or, to reduce vandalism at 3 m or more and accessed by a removable ladder. It should be mounted to reduce solar glare on the LCD panels and to reduce persons being in view of the net radiation sensor.

108. **Figure 11** illustrates proposed configurations for the hydrometeorological stations using a tower.

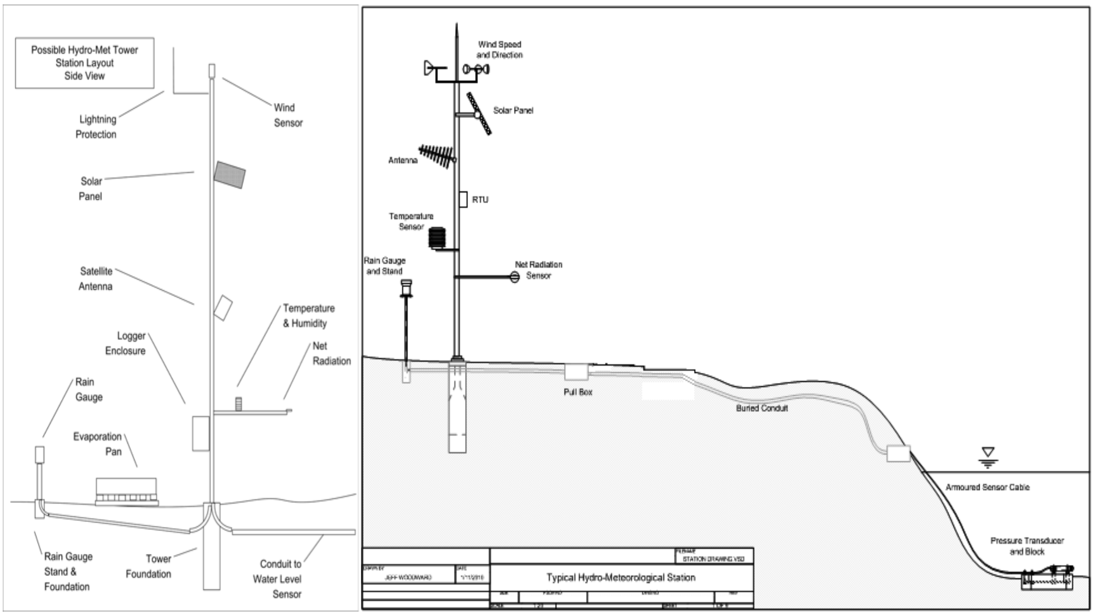

Figure 11: Typical Hydrometeorological Station with Tower Mount

4.5 Mobile Field Instrumentation

109. For calibration of the hydrologic discharge stations, field teams may be equipped with either a standard set of mechanical current meters or the newer hydro-acoustic current meters. A standard suite of sounding weights, metering cranes and reels, taglines, surveyor's level with level rods, and boats will be required. In addition, a toolkit with voltage/amp meters and a selection of hand-tools will be required for servicing the on-site observing and logging instrumentation.

110. Many hydrologic monitoring programs are implementing hydro-acoustic instruments to conduct discharge measurement. Hydro-Acoustics use the Doppler affect to measure the velocity, instrument position, and direction of travel. These elements are combined so that river discharge is determined in real time as the instrument is moved across the river section. The velocity area procedure is used to determine discharge except the number of individual velocity and area measurements are increased by several orders of magnitude. A typical measurement may contain hundreds of panels each containing multiple velocity measurements, yielding thousands of data points. This technology is proving to be very accurate as its application to many differing river situations in a range of countries grows.

111. Two types of hydro-acoustic instruments may be required: Acoustic Doppler Velocimeters (ADV) for conducting wading measurements and Acoustic Doppler Current Profilers (ADCP) for conducting large stream flow measurements from boats, bridges, and cableways.

112. Acoustic Doppler Velocimeters (ADV) such as the SonTek FlowTracker or the OTT ADC can be used as a direct replacement of the mechanical current meter for wading measurements without significant change in procedure. These instruments offer better measurements quality as they are more sensitive to low velocities, do not require ongoing calibration, and account for flow angles.

113. In general, there are two manufacturers of Acoustic Doppler Current Profilers (ADCPs); SonTek and TRDI and both are located in San Diego, California, USA. Each has a slightly different approach to the measurement process, however the end results are comparable.

114. ADCPs are equivalent to using a current meter and tag line and require a deployment mechanism or apparatus to move the ADCP across the river cross-section.

115. Ruggedized field computers are required for each field crew as well as the hydrometeorological staff on site to access and, when required, reprogram the data loggers and sensors.

116. Suitable transport will be required to support the field teams.

4.6 Telemetry of Station Observations

117. The conceptual design proposes that all stations be equipped with real-time telemetry. The incremental cost of adding telemetry to a data logger is well worth the additional benefit to flood forecasting, water management, and operational efficiency.

118. Real-time information on current meteorological and hydrological conditions will improve forecast and warnings. As well, telemetry reduces the manual effort, and lag times associated with paper and telephone and or shortwave radio based data transmission systems.

119. In addition, telemetry provides operational managers of the hydrometeorological stations near real-time information on meteorological and hydrological conditions as well as on the operational status and functionality of the monitoring equipment.

120. The basic considerations for the communications system are:

- volume and frequency of data transmission,
- life cycle cost, and
- reliability in times of extreme events.

121. Communications options are present here with a discussion on the advantages and disadvantages of each.

122. There are two broad categories of communication options, manual delivery systems and telemetry systems. Telemetry systems include digital radio, telephone modems, cellular network, and satellite.

123. Manual Delivery - There is a wide range of options, which use people as an integral link in the data acquisition chain. They fall into 3 broad categories:

- The staff making visual observations and transmitting the reading to the office in voice by telephone or radio or on paper by postal service or fax.

- The staff copying the data at the station from an electronic data logger into an electronic media, such as a USB memory stick, and forwarding the media stick to the central office.
- The staff keying the readings into a mobile phone, or using an electronic link such as Bluetooth or IR, from the data logger on site, and transmitting the data to the central office by technologies such as SMS or e-mail.

Advantages: Low capital cost.

Disadvantages: Lag time of several hours or days. Increased personnel costs. Transcription costs and increased risk of human error of the voice and paper methods.

124. Manual delivery methods are appropriate where timeliness of the data is not important and where the capital cost savings outweighs the incremental personnel costs.

125. Digital Radio - Digital electronic data can be sent between the data logger at the station and the data acquisition system at the central office via radio modems on a variety of different protocols and frequencies such as UHF, VHF, Spread Spectrum, Ethernet, Modbus, Profibus, etc. The digital radio modems provide seamless connections of data between two processors – the one in the data logger and other in the data acquisition system.

126. Digital radios can be characterized into two broad categories:

- Short-range systems, which typically provide two-way connection over distances up to a few kilometres using small antennas and not requiring assigned frequencies.
- Long-range systems, which use the UHF or VHF frequencies, and require antenna towers and radio licenses from the appropriate authorities.

Advantages: The communication system is private and self-contained within the organization.

Disadvantages: Propagation studies and the installation of antenna towers increase start-up costs as well as the maintenance effort and require annual radio license fees, which may be significant.

127. Telephone Modems - Data communication between the data logger and the acquisition centre can be achieved by having a hard-wired telephone line installed at the station and compatible telephone modems installed at the station and at the acquisition centre.

128. Typically, the connection is initiated by the acquisition centre on a daily or hourly schedule to download data, although the station itself could be programmed to call the acquisition centre when it senses emergency conditions.

Advantages: Low capital cost. Familiar technology. Able to access the station's data from any location.

Disadvantages: High ongoing costs of calls. Unreliable connections. Phone line failure in disaster situations.

129. Cellular Network - Communications by the cellular telephone network has a significant advantage over the hard-wired telephone network in that it is not necessary to have telephone lines installed. The communication can be:

- by modem to carry the digital data over a voice connection, or
- by digital text service with CDMA, SMS, GPRS, or the 3G digital services.

Advantages: Low capital cost. Familiar technology. Able to access the station's data from any location.

Disadvantages: High ongoing costs of calls. Cellular systems tend to become overloaded in disaster and emergency situations.

130. Satellite - A satellite-based system moves data from the hydrometeorological station to the acquisition centre through a satellite. The acquisition centre may receive the data directly from its own satellite dish or it may come by Internet from a main satellite receive site.

131. There are three broad categories of systems:

- Satellite phone modems based on handheld satellite phones. They consume little power or space.
- VSAT terminals function similar to modems offering continuous connections between the station and office. Typically, they use dish antennas of approximately 1 to 2 metres in diameter at the field and receiving sites.
- Meteorological satellites such as MeteoSat, MTSat or FYSat are government owned and operated for collecting weather related images but they also have data channels for relaying digital data transmitted from the ground. These data messages are short and are transmitted on a 1 or 3-hour schedule. Recent advances have enabled the transmission frequency to be on a 15-minute schedule.

Advantages: Independent of ground based systems. Low installation effort for DCP and satellite phone modems. The DCP system on the meteorological satellites has low ongoing costs.

Disadvantages: Obtaining permission from the government operators of DCP systems is not straightforward. Satellite telephones and VSATs have high usage fees and power requirements in comparison to the DCP satellite approach.

132. The decision to use one technology or another and how it is to be configured depends the costs and benefits as well as the advantages and disadvantages of each of the technologies in relation to the characteristics of the operating environment, the available infrastructure, and the organization's intended use of the data.

