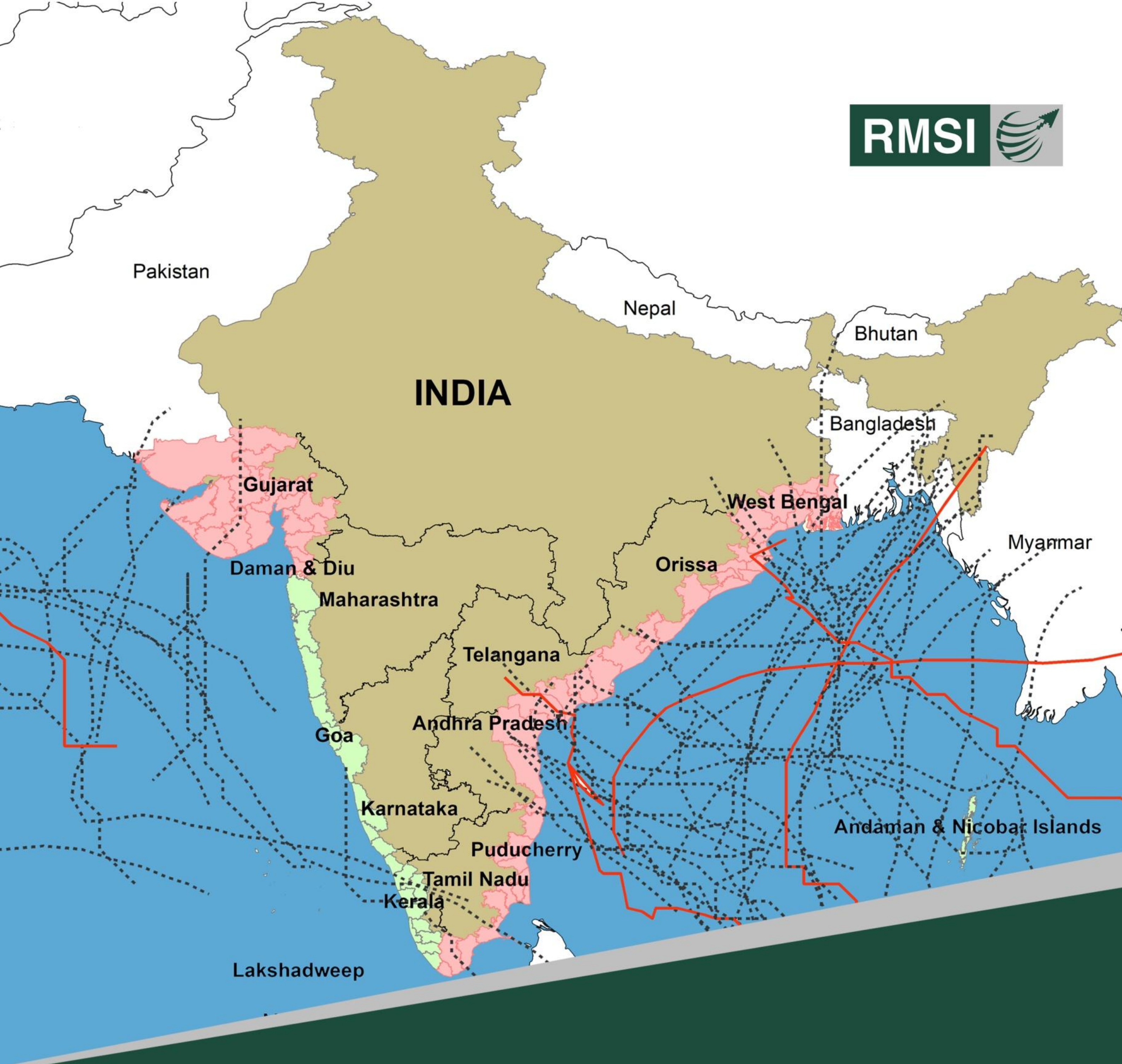

Development of Web-DCRA and DSS Tool for Cyclone and associated impacts including Storm Surge and Inland Flooding under NCRMP (Phase-II)

Inception Report (Revised)

July 2018

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Executive Summary

The Indian coast is highly vulnerable to natural hazards, particularly to severe cyclones and cyclone induced heavy rainfall and flooding. The National Cyclone Risk Mitigation Project (NCRMP) is a pioneer project of the Ministry of Home Affairs (MHA), Government of India (GOI) and is being implemented through NDMA with the financial support of the World Bank. The aim of NCRMP is to create suitable physical infrastructure to mitigate/reduce the adverse effects of cyclones.

The project has been divided into two phases. The first phase focused on developing a Web-based Composite Risk Atlas (Web-CRA) that is capable of identifying hotspots of high vulnerability coastal areas for communities at-risk. Accordingly, Hazard, Vulnerability and Risk Assessment (HVRA) study was conducted as one of the activity of NCRMP–I, and a Web-CRA was developed. This study was successfully completed by RMSI in 2016. This web-based risk assessment system provides the concerned stakeholders with a risk assessment framework that offers cross-cutting decision support for mitigation planning at all levels of Government - Central, State, District, Taluka/Tehsil/Mandal (Taluka), City/Town and Village.

It was realized that in addition to the above, mitigation planning (static pre-event planning) and dynamic response (responding to a real-time cyclone) for cyclone prone States/UTs was needed. Thus, this second phase was conceptualized with very specific objectives including:

- Development of Probabilistic Risk Assessment Maps / Products (stochastic scenario based approach to Probabilistic Risk Modeling) for depiction of cyclone risk and storm surge flooding / coastal flooding vulnerability maps for the coastline of India (not a real-time product)
- Development of Dynamic Web-Composite Risk Atlas (WEB-DCRA) for real-time analysis of impending cyclonic events (real-time product, Decision Support Tool)

It is expected that development of probabilistic risk assessment maps/products for cyclonic wind, storm surge and rainfall induced flooding and demonstrating them through interactive map viewer would be completed in 3 months from the date of contract signing. The development of Alpha version of WEB-DCRA/DSS, DRCA App., and their demonstration and presentation to key stakeholders is expected in 5 months from the date of contract signing. The Beta version and operational WEB-DCRA/DSS, DRCA App., and offline Desktop version of Web-CRA including a closure report is expected in 7 months from the date of contract signing. Further, experimental phase, and training and capacity building activities shall be carried out from 8th to 20th months after development (experimental phase).

To accomplish the above tasks, RMSI project team has initiated the work on hazard mapping and risk assessment for stochastic cyclone event sets using high-resolution numerical storm surge, hydrologic and hydraulic models, and statistical methods and GIS techniques. The modeling team is using ADvanced CIRCulation (ADCIRC) model for cyclone/ storm surge event modeling, and HEC-RAS and HEC-HMS for modeling of cyclone-induced rainfall flooding events.

These models would be imbedded into the Web-DCRA, which would provide specific and quantitative information of the exposure to a real-time cyclone event and generate information products to support decision-making at the State and District levels. The project team will also present the functionality and usage of WEB-DCRA, Offline Exposure Management, and Mobile APP to the PMU and the key stakeholders (NDMA, National Agencies, Senior Level State Officials, and key Middle Level State Officials) through various National/state level workshops.

The present report, the inception report, is the first deliverable of this assignment, and includes methodology proposed for the study, deliverables, and work plan.

As mentioned above, the highly sophisticated models such as dynamic storm model, ADCIRC storm surge model and HEC-RTS that is in open source for cyclone-induced rainfall flooding mapping are being used for the present assignment. These models use a combination of various methods and tools to drive cyclone induced multi-hazard modeling. These include cyclone frequency and severity analysis, assessment of wind fields and surge heights and associated flood inundation mapping, rainfall analysis, hydrological assessment for rainfall runoff relationships, and hydraulic modeling for flood inundation mapping.

The outcomes of these models, i.e., wind speed, surge flood, and cyclone induced rainfall flood, along with exposure vulnerability functions would be integrated in WEB-DCRA application for risk assessment. For the development of Web-DCRA, RMSI team is using web GIS based software, which are being developed on GeoNode technology. GeoNode is an open source platform that facilitates the creation, sharing, and collaborative use of geospatial data.

Following are the key methodological steps involved in the present study.

Exposure Module: As part of NCRMP Phase-I, Hazard, Vulnerability and Risk Assessment (HVRA) study for cyclonic winds, storm surge and flooding for 13 coastal states/UTs, RMSI team had collected a wide range of datasets from various sources. These sources include Central (IMD, NRSC, GSI, FSI, NHO, Census of India, CWC etc.), State Government Departments, academic, and private organizations. The Exposure dataset includes Buildings, Essential Facilities, Infrastructure (including coastal and marine infrastructure) and Demographics for all the coastal districts up to 10-meter elevation. RMSI team plans to enhance the same exposure dataset wherever more recent updates that could be provided by the state of national agencies.

Vulnerability module: For all the exposure elements, a detailed vulnerability analysis was also conducted as part of Phase 1 using vulnerability functions that were developed for all classes of exposure elements (physical vulnerability) and social vulnerability. For the present assignment, team will reuse the same vulnerability functions developed during phase 1 for assessment of impact of probabilistic as well as live events. Wherever it is possible to get additional information that requires updating the vulnerability functions, the same will be attempted as part of this study.

Development of Probabilistic Risk Assessment Maps / Products: A stochastic scenario based approach will be applied to Probabilistic Risk Modeling. Under ‘Stochastic Event Set Generation’ module, thousands of possible event scenarios will be simulated using Monte Carlo simulations based on realistic parameters and historical data. Each cyclone event will be defined by a specific strength, genesis location and path, and probability of occurrence or event rate. Each cyclonic rainfall event will be defined by duration of the event in days (1-day, 2-day, 3-day rainfall events…) and associated daily rainfall. Within the stochastic event set, RMSI project team will also develop near-worst case scenarios of wind-speed, storm surge flood and cyclone induced rainfall flood for each cyclone category based on climate change assessment.

The future projections based on theory and high-resolution dynamical models consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2-11% by 2100 (Knutson et al. 2010). In order to study the effects of climate change, the wind speed will be increased by 7% (an average value) and by 11% (extreme value) over the stochastic events.

The impact of all the stochastic events will be estimated using the above models. These scenarios (including worst-case ones) will demonstrate how various hazards associated with cyclones can impact the population, buildings, infrastructure, agriculture, etc., of the high-risk areas of the country. These scenarios will be communicated through Probabilistic Risk Assessment Products that include return period hazard and risk maps, Average Annual Loss (AAL), Loss Exceedance Curves (LEC), Maps by hazard intensity like 1-meter surge risk map, 2-meter surge risk map, etc. This will help disaster managers to understand vulnerability and associated risk, and allow them to undertake advance mitigation planning, planning of evacuation routes and destinations and preparing appropriate emergency preparedness plans. These probabilistic risk assessment products, in the form of pre-compiled worst-case scenarios for each State/UT, would also be made available in the WEB-DCRA.

Real-time Decision Support Tool (Web-based Dynamic Composite Risk Atlas):
The process of real time cyclone-event impact assessment and communication of results as part of the Web-DCRA will include Hazard and Risk Model Automation. This would be accomplished by using ADCIRC and HEC-RTS models to be automated to run through the Web based Dynamic Risk Atlas (Web-DCRA). The Web-DCRA will take real time input data, namely cyclone track details and rainfall from sources like IMD, JAXA, etc., to generate real-time analysis of an impending cyclone.

Validation of Web-DCRA: In order to validate the models during real-time events, data from the field or other national/global sources will be collected and the model will be run again with updated information to redisplay the hazard maps and associated exposed assets and loss estimates. An attempt will also be made to compare the simulated sea surface elevations with observations from local tide gauges wherever possible or with post storm surveys in experimental phase.

The Offline version of Web-CRA for exposure management will be created using a Smart Client framework that uses a thick client for desktop user interface and is capable of connecting to a database that could be on a desktop or on any computer on the LAN. Capability to auto-synchronize with the Web-CRA server will be implemented in the Smart Client.

The WEB-DCRA will be supplemented by an Android based Mobile App that will serve key features such as By clicking 'I AM SAFE' button the system will send SMS alert to predefined numbers.

One of the significant features of the web-DCRA will be its ability to investigate multiple real time forecast scenarios. For example, as the cyclonic storm moves nearer to the coast and IMD forecast of landfall becomes more accurate, the track of the cyclone will be updated at regular time intervals.

The overlay analysis will identify the exposure elements at risk. The vulnerability and risk mapping modules imbedded in the Web-DCRA will identify and quantify the losses in monetary terms due to all the three hazard components of a cyclone.

Offline Web-CRA (Desktop version): Team will develop a smart client based application to update exposure database. The Smart Client Application will have a desktop-based client that can connect to a database that is on the desktop on the LAN. Following are the key capabilities that will be made available through the Smart Client based Offline Web-CRA.

- A user interface that has all the exposure editing capabilities as are available on Web-CRA
- A person with data update privilege to the system will be able to update/modify/delete the exposure database.
- A data approval cycle where the exposure data created or updated by operators is reviewed by predefined reviewers, and approved for update to central server. Reviewer privilege will be provided to support this functionality.
- Auto synchronize capability in the database to update all the approved exposure data changes to the central server whenever internet connectivity becomes available.

WEB-DCRA App - Android based mobile phone application: A mobile-based WEB-DCRA App application will be developed that will provide below mentioned functionalities on smart-phones:

- Simple registration process to receive alerts in case of an impending disaster event like SMS and pre-recorded voice alerts regarding potential for impact, what they can do to reduce losses, etc.
- "I AM SAFE" feature: By clicking 'I AM SAFE' button the system will send SMS alert to predefined numbers. This will help the user relatives that the user is safe and a considerable effort will be reduced to search these people.
- Crowd Sourcing feature to get feedback from people, who want to submit information related to event such as Status of flooding, Approximate wind speed, surge height, Damage description, Need to be evacuated, Need Emergency Medical help" etc.

Training and Capacity building support: The information dissemination and capacity building through training and workshops is a key component of the project. The project team, with the help of NDMA, will involve disaster managers from all the 13 coastal states/UTs from the inception phase of this assignment. The outputs of this current Phase including the Enhanced Web-CRA with probabilistic analysis, web-based DCRA, WEB-DCRA app, Offline version of Web-CRA for exposure management and documentation, will be presented and demonstrated through workshops involving PMU-NCRMP, research and scientific organizations, and other identified stakeholders.

The state outreach trainings will be carried out twice in experimental phase ***(a total of 14 State Outreach trainings covering all the 13 States/UTs)*** starting from the demonstration of fully operational *WEB-DCRA, Updated Web-CRA, Offline Exposure Management and Mobile APP*. The dates and schedules of these trainings will be decided in consultation with NDMA and concerned state stakeholders.

Key States/UTs' Government representatives will be trained on the web-DCRA and the WEB-DCRA app so that they are equipped to further train officials as the need arises. Training and documentation will ensure sustainability of the project even after RMSI team hands over the project and the deliverables to PMU-NCRMP.

