NATIONAL CENTER FOR HYDROLOGY AND METEOROLOGY

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Assessment of the existing hydro-met Database Management System (HDMS) and IT Infrastructures of NCHM"

ASSESSMENT REPORT

CENTRALIZED HYDRO-MET DATABASE MANAGEMENT SYSTEM

Revision History

Name	Date	Reason for Changes	Version
Assessment Report v1.0	27/08/2020	Initial version	1.0
Assessment Report v2.0	18/09/2020	Content update	2.0
Assessment Report v3.0	28/10/2020	Content update	3.0
Assessment Report v4.0	02/11/2020	Final version	4.0

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1 Introduction

The assignment titled "Assessment of the existing hydro-met Database Management System (HDMS) and IT Infrastructures of NCHM" is part of the GCF Funded project- "Supporting Climate Resilience and Transformational Change in the Agriculture Sector in Bhutan". The assignment is being implemented with the objective to develop an assessment report on the existing hydro-met database management system (HDMS), IT infrastructures of NCHM including the Aviation-Met at Paro International airport and Glacial Lake Outburst Flood (GLOF) Early Warning System (EWS), provide recommendations and input towards developing a dynamic centralized hydro-met database system. There are three main outcomes of assignment as below:

- Assessment report as an input to develop a centralized hydro-met Database Management System (HDMS) for NCHM.
- Design architecture and technical specification of the centralized hydro-met Database Management System (HDMS).
- Recommendations and IT road map for the provision of efficient and timely hydro-met information and services.

1.1 Project Schedule

The project is planned to be completed by a team of two experts for 90 working days starting from May to September 2020. The work plan is shown in the table below.

Table 1: Project Work Plan (Rev, May 20, 2020)

	TASK	PROGRESS	WORK DAYS	START	END	Deliverables	Gantt Days
1	**Phase 1 - Assessment of existing system**						
1.1	Kick-off Meeting & Work Plan	100%	3	6-May-20	**11-May-20**	**Detailed work plan**	5
1.2	Assessment and evaluation of existing LAN & WAN	0%	10	12-May-20	26-May-20		14
1.3	Assessment of IT system, hardware/software and server requirements	0%	10	27-May-20	12-Jun-20		16
1.4	Assessment and evaluation of the existing hydromet database and computing system	0%	10	13-Jun-20	26-Jun-20		13
1.5	Assessment of NCHM website for dissemination of hydromet information and services	0%	10	27-Jun-20	10-Jul-20		13
1.6	Assessment of the hydromet database and computing system requirements	0%	10	11-Jul-20	24-Jul-20		13
1.7	Recommendations for Centralized hydro-met Database Management System	0%	6	25-Jul-20	3-Aug-20		9
2	**Phase 2 : Report compilation and Review and feedback**						
2.1	Preparation of first Draft	0%	17	4-Aug-20	**27-Aug-20**	**First Draft**	23
2.2	Presentation of 1st draft and feedback incorporation	0%	12	28-Aug-20	15-Sep-20	Final Draft	18
2.3	Presentation on final draft feedback incorporation	0%	1	16-Sep-20	**17-Sep-20**	**Final presentation**	1
2.4	Final Report	0%	1	18-Sep-20	**21-Sep-20**	**Final Report**	3
	Total Days		**90**				**115**

1.2 Work Progress Update

The team had completed several rounds of discussions with the NCHM management, divisions and carried out site visits to Paro, Wangdue Phodrang, Trongsa and Bumthang. The details of the meetings carried out is shown in Table 2, while the list of participants is in Annexure 2.

Table 2: Activities carried out

Date	Task	Remarks
May 6, 2020	Kick-Off Meeting at NCHM	Meeting with Director, Chiefs of Divisions and Project Manager (GCF-UNDP)
May 12, 2020	Site visit and Meeting at Paro	Head, Civil Aviation Meteorology Unit and team
May 13, 2020	Site assessment and Meeting at Weather and Climate Services Division	Discussion and review of systems with WCSD team
May 14, 2020	Site assessment and Meeting at Hydrology and Water Resources Services Division	Discussion and review of systems with Chief of HWRSD and team
May 15, 2020	Site assessment and Meeting at Cryosphere Services Division	Discussion and review of systems with CSD team
June 22 and June 24, 2020	Meeting with Hydro-met Operations and Infrastructure Division	Jangchub Choephel, Engineer
May 29 – June 3, 2020	Trongsa, Bumthang, Wangdue Phodrang site visit	MHEP system at Bjezam, Trongsa Rainstorm and GLOF FEWS system at Kurjey, Bumthang and of GLOF EWS system at Wangdue Phodrang.
June 17	Consultation meeting	Project Manager
June 26, 2020	Presentation to NCHM of Inception Report and Concept Plan	NCHM Management including the Director, Chiefs, and divisions.
July 22, 2020	Discussion meetings	More understanding of SEBA HydroCenter from HOID
July 27, 2020	Consultation Workshop with NCHM officials	Discussion on functional requirements for each division.
September 25, 2020	Presentation of draft report	Draft report presentation to Director, HODs and others
October 23, 2020	Consultation meeting on final draft	Consultation with representatives of all divisions on the final draft

2 Existing Systems

A review of the existing network, database, and observation systems was carried out as part of the study. The details of each of the systems, their functions, frequency of collection, parameters, network, storage system, bandwidth, etc. are also compiled and presented in subsequent sections and respective Appendices.

2.1 Hydro-met Network

The NCHM operates about 170 automatic meteorological stations and 80 manual stations[1] as shown in Figure 1. From that, 20 stations also collect information on snow depth and snow water equivalent in the high-altitude areas of the country. There are 45 river hydrological stations two of which have discharge measurement, as shown in Figure 2. Besides that, there are 27 Flood Warning Stations (FWS) that monitor rainfall and water level as shown in Figure 3. There are also two Glacier Lake Outburst Flood (GLOF) Early Warning System (EWS) in the Punatsangchhu and Mangdechhu-Chamkharchhu basin with 15 automatic water level/weather stations and warning systems. Data from all these stations are available at no cost on request.

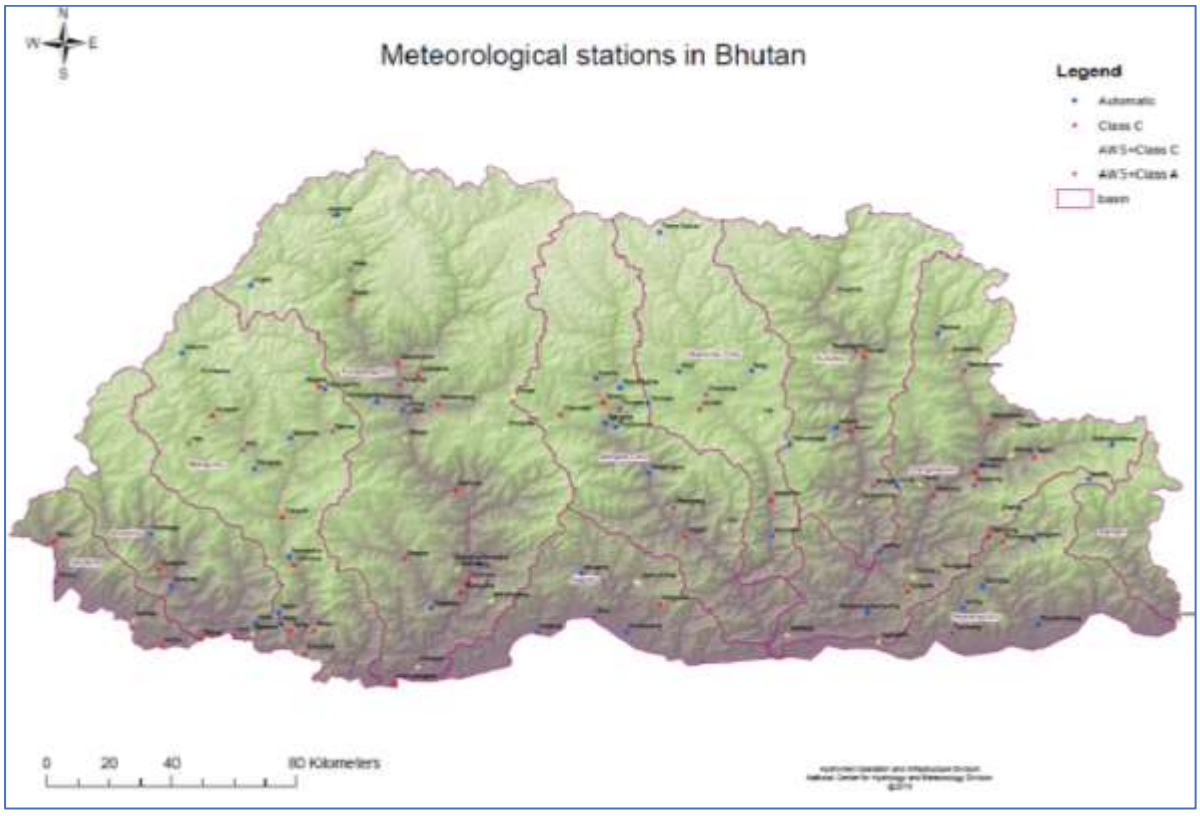

Figure 1: Meteorological Stations of NCHM (June 2020).

[1] There are many automatic and manual stations co-located in the same area for data continuity.

Figure 2: Hydrological Stations of NCHM (June 2020).

Figure 3: Flood Warning Stations of NCHM (June 2020).

2.2 Communication and Storage Systems

All manual and automatic stations are connected in varied ways of communication, network, and storage. The following sections explain each of the systems that are set up and used for the corresponding purpose.

2.2.1 Automatic Stations and their Servers

There are five sets of automatic weather/water data collection systems. All of them have a different collection, transmission, and storage system. The end-use display is also isolated with standalone servers for each system. The schematic representation is shown below in Figure 4.

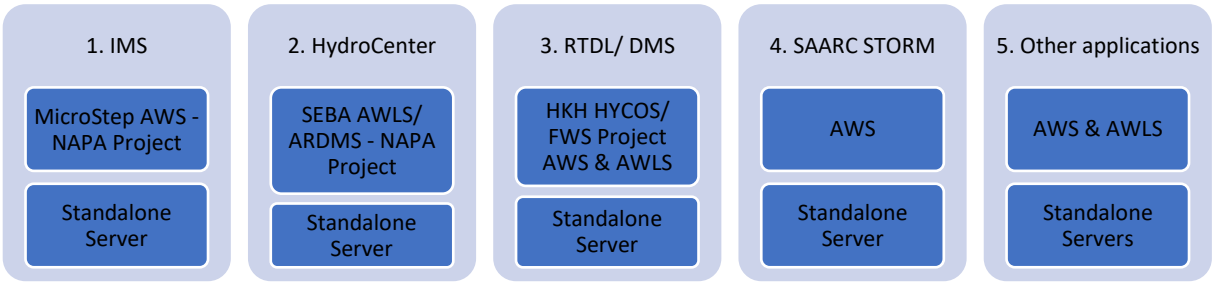

Figure 4: Automatic Stations and their systems at NCHM.

(1) IMS Interface for MicroStep AWS systems

The IMS- Integrated Meteorological System is a web-based application used for Automatic Weather Stations (AWS) set up under NAPA II Project from a company called MicroStep (MIS). As of June 2020, there are 70 stations connected with the IMS system through GSM internet. These include the stations funded by MHEP project for the Mangdechhu basin. The data acquired from AWS are stored in the IMS database server at NCHM Server room and the IMS application is set-up independently with its dedicated servers at NCHM server room.

The IMS application itself is a broad software that has dynamic functionalities such as generating various reports, Quality Control (QC) functions, data acquisition, manual data entry, and user and role management in addition to general automatic station management.

(2) SEBA Hydro-centre application for AWLS/ARDMS systems

SEBA Hydro-centre is also a web-based application from SEBA Germany for compilation and display of data from AWLS/ARDMS set-up through NAPA II Project. There are 32 stations currently connected to the Hydro-centre through GSM internet. Data for the Hydro-centre are also stored in a separate standalone server at the NCHM Server room.