133. The long-term sustainability of any communication system is one of the most crucial selection criteria. The determination of the long-term sustainability considers the lifetime cost of operating and maintaining the system, which is reflective of the year-over-year operating and maintenance cost, in comparison to the available annual departmental budget. The cost of expandability must be considered when assessing the lifetime cost of a communication system. For example, the basic communications infrastructure installed for one government department may be expandable with only minor incremental cost to service the needs of a number of other government departments and agencies.

134. From the above discussion the proposed communications system should be assessed using the following criteria:

- Cost of initial supply and installation.
- Cost of ongoing support for 10 years considering direct operating costs, repairs and support, and required person years of staff.
- Capital cost to expand the system by 50%.
- An assessment of reliability and simplicity of the proposed communications system.
- A value assessment of the additional features and functions, which are above the basic requirement.

135. The basic requirement for the data communications of the hydrometeorological network in Cambodia is one-way scheduled transmission on a minimum hourly schedule during the rainy season and less frequent during the dry season. The need for redundant transmissions and two-way transitions is not required.

4.7 Data Management

136. The data acquisition, processing, archiving, and reporting functions are the heart of a national hydrometeorological system. The general characteristics and functions of the data acquisition, data processing, data archiving, and data reporting systems are described in the following paragraphs.

137. The data acquisition system captures the transmitted field observation, decodes the field observation into standard engineering units, monitors the health of the on-site observing and transmission

system, and provides alerts for missing, non-reporting, or questionable field data. All data and information capture by the data acquisition system is placed in the raw data archive and retained as the original record.

138. The data processing system reads observational data from the raw data archive, and applies the appropriate transforms and filters to provide preliminary quality-controlled data. To perform the data processing function, the data processing system reads information stored as meta-data and acquires the appropriate transforms and data filters from the meta-data and archival database. The preliminary quality-controlled data are then placed in the centralize data archive and locked to ensure all future interventions do not overwrite the original quality controlled data. The purpose of locking the data files is to ensure all attempted interventions and the implications of these interventions are logged for future reference, if required.

139. The data archiving system is the data and information repository for the hydrometeorological data management system. The data archiving system stores all received raw data observations, preliminary quality-controlled data, and approved final data as well as meta-data including current and historical transformations and filters, which are being and have been used to transform and filter the data for each observational site.

140. The data reporting system supports the transfer of data to regional and provincial centres, other institutions and agencies, and for dissemination to a web portal. In addition, the data reporting system enables high-end modelling and decision support software to access the real-time data, archival data, and meta-data as required and to produce standard reports, graphs, maps, and related products.

141. The conceptual design for the Department of Hydrology and River Works' hydrometeorological data management system is based on the premise that the real-time acquisition of observations is required.

142. **Figure 12** presents the high level overview of the proposed hydrometeorological data management system.

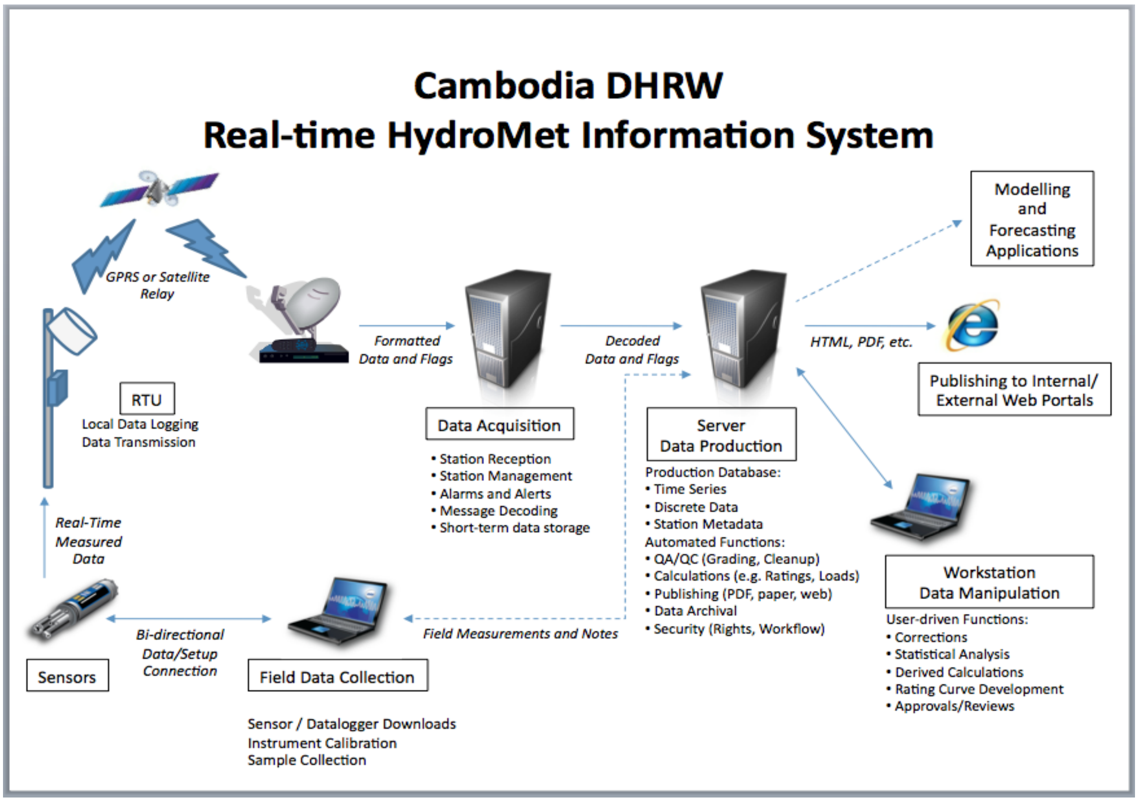

Figure 12: High level overview of the proposed hydrometeorological data management system

143. The National Flood Forecasting Centre is at the core of the DHRW HydroMet Information System. The centre will be equipped with all necessary communications, computer hardware, and software applications linked by a local communications network, for conducting the following tasks:

- Automatic acquisition of observed data from the field sites.
- Manual and bulk data download from field computers and storage devices.
- Automatic quality control and assurance of the field observational data.
- Routine and regular processing of the field observational data.
- Archive observed and processed data as well as ancillary site information using a relational database.
- Generation of hydrometeorological information, regular bulletins and products using standardized analytical software tools.
- Generation of reports, plots and graphs, and maps using pre-set and user customizable formats.
- Data distribution and exchange according to the data exchange agreements of the South East Asian countries and country-based stakeholders.
- Information production and data analysis for the generation of specialized reports, products, and services.
- Email and SMS services to staff as well as to outside contacts for the dissemination of alerts and warning.
- Website operation, complete with the required firewalls.
- System security including regular system back-ups and applications to prevent unauthorized access.

144. Front-end Acquisition System - The front-end data acquisition system, consisting of a prime and backup system, is composed of hardware and associated software needed to administer the system and perform the following tasks:

- Data acquisition from remote stations.
- Remote station monitoring.
- Alarm and alert recognition and processing.
- Manual data entry and loading of files from field computers and storage devices.
- Data decoding, screening, and validation.
- Data ingest to the data processing and database system.

145. Data Processing and Database System - The data processing and database system, consisting of a prime and backup system, is composed of peripherals and associated software for data management. The database will be a relational database using a SQL language, and be able to efficiently store and manage large amounts of hydrometeorological data collect over a period of several decades.

146. The data processing and database system must manage data and met-data for the Department of Hydrology and River Works' 111 hydrologic stations and some 200 rain gauges. The period of record for most sites exists since the mid-1980s.

147. The data processing and database system includes all hardware and software to administer the system and perform the following tasks:

- Data processing of the observed hydrometeorological data including screening of the data and the application of corrections and adjustments in an automatic mode.
- Processing of stream-flow measurements from standard mechanical meters as well as from hydro-acoustic velocity meters.
- Processing and management of stream and river cross-section data and information.

- Processing and management of discharge rating relationships using stage or velocity index information.
- Display in multiple windows of data from different sensors as well as the rating and transformation relationships in interactive and understandable visual formats.
- Processing and management of meta-data for each measurement location, including station name and number, station coordinates, site maps and drawings, site photo's, instrumentation information, period and type of data, and narrative statements.
- Data export in formats suitable for ingest into other automatic functions and software tools.
- Long-term archiving of the observed and processed data.
- Regular administration and routine backups of the system within a secure environment.

148. Hydrometeorological Information and Production System - The hydrometeorological information system, consisting of a prime and backup system, is composed of peripherals, analytical and reporting tools, and associated software for the generation of hydrometeorological products and information. The system includes all hardware and software to administer the system and perform the following tasks:

- Generation of administration information and statistics on the number of stations, period and type of data, and station performance.
- Generation of standard reports and statistics for the publication of seasonal hydrometeorological assessment reports and annual year books, in both hard and electronic formats.
- Generation of basic information on daily, weekly, and monthly averages, maximum and minimum daily hydrometeorological values, basin yields, and peak flows, minimal flows user specified meta-data, data, and information reports. Generation of standard reports and statistics for the publication of monthly, seasonally, and annual year books in both hard and electronic formats.
- Generation of flood alerts and warnings based on predetermined warning criteria to assist forecasters and administrative managers to take decisions regarding disaster prevention.
- Regular administration and routine backups of the system within a secure environment.