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Abbreviations Used

ADCIRC	ADvanced CIRCulation
CWC	Central Water Commission
DEM	Digital Elevation Model
DRM	Disaster Risk Management
DSS	Decision Support System
DTM	Digital Terrain Model
FE	Finite Element
FIA	Federal Insurance Administration
FEMA	Federal Emergency Management Administration
FIT	Flood Information Tool
GIS	Geographic Information System
GOI	Government of India
HEC	Hydrological Engineering Centre
HEC-RAS	Hydrologic Engineering Centre – River Analysis System
HMS	Hydrological Modeling System
HTTP	Hyper Text Transfer Protocol
HVRA	Hazard Vulnerability and Risk Assessment
IBTrACS	International Best Track Archive for Climate Stewardship
IMD	Indian Meteorological Department
INCOIS	Indian National Centre for Ocean Information System
JTWC	Joint Typhoon Warning Center
LULC	Land Use Land Cover
MDR	Mean Damage Ratio
MHA	Ministry of Home Affairs
MoEF	Ministry of Environment and Forest
MSL	Mean Sea Level
NCRMP	National Cyclone Risk Mitigation Project
NDMA	National Disaster Management Authority
NED	National Elevation Dataset
NGDC	National Geophysical Data Centre
NHAI	National Highway Authority of India
NHC	National Hurricane Centre
NHO	National Hydrographic Office
NRSC	National Remote Sensing Centre
PDSS	Puducherry Decision Support System
PMU	Project Management Unit
QC	Quality Control
RAS	River Analysis System
SDI	Spatial Data Infrastructures
SOI	Survey of India
SoVI	Social Vulnerability Index
SQA	Software Quality Analyst
SRS	System requirement Specification

SRTM	Shuttle Radar Topography Mission
UH	Unit Hydrograph
UNDP	United Nations Development Programme
USACE	US Army Corps of Engineers
WMO	World Meteorological Organization
WMS	Web Mapping Services

1 Introduction

1.1 Background

The Indian coast is highly vulnerable to natural hazards, particularly to severe cyclones and cyclone induced heavy rainfall and flooding. It has been observed that 5,700 kilometers of India's coastline (>75%) is highly vulnerable to the impacts of tropical cyclones and related hydro-meteorological hazards. This results in recurrent losses of life and property, with the country incurring huge damage costs. India is taking initiatives to develop a proactive approach in integrating disaster mitigation in development planning.

The Government of India had initiated the National Cyclone Risk Mitigation Project (NCRMP) in 2011 with a view to address cyclone risks in the country. The Project had identified 13 cyclone-prone States and Union Territories (UTs), with varying levels of vulnerability. National Disaster Management Authority (NDMA) under the aegis of Ministry of Home Affairs (MHA) was tasked to implement the Project in coordination with participating State Governments and the National Institute for Disaster Management (NIDM).

The aim of NCRMP is to create suitable physical infrastructure to mitigate/ reduce the adverse effects of cyclones. In order to address cyclone risks in the country, NCRMP in 2011 through NDMA with World Bank assistance has been divided into two phases – as part of the ***one of the activity of first phase*** focused into developing a Composite Risk Atlas that is capable of identifying hotspots of high vulnerability coastal areas for communities at-risk. The aim was to enable support for land use planning, shelter planning, evacuation routing, emergency and contingency planning. In accordance with the planning, Hazard, Vulnerability and Risk Assessment (HVRA) study was conducted as part of NCRMP-I, and a Web-based Composite Risk Atlas (Web-CRA) was developed. ***This study was successfully completed by RMSI in 2016***. This web-based risk assessment system provides the concerned stakeholders with a comprehensive risk assessment framework that offers cross-cutting decision support for mitigation planning at all levels of Government-Central, State, District, Taluka/Tehsil/Mandal (Taluka), City/Town and Village.

It was realized that in addition to the above, mitigation planning (static pre-event planning) and dynamic response (responding to a real-time cyclone) for cyclone prone States/UTs was needed. Thus, this activity in second phase was conceptualized with the very specific objectives, which are given in the next section.

1.2 Objectives of the Study

The objectives of the study are to provide a robust scientific and practical basis for assessing qualitative and quantitative risk from cyclone hazard for the 13 coastal States/UTs of India. The main objectives of the study include:

- Developing probabilistic products for depiction of cyclone risk and storm surge flooding / coastal flooding vulnerability maps for the coastal line of India (not a real-time product)
- Enhancing Web-CRA with capability for dynamic risk assessment of an impending cyclone (Web-DCRA)
- Providing specific and quantitative information of the exposure to a real-time cyclone event and generation of information products to support decision making at the State/District and Local level (real-time product, including development of Decision Support Tool)
- Adding capability in Web-CRA to work in offline (desktop) mode for updating the exposure database
- Developing impact graphics and standardizing the products in consultation with IMD, NDMA, MHA and other key Government and Scientific Institutions

- Developing communication protocol on the products developed and enhancing the analytics and prediction capability over a period of 18 months after development (experimental phase)
- Providing training and capacity building support on the Decision Support Tool to the designated officers of the National and State/UT administration and the Coastal District Administration (during the experimental phase)
- Developing a DCRA app that will enable users to access features of DCRA and cyclone events specific to study area through location based technology. For example, in the event of a hazard it helps people to prepare their family and home, find help, facilities/ evacuation routes and let others know they are safe in the hazard event. Perhaps one of the most comforting features on the App is the "We're safe" button. At the press of a button this message will be sent to anyone entered on user's preloaded list of contacts

A key objective that our team considers extremely important is availability of appropriate detailed documentation on the web-DCRA as well as the DCRA app. These documents will explain the operation and administration of the tools in a user-friendly manner. RMSI team would ensure that all the knowledge is transmitted to the concerned officials for smooth functioning of the system even after the project is over.

1.3 Study Area and Scope of the Study

1.3.1 STUDY AREA

The study area includes the coastal stretches that lie up to 10 m MSL in the districts of the 13 States/UTs, which are vulnerable to cyclone hazard (Figure 1-1). The landward boundary of the model is fixed from the coast based on 10 m topo contour, presuming that the surge would never exceed 10 m in this region.

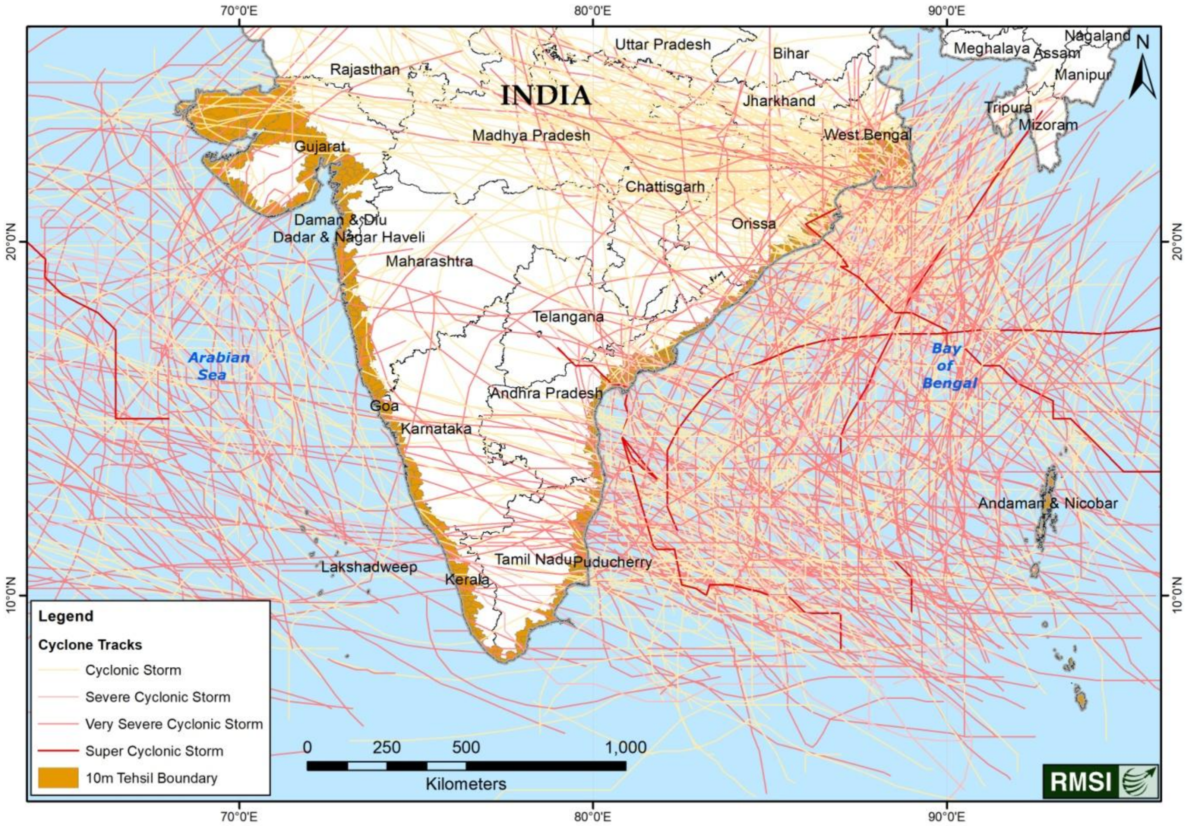


Figure 1-1: States'/UTs' coastal Talukas with land area falling up to the 10 m MSL limit along with cyclone tracks

1.3.2 SCOPE OF THE STUDY

The Scope of Services involves the development of a web-based Decision Support System (Web-DSS) that will inform a risk management framework for decision makers in the States/UTs and the Central Government to take mitigation steps to protect the people and assets of the country during a real-time cyclone event. The hazard, exposure and vulnerability assessments that will underpin the Dynamic Composite Risk Atlas (WEB-DCRA) for the 13 coastal States/UTs are provided in the next section and subsections.

1.3.2.1 Methodology development

As mentioned earlier during Phase-1, team had established a robust, scientifically founded methodology for assessing multi-peril cyclone hazard, exposure, vulnerability and risk within the 13 States/ UTs, in consultation with the NDMA, SDMAs, the Relief Commissioners, other key stakeholders and current best practice. The methodology will consider risk assessment needs at a hierarchy of spatial scales from macro to micro, spanning state/district/mandal/taluka/village/habitation levels.

1.3.2.2 Data review

As part of this assignment, the RMSI team will analyze the pre-existing exposure data collected during Phase-1 and enhance them with the latest data available with state of national agencies. For all the exposure elements, a detailed vulnerability analysis was also conducted as part of Phase 1 using which vulnerability functions were developed for all classes of exposure. RMSI team will explore the possibility to update the vulnerability functions (if required) for assessment of impact of probabilistic as well as live events.

The hazard models and Web-CRA developed under Phase-1 were designed with considerations for future Phase II requirements for dynamic modeling and decision support. Hence, model and application will be enhanced for real-time analysis, and functionalities in the WEB-DCRA app.

1.3.2.3 Training

RMSI will produce a Training and Capacity Building plan and relevant training materials aimed at key personnel within each of the 13 coastal States/UTs. The training will focus on: (a) operational scenarios where the Probabilistic Risk Assessment Maps will be used; (b) practical use of the Web-DCRA, Web-DCRA app and Offline version of Web-CRA for exposure management; (c) federated and collaborative use of the system.

The identification of officials to be trained will be done in consultation with the PMU, NCRMP, and NDMA, which shall then conduct the training program for these officials during two national workshops and 14 state outreach Training Sessions.

2 Methodology for the Development of Model and Output Expected

2.1 Inception Meeting

In close coordination with PMU, the RMSI team will undertake a project inception meeting for presentation and brainstorming on its methodology for the development of the Dynamic Web-Composite Risk Atlas (Web-DCRA) and for planning project management and communication activities. Since, this will be the first guiding meeting, the RMSI team would request PMU to invite representatives from all the 13 coastal states/UTs and expert agencies' like IMD, INCOIS, and SOI to this meeting. This will not only help in involving stakeholders from the project inception stage but will also help in getting early feedbacks on the methodology and various features of Web-DCRA.

Through the inception meeting, the RMSI team will discuss and present the review of available hazard data in Web-CRA and how it will be utilized in developing stochastic models. The team will also present the additional data needed for dynamic modeling of an incoming cyclone event and setup meetings with IMD and INCOIS to define the process in which that will be made available to Web-DCRA. In addition, the team will discuss exposure data currently available in Web-CRA with an objective of identifying exposure data updating opportunities, especially the coastal and marine infrastructure. Based on the inputs from the state and national agencies on availability of new exposure data, the team will plan on further interactions with the concerned agencies to integrate additional/modified exposure datasets into Web-DCRA.

The team will discuss the decision support framework for prototype development of Web-DCRA with all the stakeholders.

The meeting will also help in setting project management guidelines for timely progress monitoring against the set targets and communication of the results to the client-working group.

2.2 Data Requirements and Availability

As part of NCRMP Phase-I, Hazard, Vulnerability and Risk Assessment (HVRA) study for cyclonic winds, storm surge and flooding for 13 coastal states/UTs, RMSI team had collected a wide range of datasets from various sources including Central Government departments (IMD, NRSC, GSI, FSI, NHO, Census of India, CWC etc.), State Government Departments, academic, and private organizations. The Exposure dataset includes Buildings, Essential Facilities, Infrastructure (including coastal and marine infrastructure) and Demographics for all the coastal districts up to 10-meter elevation. RMSI team plans to enhance the same exposure dataset wherever more recent updates that could be provided by the state of national agencies.

A brief description of this data repository available with RMSI is given in Table 2-1 (data for strong wind, storm surge, and flood modeling) and Table 2-2 (exposure data).

Table 2-1: Data Type and Sources Utilized in Creating Hazard, Risk & Vulnerability Composite Risk Atlas under NCRMP Phase-I

S. No.	Data Description	Data Source	Remarks
1	Cyclone track and intensity data since 1877 AD	India Meteorological Department (IMD)	Cyclone tracks and intensity data from 1877-2014 is available in Web-CRA (as part of Phase -1). Cyclone tracks and intensity data

S. No.	Data Description	Data Source	Remarks
			has been updated for the up to 2017 which is available at IMD website (www.imd.gov.in)
2	Bathymetry data having high resolution for shallow sea levels	National Hydro-graphic Office (NHO), Dehradun	RMSI will contact NHO, Dehradun through NDMA. Bathymetry data shall be updated if NHO has any further updates on any part of Coastline of India over the Bathymetry data used in Web-CRA (as part of Phase-I)
3	Topographic Data	NRSC-10m elevation data	RMSI will contact NRSC/SOI through NDMA. Topographic data shall be updated if NRSC/SOI has any further update on Coastal Taluka of India over the 10m elevation data used in Web-CRA (as part of Phase-I)
4	Discharge data of rivers on daily/weekly/monthly basis	Central Water Commission (CWC)	Discharge and water level data available from 1970 onwards. RMSI will contact CWC for further updates on Discharge and water level data on daily/weekly/monthly basis for the subsequent years
5	Rainfall Data	IMD	Rainfall data since 1901-2014 is available in Web-CRA (as part of Phase -1). RMSI is further updating this data till 2016 and. will contact IMD for further update on rainfall data for 2017 -18, if available.