The database at Thimphu NCHM Server room for the IMS and SEBA Hydro-centre is powered by 65 Mbps of internet leased line. The technical details of the servers at NCHM for NAPA II are refer Annexure 3;

(3) DMS application for HYCOS and FWS Application Systems

The Database Management System (DMS) developed by Real Time Solutions (RTS), is a web-based application used for AWS and AWLS systems set up through HYCOS Project and FWS. As of June 2020, there are 13 stations connected with the DMS through GSM internet. Data is communicated from the AWS and AWLS to the DMS database server at NCHM Server room on a standalone server.

(4) SAARC STORM Application System

The SAARCSTORM system is a web-based application for 9 stations with an independent server hosted at NCHM server room. This system is on the way of being decommissioned.

(5) Other System applications

The DANIDA/Sutron AWS at Kanglung and Dodena AWLS are hosted as independent systems with separate servers. Both are planned for upgradation soon.

(6) CMPB/ BYU Systems

There are also 4 high altitude stations set up from CMPB and BYU Projects which are automatic stations with data logger/ no real-time communication. The data are downloaded from these stations on USB and saved on desktop computers.

Some issues of the data collection, archival and sharing issues of automatic stations have been identified and listed in Table 3;

Table 3: issues identified for the Automatic Stations

Sl. #	Description
1	Systems from different projects are in different servers and with different applications. No record of maintenance or meta-data is in a common system.
2	No common database or front-end interface for all systems. Many confusions and too many things to manage/handle for management.
3	Both SEBA Hydrocenter and MicroStep IMS seem to have broader applications that could be utilized to generate reports, QC, manage users, and combine besides regular station overviews.
4	Data storage and backup are not optimal – hardware duplication
5	No backup storage offsite/ Disaster Recovery Site
6	No data transmission backup/ alternate link not there
7	No proper archival system of data downloaded on USB

2.2.2 Manual Stations and their Servers

There are many existing manual data collection systems across the country where data are collected manually and sent/brought to the head-office by postal service and archived in computers. Isolated field-specific data storage and display systems exist for each division or section. All storage and services are independent and standalone with no security or automatic services as shown below.

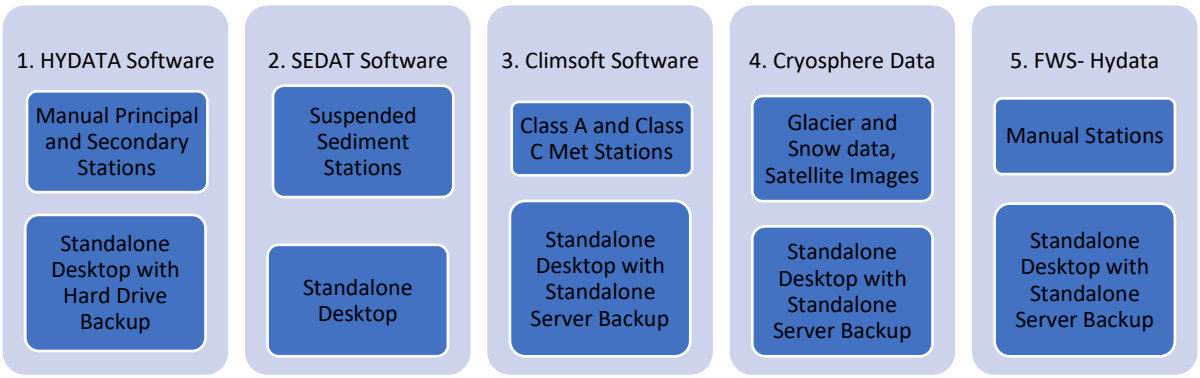

Figure 5: Manual Stations and their systems at NCHM.

(1) HYDATA Software

HYDATA (Hydrological Database and Analysis System) is commercial software developed by the UK Centre for Ecology and Hydrology (UK CEH). It is a standalone desktop application for entry and storage of hydrological data from all manual hydrological stations. HYDATA software is used as the national hydrometric archive in many developing countries[2]. It can produce hydrological analysis such as double mass curves, time-series analysis, and rating curves, etc. The data from HYDATA are backed up in an external hard drive. NCHM has been using the HYDATA (upgraded version) since 1990.

There is also a HYDATA software copy with the FWS and all manual FWS station details are stored in this system on a desktop. Backup service is provided from the FWS server in NCHM server room.

(2) SEDAT Software

SEDAT is also a desktop application used for the archival of suspended sediment data. Manual sediment data are punched into the system and stored on the computer. Backup is on an external hard drive.

[2] As of June 2020, there is no version or information about the software on the UK CEH website. https://www.ceh.ac.uk/services/software-models

(3) Climsoft Software

Climsoft is a desktop application used for storage, analysis, and sharing of climate data recommended by the World Meteorological Organization (WMO). Currently, information from all manual meteorological stations are punched into the Climsoft for storage, analysis, and sharing. The data on Climsoft software into the desktop is backed up on a local server at NCHM.

(4) Cryosphere Data

All data and records of the cryosphere are in the form of images, reports, and static tables. This information is stored on local desktop computers and a server at the NCHM server room. While there is not much dynamic information on the cryosphere, a lot of storage space is required for the storage of geospatial and image data.

2.2.3 Issues

Some issues of the data collection, archival and sharing issues of manual stations have been identified and listed in the table below;

Table 4: issues identified for Manual Stations

Sl.#	Description
1	HYDATA does not have proper backup and not shareable to other users – research/forecasting
2	Manual data collection and entry is time-consuming and susceptible to errors-observational negligence
3	SEDAT software is desktop-based and single user-oriented.
4	Data storage and backup are not robust
5	No backup storage offsite
6	Field data during monsoon and extreme weather are collected through WeChat and phone- reliability/ cost?

2.2.4 Early Warning Systems

Currently, there are two early warning systems in Bhutan. The GLOF-EWS system for Punatsangchhu basin and the GLOF and Rainstorm FEWS on Chamkharchhu-Wangdechhu Basins. Both the systems have independent data storage and interface as shown below.

1. GLOF EWS - Punatsangchhu Basin	2. GLOF and Rainstorm FEWS - Chamkharchhu-Mangdechhu Basin
Control Center in Wangdue with network of stations in Punatsangchhu Basin (AWS, AWLS, Lake WL and Sirens)	Control Center in Kurjey with network of stations in Chamkhar-Mangde Basin (AWS, AWLS and Sirens)
Standalone Server in Wangdue	Standalone Server in Kurjey
Mirror of Server with web interface at Thimphu FFWC	Web interface in Trongsa- MHEP. Desktop server
	Mirror of Server with web interface at Thimphu FFWC, Desktop server
	Link to GTS Interface- Semi- Automatic with Manual Push

Table 5: Early Warning Systems at NCHM.

(1) GLOF EWS - Punatsangchhu systems

The GLOF EWS for Punatsangchhu is set up through the NAPA I Project by a company called Sutron. There are 10 AWLS/AWS networks in the Punatsangchhu basin with 18 siren towers across the basin for warning purposes. The control room for EWS is at Wangdue Phodrang. The AWS/AWLS stations use the Iridium satellite to communicate via Iridium gateway from where data comes to the control centre via the internet. The siren stations are connected to the Iridium gateway with satellite communication capability for warning. BGAN (Broadband Global Area Network) was set-up as a back-up internet link to the control centre. This system is also hosted on a Linux server with its database (MariaDB) and web server at the Wangdue Control centre with web interface access from Thimphu Flood Warning and Forecasting Centre. The network diagram of the system and the connected computers are shown in Figures 7 and 8, while the details of the network are in Annexure.

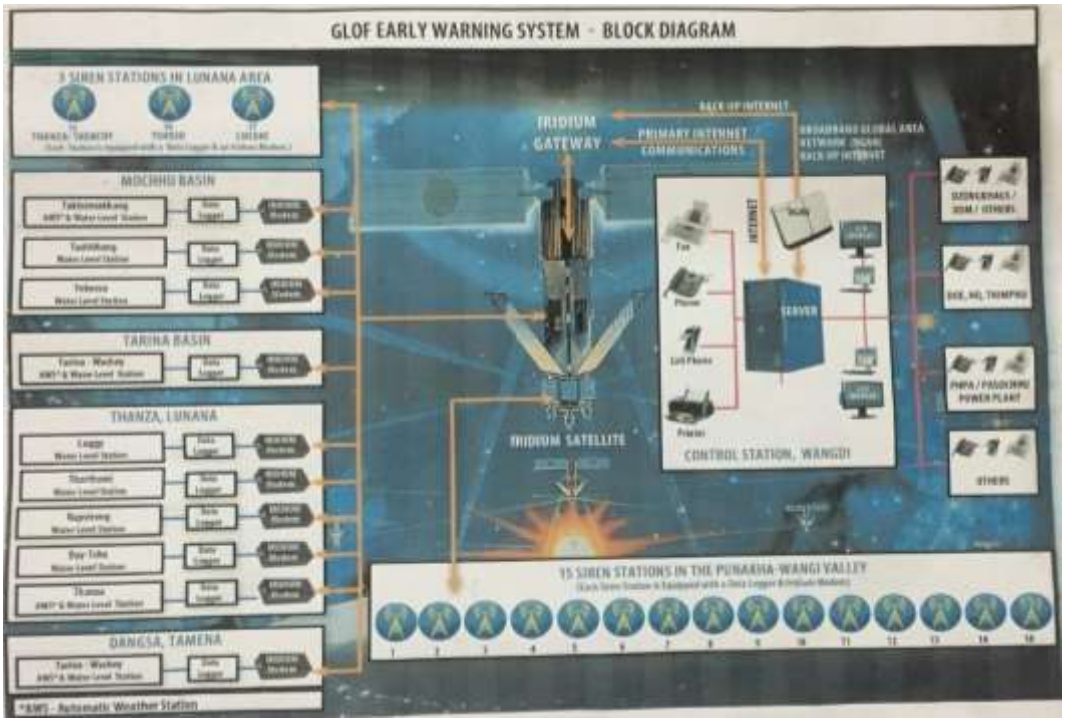

Figure 6: Network System of GLOF EWS - Punatsangchhu

Figure 7: Desktop System at Wangdue Control Room

Some issues of the GLOF EWS has been identified and listed as below;

Table 6: issues identified for the GLOF EWS System

Sl.#	Description
1	The data transfer takes a lead-time of approximately 10 minutes by design, as the data needs to be relayed via the server located in the USA (Iridium Gateway). This is not an issue per se, but maybe a limitation in case of disaster.
2	Connectivity issues –The system is dependent on availability of international internet links (cable internet from India). This is because the system is collecting data via iridium satellite which is then relayed from Iridium server to the server in Bhutan using internet connection (cable internet from India).
3	Backup internet link over BGAN is defunct
4	No backup power through battery bank or generator at Wangdue Control Centre
5	No off-site backup of data
6	Servers and software at the GLOF EWS server in the control centre are almost 10 years which are outdated. They are due to upgradation/ replacement with high risk of crashing and data loss.

(2) The GLOF and Rainstorm Flood Early Warning System (Mangdechhu and Chamkharchhu basin)

The GLOF and Rainstorm Flood Early Warning System (FEWS) for the Mangdechhu basin and Chamkharchhu Basin was established in 2015 and became operational in 2016 with funding and technical support from JICA. There are 5 automatic weather/water level stations, 9 Siren systems, and 2 control rooms (Bumthang and Trongsa). HF system is used to communicate with site stations with the Control Rooms in Bumthang and Trongsa and sirens in the localities.

The three control centres (Thimphu, Tongsa and Bumthang) are connected through an internet link. There is a web application and also a desktop application to view and manage the systems at all 3 control centres.

The voice command communication using the HF radio system is being used to communicate between the control centres including the one at NCHM Thimphu.

Information from the AWS at Tsampa is relayed to the Global Telecommunication System (GTS) of WMO manually using push command from a desktop application in Thimphu. Pictures of the system and its desktop application are shown in figures below.