149. The analytical tools consist of basic statistical software packages and report generation tools, which are linked to a Geographical Information System. Analytical tools cover the standard range of analysis to be performed on hydrometeorological data. These include but are not limited to:

- Frequency analysis
- Duration analysis
- Trend and time series analysis
- Data transformations
- Data and information contouring
- Correlation and data comparison such as mass curve analysis

150. In addition, basic tools will be required to support data completion (in-filling of missing data), tabular and graphical data presentation, and a range of mathematical operations.

4.8 Information Production and Products

151. The Department of Hydrology and River Works requires the capability to produce a number of standard and custom products for the general public, other government agencies, and commercial customers. The products include:

- Standard products and statistics for the publication of seasonally and annual year books in both hard and electronic formats.

- Basic information products on daily, weekly and monthly averages, maximum and minimum daily hydrometeorological values, basin yields, peak flows, minimal flows, climate norms, and climate summaries.
- Specialized products and bulletins for hydropower generation, agriculture, and transportation, drought and flood management, and environmental assessment

152. The number of products and their specific details and design must consider the reporting requirements to other government agencies as well as the needs of clients.

153. Access to GIS tools and applications is required to support the generation, analysis, and production of hydrometeorological information and products. Production workstations are required.

4.9 HydroMeteorological Service Delivery

154. The Department of Hydrology and River Works requires the capability to provide hydrometeorological data, products, and services.

155. The hydrometeorological service delivery system should support an alerting and flood warning service for the emailing of alerts and flood warnings either automatically or via user intervention to key operational and disaster response agencies.

156. The development of the Web Portal is proposed, which requires a clear understanding of client and user needs, which in turn will shape the data and information requirements and how these services are delivered. Furthermore, the field observational and data management systems must support the service requirements of internal clients and of the program operators and managers.

157. The Web based services and alerting system, consisting of a prime and backup system, is composed of peripherals and associated software for the dissemination of processed data, information, products, and alerts to key stakeholders and the interested public. The system includes all hardware and software to administer the system and perform the following tasks:

- Support a home page for DHRW's early warning.
- Support a user-friendly Web map interface for displaying the locations of observational stations and the type and availability of data.
- Support a real-time data dissemination service for the display and downloading of data in both graphical and numerical formats.
- Support an alerting and flood warning service for the emailing of alerts and flood warnings either automatically or via user intervention to key operational and disaster response agencies.
- Provide password-controlled access to specific data, information, and reports.
- Provide monthly statistics on the frequency and product type accessed for reporting and system management.
- Provide a secure environment for the system using appropriate firewalls

158. Access to specialized products and services such as specific data, information, and products may be password-controlled.

5. Cross-Cutting Considerations

159. There are a number of cross-cutting themes that must be considered for the successful development and implementation of a national hydrometeorological information system.

5.1 Meta Data Design

160. It is essential that a design of the meta-data structure, which is information about the data, be done prior to the upgrading and modernization of the system. There is an urgent need to standardize station naming and identifier conventions, collect site-specific information, and confirm the period of data collection complete with parameter types for each station.

5.2 Legacy Data

161. The Department of Hydrology and River Works has a large volume of legacy hydrometeorology data that must be placed in the database. The input of these legacy data to the data management system is essential to support the analysis and determination of normals, long-term trends, and event return period. Considerable effort is required to accomplish the data entry and data validation process.

162. Standardized procedures and a quality control process must be developed to support the effort of creating the historical hydrometeorological database.

5.3 IT Communications Infrastructure

163. The basic infrastructure requirement for today's information management needs is a reliable IT communications network connecting all units and divisions, which are required to contribute to or to access the department's data and information.

164. As well, a reliable IT infrastructure must be available to access common software tools and standardized applications for the validation, processing, archiving, analysis, presentation, and dissemination of data and information.

165. MOWRAM will need to make further investments in its IT communications network to improve accessibility, functionality, and reliability. These improvements are required to accommodate the movement of data and information from the provincial centres to the central database, as well as the movement of processed data amongst the Departments in Phnom Penh and to the provincial and distinct offices by electronic means.

166. These IT communications requirements are not only for the sharing of data and information, but also necessary for enabling access to a common suite of software tools and applications for the processing, retrieval, analysis, and presentation of data.

167. Further planning and development work is required before the specification for the IT communications network can be established.

5.4 Standard Operating Procedures and Guidelines

168. The deployment of the national hydrometeorological information system will require revised and new technical and procedural standards for the modern methods being implemented.

169. The requirements fall into two areas:

- Technical manuals for the new equipment, analytical tools, and models.
- Procedural manuals and guidelines for the conduct of observations, quality assurance of the observed data, data management, generation of information and products, and service standards.

170. Technical manuals will be supplied with the equipment, analytical tools, and models and will require simplification as guides to support training programs and reference.

171. As well, procedural standards and methods will require updating and new procedural standards are required, which conform to WMO and international accepted practices.

5.5 Quality Assurance and Audit Process

172. The quality management and assurance of hydrological and meteorological data requires the establishment, documentation, implementation, and maintenance of a quality management system.

173. The quality management system links technical standards and specifications, quality standards, processes and procedures, and organizational considerations, such as cost and human resources. The focus of the quality management system is on ensuring consistent product quality and confidence with the product.

174. The hydrometeorological data quality management system must:

- identify the processes needed for the quality assurance of hydrometeorological data,
- determine the sequence and interaction of these processes,
- establish criteria and methods needed to ensure that both the operations and controls of these processes are effective,
- continually monitor, measure, and analyse these processes, and
- implement actions necessary to achieve set quality objectives and regulatory requirements and to continually improve upon the processes.

175. Further work is required to define and develop the quality management and assurance process for the data as well as for the processes used to transform, archive, and disseminate these data.

5.6 Staff Training and Development

176. The implementation of improvements to the data observing and information management function requires the development of a training strategy and program. The objective of the training strategy and program is to enhance the IT capacity, the basic understanding of existing and required software applications and tools, and the English language proficiency of staff.

177. As well, the training strategy must address the training of existing and new provincial staff in observing techniques and the maintenance of upgraded and new field technologies.

178. The training strategy would identify the number of staff needed for the data observing and information function, the skills and competencies for these staff, as well as details the ongoing training and development plan for these staff.

179. The strategy requires a process for the development of training material, for the conduct of training, and for the regular evaluation of staff with respect to their ability to conduct the duties and responsibilities assigned to them.

180. Further work is required to define and develop the scope of the required data and information management training and development program.

5.7 Commercial Software Applications and Support

181. There are a number of commercial software applications available for the management of hydrological and meteorological time-series data and these commercial applications should be seriously considered.

182. Furthermore, it is suggested that local database and systems consultants be engaged to assist with the development and implementation of the database and its applications, to provide training for staff, and to assist with the development of future enhancements to the database and applications.

183. The use of the local consulting and business sector in assisting MOWRAM achieve its database software strategy and its data and information systems approach requires further consideration.

5.8 Availability of Funding

184. The level of government funding restricts the Department of Hydrology and River Works and the Department of Meteorology ability to deliver on their mandate and to conduct the necessary activities to adequately perform the duties required.

185. The issue of inadequate levels of funding for meteorological and hydrological networks is common throughout the world with similar organizations in other countries facing the same funding challenge. Some have turned to the approach of restricting the availability of data and information and charging user fees to address their funding shortfalls. In most cases the selling of data and information has had very limited success and often has generated very limited returns.

186. An approach to funding, which is realizing success, is the targeting of key business sectors and State-owned commercial agencies that require hydrometeorological data for the conduct of their business. The approach is to negotiate a partnership arrangement with these key sectors for services and the respective level of funding to support the network, observing, processing, archiving, and services function required by each particular sector. Some key business sectors to pursue are the hydropower generation sector and the aviation sector. Another potential source of funds is licence fees administered for the use and extraction of water, be it surface or groundwater.

6. Technical Design

187. Technical specifications and requirements for the national hydrometeorological system have been prepared. The specifications address the equipment and instrumentation needs of the meteorological and hydrological field sites, data transmission and communication requirements, special equipment for field teams, as well as the hardware and software requirements for the office element of the data management system, such as computers, data processing, and modelling software.

188. The general system specifications have been developed to guarantee optimum system performance and are:

a. Full compatibility of the proposed field stations and the overall system with other hydrometeorological and early warning systems existing or under consideration in Cambodia and the Mekong River basin in general;

b. All stations must be suited to work in a harsh tropical climatic with loss of data not exceeding 0.5%, maintaining full accuracy of measurements, and with a 99% data transmission success rate;

c. Durability of instrumentation and equipment to be not less than 10 years with proper maintenance;

d. All field instrumentation must be easy to use and easy to maintain, with user friendly interface;

e. The cost of maintenance and calibration of instrumentation and equipment will be minimal over the design life of the instrumentation and equipment;

f. System reliability must not be less than 99% when following recommended manufacture's maintenance programs using trained staff;

g. Data acquisition, processing, modelling, and data management applications must be compatible with data systems existing or under consideration in Cambodia and the Mekong River basin in general and guarantee ease of integration of inputs/outputs with these systems.

189. The detailed technical specifications are found in Appendix 1.

7. Capacity Strengthening and Training

190. Capacity strengthening and training is a critical element to ensure a sustainable and effective hydrometeorological system. Often, not enough attention or adequate financing is made available for training.

191. There is a need to strengthen the capacity of existing operational staff and technical managers on the new technologies and procedures as well as to train new staff in the basic fundamentals. The long-term strategy is to build capacity at the university and technical college level as well as strengthen MOWRAM's core training program.