Table 2-2: Details of aggregated and site-specific exposures

S. No.	Exposure Elements	Categories	Sub Categories	Remark
1	Buildings	Residential		In Web-CRA, source for building counts is Census 2011, which was further projected for the year 2015 by using growth rate. Now, these will be further projected to the year 2018.
		Commercial		
		Industrial		
		Religious		
		Cultural Heritage sites		
2	Infrastructure	Public Buildings	Government Buildings, Police and Fire station and Safe shelters	In Web-CRA, source for these data are "Related Government Departments, such as Survey of India (SOI), State Disaster Management Authorities (SDMAs), Geodeg.com, RMSI in-house data, Google Earth, Open Street Map".
		Essential Facilities	Schools, Health	
		Transportation	Airports, Bridges, Ports, Roads and Railway lines and stations	

S. No.	Exposure Elements	Categories	Sub Categories	Remark
				These data will be further updated as per their availability.
		Utilities	Potable water, Waste water, Oil and gas, Electric power, Communication systems	In Web-CRA, source for these data are “Telecom Regulatory Authority, Survey of India (SOI), SDMAs, Open Street Map, “Global Energy Observatory”. These data will be further updated as per their availability.
		Other critical infrastructure	Power plant, hazardous storage etc.	
3	Demographics	Census of India		In Web-CRA, source for demographics is Census 2011 that was further projected to 2015. The next Census will be carried out in 2021, however, for Web-DCRA, population projections shall be updated for 2018 using growth rates
4	Admin Boundary	Survey of India	State, District, Taluka, City, Village levels	In Web-CRA, source for Admin Boundary is Survey of India (SOI), Dehradun. These data will be further updated as per their availability.
5	Agriculture and horticulture		Major agriculture crops and natural ecosystems (plantation, mangroves)	In Web-CRA, source for this data is “Ministry of Agriculture, Govt. of India”. (1997-2016) vintage, update will be available season wise. This data is available at district level. It will be distributed at village level by using remote sensing techniques.
6	Ecological assets		Sanctuaries, National parks, Reserve areas, Protected areas and Eco sensitive zone.	In Web-CRA, source for these data are “Ministry of Forests/Space Application Centre (SAC), Google Earth, Wildlife Institute of India.”. These data will be further updated as per their availability.
7	Land-use\Land-cover			In Web-CRA, source for these data is “National Remote Sensing Center”. These data will be further updated as per their availability.
8	Fisherman landing centres	Coastal states/UTs		RMSI will approach the coastal states/UTs through NDMA for providing

S. No.	Exposure Elements	Categories	Sub Categories	Remark
				fisherman landing centres data of their respective states in GIS format. Once received, the same will be incorporated into the Web-DCRA.

The buildings were derived mainly using satellite images as building clusters for residential, commercial, and industrial buildings. The structural details derived from Census 2011 at village/city levels were grouped into 25 combinations and distributed over the building clusters. Out of these 25 combinations, mainly six building structural classes dominate the study area. These classes were further validated through sample-field verification surveys conducted. Wherever data was not available, accepted proxy data were used. Replacement values of various exposure elements were collected from various organizations and field surveys. ***As part of this assignment, the RMSI team will make efforts for updatation of all the above listed parameters with the latest data available during the course of this study.***

2.3 Data Cleansing and Gap Analysis

Data cleaning has already been performed by a series of quality control (QC) checks to identify missing values and to flag suspected values on data used during Phase 1 and the same will be applied to all new data that will be gathered during this assignment.

To recap on the processes followed, two types of data validations were carried out, namely, replacement of erroneous values and supplementing missing values using standard and internationally accepted processes.

Future updates will be applied on above datasets that RMSI team will receive from 13 Coastal States/ UTs' nodal agencies during the execution of this project. For example, there will be better cyclone shelter database than the one that went into the Phase 1 Web-CRA, simply because of recency of the information and construction of additional cyclone shelters since the Phase 1 version of Web-CRA was launched. In addition, aggregated exposure data on various exposure elements will be updated with site-specific data as per its availability.

RMSI team will do a gap analysis and in case of non-availability of data related to any exposure elements, including marine infrastructure, secondary data will be used to fill the gaps.

2.4 Data Inputs for Storm Surge Modeling for Real Time Extreme Events

The principal requirement for the operational use of numerical storm surge model is the availability of accurate data of surface wind field together with a reliable forecast of track of the tropical cyclone. India Meteorological Department (IMD) is the nodal agency of Government of India that issues cyclone-warning bulletins indicating tidal wave / gales / heavy rainfall / cyclone track at every three hours during cyclone genesis to dissipation stage in the North Indian Ocean. This information is publicity available at http://www.rsmcnewdelhi.imd.gov.in. IMD is also responsible for checking the data quality and completeness before delivering the information on public domain. A sample of cyclone warning bulletin is shown in Figure 2-1.

Date/Time(IST)	Position (Lat. ^{0}N/ long. ^{0}E)	Maximum sustained surface wind speed (kmph)	Category of cyclonic disturbance
30/0830	7.5/77.5	60-70 GUSTING TO 80	CYCLONIC STORM
30/1130	7.8/77.0	60-70 GUSTING TO 80	CYCLONIC STROM
30/1730	8.5/75.8	70-75 GUSTING TO 85	CYCLONIC STORM
30/2330	9.0/75.0	80-90 GUSTING TO 100	CYCLONIC STORM
01/0830	9.5/74.2	90-100 GUSTING TO 110	SEVERE CYCLONIC STORM
01/1730	10.4/72.7	95-105 GUSTING TO 115	SEVERE CYCLONIC STORM
02/0830	11.4/71.2	100-110 GUSTING TO 120	SEVERE CYCLONIC STORM
02/1730	12.4/69.7	110-120 GUSTING TO 130	SEVERE CYCLONIC STORM

Warning:

(i) Heavy Rainfall warning:

- Rainfall at most places with heavy to very heavy rainfall at isolated places very likely over south Tamil Nadu & south Kerala during next 24 hours and isolated heavy falls over interior Tamil Nadu and Kerala during subsequent 24 hours.
- Rainfall at most places with heavy to very heavy rainfall at a few places and isolated extremely heavy falls very likely over Lakshadweep area during next 48 hours.

(ii) Wind warning:

Spatial rainfall distribution: Isolated: <25%, A few: 26-50%, Many: 51-75%, Most: 76-100%

Rainfall amount (mm): Heavy rain: 64.5 – 115.5, Very heavy rain: 115.6 – 204.4, Extremely heavy rain: 204.5 or more.

Figure 2-1: Sample of IMD cyclone warning bulletin

The storm surge modeling system will take into account the dynamic information from a real-time cyclone (issued by IMD and other global products) and estimate the potential flooding scenarios for Indian coasts.

2.5 Data inputs for Flood Forecasting

For the real time flood forecasting due to cyclone induced rainfall, the forecasted precipitation data, available from different sources (IMD WRF, IMD GFS, Global GFS), will be used, and the real time observed rainfall data from IMD, JAXA, and TRMM will also be utilized.

The forecasted and real time observed data availability is specified in the tables below:

Table 2-3: Real time rainfall data

REALTIME RAINFALL			
Source	**Resolution**	**File type**	**Interval**
TRMM	0.25deg X 0.25 deg.	.tif	3hr
JAXA	0.1deg X 0.1deg.	.tif	1hr
JAXA	0.1deg X 0.1deg.	.tif	24hr
IMD	Station Data (Point Rainfall)	Excel	24hr

Table 2-4: Forecasted rainfall data

FORECASTED RAINFALL				
Source	**Resolution**	**File type**	**Interval**	**Forecast period**
IMD-WRF	9km X 9km	.dat	6hr/24hr	3-days
IMD-GFS	0.25deg X 0.25 deg.	.dat	24hr	7-days
Global-GFS	0.25deg X 0.25 deg.	.tif	3hr	7-days

The user would be able to forecast floods in every 3-5 hours for every rainfall forecast input to the model. The model would take about an hour to forecast the extents and depth.

2.6 Coordination with IMD

IMD provides rainfall forecasts using Weather Forecasting Model (WRF) at 9 km x 9 km as well as 3km x 3km at 3-hour interval for 7-days. RMSI will use the rainfall forecasted data whichever will made available during real time cyclonic event. RMSI, in coordination with NDMA has approached IMD to provide real time rainfall data, which is the primary requirement for HEC-RTS model to perform flood-forecasting tasks on real time basis. Hence, for this analysis, the rainfall forecasts associated to the live cyclone event will be received from IMD and used as input for flood model.

2.7 Methodology Development

The present study has two main components for which methodology has been described in this section:

a. Probabilistic Risk Assessment Maps / Products
b. Real-time Decision Support Tool (Web-based Dynamic Composite Risk Atlas)

As specified in the previous section, RMSI conducted the Hazard, Vulnerability, and Risk Assessment (HVRA) for areas of 13 coastal States and UTs as part of the Phase 1 of the NCRMP project. The ADCIRC model, developed by Luettich et al. (1992) and Westerink et al. (1994), was used to simulate the response of water levels and associated inland inundation extent to the storms formed in the Bay of Bengal and the Arabian Sea. The cyclone induced rainfall flood modeling was performed using HEC RAS for all the basins along the Indian coastline.

High-resolution location-specific storm surge model at state level developed during Phase-I will be extended from location-specific to basin level. This will be executed by developing/customizing ADCIRC for three different regions covering Bay of Bengal, Arabian Sea and the Indian peninsula.

The reason to develop the model for Indian peninsula is that, though very rarely, cyclones form south of 10ºN, there are some instances of severe cyclonic storms forming in Bay of Bengal and travelling across the India peninsula and finally dissipating in the Arabian Sea, which cause widespread destruction to life and property. Keeping this in view, ADCIRC model will be applied for the prediction of storm surges in coastal southern India regions. The northern boundary of the peninsular model will be set up to 15ºN latitude.

For the HVRA, RMSI team also developed a very detailed exposure dataset covering buildings, essential facilities, infrastructure (including coastal and marine infrastructure) and demographics for all the coastal districts up to 10-meter elevation. Under the current assignment, RMSI team will enhance the same exposure dataset with more recent updates provided by state or national agencies.

For all the exposure elements, a detailed vulnerability analysis was also conducted as part of Phase 1 using which vulnerability functions were developed for all classes of exposure. However, RMSI team will reuse the same vulnerability functions for assessment of impact of probabilistic as well as live events. Wherever we can get some more information that requires updating the vulnerability functions, the same will be attempted.

2.7.1 Methodology for Probabilistic Risk Assessment Maps and Products

Generation of risk assessment scenarios is important from a cyclone risk mitigation planning perspective, since observations suggest that coastal locations and states that only experienced low intensity cyclones earlier are now being impacted by higher intensity cyclones. This implies that there is no guarantee that if a place has not experienced a damaging cyclone in the past, it cannot experience one such devastating cyclone in the future. Thus, there is always a probability of experiencing a higher intensity cyclone than that experienced in cyclonic history. Such events are generally called low-probability-high-impact events. This task is well taken care of through stochastic modeling.

Figure 2-2 shows the Modeling Framework that will be followed for the development of probabilistic cyclone risk maps of worst-case scenarios of wind speed, storm surge, and inland flooding for each cyclone category.

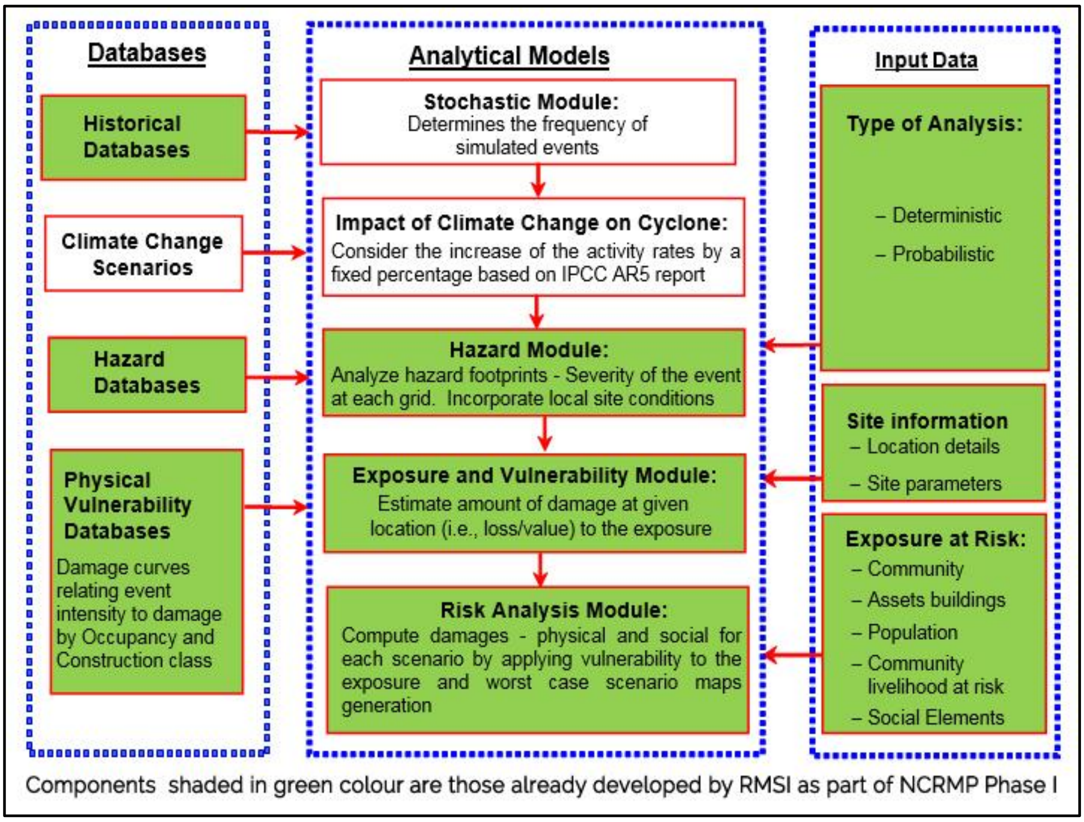


Figure 2-2: Probabilistic Risk Modeling Framework

Two key activities will be performed in generation of probabilistic risk maps. These are:

- Generation of stochastic event set using historical cyclone and rainfall data
- Analysis of climate change scenarios to derive the extent of change in frequency and severity of cyclonic events and incorporating these changes in the stochastic event set

The digital framework for probabilistic map generation for all the hazard components (Wind, Surge, and Cyclonic rainfall induced floods) has been shown in Figure 2-3 below. The desired methodology for each of the components has been elaborated in subsequent sections that follow.