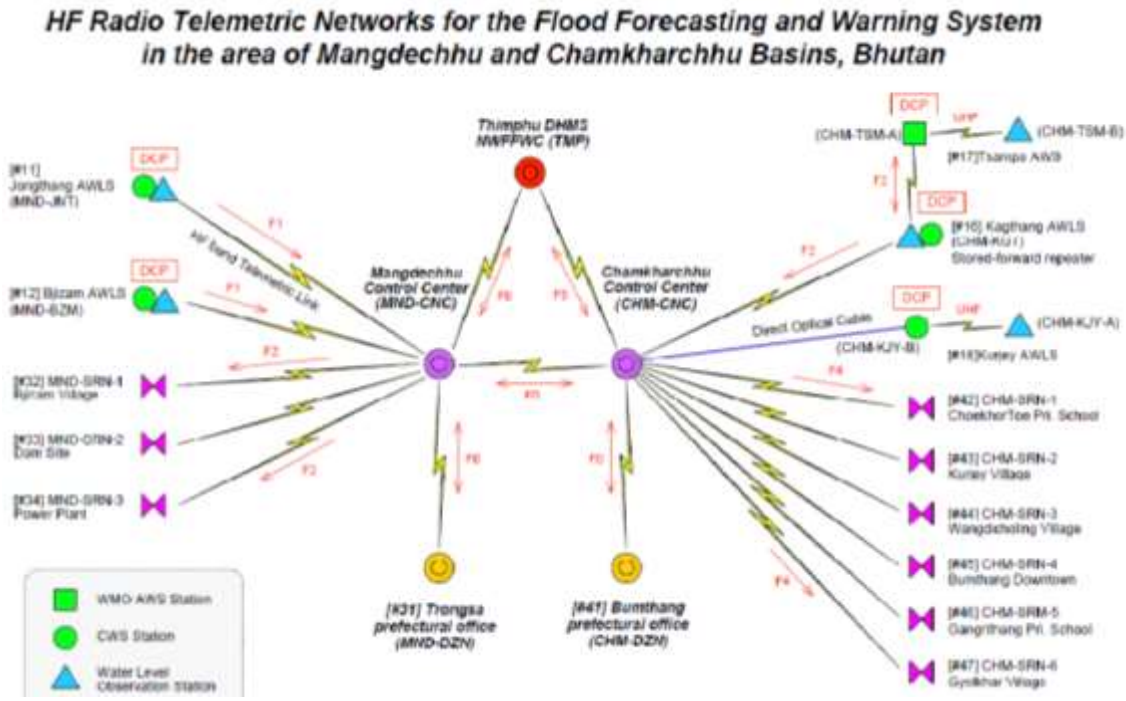

Figure 8: The GLOF and Rainstorm Flood Early Warning System (FEWS) set up

Figure 9: Computer and Communication of the GLOF and Rainstorm Flood Early Warning System (FEWS)

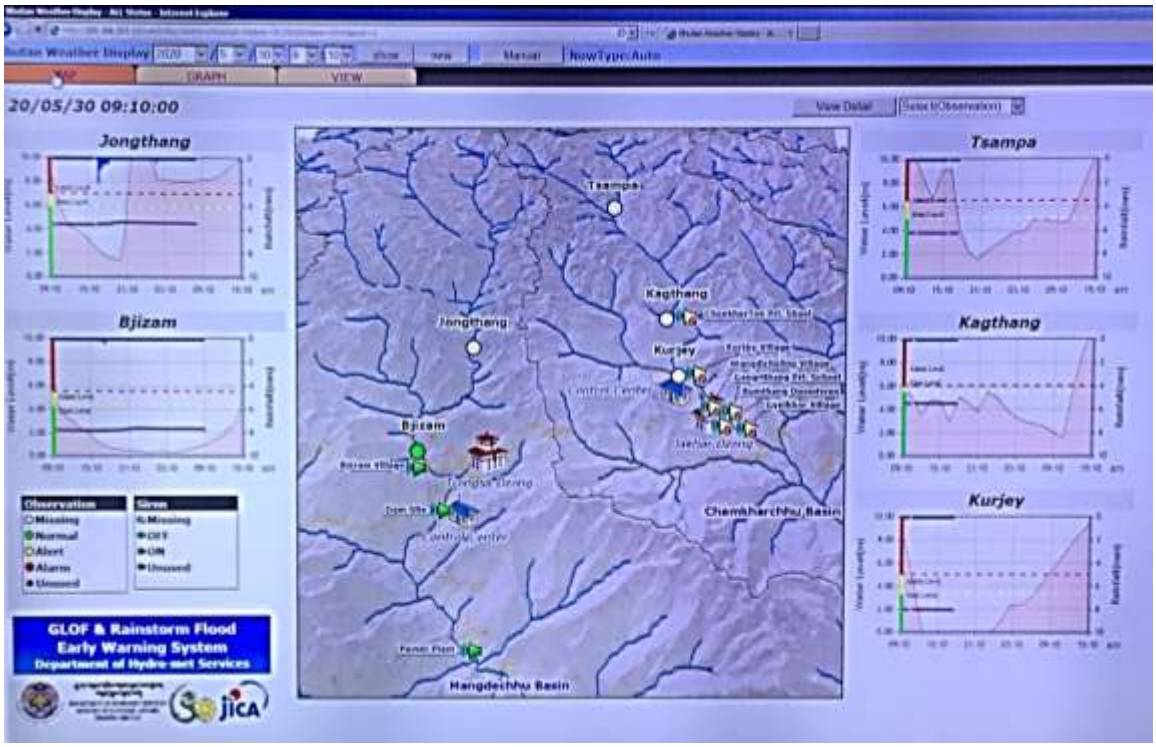

Figure 10: Web interface for GLOF and Rainstorm FEWS

The details of the control centre applications, equipment, and stations are listed in the annexure.

Some of the issues of GLOF and Rainstorm Flood EWS has been identified and listed as below;

Table 7: Issues identified for the GLOF and Rainstorm FEWS System

Sl.#	Description
1	Message drop due to remote location of the observation stations and weak HF signal
2	Since three control centres are connected via VPN over the internet, there is frequent internet disruption of connectivity between the control centres.
3	No alternate (backup) link
4	Frequent Power surge and router burnt out issue at Trongsa MHEP Control Centre

2.2.5 Aviation Weather Information and their Servers

Civil Aviation Weather Forecasting and information has been recently handed over to the Aviation Met Section of the Weather and Climate Services Division. Meteorological information to the civil aviation met section at Paro International Airport is provided through the AMHS, which is manually updated based on information in the IMS system that is connected to the data collection system and sensors. There is an IMS web interface display at the Air Traffic Controller and Thimphu head office. There are similar systems at the domestic airports wherein information from the field station is displayed and stored on the IMS for 90 days after which it is overwritten. The schematic representation of the systems and system overview is shown in Figure 11.

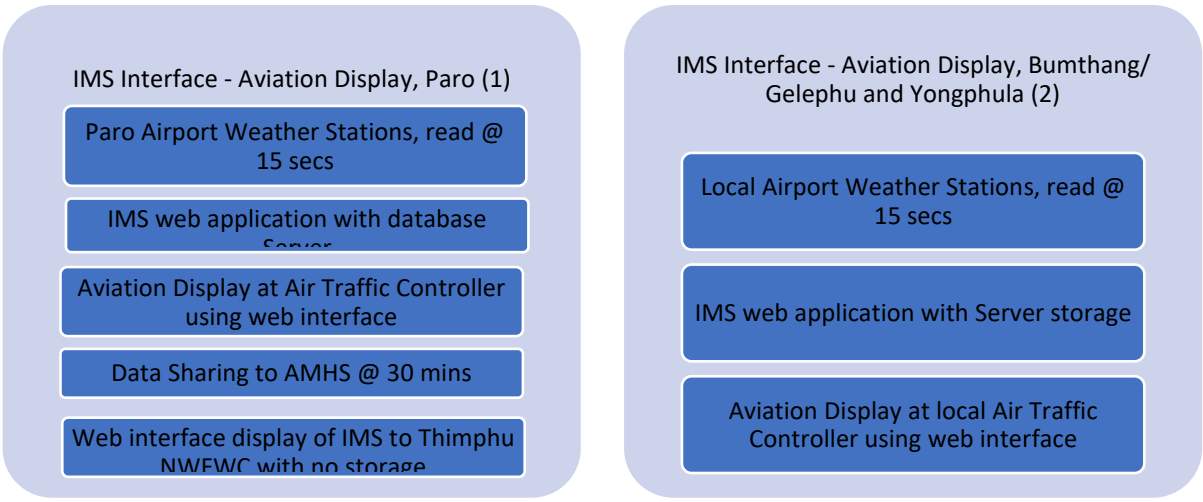

Figure 11: Aviation Meteorology Systems at NCHM.

(1) Paro International Airport Setup

The weather observation systems at the Paro International Airport include Radar Wind Profiler (RWP); Ceilometer and 2 AWS collecting and transferring data every 15 secs. The ground stations are connected by a fibre optic network to the local server. The IMS web application for aviation meteorology is being used with a separate server for the application and the database. It is also used for data sharing on the AMHS every 30 mins.

The same system is shared with the Air Traffic Controller as well. A web interface of the Paro system was also made and data shared, but it has been discontinued due to huge data size and costs. The Paro system is shown in the figure below.

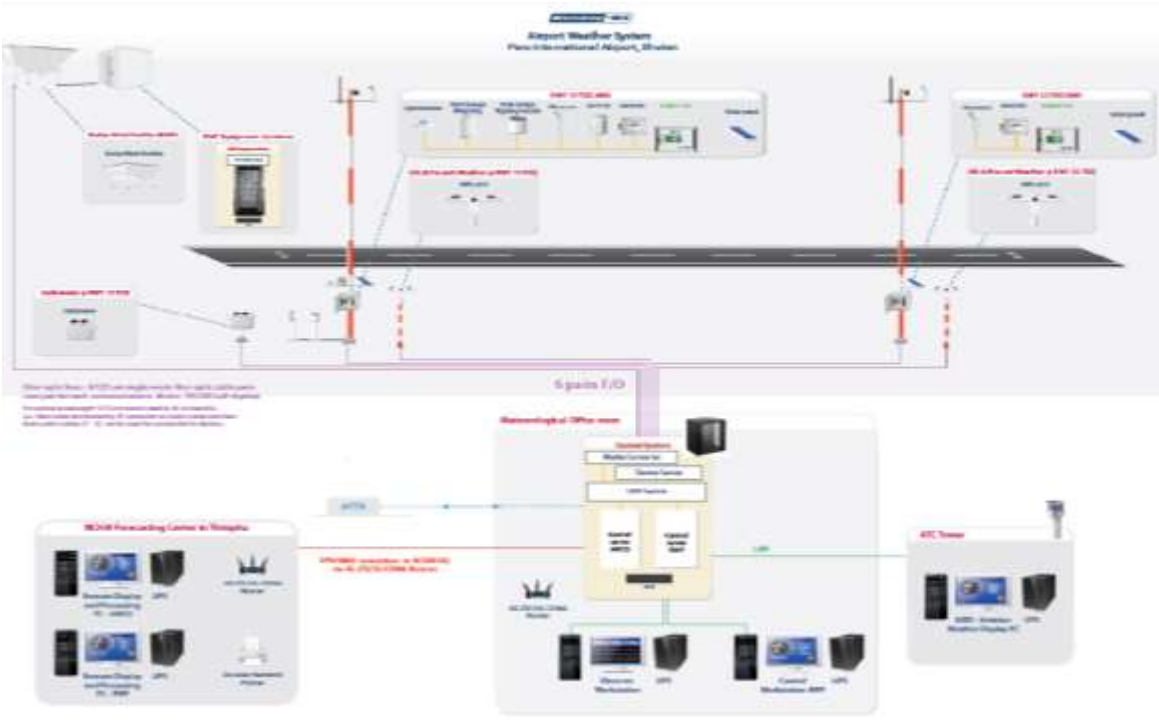

Figure 12: Aviation Meteorology Systems at Paro International Airport.