192. The ongoing operation and support of the national hydrometeorological system involves a series of functions that begin at the field site and progress through data processing to the generation of information and data reports followed by the provision of services. The key functional tasks for the "end-to-end" national hydrometeorological system are:

i. field installation and site maintenance
ii. field observations and measurements
iii. data acquisition system operations
iv. manual data entry
v. development and maintenance of rating curves
vi. establishment and maintenance of datum's and gauge history
vii. data processing and support
viii. data reports and publications
ix. web operations and support
x. hydrological information and products
xi. use of analytical and information production tools
xii. operational program management

193. The entire process from field observations to the provision of services requires an overarching operational management function to ensure the individual steps are linked and supportive. As well, the hydrometeorological observing, data management, and hydrometeorological production aspects of the system must be supported by a training and capacity development plan.

194. An outline of a capacity building plan has been prepared is presented in Appendix 2. The capacity building plan will enable staff to carry out data observation, data processing, and data analysis of the systems and technologies implemented under the proposed hydrometeorological architecture. The capacity building plan identifies training initiatives required to ensure that the national hydrometeorological system is effectively implemented, operated, and sustained.

195. The modularity of the training and capacity building is through workshops, on-the-job training, mentoring, and self-study tools using external consultants and specialists. However, on-the-job training is considered the most effective training methodology for achieving technical capacity strengthening for an organization having a mature staff complement.

196. It is important that training be followed-up with regular review and assessment of staff performance to ensure tools and processes are correctly being used in on-going operations.

8. Budget Requirements

197. A preliminary estimate of the required one-time investment to implement the proposed hydrometeorological architecture for the Pursat basin with the necessary data management and hydrometeorological services system was developed.

198. A summary of the financial investment is presented in Table 4.

Table 4: Budget Requirement

Hydromet Element	Average Cost per Unit	Number of Units		Total Budget USD
Auto observing field stations with Telemetry and civil works: • Precipitation Stations only • Hydrology Stations with Precip • Climate Stations • Meteorological Stations	$ 12,000 $20,000 $30,000 $ 35,000	6 sites 8 sites 0 sites 0 sites		$ 72,000 $ 160,000
Central Data Acquisition System: • Servers and software	$ 40,000	1 unit		$ 40,000
Data Management System: • Server and Workstations, Database, and Software License, with training and technical support	$ 80,000	1 unit		$ 80,000
Provincial Centres (1): • Computers, motorcycles, renovations • Provincial Office	$ 25,000	1 unit		$ 25,000
Information Services and Dissemination System: • Server, workstations, production and statistical tools	$ 20,000	1 unit		$ 20,000
Training and Capacity Building: • Hydromet Networks • Data Acquisition • Data Management • Information Services				$ 90,000 $ 5,000 $10,000 $10,000

9. Conclusions and Recommendations

199. This report presents a conceptual design for an “end-to-end” national hydrometeorological system, complete with a description of the systems structure and technical specifications. Station network characteristics, data management, communications and IT, integrated information platforms, and cross-cutting themes for the national hydrometeorological system are discussed. Technical specifications for each of the “end-to-end” system elements have been defined.

200. A number of cross-cutting themes have been identified and presented for consideration. These cross-cutting challenges must be addressed for the successfully development and implementation of the national hydrometeorological architecture.

201. An outline of a capacity building plan has been prepared. The capacity building plan was developed to support the data observation, data processing, and data analysis functions as implemented under the proposed national hydrometeorological system. In addition, the plan includes training for the development of information products and services.

Appendix 1: Technical Specifications

Instrumentation – Technical Specifications

General Requirements:

202. The output signals for each sensor are to be selected from the commonly available formats, such as 4-20 mA, SDI-12, RS-232, RS-485, frequency, pulse counter, DC voltage (0-5 VDC, 0-1 VDC). However, SDI -12 is the preferred format.

203. The electrical power for the sensors and data logger is to be nominal 12 VDC. The voltage range of the sensors is to be compatible with the operating voltage range of the data logger.

204. The power consumption of the sensors is to be compatible with the power availability of the power supply system of the station with a reserve to operate for a minimum of 60 days.

Specific Requirements:

Data Logger – Basic

Inputs	Six sensors using two analogue channels, one SDI-12 port, and an event counter for tipping bucket
Interface	Standard RS232 and USB port. USB port preferred for on-site access
Remote Communication Interface:	Communication port to interface with GSM/GPRS modem
Microprocessor	16 to 32 bit
Time synchronization:	Time synchronization required
Time Stamp	Individually with 1 sec. resolution
Logging Memory	8 Mb
Data storage	Non-Volatile
Display	LCD display with backlight or equivalent for bright exposure environment
Battery	Internal back-up battery and external power supply
Enclosure	IP60 rated or better for a humid environment
Protection	Lighting, over voltage, and reverse voltage
Operating Voltage	10.0 to 16.0 VDC
Power Consumption	< 3 mA quiescent
Operating Temperature	-5°C to 60°C
Functions	Basic mathematical functions, maximum, minimum, averaging, customize calculations

Data Logger - Enhanced

Same specifications as Basic data logger except as noted below. It is required that the Basic and Enhanced data loggers be of the same manufacturer and field replacement compatible.	
Inputs	Ten to twelve sensors using analogue channels, SDI-12 port, tipping bucket and additional event counters
Functions	Basic mathematical functions, maximum, minimum, averaging, customize calculations

Communications – Telemetry

205. The communication and telemetry system shall use environmental grade GSM/GPRS/3G modems and be fully integrated with the data logger.

GSM/GPRS compatible modem for harsh environments interfaced with supplied data logger. The GSM/GPRS modem must conform to county specific telecom requirements.

Solar Power Supply

206. All electrical power to operate the sensors, data loggers, and the communication system at the field stations should be provided using a solar panel system. The bidder is to provide a power budget for the system with all sensors sampling at a 10-minute interval.

Solar panel(s)	Sized as required. Certified for damp heat applications
Battery	Spill proof maintenance free rated recharged batteries sized for 60 days of power supply without recharge and have an expected lifetime of not less than 60 months
Charge controller	Must protect battery from over charging and discharge with temperature compensation with status lights

Instrument Enclosure

Instrument Enclosure	Weatherproof IP66 rated enclosure sized to house the data logger, batteries, solar regulator, connectors, and GSM/GPRS modem with key lock.
Data logger, batteries, solar regulator, connectors, and GSM/GPRS modem are to be integrated within the instrument enclosure complete with wiring and terminal block for the connection all required sensors. The external cabling from the sensors are to have a single entry point to the instrument enclosure with appropriate environmental protection	

Water Level Sensor – Vented Submersible Pressure Transducer

Measuring Range	0 to 20 m with programmable offset and scale range
Measurement Parameters	Water level in mm and water temperature in °C
Resolution – Water Level	0.001 m
Resolution – Water Temperature	0.5°C
Accuracy – Water Level	0.05% F.S. or better

Accuracy – Water Temperature	0.5°C
Long Term Stability	± 0.1% / year FS
Temperature Compensated Range	0°C to 30°C
Safe Pressure Overload	Minimum - twice the measuring range
Output Signal	SDI-12 preferred
Material	Stainless Steel DIN 1.4539 or equivalent
Protection	IP 68 or equivalent
Operating Voltage	10.0 to 16.0 VDC
Power Consumption	< 15 mA active
Operating Temperature	-5°C to 60°C
Lightning Protection	Shunts 20,000 Amperes, response time less than 10 nsecs
Cable	Integral vented cable with pull strength of 100 kg minimum and suitable for placement underground.
Humidity Absorber	Supplied with required desiccant and desiccant chamber or humidity absorber.

Water Level Sensor – Shaft Encoder

Measuring Range	1.5 to 30 m
Typical Measurement Range	0 to 15 m
Measurement	Absolute
Resolution	0.001 m
Accuracy	0.001 m
Reporting Resolution	User selectable with range of 7 decimal digits
Display	Built-in 8-character LCD display with backlight
Battery	Externally accessible, internal back-up battery
Output Signal	SDI-12
Protection	Over voltage and reverse voltage protected
Operating Voltage	10.0 to 16.0 VDC
Power Consumption	< 2.5 mA @ 12 VDC
Operating Temperature	-5°C to 60°C
Float Size	Between 100 to 160 mm
Float Material	Sealed float of plastic or painted corrosion resistant metal

Water Level Sensor - Radar

Measuring Range	1.5 to 30 m (electrical output programmable to any lower full scale and offset range, typical relative value of 0 to 10 m)
Beam width	< ± 23°
Resolution	1 mm
Maximum dead range	1.5 m
Accuracy	0.1% F.S. (±1 cm @ 10 m F.S.)
Output Signal	4-20 mA or SDI-12
Maximum electrical cable length	200 m
Operating Temperature	-5°C to 30°C
Environment protection	IP66 for humid environment
Operating Voltage	10.0 to 16.0 VDC
Current	< 4 mA (average) in SDI mode

Staff Gauge Plate

Manufactured from either white polyester painted aluminium with a black thermoplastic bonded core top coated with 5 mils of clear polyester, or 18-gauge or 2 mm plate steel, porcelain coated to resist rust and discolouration with clear dark markings on a white background	
Length	1.0 m
Wide	60 to 80 mm, ± 10 mm
Markings	Centimetre markings with labelled decimetres, supply with separate metre number plates