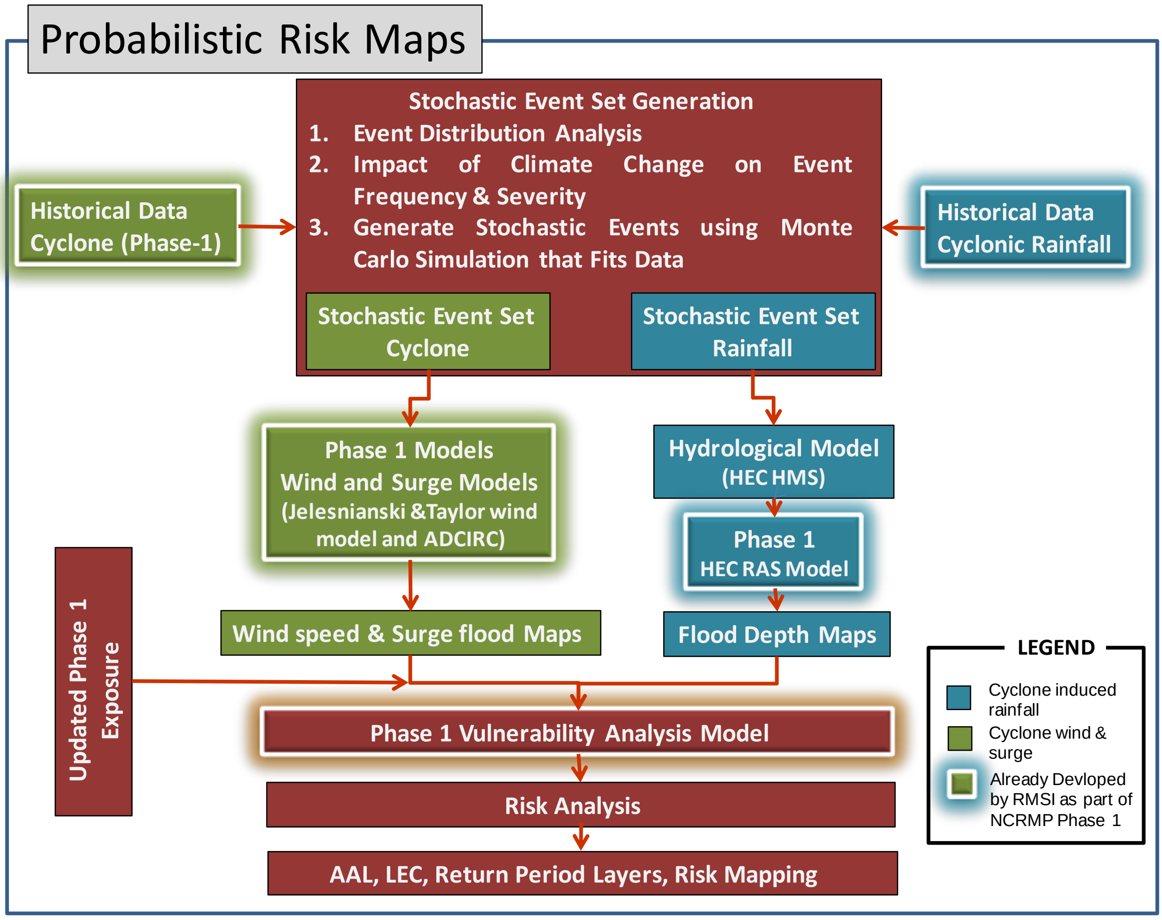


Figure 2-3: Probabilistic risk maps generation

2.7.1.1 Stochastic event module

The first module (first white box in center in Figure 2-2) generates stochastic events from the characteristics of historical events. The main activities that will be carried out in this module are enumerated in Figure 2-3 under 'Stochastic Event Set Generation'. Thousands of possible event scenarios will be simulated using Monte Carlo simulations based on realistic parameters and historical data. Each cyclone event will be defined by a specific strength, genesis location and path, and probability of occurrence or event rate. Each cyclonic rainfall event will be defined by duration of the event in days (1- day, 2-day, 3-day rainfall events…) and associated daily rainfall.

The detailed model will be based on historical cyclone track data from the North Indian Ocean. The data consists of the location and the maximum wind speeds of every known tropical cyclone in that area from the period 1877–2017, recorded at intervals of 6 hours. The data set is a composite of best track data in the North Indian Ocean of India Meteorological Department (IMD) and International Best Track Archive for Climate Stewardship (IBTrACS). Figure 2-4 shows the tracks of all the cyclonic disturbances to be considered for stochastic modeling of cyclone tracks. For stochastic rainfall modeling, rainfall associated to all these cyclones will be used as a basis.

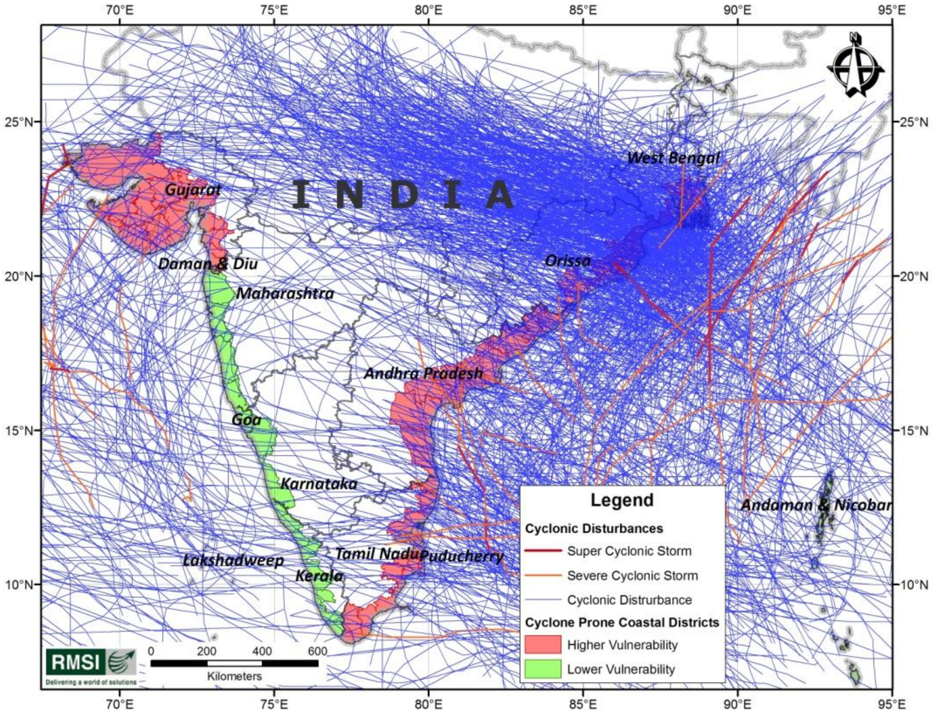


Figure 2-4: Storm tracks in the North Indian Ocean from 1877–2016

The following activities will be undertaken in generation of stochastic event sets:

- Analyze historical cyclone tracks to extract important characteristics. As can be seen in Figure 2-4, the cyclones show some strong inhomogeneity. Therefore, before creating a simulation from observed data, all the historical cyclones will be separated into more homogeneous classes and observation windows will be segmented into 3-4 zones. On the same lines, rainfall events of various durations will be identified using historical data to ascertain the frequency of various duration rainfall events. This will give various rainfall duration events into which the entire history can be categorized.
- Next, the historical cyclones will be assigned to different classes according to the combinations of zones they started or ended in or across which they moved during their life span.

The model will include the following characteristics:

- ***Point of genesis of storm*** within the observation window, they will be modeled as random point processes, therefore, an inhomogeneous Poisson point process will be used to model the distribution of genesis points
- ***Rainfall Event*** for every duration will also be modeled as random point processes, therefore, an inhomogeneous Poisson point process will be used to model the distribution of rainfall events
- ***Direction of storm movement and Translation speed*** to model storm movement from the points of genesis, a travelling direction and a translation speed are needed. A density for the initial direction of a storm will be estimated from the data using kernel techniques. The same will be done for the change in the cyclone's direction. An analogue procedure will be employed for modeling translation speed and maximum wind speed.
- ***A probability of exceedance*** of any particular peak gust will be calculated using a Poisson Point Process
- ***The termination (or death) of a storm*** will also be modeled as a random variable. Depending on its location and maximum wind speed, the storm will be

assigned a certain termination probability according to the storm's current position

- With the ***Monte Carlo technique***, the adequacy of the model for the simulation of the tracks can be tested by comparing the point patterns of the second points, third points, etc. of synthetic cyclones with the corresponding historical data.

It is important to note that for generating the actual event sets of cyclone tracks, an acceptance-rejection method will be used. After generating a storm track originating from one of the initial points, the obtained track will be classified to determine whether a track has been produced that matches the class of its initial point. If this is not the case, the track will be rejected and a new track will be generated, until a track with the correct classification is obtained.

The simulation parameters in the case of cyclones are location of genesis, central pressure, forward velocity, and location of landfall. In the case of floods, rainfall is the primary parameter. A sample stochastic event set of location of cyclone genesis is presented in Figure 2-5.

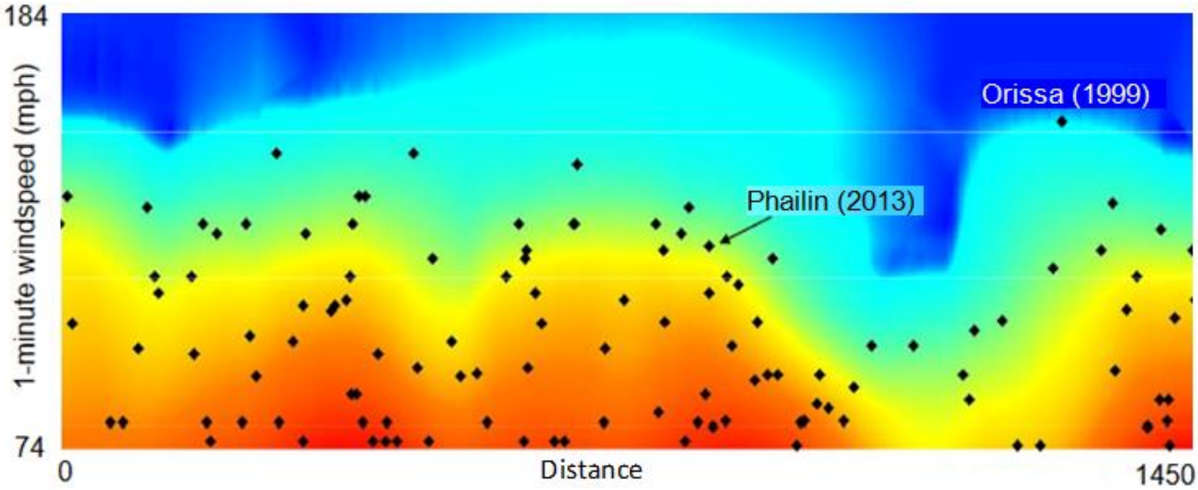


Figure 2-5: Sample output of stochastic event set of location of genesis. Shading indicates annual exceedance frequency where red is highest and dark blue is lowest

All the stochastic cyclonic event sets will be grouped according to their frequency and severity, i.e., Depressions, Deep depressions, Cyclone Storms, Severe Cyclonic Storms, Very Severe Cyclonic Storms, Extreme Severe Cyclonic Storms and Super Cyclonic Storms. The probabilistic worst-case scenarios of cyclonic wind speed, associated inland inundation due to surge, and cyclonic rainfall induced flooding will be prepared using cyclone model, ADCIRC model and the HEC-RAS and HEC-HMS models.

The stochastic cyclonic rainfall events will be used to generate probabilistic flood depth maps. The stochastic rainfall event will be input to the HEC-HMS model that will generate the flows associated to that rainfall event. These flows will be input to the HEC-RAS model to generate the inundation and depth maps.

Finally, wind speed, flood inundation, and flood depth maps generated based on the stochastic events will be the part of updated Web-CRA.

2.7.1.2 Climate Change Impact on cyclone hazard

The implications of climate change on cyclone severity will be assessed based on published research results. The future projections based on theory and high-resolution dynamical models consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2-11% by 2100 (Knutson et al. 2010). In order to study the effects of climate change, the wind stress will be increased by 7% (an average value) and by 11% (extreme value) over the stochastic events.

2.7.1.3 Hazard module: Cyclonic Wind, Storm Surge and Flood Hazard Modeling

Since these models were already developed as part of NCRMP Phase 1, the methodology used there is highlighted here in brief and details are appended in Annexes.

2.7.1.3.1 Cyclonic Wind Hazard Modeling

Surface winds associated with a tropical cyclone were derived using a dynamic storm model (Jelesnianski and Taylor, 1973). Meteorological inputs used for this model include positions of the cyclone, pressure drop, and radii of maximum winds at any fixed interval of times. The model was used for the computation of maximum wind at each grid point of the analysis area and these wind speeds were retained for input to the surge model. The wind model was calibrated and validated using available observed data related to important historical cyclones.

Further, the validated wind hazard model was used for the computation of wind speeds associated with historical cyclonic events that made landfall in and around the coast during 1877-2014. The Gumbel's extreme value probability distribution was applied to the modeled wind speeds at each grid point of the model domain and wind speeds for key return periods (2, 5, 10, 25, 50, and 100 years) were estimated. The key output of the wind model is a wind speed that provides peak gust at every grid point covering the area of impact. This output of the cyclone hazard analysis has been used to develop wind hazard maps at village level.

2.7.1.3.2 Storm Surge Hazard Modeling

Storm surge hazard modeling was performed using the ADCIRC-2DDI hydrodynamic finite-element model. A finite-element mesh for the study area was constructed using the software package Surface Modeling System (SMS) (Westerink et al. 1994). The maximum surge height computed with the model was calibrated and validated against observed surge heights. The validated storm surge model was then applied for historical cyclone events that made landfall and the associated surge amplitude, velocity, and surge flood depths and extent were computed accordingly.

The Gumbel's extreme value probability distribution was applied to the modeled surge flood depths at each grid point and flood depths for key return periods (2, 5, 10, 25, 50, and 100 years) were calculated. Finally, scenarios of storm surge flooding were prepared for all the return period events. The framework shown in Figure 2-6 shows the complete methodology followed for storm surge hazard assessment. Finally, stochastic cyclone event sets generated based on the stochastic modeling will be the part of Web-DCRA.