(2) Domestic Airport Setup

Domestic Airports at Yongphula, Gelephu, and Bumthang share the same set-up and operate in silos with its own and local standalone servers using IMS applications. They each have a ground AWS collecting and transferring data every 15 seconds. The ground stations are connected by a fibre-optic network to the local server. The domestic airport weather system is shown in the figure below.

Figure 13: Aviation Meteorology Systems at Domestic Airports.

An overall explanation of the Civil Aviation Meteorological system is shown in the table below.

Table 8: System Overview of Civil Aviation System

Sl.#	Name	Description
1	Application System	MicroStep – IMS (Web-based) system
2	Database	MariaDB
3	System access Mode	Web Interface
4	Communication & Network	Observation station- Fibre optic connection is for connecting AWS & towers with the Meteorological Office room to fetch data from the data loggers. ATC Tower – LAN connection. The system is accessed via a web interface at the air traffic controller and the information is relayed to aircraft via a radio link. NCHM, Thimphu Office - WAN with VPN over 4G LTE/3G. The system is accessed via web-interface.

Some issues of the Civil Aviation Meteorology have been identified and listed as below;

Table 9: Common issues encountered for Civil Aviation Meteorology

Sl.#	Description
1	Data Storage issue as data is overwritten after every 90 days. Storage at Thimphu was not possible.
2	Aviation met station systems at Paro and other domestic airports operate in silos, need to integrate. Data communication is made through telephone for flight operations and planning.
3	IMS is being used in all 3 domestic airports, which is similar to IMS at Paro. High possibility of being able to use the same application on one platform with easy sharing of data.

3 PROPOSED SOLUTION

3.1 Functions of the Centre

The National Centre for Hydrology and Meteorology (NCHM) is an autonomous scientific and technical organization of the Royal Government of Bhutan responsible for understanding the behaviours of atmosphere, its interaction with cryosphere and water bodies, the weather and climate and distribution of the country's water resources. It is the national focal agency responsible for collection and dissemination of information on weather, climate, hydrology, water and cryosphere in Bhutan. It is also mandated to provide reliable and timely hydro-meteorological information and services to various agencies, users and the public. The vision of NCHM is to make Bhutan a hydro-met ready and resilient nation by taking on the challenges of working with complex physical processes utilizing advanced technologies, modern communication systems and highly skilled employees. Its mission is to provide quality, accurate, reliable, usable, location-specific and timely services to reduce risks and to optimize benefits.

NCHM is governed by a Governing Board, which oversees the operation, planning and development of the centre as the managing board. Board Members (BM) are from the relevant sectors such as Hydropower, Agriculture, Disaster and Environment. The NCHM secretariat is structured into four functional divisions as below:

1. Hydro-met Operations and Infrastructure Division (HOID) which looks after the hydro-meteorological networks and other infrastructures;
2. Cryosphere Services Division (CSD) responsible for generation of products and services on snow, ice and glaciers;
3. Weather and Climate Services Division (WCSD) responsible for providing products and services on weather, meteorology and climate; and,
4. Hydrology and Water Resources Services (HWRSD) responsible for delivering products and services on hydrology and water.

NHCM's main objective is to provide timely and reliable hydro-meteorological information to the society so that impacts of hydro-meteorological hazards are reduced to the extent possible and also assist in proper planning and development. A brief overview of the status of current functions and services provided by NCHM are below.

1. Operation and maintenance of Hydrological, Snow and Meteorological/Climate stations
2. Maintaining inventory of climate data (processing, storing, retrieving and publication) and dissemination to users
3. Providing weather forecasts information and warnings
4. Providing seasonal climate information

5. Managing inventory of hydrological data (processing, storing, retrieving and publication) and dissemination to users
6. Providing Early Warning on Glacier Lake Outburst Flood (GLOF) and Rainstorm Flood based on the principle of water level detection system in three (03) main river basins in Bhutan as follows;
7. Punatsangchhu River Basin in 2011 under UNDP GEF (NAPA-I Project)
8. Mangdechhu Basin in 2015 under JICA supported Project
9. Chamkharchhu Basin in 2015 under JICA supported Project
10. Undertaking glacial studies and updating the information and services

The above functions of NCHM are with respective divisions as displayed in the following figure 15.

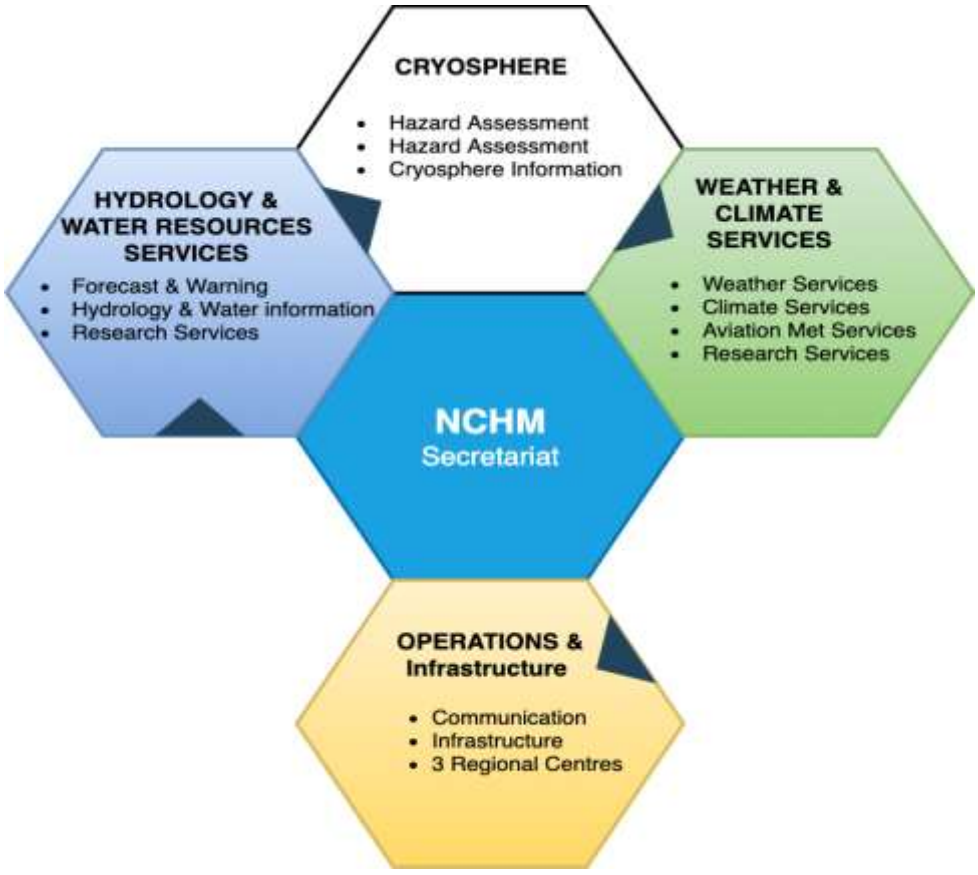

Figure 14: NCHM by Functions[3]

[3] Source: Technical assessment report, NAPA II, NECS

The organogram of NCHM as an autonomous centre is in following figure.

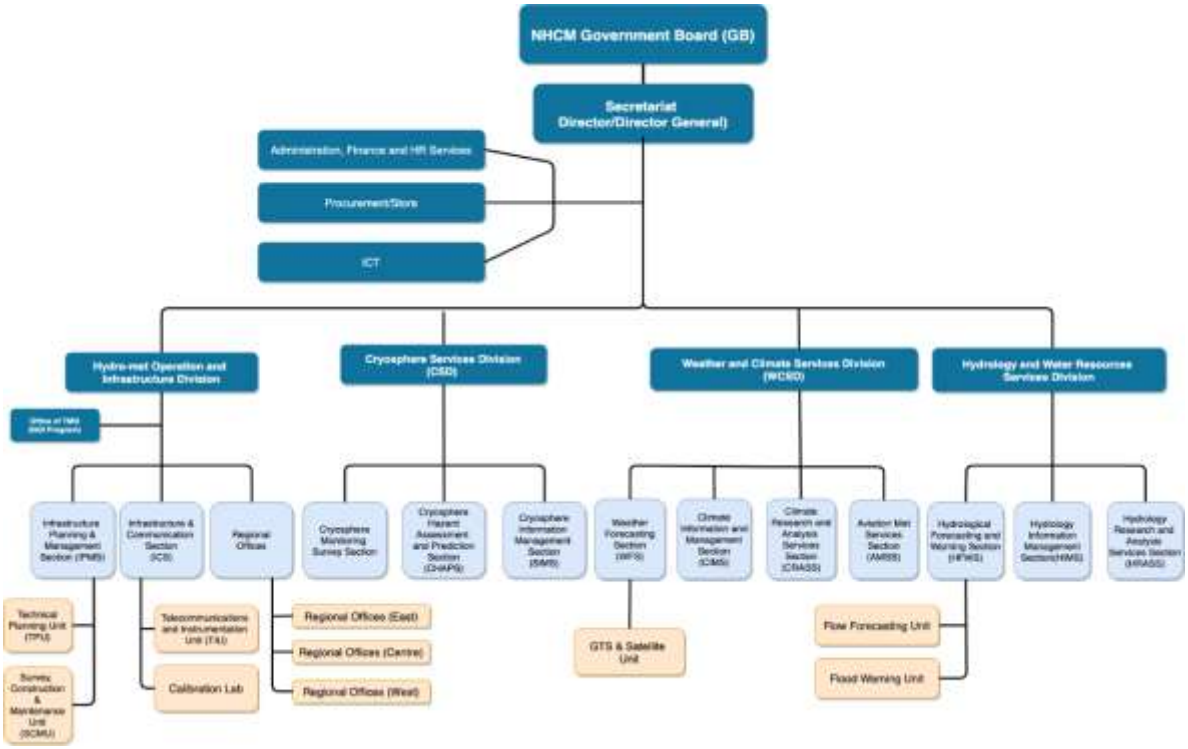

Figure 15: NCHM Organogram (NCHM 2020).

3.2 Summary of Functional Requirements

A consultative workshop was held by the consultants with technical officials of NCHM on July 27, 2020. The goal of the workshop was to understand and list the core functions of the divisions, data input, processes required, and outputs desired by respective divisions of NCHM. The list of participants is in Appendix 2. The main requirements of each division's functional requirements are as below. The technical details and specific function, process, and outputs are in the System Requirement Specification (SRS) which is submitted as Annexure to this document.

3.2.1 Hydrology and Water Resources Services (HWRS)

The requirements of the HWRS are in following table.

Table 10: Hydrology and Water Resources Services (HWRS)

Functions of the Division	● Manual data entry sent from the field in Hydata (date and water level) ● Sediment data entry manually in SEDAT ● AWLS- water level and discharge automatic ● Early Warning System (EWS) ● Flood Hazard mapping ● Data archival

	• Storage of rating curve manually • Historical Data sharing- water level, discharge (Q) and sediment data • Flood forecasting for DGPC and some other basins. HBV/HEC-HMS. Model result shared with DHPC via Google sheet right now,
Inputs Expected	• Provision for Manual data entry sent from the field (date, time, location and water level) • Automatic data input from field devices – using mobile/telemetry devices - mobile application/ web interface. • Sediment data entry manually • AWLS- water level and discharge • EWS network systems • Insertion of Rating Curves/ Cross Section data • Outputs from hydrological models • Automatic Ground Water levels • Manual Ground Water levels • Automatic Water quality parameters • Manual Water quality parameters • Historical data update from old EWS • Storage of processed data from global sources. (file server, linked with HDMS)
Outputs desired	• Quality checks – limits, trends • Water levels and Discharge using a rating curve • Basic Statistics; 5-no summary (max, min, 3Qs) • Advanced Statistics: Standard deviation- Coefficient of variation- monthly, daily, annual, hourly, Trend • Compendium of flood disasters; List of flood events- name, place, incident • Viewer- graphical and tabular result- both options are required. • Data for a particular time, 9 am/2 pm every day for date X-Y • Hydrological Information system for the hydrological stations on a network map (detailed metadata - Highest flood, lowest flow, historical flow, Catchment area, pictures, etc.) • Flood hazard mapping – dynamic for Flood decision support system- link results from the hydrological model (results from the hydrological models are shown on this system automatically with pre-assigned levels).