Rainfall – Tipping Bucket

Collecting Area	200 cm² or greater
Intensity	0 to 700 mm/hr
Sensitivity/Resolution	0.2 mm
Accuracy	Intensity and accumulated rainfall ± 3 % or better
Output Signal	Switch close/open
Operating Temperature	0°C to 60°C
Housing Material	UV resistant and non-corrosive materials

Standard Rain gauge (manual)

Type	Classic standard manual accumulation rain gauges, recognized by the WMO.
Collecting Area	200 cm² or greater
Reading Accuracy	0.2 mm
Collecting Bottle Capacity	300 mm or greater
Operating Temperature	0°C to 60°C
Housing Material	UV resistant and non-corrosive materials

Wind Speed – Ultrasonic

Measuring Range	0 to 60 m/s
Threshold	0.05 m/s
Maximum gust	100 m/s
Resolution	0.1 m/s
Accuracy	± 0.5 m/s for V < 5 m/s ± 10% or better for V > 5 m/s
Linearity	0.25%
Operating Voltage	10.0 to 16.0 VDC
Power Consumption	< 10 mA operating and < 2 mA standby
Operating Temperature	-5°C to 60°C
Operating Humidity	10 to 100%
Output Signal	SDI-12

Wind Direction – Ultrasonic

Measuring Range	0 to 359°
Resolution	Better than 5°
Accuracy	Better than ± 5°
Operating Voltage	10.0 to 16.0 VDC
Power Consumption	< 10 mA operating and < 2 mA standby
Operating Temperature	-5°C to 60°C
Operating Humidity	10 to 100%
Output Signal	SDI-12

Air Temperature

Sensing Element	Platinum Resistor Pt-100
Electrical interface	4-wire
Accuracy	Better than ±0.05°C @ 0°C
Calibrated Measuring Range	-10°C to 50°C
Resolution	0.1ºC
Time constant	30 – 40 sec.
Operating Voltage	10.0 to 16.0 VDC
Power Consumption	< 20 mA
Output Signal	4-20 mA (4 wire Pt-100)

Radiation Shield

Temperature Conditions	-10 to 50°C
Material	Non-metal
Colour	White
Mounting	On mast with bracket
Shield	Standard meteorological cage with al least five elements

Relative Humidity

Measuring Range	0 to 100% RH
Resolution	1% RH
Accuracy (@ 20°C and including non-linearity and hysteresis)	Against factory references ± 1% RH Field calibration (0 to 90% RH) ± 2% RH Field calibration (90 to 100% RH) ± 3% RH
Long Term Stability	Better than 1% RH a year
Temperature Dependence	± 0.05% RH/°C
Response Time	10 s with membrane filter
Operating Voltage	10.0 to 16.0 VDC
Power Consumption	< 20 mA
Operating Temperature	-5°C to 60°C
Output Signal	4-20 mA (4 wire Pt-100)

Solar Radiation Global (Net Radiometer)

Measuring Range	-2000 to +2000 W/m² radiation balance within a range of 0.2 to 100 µm
Sensitivity	10 µV/Wm²
Standards	Certificate for sensitivity to DIN EN 10204
Response Time	< 20 secs
Operating Voltage	10.0 to 16.0 VDC
Power Consumption	< 5 mA
Operating Temperature	-5°C to 60°C

Barometric Pressure

207. The design of the Barometric Pressure sensor shall be a hermetical structure, with an output connector, to ensure compensation of the environment temperature influence on the measured pressure and protection against aggressive airborne contaminants. The barometers may be supplied with conversion modules to provide output data signals compatible with the data logger's inputs.

Measuring Range	600 to 1100 hPa
Resolution	0.1 hPa
Accuracy	±0.15 hPa
Long Term Stability	0.1 hPa drift per year
Temperature Dependence	±0.20 hPa
Response Time	5 secs
Operating Voltage	10.0 to 16.0 VDC
Power Consumption	< 5 mA
Operating Temperature	-5°C to 60°C
Inlet	Supplied with pressure port or static head to minimize wind effect

Soil Temperature

Accuracy	Better than ±0.1°C @ 0°C
Measuring Range	-10°C to 55°C
Resolution	0.1°C
Operating Voltage	10.0 to 16.0 VDC
Power Consumption	< 3 mA idle and <30 mA active
Output Signal	SDI-12

Class A Evaporation Pan

Type	Standard Class A Pan 120.7 cm X 25 cm, coated to resist rust and discolouration or constructed of non-corrosive steel
Anemometer	Totalizing 0.1 km resolution mechanical counter
Thermometer	Submersible Celsius liquid thermometer in metal support
Hook gauge	Metric with stilling-well
Base	Standard Class A base of rot-resistant wood
Bird Guard	Cover of galvanized or stainless steel metal grid

Stevenson Screen

Type	Stevenson Screen constructed of wood or suitable materials using a double-louvered design according to the WMO requirements. The interior size of the screen must measure 75 by 60 by 60 centimetres. The screen between 1.25 m and 2 m above ground level supported by a metal frame. The screen and support is to be painted or coated white to reflect sunlight radiation

Auto Surveyor's Level

Automatic Level, Tripod, and Aluminium Rod (4 metre), Hard-shell Carrying Case with Dual Latches, Plumb Bob, Allen Wrench, Adjusting Pin, and Instruction Manual.

- Professional grade surveyors level with magnetically-dampened, wire-hung compensator for optimum range and accuracy, compensator lock to protect instrument during transport or storage, large effective aperture and minimum focus of 1 foot (0.3 m), top-mounted optical peep-sight for quick reference, large, easy-to-use precise focusing knob, Penta prism for easy bubble viewing, sealed, dust-protected levelling screws, water-resistant, sealed construction plus sunshade for use in various weather conditions, fine motion knobs on left and right sides with friction-braked rotation, endless horizontal drive, 1:100 stadia for distance estimation, 5/8" x 11 threads to fit standard tripods, manufacturers five year warranty.

Acoustic Doppler Current Profiler

The Acoustic Doppler Current Profiler (ADCP) is to be used for automated discharge measurements on rivers and canals. The ADCP will be deployed in a roving mode, being transported from the one site of interest to the other.

The ADCP is required to measure discrete river discharges in conditions ranging from streams with cross sections up to 10m wide and 1m deep to rivers with cross sections up to 400m wide and 40m deep. Measurements are based on the measurement of three dimensional water velocity vectors and platform position using acoustic bottom tracking.

The ADCP measurement systems are to be complete including ADCP, PDA, measurement platform or boat, measurement computer and software, differential GPS, all cabling and power supply.

Depth Profiling Range	0.3 m to 40 m
Velocity Profiling Range	±10 m/s
Measurement Profiling Range (minimum effective depth of water required to obtain a valid velocity profile including the draft of the instrument as mounted on the operational floating platform, blanking distances, and one valid depth cell)	Minimum required depth 0.4m. Maximum required depth 40m.
Velocity Measurement Accuracy	0.3% of relative velocity with a minimum of 3 mm/s
Velocity Resolution	1 mm/s
Maximum Number of Depth Cells	100
Minimum Cell Size	20 cm
Depth Profiling	Independent vertical beam
Depth Profiling Range	0.3m to 70m
Depth Profiling Accuracy	1% of measured depth
Depth Profiling Resolution	1 mm
Temperature Measurement Range	1°C - 50°C
Temperature Measurement Accuracy	± 0.5°C
Temperature Measurement Resolution	0.01°C
Tilt Sensor Measurement Range	±15°
Tilt Sensor Accuracy	±1°
Tilt Sensor Resolution	.05°
Compass Measurement Range	0 - 360°
Compass Measurement Accuracy	± 2°
Compass Measurement Resolution	0.1°
Measurement Control	PDA, laptop or equivalent using Bluetooth, WiFi or spread spectrum radio.
Moving Platform Software	Intuitive software including ship track, measured velocity profile, velocity contour plot, measurement statistics and quality assurance parameters.
Stationary Position, Velocity Area, based Measurement Software.	Intuitive stationary position software including measurement position, measurement progress,

	measured velocity profile, velocity contour plot, total discharge, measurement statistics and quality assurance parameters.
Positioning	Primary high precision platform positioning using bottom track (without GPS). Secondary positioning using GPS with VTG and GGA option under moving bed conditions.
GPS	Integrated RTK GPS with accuracy 0.04 m or better. DGPS positioning with accuracy of 1.5 m or better.
Floating Platform	Rugged, stable platform or trimaran from non-corrosive material, as needed for ADCP operation
Power System	Rechargeable with reverse polarity and over voltage protection and with inbuilt waterproof battery housing and charger. Must support 8 hours of continuous operation between charges.

Acoustic Doppler Velocimeter

Functionally required to measure flow velocity for determining river flow using the velocity area wading measurement technique. Measurement system is to be complete including meter, display, cabling, and top setting wading rod.	
Sensor Configuration	Minimum 2 dimensional vector measurement (typically referenced as x and y dimensions)
Velocity Measurement	-0.1 m/s to 2.5 m/s
Velocity Measurement Accuracy	± 1% of measured value, ± 0.25 cm/s
Velocity Measurement Resolution	0.001 m/s
Discharge Measurement Software	Intuitive onboard software using linear programming to step through the velocity area measurement process. Discharge measurement software based on ISO mid section measurement procedures.
Measurement download and QA/QC software	Measurements shall be downloadable through direct connect cable and processed using stand alone quality assurance software. QA software to include measurement assessment and instrument diagnostics in an intuitive format.
Internal data storage	Record space for up to 50 discharge measurements onboard.
Power	Batteries to support 20 hours of continuous operation between charging.
Electronics	System shall be capable of 1 m submersion for short periods of time.
Storage Temperature	-5°C to 50°C.
Wading Rod	Instrument to come complete with high quality top setting wading rod. Wading rod to be available in 2

	m, 4 m, and 6 m lengths marked in minimum of 2 cm increments. Instrument to come complete with all necessary operational and instrument mounting hardware.