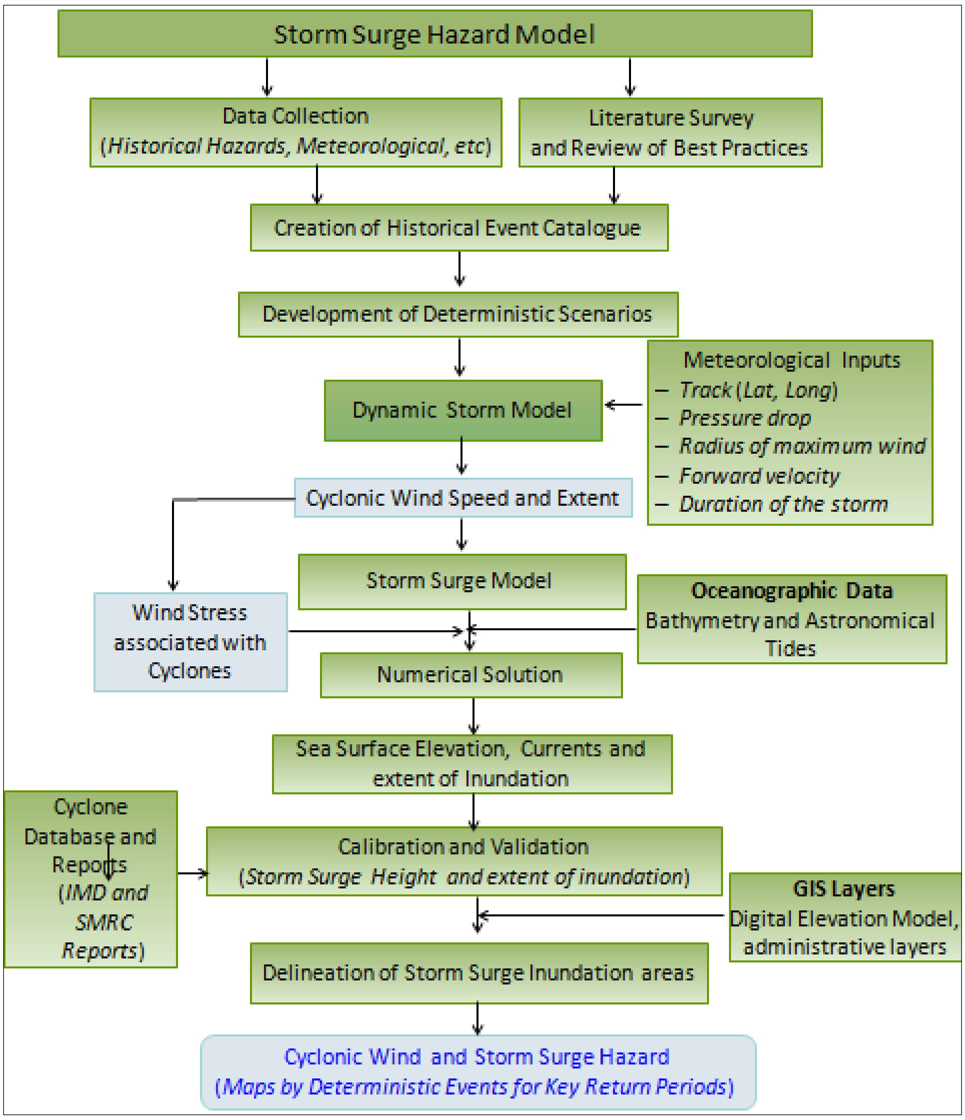


Figure 2-6: Framework of storm surge modeling

2.7.1.3.3 Cyclone Induced Rainfall Flood Modeling

For the flood inundation and flood depths at coastal cities and areas, the methodological framework based on the integration of hydrological and hydrodynamic models, namely HEC-RAS and HEC-HMS, is used. Out of these HEC-RAS has been already formulated by RMSI during NCRMP- Phase 1. For Phase 2 implementation, only the HEC-HMS model will have to be created for all the basins. The stochastic cyclonic rainfall events will be used to generate probabilistic flood depth maps. The stochastic rainfall event will be input to the HEC-HMS model that will generate the flows associated to that rainfall event. These flows will be input to the HEC-RAS model to generate the inundation and depth maps. The updated stochastic flood inundation and flood depth maps generated based on the stochastic events will be the part of Web-DCRA.

2.7.1.3.4 Calibration and Validation of Cyclone, Storm Surge and Flood Models

The stochastic event sets of cyclones and rainfall events will be generated as a part of storm surge and flood modeling. However, for stochastic events set, the models will require further calibration and validation for preparing the worst-case cyclone wind speed and storm surge flooding vulnerability maps. Validation of models shall be done with recent cyclones such as, Phaillin, and Hudhud and new damaging cyclonic events during testing phase of Web-DCRA. The criterion that will be used for calibration and validation of hazard models is described below.

The calibration and validation process is intended to ensure that the model parameters are well set to reflect the physical nature of each cyclone. A good fit indicates a robust simulation, which can be used with reasonable confidence. A poor fit, on the other hand, indicates low confidence. Model calibration consists of changing values of model input parameters in an attempt to match field conditions within some acceptable criteria.

Validation runs will be made with the selected “best fit” parameters without further parameter changes. The validation process uses events that were not included in the calibration to evaluate the reliability of the model for other historical events. Therefore, an independent sample of events will be used to validate the cyclone model in terms of pressure drop, which plays a fundamental role over the wind speed for the episode, and surge height and associated extent of inundation in the coastal areas, an important factor owing to the high flow velocities. The performance of the model parameters (wind speed, surge height, and flood depth) simulations will be checked by means of relative error against observed values, expressed as percentage (%ERR):

$$\%\mathrm{ERR} = \frac{(\mathrm{Vs} - \mathrm{Vo})}{\mathrm{Vo}} * 100$$

Where Vo and Vs are the observed and simulated parameters (e.g. surge height, wind speed and flood depth). Therefore, %ERR > 0 and %ERR < 0 indicates an over- and underestimation by the model, respectively.

2.7.1.4 Probabilistic risk assessment products

Probabilistic Risk Assessment products will be derived from the outputs of the hazard and vulnerability assessment models. While hazard model provides the intensity of the hazard at various locations for all the events in the stochastic event set, the vulnerability analysis provides an understanding of the impact of the hazard intensity at a location on the exposure element present there. The exposure elements could be population, buildings, essential facilities, and coastal and marine infrastructure. As part of post-processing, return periods associated to all the events in the stochastic set will be aligned with the hazard intensity value by location. This will help specify a return period of hazard intensity at a location, e.g., at a particular coastal village a 2-meter surge has a once in 100-year chance of occurrence.

Following probabilistic risk assessment products will be provided:

- Probabilistic wind, surge and cyclone induced flood maps by return period
- Probabilistic wind, surge and cyclone induced flood maps by hazard value. For example, hazard map of 2-meter surge with a once in 100-year chance of occurrence.
- Wind, surge and cyclone induced flood maps of worst-case scenarios for each State/UT
- Loss Exceedance Curve (LEC): LEC shows the probability that a loss will exceed a certain amount in a year. It is displayed as a curve, to illustrate the probability of exceeding a range of losses, with the losses (often in millions) running along the X-axis, and the exceedance probability running along the Y-axis. Figure 2-7 shows a sample EP curve.

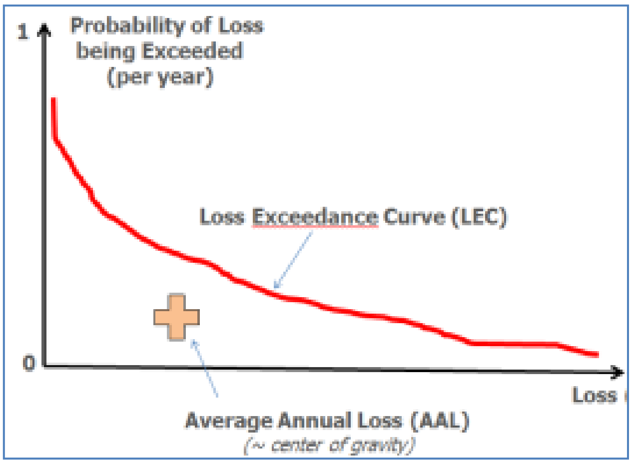


Figure 2-7: Loss Exceedance Curve and Average Annual Loss

LEC curves will be provided by:

- Exposure Type (Residential, Commercial, Industrial, Essential Facilities, Coastal Infrastructure, Marine Infrastructure, etc.)
- State/District
- Combination of the above, i.e. By State by Exposure Type

- **Return Period Loss:** Return periods provide another way to express exceedance probability. Rather than describing the probability of exceeding a given amount in a single year, return periods describe how many years might pass between times when such an amount might be exceeded. For example, a 0.4% probability of exceeding a loss amount in a year corresponds to a probability of exceeding that loss once every 250 years, or “a 250-year return period loss.”
- **Loss by Hazard Intensity:** As mentioned in case of return-period hazard maps, we will also provide the view of the loss in relation to hazard intensity. *For example, loss due to a 1 or 2 or 3-meter surge in a coastal area.*
- **Annual Average Loss (AAL):** AAL is the average loss of all modeled events, weighted by their probability of annual occurrence. In an LEC curve, AAL corresponds to the area underneath the curve (Figure 2-7), or the average expected losses that do not exceed the norm. *It provides a useful, normalized metric for comparing the risks due to Wind, Surge and Cyclone Induced Flood*. AAL will be provided as Maps as well as Tables by

    - Exposure Type (Residential, Commercial, Industrial, Essential Facilities, Coastal Infrastructure, Marine Infrastructure, etc.)
    - State/District
    - Combination of the above, i.e. By State by Exposure Type

- **Coefficient of Variation (CV):** The CV measures the size, or degree of variation, of each set of damage outcomes estimated in the vulnerability module. This is important because damage estimates with high variation, and therefore a high CV, will be more volatile than an estimate with a low CV. Mathematically, the CV is the ratio of the standard deviation of the losses (or the “breadth” of variation in a set of possible damage outcomes) over the mean (or average) of the possible losses.

All the above products will be provided as maps and tables by:

- Exposure Type (Residential, Commercial, Industrial, Essential Facilities, Coastal Infrastructure, Marine Infrastructure, Population, Agriculture, etc.)
- State/District
- Combination of the above, i.e. By State by Exposure Type
- These key probabilistic risk assessment products will be made accessible through the Web-CRA as:

- **Reports** – Summary reports by country, state or district. Summary reports by exposure type as country/state/district level. These reports will include charts, maps and tables of LEC, AAL, Return Period Losses and Losses by hazard intensity.
- **Pre-complied maps** – The Risk Atlas within the Web-CRA will be extended to show pre-compiled probabilistic hazard and loss maps.
- **Query** – A query capability will be added to Web-CRA where a user can specify the exposure, location of interest and type of result to generate a dynamic tabular view of the risk.
- **Probabilistic Risk Analyzer** – The Web-CRA Risk Analyzer will be enhanced to run probabilistic analysis. This will provide mitigation planners with options to estimate the benefits of mitigation options being planned. ***Through this approach, the users will be able to compare the benefits from multiple mitigation options and then implement the ones that give the best cost benefit ratio.***

The various probabilistic risk assessment products discussed above will help State/UT disaster managers not only in mitigation planning, but also in preparedness phases through the years. These products would also help disaster managers in identifying the various exposure elements at risk and prioritizing various risk mitigation options based on the principle of benefit-cost analysis (BCA).

2.7.2 REAL TIME CYCLONE IMPACT FORECASTING

2.7.2.1 Real time Cyclonic wind and storm surge flood forecasting

Storm surge model (ADCIRC) coupled with a dynamic storm model imbedded within Web-DCRA will be run on a Server in an automated mode for the computation of wind, and surge flood extents, and depths along the coast. The vulnerability and risk mapping modules imbedded in the Web-DCRA will help identify the exposure and quantify the losses in monetary terms due to all the three hazards associated with extreme cyclone events. The model set-up steps are as follows:

Initially, surface winds associated with real time tropical cyclone will be derived using a dynamic storm model (Jelesnianski and Taylor) along with setting up Web-DCRA for executing the appropriate window (forecast domain) based on initial and likely final positions of cyclone tracks and associated event parameters.

The Web-DCRA will next automatically take model input parameters from IMD bulletins (characteristics of tropical cyclone) for computing the wind distribution. These inputs will include:

1. Cyclone positions (latitude and longitude),
2. Pressure drop (hPa) and
3. Radius of maximum winds (km) at any time interval (preferably six hourly observations), and probable landfall location

IMD provides these input data from INSAT imageries, cyclone detecting radars, and surface synoptic analysis. The duration of the forecast will be for 48-72 hours as per IMD bulletins.

The final step will be to run the storm model and the surge model. Storm model will compute the required surface wind stress associated with the tropical cyclone in the model domain for each time step. This wind stress along with tides and waves go as input to the Surge model. RMSI team will approach INCOIS to get the wave model output to integrate it with ADCIRC model. The output of the surge model will be surge flood extent and water levels associated with respective real time cyclone event. A framework of a real-time forecasting system for storm surge hazard and risk assessment is provided in Figure 2-8 below.

The cyclone features described above will be displayed through an appropriate user interface where the user may select any part of the coastal region to get more detailed expected results/features, if needed.

The web-WEB-DCRA is being designed in such a way that the whole process of running the model for a 48-hour forecast will take less than 120 minutes. However, it will depend upon the computing resource capability.

The web-DCRA will have the feature to update forecast scenario in real time based on IMD's forecast available at regular time intervals.

Following will be the model outputs displayed on the screen:

- Surge wave height and direction
- Probable surge inundation extent and water level
- Wind speed distribution
- Assets/exposure at risk
- Suggested action/advice
- Detailed event report with maps

Validation of Web-DCRA: In order to validate the models during real-time events, data from the field or other national/global sources will be collected and the model will be run again with updated information to redisplay the hazard maps and associated exposed assets and loss estimates. An attempt will also be made to compare the simulated sea surface elevations with observations from local tide gauges wherever possible or with post storm survey.

Web-DCRA will estimate, in this sequence of order, the losses due to cyclonic wind, storm surge flood, and cyclonic rainfall induced flooding from the event. These individual losses will then be combined to obtain the composite loss from cyclonic wind, storm surge flood, and cyclonic rainfall induced flood. Losses aggregated at administrative level (village/city/tehsil/ district/ state) will also be displayed.

2.7.2.2 Integration of Web-DCRA with existing platforms

RMSI understands that the Web-DCRA has to be integrated to the forecasting platforms from IMD and INCOIS as well as with the Warning Dissemination Systems (EWDS) of NDMA. Accordingly, RMSI will reach out to IMD and INCOIS to setup a mechanism for sharing of their respective forecast data to display and integrate into the surge model during real time cyclonic event's modeling through Web-DCRA. The output/product of the application shall also be integrated with EWDS of NDMA. This would be accomplished only after discussing integration options with the EWDS developers and INCOIS.