3.2.2 Weather and Climate Services (WCS)

The requirements of the WCS are in following table.

Table 11: Weather and Climate Services (WCS)

Functions of the division	• Data processing, quality control and archiving • Data supply • Weather forecast • Seasonal predictions • Climate projection • Agro-met Services • Climate monitoring (monthly and annually) • Aviation Met services
Inputs Expected	• Provision for Manual data entry sent from the field (date, time, location and water level) • Automatic data input from field device – using mobile/telemetry devices - mobile application/ web-interface. • AWS- Weather data • EWS network systems • Automatic Air Quality Stations • Manual Air Quality Stations • Historical data update from old EWS • Aviation Weather forecast summary to HDMS • Seasonal forecasts • Scanned data archival (old data) input • Pull WRF, Satellite, other GFS/ ECMWF data into the system for storage and sharing • The output from Smart-met Weather Forecast to go into HDMS for comparison study and accuracy of the forecast.
Outputs desired	• Quality checks – limits, trends • Basic Statistics; 5-no summary (max, min, 3Qs) • Advanced Statistics: Standard deviation- Coefficient of variation- monthly, daily, annual, hourly, Trend • Data frequency counts • Auto filling/ missing interpolation data • Climate indices • Station view with details, key data, location details

	• API- AgroMet (DSS)- data sharing to AgroMet directly • Wind rose • Extreme event record • Graphs, tables, plots, histogram • Scanned data view • Seasonal forecast reports- CPT format, NetCDF, trends • Integration for airports-pull from airport forecast, store in HDMS and show general forecast on NCHM website • Format for customized daily net data provision (historical data) on different time scales, and different basic stats • Route forecasts (tourism, road, helicopter) • Provide data for SmartMet from AWS/Manual stations • Provision to do comparison study and accuracy of forecast from SmartMet and observed data. • Storage of processed data from global sources. (file server, linked with HDMS)

3.2.3 Maintenance and Instrumentation Services (MIS)

The requirements of the MIS are in following table.

Table 12: Maintenance and Instrumentation Services

Technical Functions of the Division	• Ensure stations are up and running (Annual maintenance, Troubleshooting) • Network study, site selection, and new installations. • Calibration of sensors • Stock adequate spare parts • Study for the latest equipment and technology for Hydrometeorology
Inputs Expected	• Station Details with details of location, sensors, observers • Maintenance record – GPS with time steps, history, what was done time, and activities performed • cross-section details (hydro) • Manual data entry-updated on HDMS
Outputs desired	• Equipment/sensor info-parameters • Site details with observer, location, data, status • New station/up-gradation add/delete/edit functions • Raw data info

	• Station map updated with the status • Manual data-verification/endorsement system check after transmission • Last reporting time • Daily QC checked SMS/ email notification • Quick View option for the station with its key parameters

3.2.4 Cryosphere Services (CS)

The requirements of the CS are in following table.

Table 13: Cryosphere Services (CS)

Technical Functions of the Division	• Glacier (GI), Glacier Lake (GL) and snow monitoring • GL, GI inventory update • Glacier lake level monitoring • Satellite image analysis and reporting (GI. Lakes in tables with all Information/graphical)
Inputs Expected	• Glacier mass balance records • Snow depth and SWE from AWS/ Manual stations • Glacier lake study reports (potentially dangerous lakes, techniques used, results.) • Snow/glacier camera • Satellite images from various sources • Snow incident reporting form with pictures (Where, when, how much, picture)
Outputs desired	• Satellite image analysis and reporting with dates (GI. Lakes in tables with all Information/graphical) • PGDL details info- image, technique • Image download with date and locations (DB access to the image) • Glacier surface change report • Snow depth + SWE data for different locations with time- basic statistics • GL+ GI. Lake met data on map with recent survey, observation, picture, download with recent source • Net-geo meter-possibility to generate – energy mass balance with precipitation and temperature data

	• Glacier mass balance: Glacio-hydrological year, glacier mass balance, method adopted (direct/geodetic), location, specific mass balance, cumulative mass balance, hypsometry (graph) • Glacier inventory: report, glacier list (ID, Lat/long/elev, area, year of publication), map-based location, pop-out graph (y-axis: surface area, x-axis: year) • Glacier cumulative front variation (map-based). Pop-out graph with y-axis: frontal variation (m), x-axis: year, raw CSV, table, shapefile. • Potentially dangerous glacial lakes (PGDL): map-based location, pop out (location, volume, depth, surface area, imageries, lat/long/elev, surrounding geomorphology (list out), date and year of update. • Snow incident report; name of observer, location, date and time of observation. Basic statistics.

3.2.5 Events and Publications Library (EPL)

The requirements of the EPL are in following table.

Table 14: Events and Publications Library

Technical Functions	• Inventory of extreme weather events • Archival of publications by the centre • Dissemination of information
Inputs Expected	• Manual input of extreme weather events such as hailstorm, snow events, flood etc with basic information, pictures and dates. • Publication details, authors and metadata along with the publication
Outputs desired	• Historical extreme weather events with dates and details searchable by date or event or location. • publications by NCHM searchable by topics, dates or authors

3.3 System Overview and Architecture

The proposed system and network architecture of the HDMS with centralised database system is shown in Figure below. This architecture has data centre with centralised servers located at the head office in Thimphu. The manual remote observation stations are proposed to be connected to the HDMS through manual data punching or mobile telemetry using mobile application or web-interface. Automatic remote stations, both AWS and AWLS, may continue to be connected to the HDMS through GSM internet. Remote stations for Aviation Met Services and Flood Early Warning Systems (FEWS) are also proposed to be

connected to respective control centres using the most reliable network such as LAN, VHF or satellite communication. The respective divisions at the head office are connected via local area network, the EWS Control Centres and Aviation stations are connected to the data centre through wide area network (WAN) secured by virtual private network (VPN). The VPN creates a secure tunnel that protects the data and allows all traffic, voice, or data to pass through a public WAN as if it were on a LAN. The network is further secured by creating a demilitarized zone (DMZ) within the LAN and also by installing a hardware-based firewall which can monitor the incoming and outgoing network traffic that permits or blocks data packets based on a set of security rules.

Since database servers are required to record time series data from the remote stations, the server should be optimised for high performance and high availability. Therefore, the proposed architecture has a cluster of servers with a minimum of two nodes and a hardware-based load balancer. It has the following advantages:

- **Increased resource availability:** If one server in a cluster fails, the other server in the cluster can pick up the workload. This prevents the loss of valuable time and information if a server fails.
- **Increased performance**: Multiple machines provide greater processing power.
- **Greater scalability**: As your data grows and reporting complexity increases, it is easier to add more resources (servers).
- **Failover Support:** It ensures that the system remains available for use if an application or hardware failure occurs. When a node fails, the work for which it is responsible is directed to another node.
- **Load Balancing:** It is a strategy aimed at achieving even distribution of user sessions across the servers, so that no single machine is overwhelmed.

The architecture of the proposed system uses land-based internet connectivity as the main link and satellite link as a redundant link for providing support for network failover.

Additionally, the older servers can be configured for using processor-intensive applications via thin-client computing. So that the user licenses for software such as GIS/ Agisoft/ AutoCAD, etc. can be shared, while optimising the server usage for storing data files and images on these servers. The overview system and network diagram for NCHM is as below;

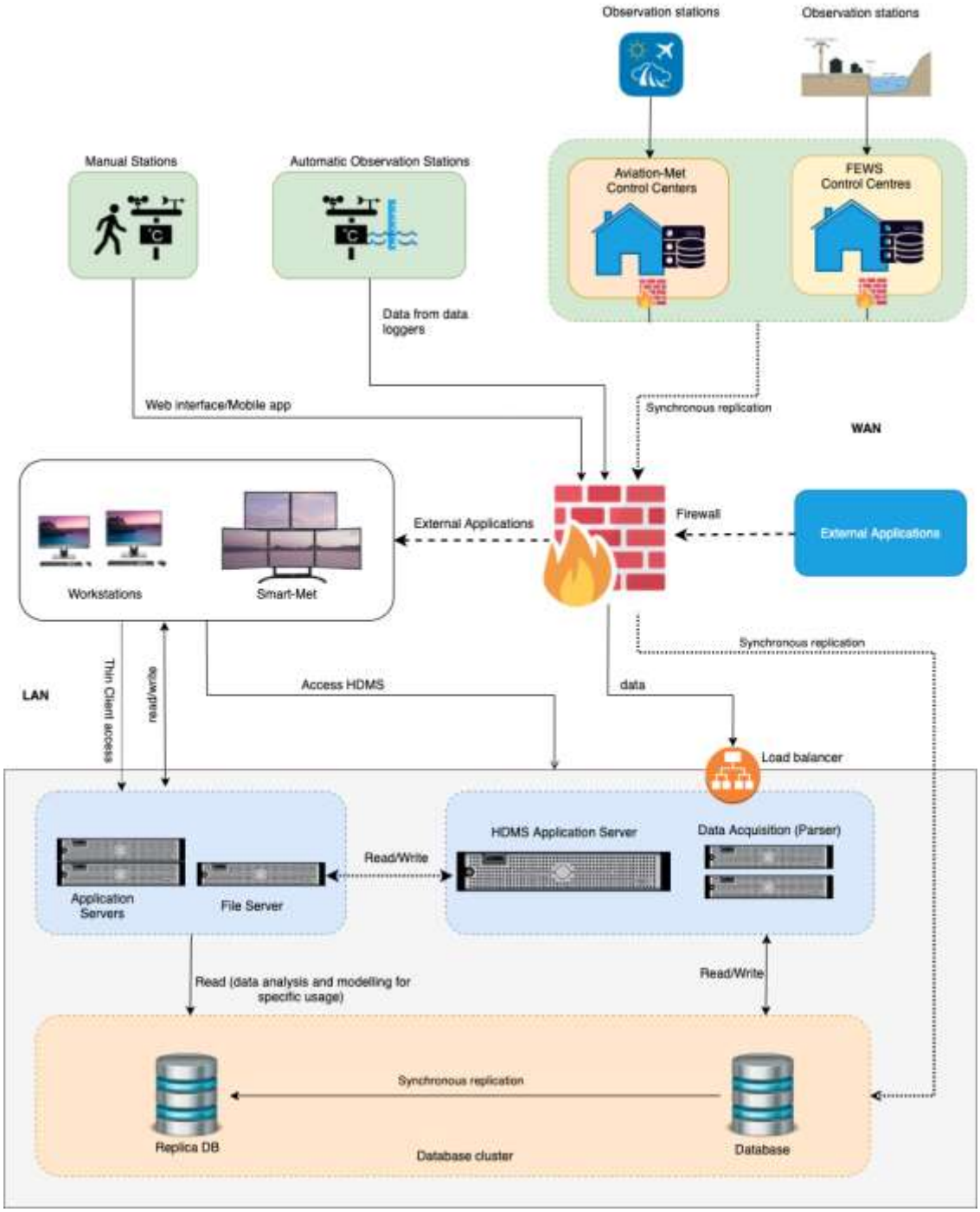

Figure 16: Proposed system for NCHM

3.4 Data exchange and dissemination

The Second Governing Board (GB) meeting of the National Centre for Hydrology and Meteorology (NCHM) held on April 2, 2018 directed the Centre to formulate “Guidelines on the Exchange and Dissemination of Hydro-meteorological Data and Information” until a new Hydro met Policy of Bhutan is adopted (NCHM, 2019). Currently, all historical data from NCHM are available and provided for free to all interested parties on signing an application

and liability waiver form either through email or in person. The most common service provided by NCHM is historical water and climate data followed by weather forecast as shown in figure below based on a study by NCHM and UNDP.