Field Tool Kit

Basic tool kit with a range of tools to service and maintain the field instrumentation supplied. The tool kit is to be of professional quality manufactured from high quality materials and include as a minimum:

- Compete set of professional grade combination wrenches in metric and SAE, 1/4 and 3/8 inch drive sockets, a full range of screw drivers (Phillips and slotted), 16 hex key set, professional grade pliers, a 10-22 AWG wire stripper, electrician grade wire cutters, and a combo stripper/crimper for attaching wire terminals, 12 oz claw hammer, professional grade hacksaw, professional grade 25m tape measure, and other needed tools
- Industrial grade cordless power drill and impact driver with Li-on batteries and charger complete with carrying case and a set of drill bits for wood and metal, a set of screwdriver bits, and a set of nut drivers.
- Digital multi-meter and voltage tester combo kit includes heavy-duty alligator clips, industrial test probe set, and tool storage box.
- Heavy duty 35-watt soldering iron

The tool set is to be supplied in a polycarbonate or powder coated steel tool chest with a carry handle and moulded insert trays to keep tools safe and tidy.

Computer Infrastructure - Technical Specifications

General Computer Requirements:

208. All computer hardware shall be supplied with adequate licensed operating systems and licenses for professional productive software, including anti-virus and similar software as required.

Specific Computer Infrastructure Requirements:

Computer Servers

Server	Must meet or exceed these specifications	
	Processor	3.2 GHz Quad-core - Intel Xeon 4C E3-1270v2 69W with 16GB RAM
	Motherboard	Server grade with 4 x ECC DDR4 RAM
	Memory	16 GB with expansion slots for additional memory
	OS Disks	(2 in RAID 1 mirror) 500 GB, 7200 RPM, 16 MB cache, SATA
	Data disks	(2 in RAID 1 mirror) 1 TB, 7200 RPM, 16 MB cache, SATA
	Power supply	400 watts
	DVD	Combo DVD +/- RW, (DVD-ROM, DVD-RW, CD-RW)
	Available Expansion Slots	1 PCIe 3.0 x8 full height 1 PCIe 2.0 x 4 after any cards installed
	Sound	Basic sound card or on-board, supplied with speakers
	Video Monitor	LCD 19 inch, 1280X1024
	Ports	6 USB 2 ports with additional support for PS/2 Keyboard and Mouse, 2 RJ-45 Network ports
	Network	Two 10/100/1000 Mbps Ethernet
	Form factor	Full tower
	Keyboard	Standard full size (US English and Cambodia typical)
	Mouse	2 button optical wheel mouse - USB
	Additional Cooling	Extra dual ball bearing case fans
	Electrical Supply	220V AC 50 HZ, Cambodia socket
	External drive (for backups)	1 TB USB external hard drive
	UPS	For 4 hours operation

209. All computer hardware shall be supplied with an adequate operating system and licenses for professional software, including anti-virus, as required. The Operating System Requirements must meet or exceed the following:

- Microsoft Windows Server 2012
- Microsoft SQL Server 2012

- SQL Server Management Studio.
- IIS Server for web browser access to the database(s).

Desktop Computer

Desktop Computer	Must meet or exceed these specifications	
	Processor	2.4 GHz Core i5
	Motherboard	Desktop grade
	Memory	6 GB DDR3 RAM
	Hard drives	(2 in RAID 1) 500 GB, 7200 RPM, 16 MB cache, SATA
	Power supply	300 Watt
	DVD	Combo; DVD +/- RW, DVD-ROM, CD-RW/DVD
	Available Expansion Slots	2 PCI, 1 PCIe after cards installed
	Sound	Basic sound card or on-board, supplied with speakers
	Video	LCD 19 inch, 1280X1024
	Ports	4 USB Ports, (1) audio in, (1) audio out, (1) VGA, (1) Display Port, (1) RJ- 45 Ethernet, (1) serial, PS/2 keyboard, PS/2 mouse
	Network	10/100/1000 Mbps Ethernet
	Form factor	Micro Tower
	Keyboard	Standard full size (US English and Cambodia typical)
	Mouse	2 button optical wheel mouse
	Additional Cooling	Extra dual ball bearing case fan
	Media card reader	Multiple formats
	OS and Software	Microsoft Windows 7 Professional Edition 32 bit OS with recovery media and Microsoft Professional Office Suite
	Electrical Supply	Nominal 220V AC 50 HZ, Cambodia socket.

Printer - Black and White

Printer B&W	Must meet or exceed these specifications	
	A multifunction (printer, scanner, fax) laser Ethernet network printer.	
	Trays	A4 and A3
	Pages/minute	30
	Electrical	Nominal 220V AC, Lao socket
	Monthly print volume recommended 10,000 pages/month or maximum 30,000 pages month	
	To be supplied with 4 cases (10,000 sheets) A4 paper, 3 extra toner cartridges, and 1 extra drum cartridge.	

Printer - Colour

Printer Colour	Must meet or exceed these specifications	
	Colour laser Ethernet Network printer, A3 and A4	
	Trays	A4 and A3
	Pages/minute	15 colour A3 pages / minute
	Electrical	Nominal 220V Cambodia socket
	Monthly print volume recommended 5,000 pages/month or maximum 15,000 pages month	
	To be supplied with 2 cases (5000 sheets) A4 paper, 5000 sheets A3 paper, 3 extra toner cartridge sets, and 1 extra drum cartridge set	

Field Laptop (Tablet) - Rugged

Field Laptop or Tablet	Must meet or exceed these specifications	
Rugged Laptops or tablets are designed for use in the field and compatible to interface with data logger and sensors complete. The laptop or tablet is to be supplied with desktop cradle, battery chargers (one for office and one for vehicle use), and carrying case. The laptop or tablet must be drop, shock, and spill protected.		
	Fully Rugged Housing	IP65 rating with metal with rubber bumpers, covers on ports, and hand and carrying straps
	LCD	10.1 inch outdoor full HD, sunlight viewable, colour LCD with circular polarizer for up to 800 cd/m^2 brightness
	Touchscreen	10 finger capacity multi touch screen
	Processor	Intel Core i5 VPro Processor
	RAM	8GB SDRAM
	Hard Drive	120 GB Shock resistant solid state
	Communication	Dual Band Wireless, Bluetooth, and LAN port for minimum of 10Base-T
	I/O ports	one USB 3.0, one DB9 serial
	OS	Windows 8.1 Pro or latest version available
	Battery Life	8 hours minimum
	Operating Conditions	0 to 50^{0}C, 95% humidity
	Power Supply	Nominal 220V, AC Adapter, Cambodia socket

Hydrological Data Processing Software – Technical Specifications

1. Introduction

210. The national hydrometeorological system comprises all physical infrastructure and software required to sense, collect, process, validate, store and disseminate the required hydrometeorological data. The physical infrastructure includes observation networks, communication systems, and data entry, processing and storage centre(s). Efficiency requires that all activities for hydrometeorological data management and information generation are well tuned to each other. The requirement for consistency and exchangeability of data demands the use of compatible tools and standardized techniques and procedures.

2. General Requirements

211. The hydrometeorological data processing software is expected to facilitate data entry, processing, validation and dissemination of periodic reports, under an integrated software environment that comprises a database and a suite of application tools.

212. The system needs to have a modular structure, where the different models, tools and utilities are integrated into a well-designed and consistent system.

213. The software will follow an approach that embraces an integrated software environment with standard compatible components and operational procedures. The software solution shall have an open architecture using internationally available commercial packages. The user interface is to be developed by well-known languages and tools. The use of non-proprietary tools is generally seen as an advantage. Open and well documented interfaces and detailed documentation are required and at least conditional access to the source code should be possible to facilitate future development.

- **Hardware platforms -** The software must be supported by commonly used hardware platforms. The hardware requirements are software-dependent, and therefore, the Bidder will specify the hardware platforms and all peripheral equipment required for the use of the software system. The specifications for hardware will include: CPU requirements, central memory, disk space, and all other technical requirements so as to provide adequate response-time for the users in all operations to be carried out at the data centres.
- **Working environment -** The Operating Systems and tools will be based on Client/Server architecture. The software is to operate on standard working environment and operating systems.
- **Database tools -** The database tools are to be scalable and open confirming to the ODBC standard and the industry standard RDBMS package.
- **Development tools -** The development tools are to be based on standard application development tools and languages of the leading vendors in the market and industry standards such as C, C++, Visual Basic or other much used and well established programming languages and 4GL (4th Generation Language) tools. All the tools are to be integral part of the proposed software system.
- **Data security -** Data security following accepted international standards is to be supported by the software system will be supplied as part of the software.
- **Addition of user modules** - Facility to include user-friendly software interfaces for addition of user-developed modules must be available as an integral part of the software.
- **Initiation and integration of external software** - A screen menu for initiation of standard external software processing systems such as standard spreadsheet (e.g. MS Excel) and data exchange with them using clipboard etc. must be available.
- **Ease of use** - The software should be easy to learn, intuitive, easy to customize and adjustable to the agency's needs. A menu-driven help facility must be available.