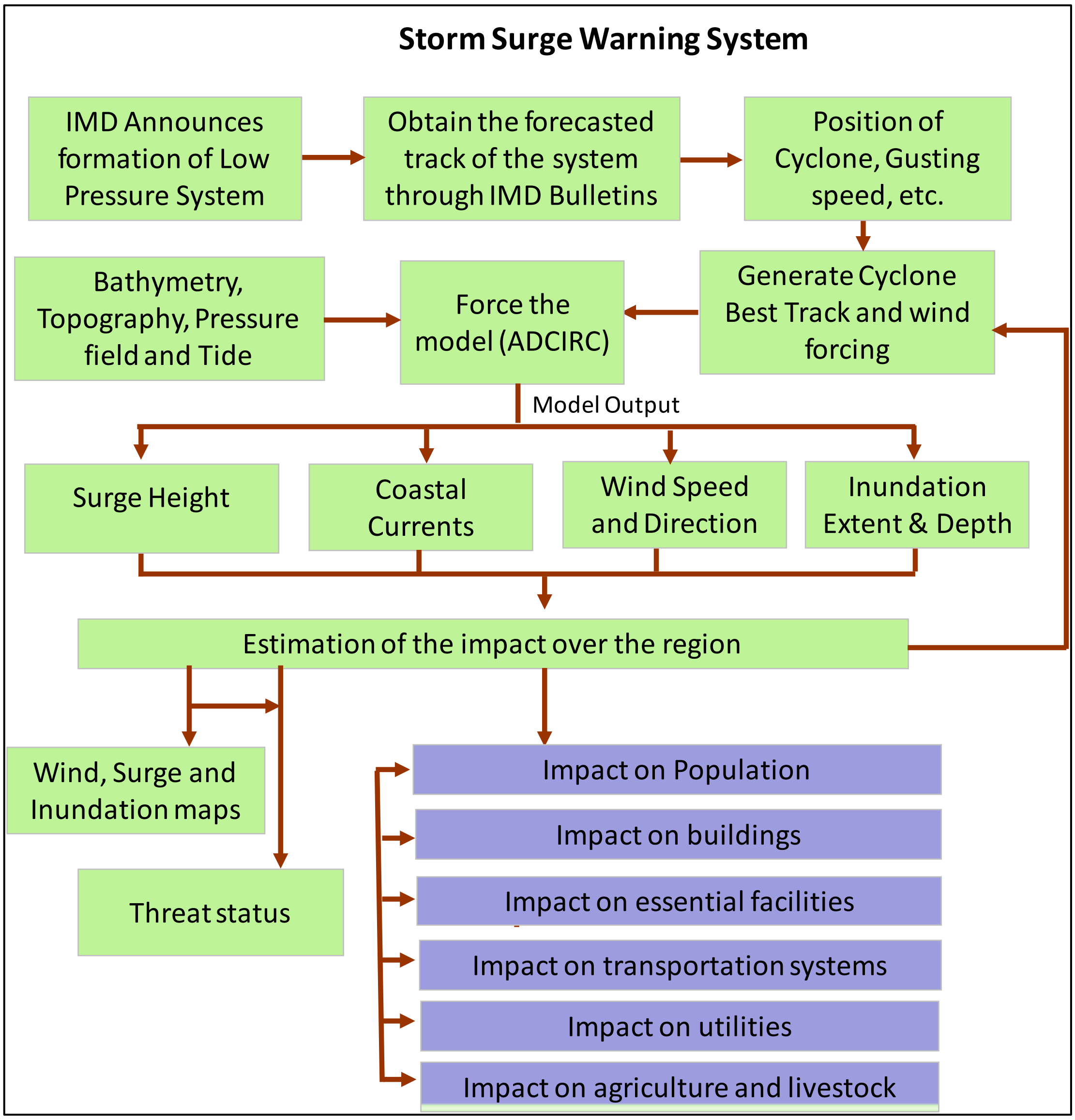


Figure 2-8: Framework of real-time forecasting system

2.7.2.3 Real-time Flood Forecasting

There are many ways in which recently observed storm flood flows and extreme rainfall data can be used for updating forecasts and various updating procedures are available. They differ in detail or in their mode of operation, but essentially, they provide the hydrological simulation model with feedback information from the most recently observed flows to estimate errors and thereby improve the accuracy of forecasts. The updating procedures can either be continuous, that is, they can be applied at each time step, or periodic, which will involve periodic recalibration of the model. A dynamic web-enabled flood-forecasting module is proposed that is calibrated and validated against historical events and tested on the stochastic events sets for the preparation of probabilistic risk maps.

HEC-RTS Framework

HEC-RTS is an all-inclusive system that picks up precipitation data, simulates a rainfall-runoff model, runs a hydraulic model and makes available inundation maps, stage and plots. Once the models have been calibrated and validated to reflect current hydro-meteorological conditions, they can be executed to produce forecasts of flood characteristics. That will assist the concerned agencies to evaluate the effects of their operating decisions in the near future. Reservoirs, bridges and other data from the field will be incorporated in the model to make it robust. The ability of HEC-RTS is to forecast floods with a sufficient lead-time for early flood warning dissemination and to take timely protection measures. This will also help in effectively undertaking flood mitigation measures and minimizing damage during floods in coastal cities. It will specifically address flood risk management and loss-of-life concerns in the coastal cities.

The integrated hydrological-hydrodynamic modeling framework HEC-RTS (Figure 2-9) will be capable of providing probabilistic flood details using stochastically generated cyclonic rainfall as well as flood forecasting.

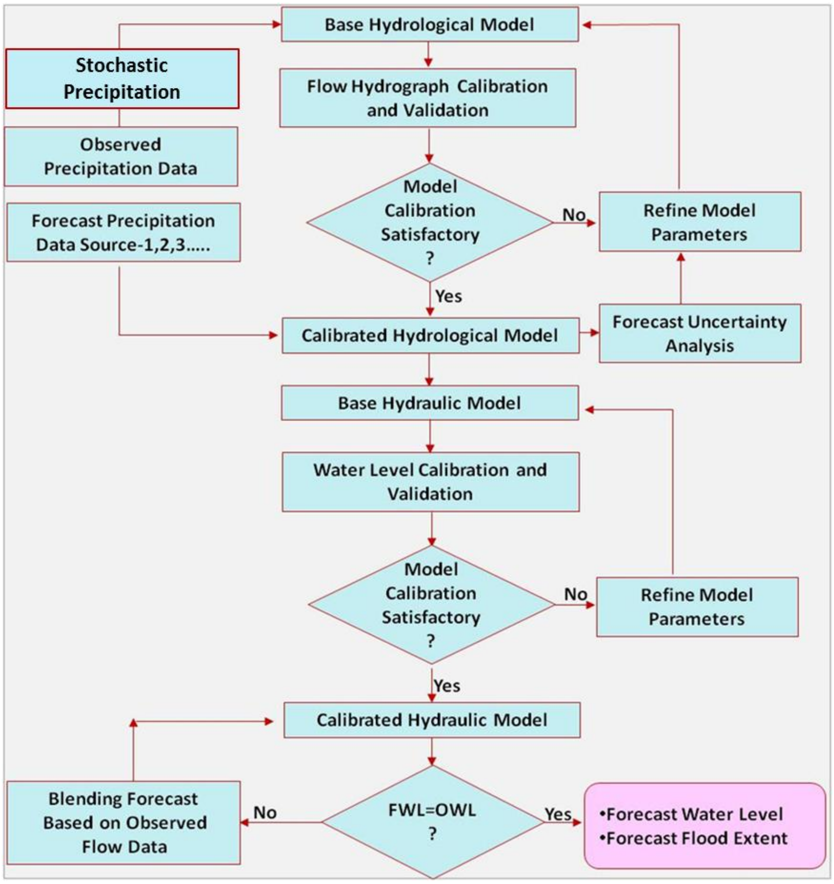


Figure 2-9: Flood forecasting model/components of HEC-RTS

The flowchart of the flood-forecasting model has been shown in Figure 2-9 above. The flood-forecasting model can be viewed as having the following major components:

1. The HEC-RTS framework incorporates hydrological modeling using HEC-HMS and hydrodynamic flood modeling using HEC-RAS. The HEC-RTS model for this project will use the same HEC-RAS based basin models that were developed as part of NCRMP Phase 1. The HEC-HMS models will be created for all the basins involved in the study.
2. Both the key components of HEC-RTS framework, HEC-HMS and HEC-RAS, can run independently. However, in HEC-RTS they are combined to provide a comprehensive watershed forecast that includes river stages and flooding extents.
3. Probabilistic Flood Modeling
    a. The above HEC-RTS framework will be used for the generation of stochastic flood flows using stochastic rainfall events, integration of pluvial floods, and generation of probabilistic flood depth maps and inundation maps.
    b. The stochastic flows generated from HEC-HMS will be taken as input into the HEC-RAS module to generate the various probabilistic scenarios of floods.

c. Various components of HEC-RTS contain, to some extent, some uncertainty in their outputs. Therefore, an uncertainty analysis of stochastic rainfall will be done prior to probabilistic analysis of flood.
d. For model calibration and validation flood flows, extents and depths of historical floods would be used. Global mapping agencies, such as the Dartmouth Flood Observatory (DFO), and government agencies record the behavior of historical flood events and provide footprints of recent floods. IMD has historical storm event datasets. All these will be utilized for the validation of the flood inundation maps.

4. The same framework will also be used for real time flood forecasting from cyclonic rainfall due to a live cyclone. For this analysis, the rainfall forecasts associated to the live cyclone from various sources will be used as input.

Pluvial/Flash flooding, as a result of extreme rainfall event due to their storm characteristics, accumulate large amounts of water over the ground before it enters a natural or man-made drainage system. Pluvial flooding is associated with short duration with high intensity rainfall. It includes different dynamic processes such as flow paths and ponding, steepness, barriers to flow, wetness, permeability and antecedent soil conditions. For Pluvial flooding, the road network and canal network will be used as water channels. Pluvial/Flash flooding will be incorporated in the present framework and will be used for both probabilistic flood modeling as well as flood forecasting in cities.

A detailed methodology has been provided in the Annexes. The data inputs required for flood forecasting are given in section 2.5

The user would be able to forecast floods every 3-5 hours for every rainfall forecast input to the model. A mechanism will be provided to input the discharge from reservoir/dam to model its impact on the generated flood extents and depth grid in Web-DCRA. However, it needs information on discharge of water from dam gates in real time. The model would take about an hour to forecast the extents and depth.

HEC-RTS modeling framework for real time flood maps generation

The dynamic maps generation and flood inundation will be created at smaller scale (e.g. focus will be on exposure area) for all coastal cities. The flood discharge will be generated in HEC-HMS module utilizing real time physical and meteorological data inputs. The main dynamic real time/forecasted meteorological variable, namely rainfall, will be input to the model to generate real time/forecasted flood flows. The real time/forecasted flood flows will be the main input to the HEC-RAS module to generate flood depths and inundation maps, which will be able to illustrate the effect of cyclonic extreme rainfall events. Pluvial flooding will be incorporated in the present framework by incorporating extreme rainfall events that occur with real time and forecasted precipitation data. The inundation from the pluvial impact will be assessed and then incorporated with the riverine floods. The HEC-HMS module of HEC-RTS will be updated based on pluvial and riverine floods.

Calibration and validation of a flood-forecasting model requires flood extent and/or depth measurements (spatial distribution) for particular events based on the real time observed and real time flood forecasting. The high flood marks will be used to calibrate and validate the hydraulic model for the flood event. The real time and forecasted scenarios of flash floods and flood depth maps would be a great asset for the user prior to estimating the severity of future cyclonic events. The RAS Mapper tool in HEC-RAS enables the modeler to visualize the flood inundation areas. Computed model results can be displayed dynamically on the fly. A sample of RAS output flood map for Rapti River has been shown in Figure 2-10.

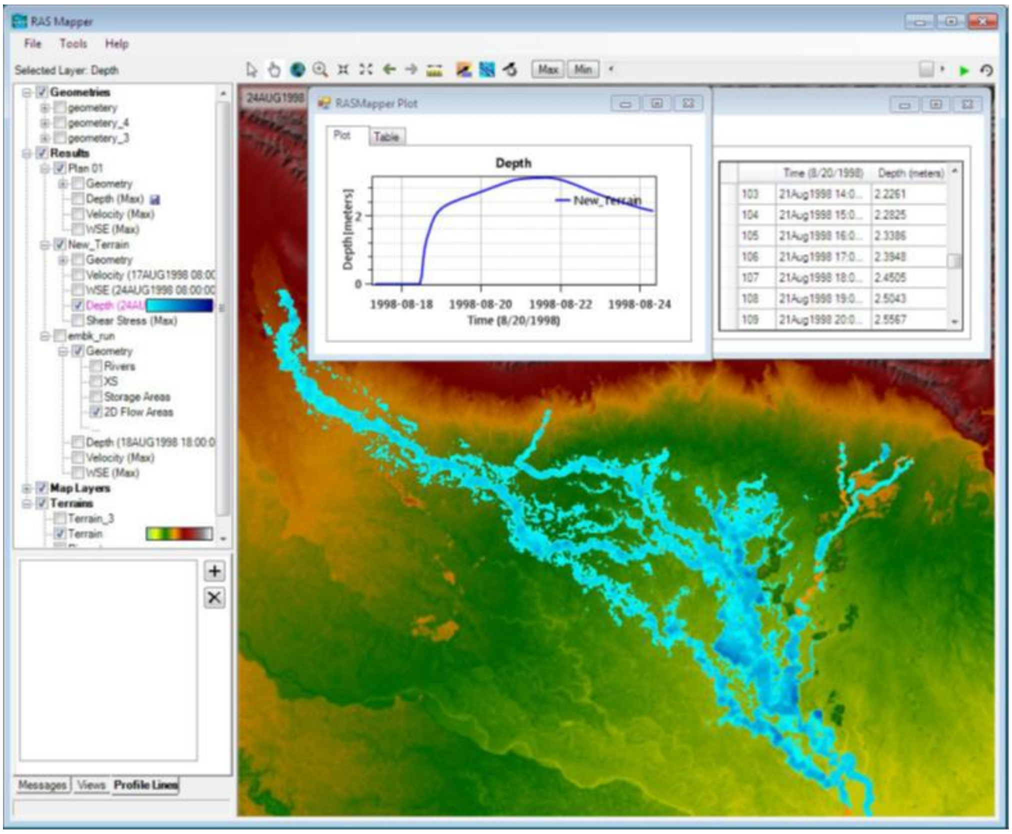


Figure 2-10: A sample of RAS output flood map

2.7.2.4 Real Time Cyclone Hazard and Risk Model Automation and Impact Forecasting

The proposed WEB-CRA will be an enhanced version of the present WEB-CRA, which was developed as part of NCRMP phase-I project. The proposed enhancements to WEB-CRA functionalities can be divided under three main heads:

1. Enhance Web-CRA
2. Offline Web-CRA (Desktop version)
3. WEB-DCRA App - Android based mobile phone application

Enhance Web-CRA

The below mentioned enhancements will be done in the existing WEB-CRA:

- The proposed enhanced Web-CRA will be able to perform probabilistic risk analysis for cyclone risk and storm surge flooding / coastal flooding and will be able to generate vulnerability maps for the coastal line of India. This will not be a real time product.
- Integrate a Dynamic Cyclone Risk Assessment capability (WEB-DCRA) to Web-CRA.
- The Web-CRA will be enhanced further into an open source web GIS based decision support system (DSS) for Natural Disaster Management for coastal states of India.