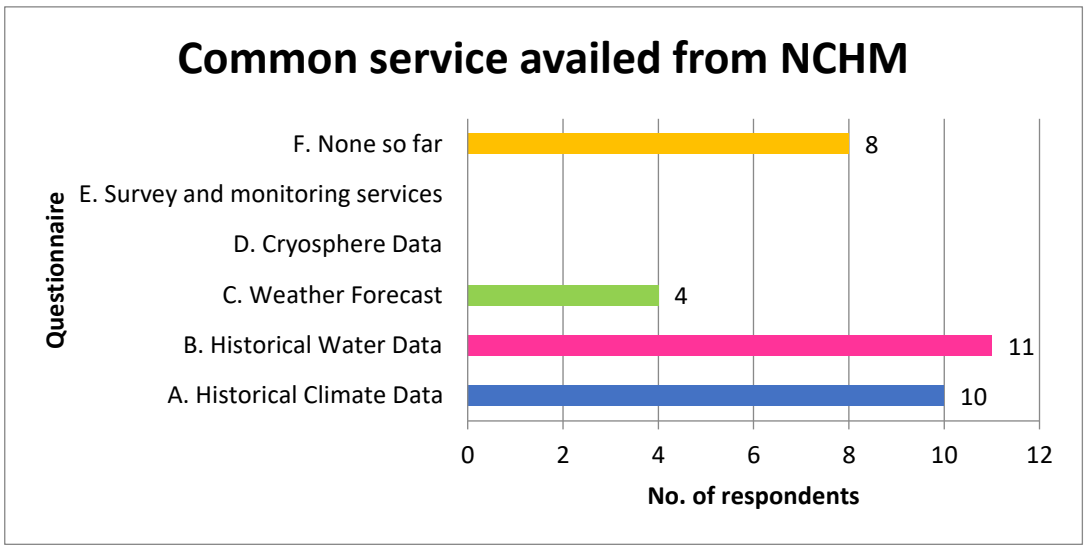

Figure 17: Common service availed from NCHM

3.4.1 Online Data Request System

For the future, it is proposed that an online data request and approval system is set up to ensure minimum Turn-Around-Time (TAT). There should also be an option for online payment which may be activated when necessary. The details of the proposed system are as below.

An applicant needs to first register on the NCHM website for data requisition through a simple email verification process. Thereafter, an online form should be filled up for the data request which will have options for selecting parameters, stations, frequency and time period.

Once the form is submitted, it shall go to the NCHM focal person for data request verification. If approved, the instruction goes to the data manager for data compilation and also to the website for payment information (if required/ invoice). A notification shall also be sent to the applicant if the application is rejected. Once the payment is made (if applicable), a notification is sent to the data manager. Thereafter, the data manager uploads the compiled data to the NCHM website under the profile of the applicant. The applicant could then download the data from his/her profile on NCHM website. The flowchart for data disbursement is Figure 18.

Refer SRS for detailed processes.

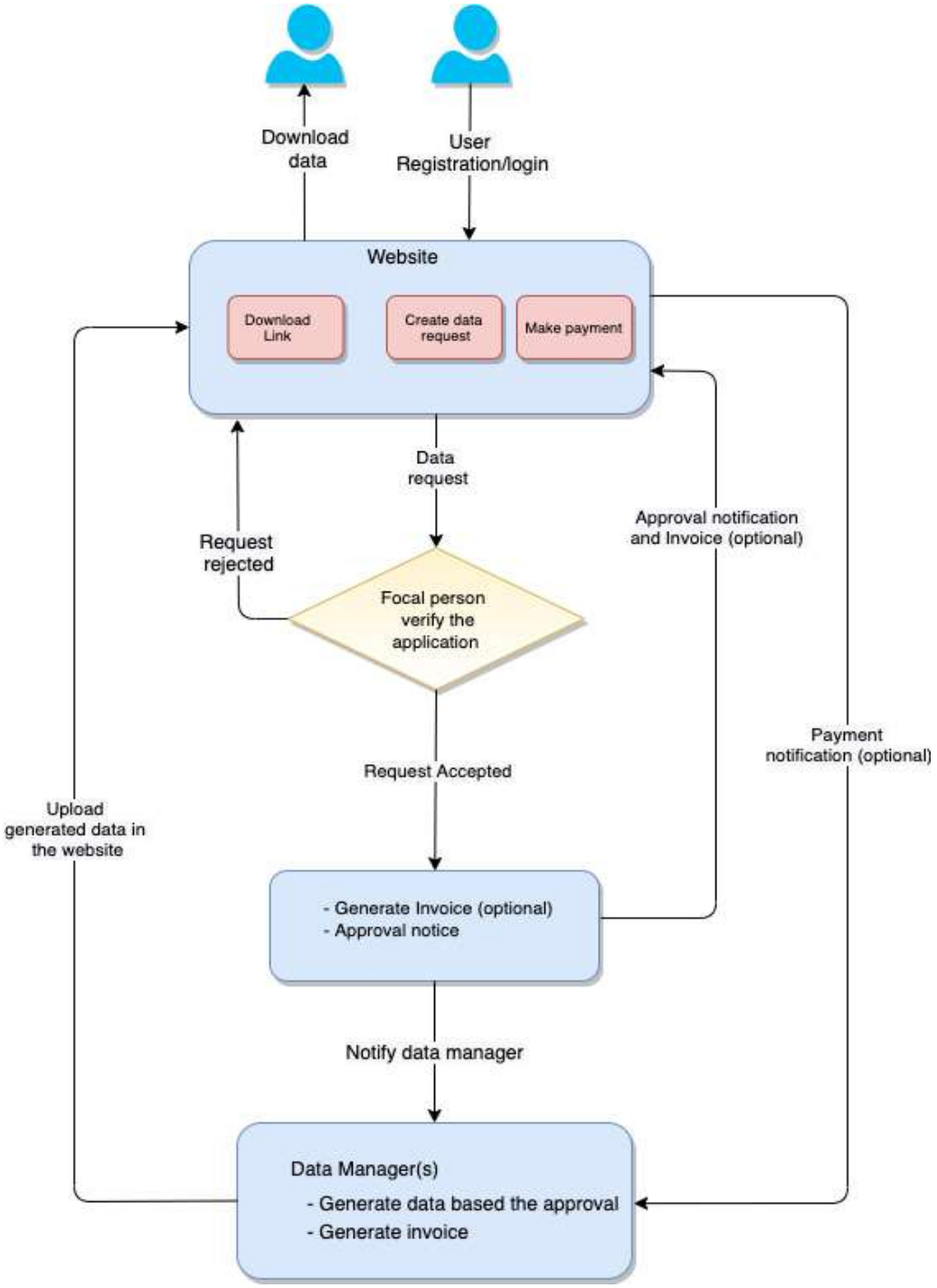

Figure 18: Flow Chart for Online Data Dissemination

3.5 System and Network Security

Computer systems face a number of security threats such as data loss, which could be the result of physical damage to the storage medium (like fire or water damage), human error or hardware failures. Another security threat is unauthorized access to data in a system without permission to access that data. A third category of security threats consists of viruses and other harmful programs.

The following sections list the recommended solutions for the possible security threats.

3.5.1 Data Backup and Recovery

The purpose of the backup is to create a copy of data that can be recovered in the event of a primary data failure. It can be the result of hardware or software failure, data corruption, or a human-caused event, such as virus or malware attack, or accidental deletion of data or primary location or systems become inaccessible due to unforeseen events, such as fire, flood, or data breach. Backup copies allow data to be restored from an earlier point in time to help the system recover from an unplanned event. The recommendations are listed in the table

Failure Types	Recommended Solutions
Hardware & Software Failure	Setup RAID 5 on the application and database server so that so that it provides following benefits: - higher Data Security, - fault tolerance - improved availability and performance and - ensures data reliability
Data corruption, or a human-caused event, such as virus or malware attack, or accidental deletion of data	Set onsite backup server and perform daily or weekly backup of the entire system-based resources available.
Failure due to unforeseen event, such as fire, flood, or data breach	Setup disaster recovery site and configure continuous replication of the whole system.

Table 15: Backup and recovery

3.5.2 Technical Security Measures

- Install hardware-based firewalls
- Setup VPN for communication with the stations and control centres.
- Setup DMZ and place servers inside the zone.
- Use antivirus software

3.5.3 Administrative Security Measures

- Define access rights and review periodically. The user and corresponding access roles are in Table 14.
- Implement audit logs in the system
- Check unauthorized access in the system

3.5.4 Role-Based Access Control (admin, engineer, user)

Role-based access control is necessary for different types of users. The following are the users proposed along with their roles.

Table 16: User and Role

Name	Role	Description	Who
Admin	All	Overall system administrator, including creating or deleting users.	IT Officer/s
Engineers	Maintenance and Instrumentation Services (MIS) module	Station Creation/ Deletion, Station Details, Maintenance functions, sensors change, raw data access, access to all systems. But cannot create or del users.	HOID Team
WCS	Weather and Climate Services (WCS) Module	Meteorological data and functions, data input for met data, analysis, report generation. Write access to Met-Stations/data only. Storage and visualization of satellite images.	WCSD Engineers and Data team
HWRS	Hydrology and Water Resources Services (HWRS) Module	Hydrological data and functions, data input for hydro data, analysis, report generation. Write access to Hydro stations/data only.	HWRD Engineers and Data team
CS	Cryosphere Services Module	Cryosphere data and functions, data input for Cryosphere data, analysis, report generation. View access to selected stations/data only.	CSD Engineers and Data team
Management	View rights to all the modules	View the status of all stations, view issues, maintenance records, view/download all data but no write access.	Chiefs, Specialists, Researchers, and Director

3.6 Data Quality Control

- HDMS should have a feature under the Data Management Module to perform quality control of the data received from the stations by allowing the data manager to define upper and lower limits for each data unit.
- A daily quality assurance system is desired by all divisions for both automatic and manual data coming in. After a QC system has been set up, erroneous data coming in

will be flagged and an SMS/email sent to respective officials of the concerned division. He/she will then check and rectify the data before it goes into the HDMS.

4 ISSUES AND RECOMMENDATIONS

Based on the review of the existing systems, past experiences and discussion with concerned officials, the up-gradation to respective systems are proposed as an assessment matrix and detailed recommendations.

4.1 Analysis Matrix

The activities to be carried out and the modules to work on are categorically listed under respective thematic area, key issues, corresponding recommendations, remarks and phase on implementation.

Table 17: Analysis Matrix for the study

#	Thematic area	Key issues/gaps/barriers	Proposed recommendation/solutions	Any major implications / Recommendations	Phases
1	Manual Stations and their Servers	- No proper backup and storage which is susceptible to data loss. - Data stored on the desktop computers are not easily accessible to other users. - Manual data collection and entry is time-consuming and susceptible to errors - Field data during monsoon and extreme weather are collected through WeChat and phone	- Centralized Database system with option for manual data entry. - Role-based access control (admin, engineer, user). - Centralized HDMS system with ability to accept manual data sent through the telemetry system. - Setup data backup and recovery mechanism. - Daily QC checked SMS/ email notification. - Online data disbursement System.	For details refer section 4.2. R1	1 - priority
2	Automatic Stations and their Servers	- Systems from different projects are in different servers and with different applications.	- Centralized Database system with ability to accept data from different stations/ systems.	R1 R2 R3.	1 - priority

		- No record of maintenance or meta-data is in a common system - No common database or front-end interface for all systems. - Data storage and backup are not optimal – hardware duplication - No backup storage offsite/ Disaster Recovery Site - No data transmission backup/ alternate link not there - No proper archival system of data downloaded on USB	- Setup data backup and disaster recovery mechanism. - Daily QC checked SMS/ email notification. - Online data disbursement system. - Redundant communication lines to be set up using satellite internet secured using VPN.		
3	GLOF EWS - Punatsangchhu	- The data transfer takes a lead-time of approximately 10 minutes by design. - Connectivity issues –The system is dependent on availability of international internet link (cable internet from India); - No backup power through battery bank or generator at Wangdue Control Centre - No off-site backup of data - Servers and software at the GLOF EWS server in the control centre are almost 10 years.	- Setup direct data communication link from the remote station to the control room in Wangdue. - Establish satellite internet as a backup link. - Setup and connect to a disaster recovery site with near real-time data synchronization. - Upgradation of the software system and hardware is required (ageing). - Explore flow-forecasting model for the Punatsangchhu Hydropower Projects. - Set up power backup using battery and/ or generator.	Can be taken up as a separate project and not a part of DMS upgradation.	Not included