- **On-line help -** There should be a comprehensive on-line help available for each feature of the software while running it. The complete software documentation should be available on-line with context sensitive help.
- **Flexible and modular system** - The system must have a **m**odular structure, which is flexible to changes or addition of new modules, features or functions.
- **Performance** - The software must ensure satisfactory and adequate response times for users in LAN and stand alone environment (both in interactive and batch processing).

3. Database Requirements

214. The dedicated hydrometeorological data processing software would include temporary databases. From these temporary databases the data would be transferred to the industry standard database management system.

215. Databases must be structured to ensure data security, integrity, portability and easy maintenance. The system must include:

- A module for establishment and administration of user authorization - to permit access for authorized users only based on security checks at log-on through username, password
- Different levels of authorization, including read, write, edit and special supervisory privilege.
- Simple maintenance modules for database management, back up and recovery to be used by office personnel (no need for system specialist). A backup strategy shall be maintained and automated through a hidden logged file. The operator may be forced to take up backups after certain period of times.
- Data integrity function to avoid data corruption and losses.
- The software has to provide for efficient archival facility of raw and processed data distinctly at various levels of data handling stages
- An activity log for audit purposes indicating the date/time, user and activity description.
- Facility to assess the work of individual users especially with respect to the volume of data entered.
- The database must efficiently operate on voluminous time series data.
- The database must have ample capacity to handle all the data associated with the basins under analysis.

4. Data Types

216. The types of data required to be processed, compiled, and stored in the hydrometeorological data management and information system include:

- **Location oriented data**, including static or semi-static data of the observation stations,
- **Time oriented data**, covering equidistant and non-equidistant time series for all types of meteorological, water quantity, and
- **Relation oriented data** on two or more variables/parameters used with respect to meteorological and water quantity data.

4.1 Location Oriented Data

217. These data comprise a wide range of static and semi-static information at point locations related to observation stations.

Observation stations

218. The software must have the facility to hold data of the following general types:

- **Identification name and code -** by which the station is identified.
- **Summary station data -** on location (e.g. latitude, longitude, altitude, river name, basin name, administrative and political regions and responsible agency), for which a facility must be available to group stations for reports.
- **Station description -** information comprises all relevant data about the site and its surroundings and may include:
    - Site description, channel and control (hydraulic and morphological conditions)
    - Station access
    - Benchmarks locations and levels
    - Facilities and equipment in use
    - Record of repair, maintenance and replacement of equipment
- **Station log** - information related to the interpretation, reliability and processing of a record over specified periods of time.
- **Survey records** - reference to survey data on longitudinal profiles and cross sectional profiles at and adjacent to the gauging station.
- **Catalogue of station series** - a listing of the time series available at a station including a descriptor, units, reference, identification codes for missing data, and start and end dates.

4.2 Time Oriented Data

Equidistant time series

219. Records with a fixed time interval or with a group of unequal time intervals, which repeats in a perfect cyclic manner, are time-labelled and facilities must be available to hold records for a measurement interval of 1 minute to 1 year. Such records must include all possible periodically measured instantaneous observations (e.g. stage observations), accumulative observations over the time interval (e.g. daily rainfall) and average of observations (e.g. daily mean flow). Facility must be available to distinguish such records. The user must be free to choose an appropriate indicator for missing values.

220. Provision must be available to flag the data with respect to whether it is original or estimated and with respect to its quality. These flags must be visible at the time of data validation and reporting.

Non-equidistant time series

221. Records taken with an unequally spaced time interval must be stored with an entered time label and include:

- Event-based observations (e.g. rainfall or stream flow measured at a given time)
- Threshold-based observations (e.g. occurrence of the change in a variable exceeding a specified magnitude).

4.3 Relation Oriented Data

222. The software must have the ability to store relation-oriented data of the following kind:

- Profile measurement data
- The parameters of the relationships between two or more quantities.

Profile measurement data

223. Profile measurement data include stream flow data obtained by measuring at a number of points in the cross-section. The software shall be able to store the results of stream flow measurements according to the velocity area method.

Relationship parameters

224. These records store the parameters of a relation, e.g. stage-relation curves, current meter ratings, stage-discharge rating curves. The records must include a station name/instrument code, validity period of the relation, type of equation, equation boundaries, parameter values and summary error statistics for each equation. Facility for flagging a relationship for making a distinction between a good quality and a doubtful relationship must be available.

5. Data Entry and Editing

225. The software system must include user-friendly data entry screens and menus. Data entry screens for field data must fully resemble the standard layouts of the field notebooks. Facility must be available to prompt at faulty data entry of any value and reject them (e.g. alpha character in a numeric field, negative rainfall, day number above 31, etc.). The screen must have calculator functions associated with entry of numeric data.

226. Facility must be available for entry of time series data from a variety of sources including:

- Keyboard
- ASCII data held on computer disk file in fixed and free formats.
- Digital data originating from a variety of digital loggers and recorders and the ability to customize input from new logger formats assisted by user prepared data entry templates.
- Comma separated variable (CSV) files originating from data entered to standard spreadsheet packages.
- Data capture from remote sites through telemetry interfaces.

227. With respect to time series, the software must permit either simultaneous display in tabular and graphical format or toggle switching between them.

228. For convenience in accessing a particular data set for keyboard entry or editing, the user must have ready access to a list and map of the region showing the stations, and from each station a list of time series. The user must have the option to specify a start date or start and end dates for display.

229. The software must allow relation-oriented and survey data to be entered from ASCII data files or directly from keyboard for which templates must be available. There must also be a facility to transfer directly the parameters of stage-discharge relations from the modules in which these are computed.

6. Data Alarms and Validation

Alarms and Validation categories

230. The software must provide wide-ranging facilities for the validation of measured and derived variables, including methods to perform the following categories of validation:

i. Comparison of observations against physical or previous numerical limits for a variable

ii. Comparison of observations against preceding or following observations of a variable (limits in rate of rise and rate of fall).

231. The original data, as retrieved from the field and entered into computer file, may not be altered except for repair of gross errors such as typing errors. All other repairs and adaptations can only be executed on descendants of the original data.

Validation procedures

232. The software must provide both objective validation rules and graphical screening methods, each of which may be applied to the above four categories. The following procedures must be available:

- Listing of data

For easy reference during validation the software must have the facility to display in appropriate tables all station information and time series records. Tables must resemble the field notebook layout, and must be able to present dedicated tables for data having hourly, daily, weekly, 10-daily, monthly, or any other user defined time interval. The tables should display the following statistics: number of data points, number of missing data, minimum and maximum, sum, mean, standard deviation and coefficient of variation.

- Test on extremes

Flagging and listing of input data if values exceed pre-set seasonal numerical or physical limits. Values may refer to upper and lower limits, absolute limits and statistically determined limits, and limits in rise and fall between successive values.

- Inspection of temporal variation

Graphical display of a time series and its time derivative, showing also limits of rise and fall.

For the vertical axis, linear and logarithmic scales should be available. Series can be plotted as lines and/or bars (in different styles/colours). Different grids must be available and addition of text to axes, series, and legends shall be possible.

7. Data Correction

233. The following data correction, replacement, or infilling methods for missing or suspect data must be available:

- Simple procedures must be available to scroll through data sets (graphs and tables) and to rescale to inspect suspect values. For clearly erroneous values, (e.g. a spike) correction must be available either through graphical editing or via a table showing the graphed data in tabular form, simultaneously displayed or accessed by toggle.
- Linear interpolation over periods of missing data.
- A constant correction can be applied to a range of values to adjust for zero and scale.
- A drift correction can be applied to a range of values.
- Data can be time-shifted.

8. Data Processing and Analysis

234. The software must provide hydrological processing and analysis facilities to enable the field data to be transformed to useful values, formats and time scales, in order to perform hydrological validation, to prepare data for reporting, to respond to queries, and for subsequent analysis.

8.1 Processing of flow measurements and stage discharge data

235. For the processing of streamflow measurements and stage discharge data the software must include the following facilities:

Processing of flow measurements

- For entry of flow measurement data templates must be available which resemble the standard field discharge measurement notes
- Facilities should be available to compute the discharge from current meter measurements (mid-section method) according to International Standards. The computation should generate the summary flow measurement information.

- For validation purposes facilities should be available to display the observed flow velocities in the cross-section

The template for the input of summary flow measurement information must include fields for station identification, date, start time, finish time, gauging number, mean gauge height, discharge, cross sectional area, channel width, mean velocity, change of stage during gauging, fall between gauges, surface slope, method of suspension, meter number and rating number, observer, and remarks.

Establishment and verification of discharge rating equations

Fitting of rating equations - A least squares procedure must be used to fit the rating equation and an error of fit statistic must be calculated for the overall fit and for individual ranges. The software must allow the user to select or exclude the discharge measurement to be fitted and select and test the number of segments to be used. Where the stage level of zero flow is known, a procedure to force fit the bottom segment must be available. Graphical presentation of relationships with the discharge measurement's time (or sequence) labelled is required. It should also be possible to get the summary current metering data in tabular form simultaneously with the graphics. The cursor in the tabular form must correspond to a marker locating the data in the graph.

Extrapolation of rating equations - Procedures are required to extrapolate ratings beyond the limits of observed discharge measurements. These must include logarithmic extrapolation, combined extrapolation of stage-area and stage-velocity relationships, and extrapolation based on Chezy or Manning equations.

Validation of rating equations - A procedure is required to make statistical tests with necessary graphics to check that additional measurements are satisfactorily fitted by an existing rating curve. It must also be possible to compare the ratings pertaining to different time periods graphically and statistically.