			- Integrate visual and motion sensors on the lakes itself.		
4	The GLOF and Rainstorm Flood Early Warning System (Mangdechhu and Chamkharchhu basin)	- Message drop - Frequent connectivity disruption between the control centres. - Occasional HF data Communication failure and problem with HF voice communication at night. - MeteoSat 8 - reorientation of Horizon - No Web application for viewing beyond the NCHMs facility. - No alternate (backup) link. - Frequent Power surge and router burnt out issue at Trongsa MHEP Control Centre	- Mangdechhu- Chamkharchhu data acquisition layer could be upgraded along with Wangchhu EWS incorporation and to comply with the HDMS specifications; - Install a power surge protector at all the Control Centres- Bjezam and Kurjey; and - Establish a backup link using a satellite internet.	DMS specification for EWs module to be applied.	Phase 2
5	Future EWS	- No system right now for any modular enhancement. All developed as independent systems.	- All future EWS systems should comply with the proposed solution's database structure. - The control centre personnel could use the HDMS system's EWS Management module. - All future EWS should be connected to disaster recovery site.	R1 to be strictly compiled along with R2, and R3.	
6	Aviation Weather	- Data Storage issue as data is overwritten after every 90 days. - Aviation met station systems at Paro and other domestic	- Continue using the current setup of respective local systems to mitigate disaster risks.	R1 – not complicated	Phase 1

	Information and their Servers	airports operate in silos. Data communication through radio link for flight operations and planning. - IMS is being used in all 3 domestic airports, which is similar to IMS at Paro- but not centralised.	- Link all the airports' Aviation Met systems to each other (Centralise) and have viewing functionality of other stations. - Setup backup site in Thimphu database that is viewable via the HDMS. Data frequency can be optimized to hourly or as desired to reduce communication charges and storage space. - Connect to a disaster recovery site.		
7	Network	- Stations and control centres are connected using GSM, leased line internet or HF communications that are sometimes delayed and susceptible to connectivity disruption	- Upgrade communication devices with higher data transmitting range. - Establish an alternate backup link using satellite communication secured using VPN.	Follow the proposed system and network architecture of the DMS	Phase 2
8	Servers	- Old and outdated servers - Duplication of servers - No back services	- Upgrade server hardware and software along with security features. - Proposed for reusing old servers for performing processor-intensive applications via thin-client computing. - Licenses for software such as GIS/ Agisoft/ AutoCAD, etc. can be shared - Old servers can be used as file servers.	R2 and R3.	1 - priority
9	HR capacity	- Only one IT officer for NCHM - Data Managers work in isolation at respective divisions - Limited staff capacity	- Employing a dedicated IT officer with backup support staff.	Details are proposed in R4.	Not included

			- Establishment of central knowledge repository of SOPs/ Manuals / Issues logs with solutions etc of all systems. - Training, seminars, and workshops. - Encourage informal knowledge sharing. - Monthly training and coordination meetings.		

4.2 Recommendations

Details of important recommendations listed above are explained in the following section.

4.2.1 R1. Hydro-Met Data Management System (HDMS)

Centralized HDMS is recommended with following functionalities

- Data Visualization using charts and graphs for Meteorology and Hydrology.
- Generation of customized reports based on selected parameters, time, and locations.
- User Management based on Role-Based Access Control.
- APIs for data sharing to relevant agencies (Agromet, Hydropower, SmartMet, Website, etc).
- Support for defining Quality Control rules and application for report generation.
- Inventory of Stations with metadata details including sensors, maintenance, numbers, location, etc.
- Early Warning System module for control centres with decision support systems.
- Modules for Water Quality, Air Quality, and Groundwater observations.
- Data export to various file formats.
- System management module for station addition, deleting and updating.

Refer SRS for detailed functional requirement

4.2.1.1 HDMS architecture and HDMS Options

Based on discussion with officers at the centre, it is proposed to have a comprehensive and dedicated HDMS - Hydro-Met Database Management System for NCHM. Currently, the proposal is to set up the functions for weather and climate services, while the ones for hydrology and cryosphere may be implemented at a later date. Nevertheless, the system specification and planning are structured in such a fashion that it will be easy to incorporate these functions later directly or using various other methods mentioned below.

4.2.1.2 Data Acquisition System (DAS)

To support and for easy integration of equipment from different vendors the HDMS should include an open and user configurable parser that can parse data from various sources to a standard database format of the HDMS.

4.2.2 R2. NCHM Server Room Enhancement

The existing server room at NCHM is well set up, however, it can be further enhanced to Tier I data canter with following;

- Proper power backup.
- Main link using BT/ TashiCell with Redundant link using Satellite.
- Standard Operating Procedure (SOP) for server room and server maintenance and operations.

- Database synchronization on a daily basis (user defined) to Disaster Recovery Site (DRS).

Refer SRS in Annexure for details.

4.2.3 R3. Disaster Recovery Site (DRS)

It is indispensable for NCHM to have a proper Disaster Recovery Site (DRS) for unforeseen disasters. It is suggested for NCHM to set up a DRS at Bumthang Regional Office with following capabilities;

- Replication of NCHM Head office servers and applications
- Backup power
- Main internet line with Redundant line (BT/ TashiCell/ Satellite.)
- Proper Data Server room amenities and infrastructure,
- Standard Operating Procedure (SOP) for server room and server maintenance and operation.
- Database synchronization on a daily basis (user defined).

Refer System Specification Document (Annexure)

4.2.4 R4. Development of Human Resource Capacity and Knowledge Management

Several officers in NCHM are dealing with different databases and applications such as separate officers for HYDATA, Climsoft, IMS, SEBA Hydro centre, etc. At the moment officials are working on their own systems only and there is a limited mechanism to share knowledge among themselves. Hence, they are not aware of workings of other systems and at times there are voids in the system whereby no one could operate a system if the particular person is not available. It is suggested to develop the HR capacity of the relevant officials and enhance knowledge sharing mechanism through the following measures;

- Setting up of a dedicated IT officer for the centre whose main responsibility is on the database and server management without other duplicating responsibilities. He/she may also need a backup in case of transfer/ resignation or further studies.
- Establishment of central knowledge repository of SOPs/ Manuals / Issues logs with solutions etc of all systems.
- Formal knowledge sharing through training, seminars, and workshops.
- Conduct social gatherings, events, or team lunch of all personnel involved in database and IT-related works of NCHM to encourage informal knowledge sharing.
- Presentation of issues, challenges, and solutions on a monthly basis for IT/data-related tasks.

5 Appendix 1 – List of Control Center & Stations

5.1 WANGDI CONTROL CENTER & STATIONS

Sl. #	Location	Station Details
LUNANA AREA		
1	Thanza/Thenchy	Siren Station
2	Tshojo	Siren Station
3	Lhedi	Siren Station
MOCHHU		
4	Tastsemakhang	Automatic Weather Station & Water Level Station
5	Tashithang	Water Level Station
6	Yebessa	Water Level Station
TARINA		
7	Tanina – Wachey	Automatic Weather Station & Water Level Station
THANZA, LUNANA		
8	Luggy	Water Level Station
9	Thorthomi	Water Level Station
10	Rapstreng	Water Level Station
11	Bayo Tsho	Water Level Station
12	Thanza	Automatic Weather Station and Water Level Station
DANGSA, TAMENA		
13	Tarina – Wachey	Automatic Weather Station & Water Level Station
WANGDI – PUNAKHA VALLEY		
14	Wangdi-Punakha valley	15 Siren Stations in the valley and 3 sirens in Lunana area.

5.2 MHEP CONTROL CENTER & STATIONS

Sl. #	Location	Station Details
1	MHEP	Control Centre
2	Jongthang	Observation Station
3	Bjizam	Observation Station

4	Bjizam Village	Siren Tower
4	Dam Site	Siren Tower
5	Power Plant	Siren Tower

Table 9: MHEP Control Centre

5.3 LIST OF EQUIPMENT at Trongsa Control Centre

Sl.#	Equipment Details	Age	Qty	Operational Condition
1	Data collection and Processing			
	- DELL PC SET - Voice Command Equipment - Telemetry Controller			
2	Backup - Data collection and Processing			
	- DELL PC SET - Voice Command Equipment - Telemetry Controller			

5.4 KURJEY CONTROL CENTER & STATIONS

Sl. #	Location	Station Details
1	Tsampa	Observation Station
2	Kagthang	Observation Station
3	Kurjey	Observation Station
4	Choekhor Toe	Siren Tower
5	Kurjey Village	Siren Tower
6	Wangdicholing	Siren Tower
7	Bumthang	Siren Tower
8	Gangrithang	Siren Tower
9	Geylkhar Village	Siren Tower

Table 10: Kurjey Control Center

5.5 LIST OF EQUIPMENT at Bumthang Control Center

Sl.#	Equipment Details	Age	Qty	Operational Condition
1	Data collection and Processing			
	- DELL PC SET - Voice Command Equipment - Telemetry Controller			
2	Backup - Data collection and Processing			
	- DELL PC SET - Voice Command Equipment - Telemetry Controller			
3	Server Room equipment List			

5.6 LIST OF EQUIPMENT at Paro International Airport Aviation Meteorology

Sl.#	Equipment Details	Age	Qty	Operational Condition
1	IMS Central Computer			
	FUJITSU PC Server 19" rack mountable	2 Years	2	Good
	IMS Client computer			
2	PC FUJITSU Esprimo	2 Years	5	Good
3	IMS4 AWOS Application Software for Central System SERVERS	2 Years	1	Good
4	SRun software	2 Years	1	Good
5	AWS Services software	2 Years	1	Good

5.7 LIST OF EQUIPMENT at Bumthang/ Yongphula and Gelephu Domestic Airport Aviation Meteorology

Sl.#	Equipment Details	Age	Qty	Operational Condition
1	IMS Central Computer			
	PC Server Floorstand Tower, FUJITSU, TX150S8R (Intel Xeon E5-2400 CPU, 8GB RAM, Gigabit LAN, DVDRW, SAS 3G HW RAID1 with	6 Years	3	Good

	2x 300GB SAS HDD, Std PSU, iRMC-S2), OEM Win 2008 SVR)			
2	IMS Client Computer			
	PC FUJITSU Esprimo P520 (Intel Core i7-4770, 4GB RAM, 500GB SATA HDD, DRW, DVD+-RW, Win8Pro+Win7Pro)	6 Years	6	Good
3	IMS 4.0 Central Single (AWOS Central Server), IMS/CC/S-J, MicroStep-MIS, Version 4.1 BT20140507	6 Years	3	Good
4	IMS 4.0 AWD, IMS/AWD-J, MicroStep-MIS, 4.1 BT20140507	6 Years	3	Good
5	AMS 111 Basic Meteo Software (data-logger), PL-SWBM, MicroStep-MIS	6 Years	3	Good

6 Appendix 2 - Implementation Plan and Cost Estimation

The execution plan for the Hydro-Met Database Management System (HDMS) and IT Infrastructures of NCHM is phased out in three phases for smooth and staggered implementation. Phase 1 is proposed to be implemented in the immediate future within the next 3 years as they are of priority and critical for the function of the centre. These are activities required within the 12th FYP. Phase Two is proposed for the medium term within the first half of the 13th FYP in the next 3-5 years. Finally, the activities in the third phase are to be implemented in the long term between next 5-10 years. The details of activities and their tentative costing are listed in the implementation plan below.