Stage-discharge transformation - Provision must be available for the transformation of river level to discharge. For a discharge series the appropriate water level time series and rating equation will be selected automatically based on the validity period of the rating equations.

9. Data Compilation

236. The software should include the following general data compilation facilities:

Aggregation and disaggregation options

237. Facilities are required to aggregate or average data from the interval of measurement to longer time intervals, specifically from hourly or less to daily, 10-daily, monthly, seasonally and yearly. Disaggregation options should be available from monthly and 10-daily to daily data and from monthly to 10-daily data with and without interpolation.

Series transformation

238. The software should allow for user defined transformation options including standard mathematical operations. Facilities are required to extract and store the following characteristics of series:

- Minimum, maximum and mean values for different time periods from a record.
- Peaks (instantaneous values) or totals (accumulated values) over a threshold.

Computation of areal rainfall

239. The software must provide methods of computing areal rainfall or other variables over a basin from point measurements within the catchment or close to its boundary. The following methods of deriving weights are required:

- Equal station weights
- User specified weights based on orography or mean annual rainfall
- Thiessen polygon derived weights

240. The availability of other interpolation methods including Kriging is desirable.

241. The methods are to be applied to a range of data intervals including daily, storm (1 to 10 days), monthly or annually. Plotting of isohyets must be possible for the same periods using graphical interface.

242. Facility must also be available for making contours from point values showing iso-lines for a parameter such as rainfall.

Evapotranspiration

243. The software must provide procedures for estimating daily potential evapotranspiration from measurement of meteorological variables. The primary requirement is for estimation using the Penman – Monteith method. Other options may be offered as optional extras.

10. Statistical Analysis

244. The software should include the following statistical analysis tools:

Statistical tests - Statistical tests for stationarity, homogeneity and randomness must be available.

Basic statistics - Facilities should be available to compute of any part of time series basic statistics like minimum, maximum, mean, median, mode, standard deviation, skewness and empirical frequency and cumulative frequency distributions. The latter two options should be supported by graphical output.

Fitting of frequency distributions - Facilities should be available to fit at least the following theoretical frequency distribution to data sets: Normal, Log-normal, Pearson III, Log-Pearson III, Exponential, Extreme Types I, II and III distributions.

The facility should include efficient parameter estimation procedures, goodness of fit tests, graphical display of frequency distribution with confidence limits and tabular output showing extremes for user defined distinct return periods with confidence limits.

Duration Curves - It is required to produce a duration analysis of a time series over a given time period, giving the percentage of time that a particular value is exceeded. Duration analysis will normally be applied to flow (flow duration curves) but it may equally be applied to other variables. The following options are required:

- The analysis must be available both on the basis of flow and expressed as a percentage of average flow (to permit comparison between basins). The time period over which the analysis is applied must be available for the full year, for seasonal analysis (monsoon months only) or for a particular month.
- Tabular output must give data values corresponding to percentiles and probability scales. In particular, there is a requirement for the median (50%ile) and 5, 10, 20, 80, 90 and 95%iles. Alternately, the percentiles may be selectable by the user.
- Graphical displays and reports must be available to provide comparisons for a single site for different periods of record, for different months or seasons, or for different sites.

Depth-Area-Duration and Intensity-Frequency-Duration analysis - Facility must be available for getting the Depth-Area-Duration and Intensity-Frequency-Duration analysis done by inputting the basic rainfall series along with the location details of the rainfall stations. It must be possible to obtain the output in tabular and graphical form giving the necessary curves.

11. Data Reporting

245. The software must provide a wide range of graphical and tabular reporting options, to screen, output to file, printer, or colour plotter. Many of these have already been implied by requirements of processing and validation. Facility must also be available for combining the graphical output with the tabular output. It must be possible to generate report in user-defined formats for all types of data.

246. The tabular outputs must include but not be limited to the following:

- Monthly summary of daily mean, maximum and minimum rainfall, temperature, wind, flow, daily runoff, with summary statistics for the month of mean flow, total runoff, total volume maxima and minima for a single station.
- Annual summary of daily values with summary statistics for each month and or the year (including maxima, minima, means, median, number of rainy days, total volume, runoff, as appropriate) for a single station.
- Long-term summary of monthly values with summary statistics for the entire record.
- Monthly report of daily values for multiple stations in a group to permit comparison, with monthly statistics for each station.
- Tabular output of stage-discharge summary data for a selected period.
- Listing of information held under station characteristics, station description and history and station log.
- Inventory of the data available in the database at every level of data handling.

247. Graphical outputs must include standard set-ups in which there must be flexibility to select the output size, the scale (including auto-scaling), gridlines, headings and axes text. Line and bar and scatter graph formats must be available and there must be the option to choose the type of line (coded or coloured). It must be possible to display different variables on the same graph and to mix line and bar graphs (e.g. hydrograph as line; hyetograph as bar). The software must also permit user configuration and storage of new graph types.

248. Following graphical output must be possible on the screen, plotters and printers:

- Time series for single or multiple stations for a selected period, including month and year.
- Stage discharge rating curves (with individual plotted points).
- Flow duration and frequency curves.
- Depth-area-duration and intensity-frequency-duration curves.
- Areal (map) reports of location of stations.
- Areal reports of isolines and other mapped variables.
- Availability of time series, stage-discharge and other types of data over a selected period in bar chart or other format.
- Time axes must be in common date and time units and easily understandable.
- Vertical and horizontal axes must be in clear and rounded increments, easily understandable.

249. In addition to the above-defined tabular and graphical output the system must facilitate the user with efficient tools for design of document layout for text, tables and graphics. It must be possible to mix text, tables and graphics on a single page at the user's convenience. Output to file is required in both text and spreadsheet compatible format.

12. Performance

250. The proposed software system will have adequate response-times for all the operations for both online users and batch processing. For all the stand-alone computers the response times for features on data entry/editing, retrieval and simple processing activities must be negligible (almost instantaneous). The response time for carrying out any other processing activity must also be within a few seconds. It is recognized that response-time is dependent on the hardware as well as on the software.

13. Documentation and Manuals

251. The software system will be supplied with all the documents required to operate, maintain, configure, and develop the system at the user's specific environment. The manuals should cover all aspects of the software, specifically dealing in detail about various processing features. The documents will be in English and include at least:

- General description of the software system.
- List of modules included, and a description of each module, specifying inputs and outputs for each module and cross-reference and module dependencies.
- Error handling and trouble-shooting - message list and error handling specifications for all errors encountered.
- System installation and maintenance guide - containing all the information required to operate and maintain the system by the data centre staff.
- Manual giving in detail the contents of each computational procedure used in the software.
- Manual and user guides for the databases and developmental tools used by the software.
- Advanced customization guide - for plugging in user developed modules including programming interface references.

252. Each of the documentation motioned above, shall be provided in printed form as well as in electronic form.

Appendix 2: Training and Capacity Building Plan

Training Theme	Training Elements	Training Method
1. Field installation and site maintenance	• Civil Works Installation • Instrumentation Installation • Power System Installation • Communication System Installation • Site Servicing and Maintenance	• One-week classroom and demonstration workshop • On-the-job training during implementation.
2. Field observations and measurements	• Meteorological Observations • Water Level Observations • Conduct of Discharge Measurements • Power and Communications Status	• One-week classroom and demonstration workshop • Programming of data logger • Programming of sensors • Hydro-acoustic level I workshop • Hydro-acoustic level II workshop • Calibration of Meteorological sensors • Calibration of in-situ velocity meters • On-the-job training during implementation
3. Data acquisition system operations	• Data Acquisition System - Software • Data Acquisition System - Hardware • Data Acquisition System - Operations • Data Acquisition System - Diagnostics	• One-week classroom and demonstration workshop • One-week operational training • On-the-job training during implementation
4. Manual data entry	• Ingest of Legacy Data • Ingest of Manual Field Observations • Ingest of Manual Measurements	• One-week classroom and demonstration workshop • One-week operational training • On-the-job training during implementation
5. Development and maintenance of rating curves	• Rating Curve Theory • Hydraulic Considerations • Rating Curve Development - Software	• One-week workshop on theory • One-week workshop on using software application • On-the-job training during implementation

Training Theme	Training Elements	Training Method
6. Establishment and maintenance of datum's and gauge history	• Datum and Benchmark Theory • Levelling Techniques • Site Description, Datum and Gauge History Documentation	• One-week workshop on theory and practical • On-the-job training during implementation
7. Data processing and support	• Data Processing System - Software • Data Processing System - Hardware • Data Processing System - Operations • Data Processing System - Trouble Shooting • Database and Data Management Principles	• One-week classroom and demonstration workshop • One-week operational training • On-the-job training during implementation
8. Data reports and publications	• Data Report Generation System • Production tools and methods	• One-week classroom and operational training • On-the-job training during implementation
9. Web operations and support	• Web Design and Applications • Web Data and Information Applications • Web Data and Information - Software	• One-week formal classroom training • One-week operational training • On-the-job training during implementation
10. Use of analytical tools	• Data Analysis Tools and Applications i. Flow frequency analysis ii. Flow duration analysis iii. Trend analysis iv. Low flow analyses v. Inundation duration analyses vi. Correlation and data comparisons	• A series of one-day training sessions for each analytical application with practical demonstrations • On-the-job training during implementation

11. Operational program management	• HMIS Operational Program Requirements and Considerations • Life Cycle Management and Budgeting • Human Resources Planning	• A series of one-day seminars • On-the-job support and mentoring