6.1 HDMS implementation plan

Phases	Modules/ Activities	Approximate Cost (USD)
Phase 1	1. Core Module - System Management	$ 150,000.00
	- Data Management	
	2. WCS Module	
	3. MIS Module	
	4. Website and Data Sharing Module	
	Total estimated cost (USD)	**$ 150,000.00**
Phase 2	1. Hydrology Module	$ 150,000.00
	2. Data Management ● Update hydrology requirements	
	3. MIS Module ● Update Maintenance and Instrumentation requirements	
	4. EWS Module	
	Total estimated cost (USD)	**$ 150,000.00**
Phase 3	1. Cryosphere Services Module	$ 100,000.00
	2. Data Management ▪ Update cryosphere requirements	
	3. HWRS Module ● Update hydrology module with cryosphere requirements	
	4. MIS Module ● Update MIS module with cryosphere requirements	
	Total estimated cost (USD)	**$ 100,000.00**
	Grand Total (estimated cost)	**$ 400,000.00**

Table 16: HDMS implementation Plan with cost

6.2 Hardware implementation plan

PHASE 1

Sl.	Item/Specification	Qty	Rate (USD)	Total (USD)
1	**DB Server** - Form Factor: 1U - Processor: 2 x minimum 2.8GHz/16-Core CPU - Memory: 128GB DDR4 RAM - Storage: 2 x 300GB SAS 12G 10K SFF HDD; 4 x 1.8TB SAS 12G 10K SFF HDD - RAID Controller: Should offer RAID 0,1,5,6,10 with 2GB cache - Network: 1 x 4-Port 1Gbps NIC - Redundant power supply, rail kit	2	$15,000	$30,000.00
2	**Application Server** - Form Factor: 1U - Processor: 2 x minimum 2.1GHz/24-Core CPU - Memory: 128GB DDR4 RAM - Storage: 2 x 600GB SAS 12G 10K SFF HDD - RAID Controller: Should offer RAID 0,1,5,6,10 with 2GB cache - Network: 1 x 4-Port 1Gbps NIC - Redundant power supply, rail kit	1	$15,000.00	$15,000.00
3	**Firewall** - Form Factor: 1U - Minimum 12 x GE RJ45 ports - 1 x dedicated management port - 1 x console port - Firewall throughput: minimum 4.4 Gbps - Firewall Policies: minimum 8000 - Gateway-to-Gateway IPsec VPN tunnels: minimum 1800 - SSL-VPN Throughput: minimum 250 Mbps - High availability Active/Active, Active/Passive - Minimum feature that should be available - Should offer single pane-of-glass platform - Should be able to control applications, block the latest exploits and filter web traffic based on millions of real-time URL ratings	1	$5,000.00	$5,000.00

	- Should automatically prevent, detect, and mitigate advanced attacks - Should offer real-time intelligence on the threat landscape			
4	**Switch** - Form Factor: 1U - Minimum 24 x RJ45 GE Ports - ComboPorts - 2 SFP slots, 2 GE combo - Memory: Minimum 256MB - Switching Capacity: minimum 50 Gbps - Layer 2 Switching (minimum): 802.1d STP support, 802.3ad LACP support, DHCP relay - Layer 3 (minimum): IPv4 routing, configuration of layer 3 interface on physical port, LAG, VLAN interface, or loopback interface, classless interdomain routing, DHCP server role support, DHCP relay at layer 3 support.	1	$700	$700
			Total Estimated cost (USD)	**$50,700.00**

PHASE 2

Sl.	Item/Specification	Qty	Rate (USD)	Total (USD)
	DB Server (Control Centres) - Form Factor: 1U - Processor: 2 x minimum 2.8GHz/16-Core CPU - Memory: 128GB DDR4 RAM - Storage: 2 x 300GB SAS 12G 10K SFF HDD; 4 x 1.8TB SAS 12G 10K SFF HDD - RAID Controller: Should offer RAID 0,1,5,6,10 with 2GB cache - Network: 1 x 4-Port 1Gbps NIC - Redundant power supply, rail kit	3	$15,000	$45,000.00
	Application Server (Control Centres) - Form Factor: 1U - Processor: 2 x minimum 2.1GHz/24-Core CPU - Memory: 128GB DDR4 RAM - Storage: 2 x 600GB SAS 12G 10K SFF HDD - RAID Controller: Should offer RAID 0,1,5,6,10 with 2GB cache - Network: 1 x 4-Port 1Gbps NIC - Redundant power supply, rail kit	3	$15,000.00	$45,000.00

1	**Switch (Control Centres)** - Form Factor: 1U - Minimum 24 x RJ45 GE Ports - ComboPorts - 2 SFP slots, 2 GE combo - Memory: Minimum 256MB - Switching Capacity: minimum 50 Gbps - Layer 2 Switching (minimum): 802.1d STP support, 802.3ad LACP supported relay - Layer 3 (minimum): IPv4 routing, configuration of layer 3 interface on physical port, LAG, VLAN interface, or loopback interface, classless interdomain routing, DHCP server role support, DHCP relay at layer 3 support.	3	$700	$2,100
3	**Firewall (Control Centres)** - Minimum 4 x GE RJ45 Switch Ports - 1 x dedicated WAN port - 1 x console port - Firewall throughput: minimum 950 Mbps - Firewall policies: minimum 4000 - Gateway-to-Gateway IPsec VPN tunnels: minimum 150 - SSL-VPN Throughput: minimum 35 Mbps - Minimum feature that should be available - Should offer single pane-of-glass platform - Should be able to control applications, block the latest exploits and filter web traffic based on millions of real-time URL ratings - Should automatically prevent, detect, and mitigate advanced attacks - Should offer real-time intelligence on the threat landscape	3	1,000.00	3,000.00
4	Backup UPS	1	$15,000	$15,000
5	Diesel Generator	1	$10,000	$10,000
			Total Estimate Cost (USD)	$120,100

Table 17: Hardware implementation Plan with cost

6.3 Summary of Estimated Cost

PHASE 1

Location	HDMS	Hardware	Total Amount
Production Site cost	$150,000	$50,700	$200,700
DR Site Setup cost	0	$50,000	$50,000
	Total estimated cost (USD)		**$250,700**

PHASE 2

Location	HDMS	Hardware	Total Amount
Production Site	$150,000	$0	$150,000
Control centres	$0	$120,100	$120,100
	Total estimated cost (USD)		**$270,100**

PHASE 3

Location	HDMS	Hardware	Total Amount
Production Site	$100,000	$	$180,100
Control Centres	$0	$	$0
	Total estimated cost (USD)		**$180,000**

7 Appendix 3 - Meeting Officials

Following are the list of officials met and meetings conducted as part of the assessment

Date	Task	Remarks
May 6, 2020	Kick Off Meeting at NCHM	Meeting with Director, Chiefs of Divisions and Project Manager (GCF- UNDP)
May 12, 2020	Site visit and Meeting at Paro Civil Aviation Meteorology Unit	Sonam Rabten and team of Aviation Met Section, WCSD, Paro International Airport. Kuenzang Dorji, Project Manager.
May 13, 2020	Site assessment and Meeting at Weather and Climate Services Division	Pema Syaldon, Kuenzang Dorji
May 14, 2020	Site assessment and Meeting at Hydrology and Water Resources Division	Tayba Buddha Tamang, Chief, Chhimi Namgyel, Yeshi Choki, Sangay Tenzin
May 15, 2020	Site assessment and Meeting at Cryosphere Services Division	Phuntsho Tshering, Wangchuk Namgyel
June 22 & June 24, 2020	Meeting with Hydromet Operations and Infrastructure Division	Jangchub Chhophel, Engineer,
May 29 – June 3, 2020	Trongsa, Bumthang, Wangdue Phodrang site visit Jangchub Choephel, Engineer and Tshencho Dorji, PM	MHEP system at Bjezam, Trongsa Rainstorm and GLOF FEWS system at Kurjey, Bumthang and of GLOF EWS system at Wangdue Phodrang.
June 17	Consultation meeting	Project Manager
June 26, 2020	Presentation to NCHM of Inception Report and Concept Plan	NCHM Management including the Director, Chiefs and all divisions.
July 22, 2020	Discussion meetings	More understanding of SEBA HydroCenter from HOID. Trashi Namgyel.
July 27, 2020	Consultation Workshop with NCHM officials	Discussion on functional requirements for each division.

Meeting: GCF meeting for requirement of report, products and information
Venue: formats for Database Management System
Date: 27th July, 2020, Mini Conference Hall

Sl No	Name	Designation/Division	Signature
1	Tshewang Dorji	Dy.Chief/PM/HRSD	
2	Tandin Wangchuk	Dy. GE	
3	Sangay Choephel Dorji	Hydrological Officer	
4.	Chimi Namgyel	Statistician	
5.	Wangchuk Nangay	Geologist	
6.	Sonam Wangmo	Hydro-Met. Tech.	
7	Tashi Namgyal	Dy. Exec. E	
8	Thinley Wangchuk	Hydro-Met Officer	
9	Nima Tshering	Consultant	
10	Chimi Dorji	"	
11	Chimi Wangchuk	Technician/HRSD	
12	Tshering Tashi	Hydro-met officer/CSD	
13	Phuntsho Wangmo	Asst. Envt officer	

8 Appendix 4 - Server Details

According to information provided by the IT officer, following are the existing servers.

Sl. no	Equipment Details (Brand, Capacity, Speed)	Function / Purpose	Age	Operational Condition	Model	Specifications	Storage	Operating System	Application	Database	Remarks (Description of any problems)
1	Weather Research and Forecasting model (WRF)	It downloads the data from NCEP at NOAA using FT. This data has to undergo certain processing before giving the final output to GRADSC usually in the graphical image.		Yes	Dell PowerEdge R730	28 core Intel(R) Xeon(R) CPU E5-2697 v3 @ 2.6 GHz Ram:64GB	3TB	CentOS Linux 7	php	MySQL 5.5.44	
2	Data Management System (DMS)	It is a system that automatically collects real time data of weather and water parameters from the field station and feeds in the database at Head Quarter.		yes	Dell PowerEdge R430	12 core Intel(R) Xeon(R) CPU E5-2620 v3 @2.40GHz Ram 32 GB	2 TB	Linux (SMP Debian 3.16.7)	NodeJS	MySQL 5.5	
3	DHMS Web portal and system(old)	This is a portal as well as system that is capable of feeding in real time data with respect to temperature, pressure, wind speed and direction into the portal. It will give all the forecast related to weather and flood related events.		yes	Dell PowerEdge 2900	Dual core Inter(R) Xeon(R) 5160 @3.00GHz Ram 4GB	1 TB	Debian GNU/Linux 8 (jessie)	Jooma	MySQL	
4	GLOF SUTRON early warning system at Wangdue	Advance Web Information portal and control GUI, For GLACIAL LAKE OUTBURST FLOOD early warning system to the Vulnerable communities, Dzo, DDM, PHPA									
5	GLOF JICA EWS at Bumthang and Trongsa	Control GUI, For GLACIAL LAKE OUTBURST FLOOD early warning system to the Vulnerable communities, Dzo, DDM, along Mangde chhu and Chamkhar chuu basin									
6	IMS	Stores NAPA Station's Data for Meteorology(automatic Weather Station)		yes	HP Proliant DL580 Gen8 Version P79	24 core Intel Xeon E7-4860 v2 @ 2.6 GHz Ram 64 GB	2TB	Centos 7	java		

7	SEBA hydro Centre	Stores Hydrological Data for Hydrological automatic stations		yes	HP Proliant DL580 Gen8	Intel(R) Xeon CPU E7-4860 v2 @2.6GHz 2.6GHz (2 processors) Ram 64GB 2TB SSD	2 TB	Windows Server 2012 R2 Standard	PHP web based	MySQL 5.7	
8	FWS server	Stores FWS hydrological station data		no	PowerEdge T110 II	Quad Core Genuine Intel 1600MHz Ram 8GB	1TB	Debian 3.2.65	PHP web based	MySQL 5.7	
9	SAARC Storm Server	Stores meteorological data for SAARC STORM									
10	Cryosphere Information Centre	Stores information on studies done on cryosphere									
11	DANIDA RS System	Stores 10 Meteorological data									
12	CLIMSOFT	Stores Meteorological Data Class C and Class A met stations									
13	HYDATA	Stores Principle, Secondary and Sediment Stations data									
14	SMART MET system	Central system for weather forecasting									
15	Web Server	Displays information about NCHM and its services									

9 Appendix 5 – System Requirement Specification