The key features of the DSS are as follows:

- Providing vital information of exposure at risk on real time basis for an impounding cyclone at the State/District and Local-level Support response and recovery operations
- A decision support system for planning and to catalyze the process of preparedness, response and mitigation

- Early warning dissemination through e-mail and SMS (mobile based application)
- Emergency communication for timely relief and response measures.
- Building Knowledge base to facilitate planning and policy making

WEB-CRA- Probabilistic Risk Assessment

The existing WEB-CRA can perform deterministic risk assessment. This functionality will be enhanced to perform probabilistic risk assessment. The system will utilize the stochastic events sets generated as part of modeling enhancement done in this phase to perform probabilistic risk assessment.

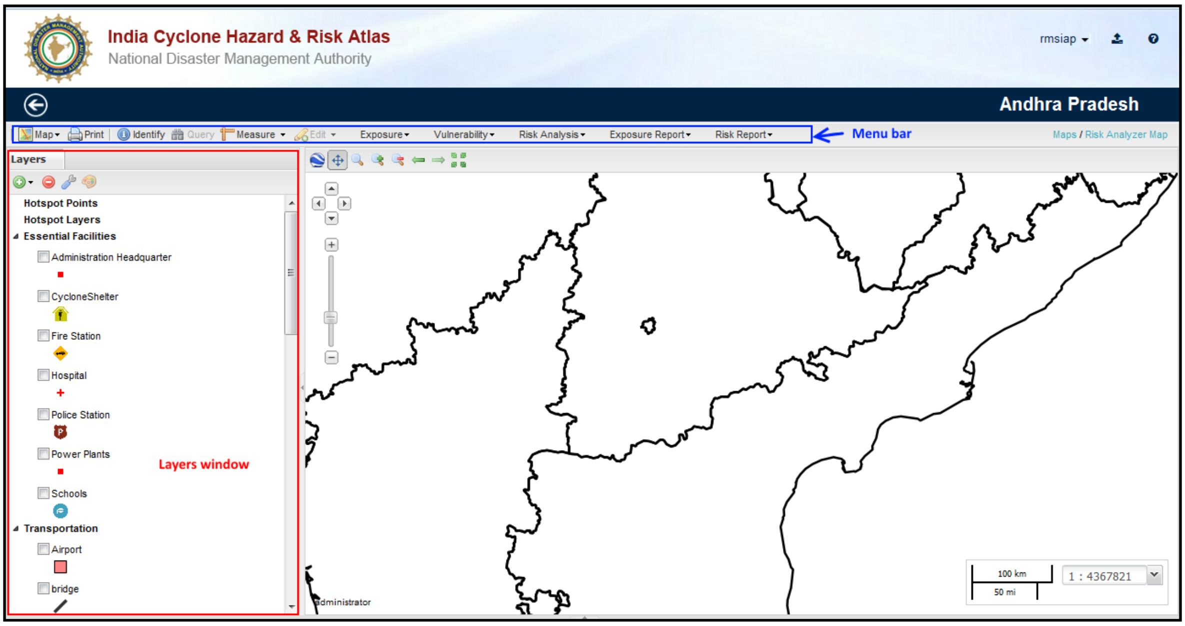


Figure 2-11: Enhancement on Risk Analyzer Module to perform probabilistic risk assessment

This option will allow users to perform probabilistic risk analysis on base and the user-defined data. Users can also view the status of the various analysis job submitted. The three hazards listed for Risk Analysis are:

- Cyclone
- Flood
- Surge

To perform Probabilistic Risk Analysis user has to select Probabilistic Risk Analysis option from the drop down of Model Type on the Risk Analysis Dialog Box. The dialog box below shows the sample user interface for risk analysis menu and risk analysis options:

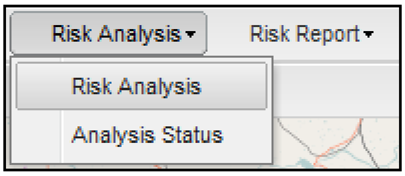


Figure 2-12: Risk Analysis menu

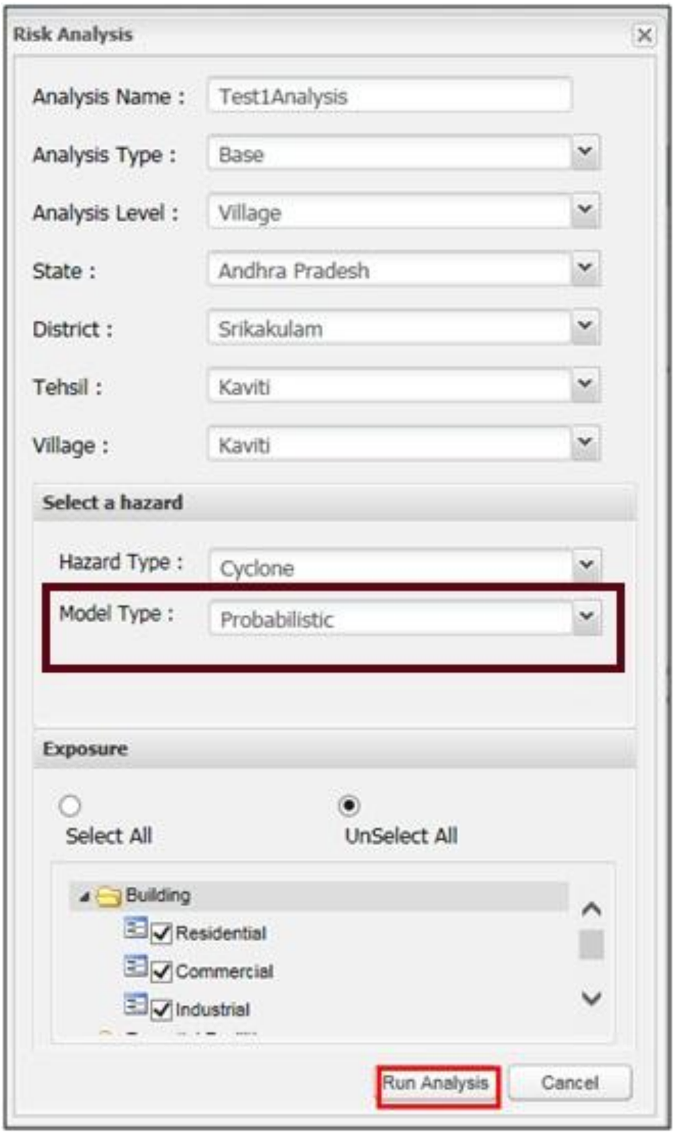


Figure 2-13: Risk Analysis window

The sample report generated by the WEB-CRA for probabilistic risk analysis is shown below:

India Cyclone Hazard & Risk Atlas
National Disaster Management Authority

Risk Assessment Summary Report

Scenario

Analysis Name	TestAnalysis
State	Andhra Pradesh
District	Srikakulam
Tehsil	Kaviti
Village	Kaviti
Analysis Level	Village
Analysis Date	2016-07-11 19:10:00
Structure Type	All (For details see Annexure 1)
Hazard Type	Cyclone
Scenario	Cyclone 100 Year Return Period

Exposure	100 Year RP Loss
5,185	79

Exposure	100 Year RP Loss
5,185	79

Total Exposure and Loss in INR Lakhs

Exposure	100 Year RP Loss
5,185	79

Exposure Map

NOTE:
1. Exposure and Loss in INR Lakhs
2. Structure Type: The Building Type In India is divided into different classes based on their material type user in there walls ,foundation and there Structural types

Risk Assessment Summary Report - Page No. 1 of 6

Figure 2-14: Risk Assessment Summary report

Dynamic Cyclone Risk Assessment (Web-DCRA) - Decision Support System for Disaster Management

The emergency response activities can only be successful through multi-departmental coordination. This demands the availability of spatial and non-spatial data of various departments in single platform. Effective emergency information management requires concerted planning, organizing, controlling, and influencing of human, material, and information resources so that information is disseminated to the right decision-makers at the right time to satisfy those needs. The high-level design of the proposed WEB-CRA DSS is given in the Figure below.

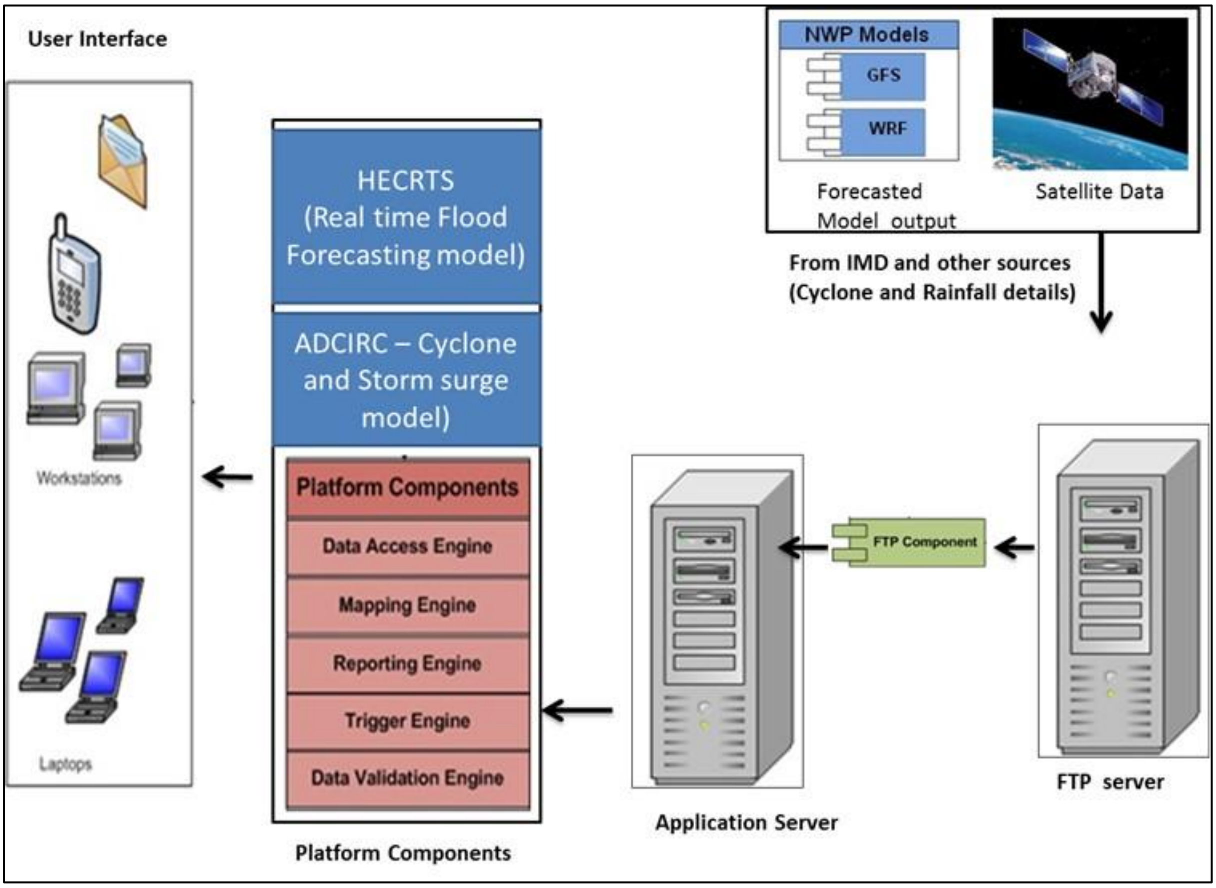


Figure 2-15: High-level design of DSS

The proposed WEB-DCRA will be an open source web GIS application that will be based on the existing WEB-CRA platform. It will provide information about exposure, hazards and vulnerability from an impending cyclone, to support planning, coordination, response, guidance, and decision making for emergency management personnel.

To perform this analysis on real-time basis, existing WEB-CRA analysis engine will be enhanced so that the below mentioned tasks will run in automatic mode:

- Fetching cyclone information from IMD in automatic mode
- Running hazard models viz. – Cyclone, Flood, and Storm surge
- Running vulnerability module
- Running loss module

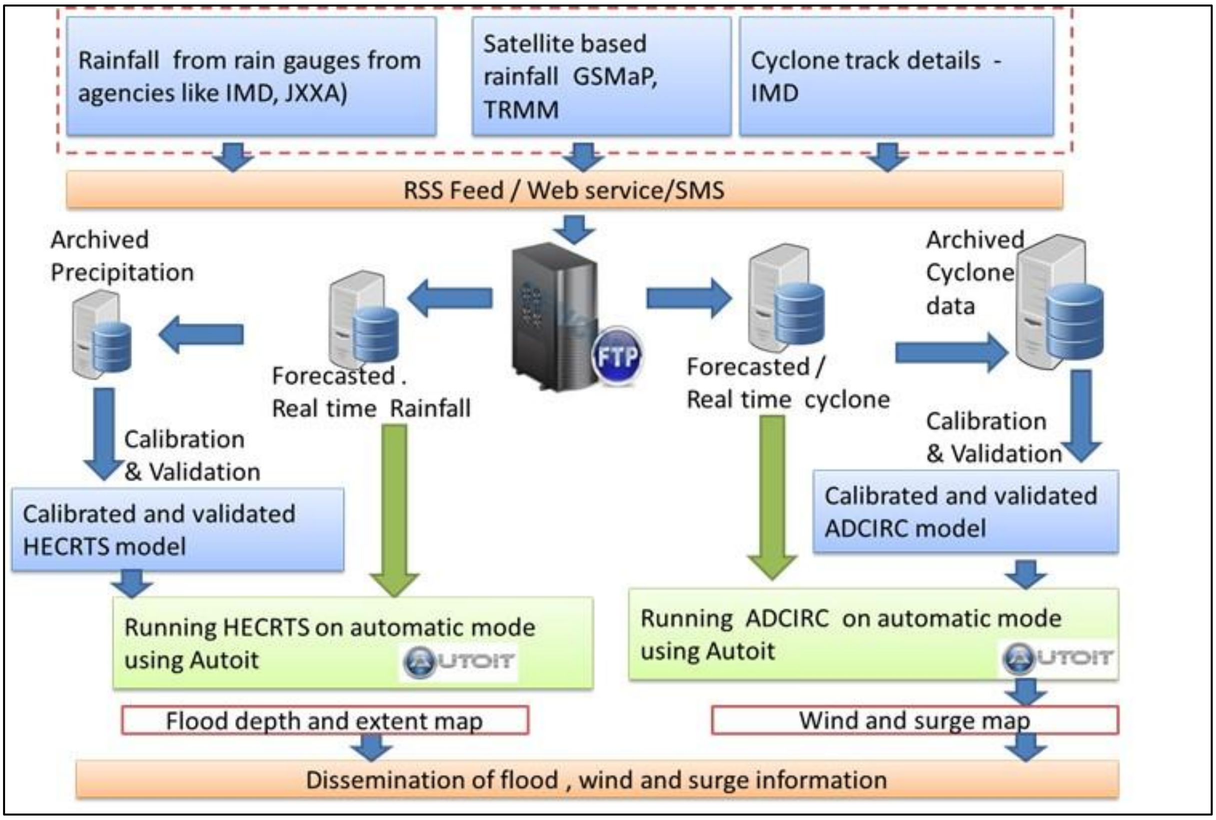


Figure 2-16 : Process flow of WEB-CRA dynamic analysis engine

The following five are the major components that will be added in the existing WEB-CRA analysis engine:

1. Real time input data collection: This module will fetch the input data such as cyclone track details and rainfall from the various sources (IMD. JXXA, OpenWeatherMap, Weather Underground etc.) finalized for the model on real time basis through RSS feed, web services and SMS and store that in FTP server located at data center.
2. Wind and Surge Module – This module will use ADCIRC model to generate wind and storm surge hazard maps using IMD's cyclone track details on real time basis. The AUTOIT software will be customized to run calibrated and validated ADCIRC model to perform cyclone wind and storm surge estimation tasks on real time basis.
3. Flood forecasting module – Flood forecasting module will use HECRTS Model to forecast flood (Convert rainfall to run off and generated flood inundation map) on a real time basis. The AUTOIT software will be customized to run calibrated and validated HECRTS model to perform flood-forecasting tasks on a real time basis.
4. Vulnerability and loss module – This module will generate damage and loss information based on hazard information generated by the previous two modules and exposure information and vulnerability functions available within the Web-CRA.
5. Dissemination module – This will be developed to perform dissemination of cyclone warning to decision makers and general public through websites, media and mobile SMS. It will include the following functionality:
    - Send event situation report to pre-defined individuals via email
    - Web service to extract event related risk details to connect the WEB-DCRA to any other government web-sites
    - Send SMS and pre-recorded voice alerts to all mobiles in the coastal areas, near airports, train stations, etc.
    - Send SMS and pre-recorded voice alerts to homes that are potentially likely to be impacted and on what they can do to reduce losses

- Register missing people information
- SMS alert to mobiles in the area regarding missing people
- Reporting of missing identified

For Common Alert Protocol (CAP), as final product of the system, compatible to disseminate text-cum-visual product on risk based warning, RMSI team will need the details of the Common Alert Protocol (CAP) to ensure compliance.

The sample user interface of WEB-DCRA Dashboard is shown below in Figure 2-17. The user can view results on maps, graphs or tables. The system will display the following layers by default as the application is loaded:

- Cyclone track
- River network with basin boundary
- District, state and country boundary map
- Basic GIS tools like zoom, pan, Zoom to selection, zoom to entire layer, location attribute information and calculate distance.
- Observed and forecasted flow levels from various hydrological/hydrodynamic model as table and chart in map
- Wind hazard map

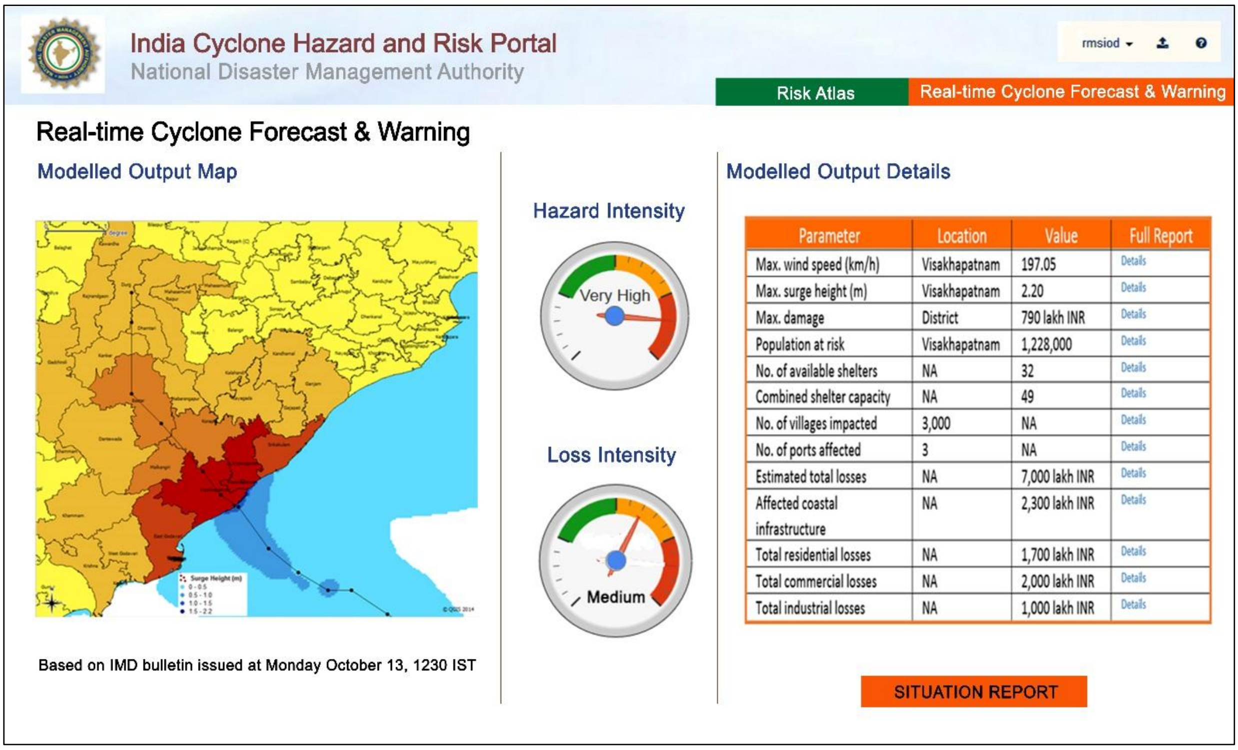
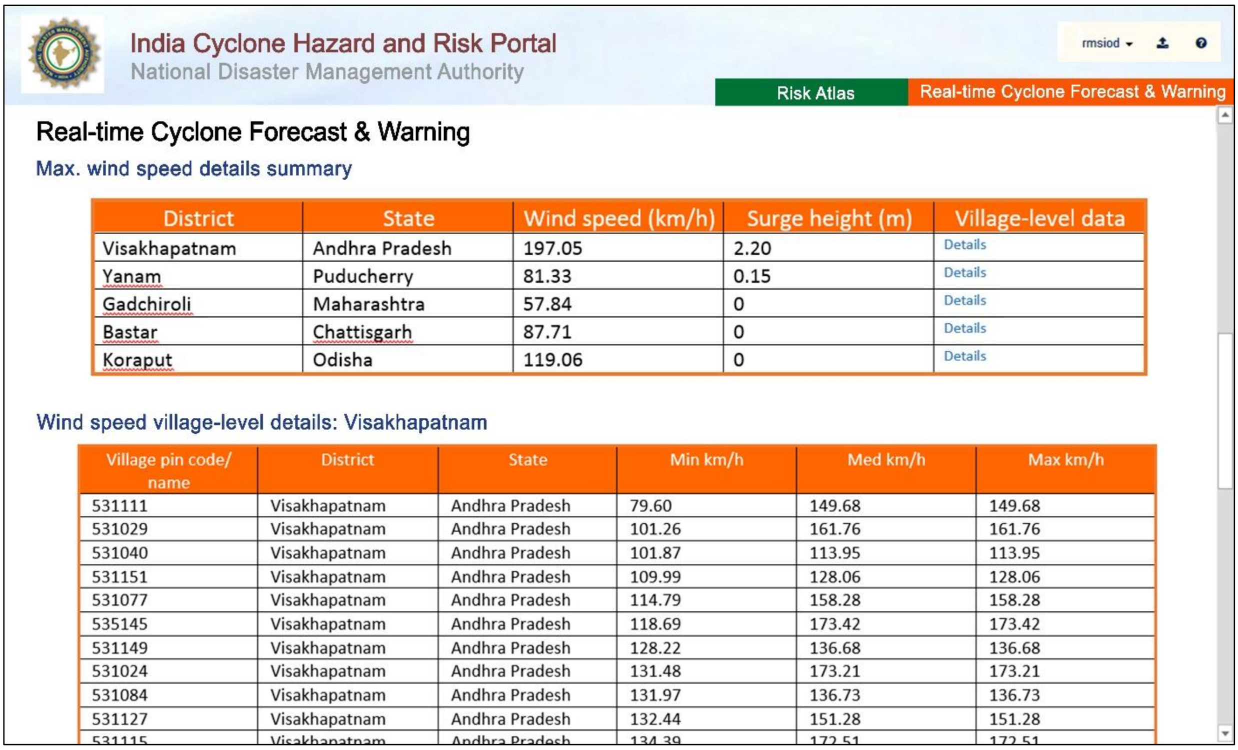


Figure 2-17: Sample user interface - WEB-DCRA/DSS

Clicking the Detail hyperlink in the table (to the right in above figure) will allow users to navigate to detailed modeled results at a more granular level of the selected parameter. A sample screen shot is shown in Figure 2-18 below:



India Cyclone Hazard and Risk Portal
National Disaster Management Authority

rmsiod

Risk Atlas | Real-time Cyclone Forecast & Warning

Real-time Cyclone Forecast & Warning

Max. wind speed details summary

District	State	Wind speed (km/h)	Surge height (m)	Village-level data
Visakhapatnam	Andhra Pradesh	197.05	2.20	Details
Yanam	Puducherry	81.33	0.15	Details
Gadchiroli	Maharashtra	57.84	0	Details
Bastar	Chattisgarh	87.71	0	Details
Koraput	Odisha	119.06	0	Details

Wind speed village-level details: Visakhapatnam

Village pin code/ name	District	State	Min km/h	Med km/h	Max km/h
531111	Visakhapatnam	Andhra Pradesh	79.60	149.68	149.68
531029	Visakhapatnam	Andhra Pradesh	101.26	161.76	161.76
531040	Visakhapatnam	Andhra Pradesh	101.87	113.95	113.95
531151	Visakhapatnam	Andhra Pradesh	109.99	128.06	128.06
531077	Visakhapatnam	Andhra Pradesh	114.79	158.28	158.28
535145	Visakhapatnam	Andhra Pradesh	118.69	173.42	173.42
531149	Visakhapatnam	Andhra Pradesh	128.22	136.68	136.68
531024	Visakhapatnam	Andhra Pradesh	131.48	173.21	173.21
531084	Visakhapatnam	Andhra Pradesh	131.97	136.73	136.73
531127	Visakhapatnam	Andhra Pradesh	132.44	151.28	151.28
531115	Visakhapatnam	Andhra Pradesh	134.39	172.51	172.51

Figure 2-18: Details screen of Max wind speed

The application will generate a situation report based on model output. A sample report is given below:

Cyclone Situation Analysis

Summary

District name: Puducherry
Analysis name: Analysis_2
Event name: Cyclone_Test
Hazard: Cyclone
Scenario level: Village
Demographic source: Census
Analysis date:

Cyclone Event Description

Maximum wind speed(kmph): 197.88
Minimum wind speed(kmph): 165.50

Exposure Name	Total	Damaged/Loss/Affected
Paddy(Mts)	374067880	117568480.8
Buildings	199346	112395
Residential Kachcha buildings	53510	48428
Residential Masonary buildings	30590	20283
Residential Concrete buildings	83982	33271
Commercial Masonary buildings	7745	3810
Commercial Concrete buildings	20477	6000
Industrial Masonary buildings	826	284
Industrial Concrete buildings	2216	519

Figure 2-19: Sample situation analysis report

The information provided by this report will be updated in real time based on information received in the server through WEB-DCRA App (mobile application).

Offline Web-CRA (Desktop version)

We propose to develop a smart client based application to update exposure database. The Smart Client Application has a desktop-based client that can connect to a database that is on a desktop on a LAN. Following are the key capabilities that will be made available through the Smart Client based Offline Web-CRA.

- A user interface that has all the exposure editing capabilities as are available on WebCRA
- A Map based user interface to insert new point type exposure elements (like hospitals, Fire stations bridges, airports, communication facilities, etc.) and polyline type exposure elements (like roads, pipelines, etc.). A tool will be provided in the toolbar for respective editing types. The user can select the tool and then specify the location on the map using the mouse pointer. Once the location is provided, the application will show a table to insert the attributes.
- A separate interface to insert details of ports as a group of buildings and structures.
- Person with data update privilege to the system will be able to update/modify/delete the exposure database.
- A data approval cycle where the exposure data created or updated by operators is reviewed by predefined reviewers, and approved for update to central server. Reviewer privilege will be provided to support this functionality.

- Auto synchronize capability in the database to update all the approved exposure data changes to the central server whenever internet connectivity becomes available.

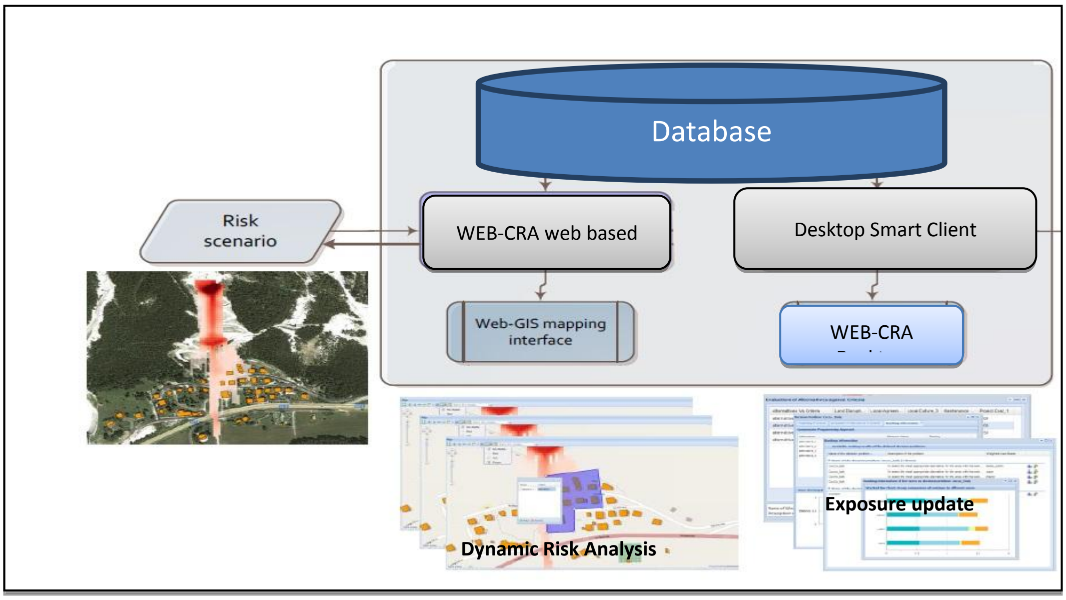


Figure 2-20: WEB-CRA – Layout of web and desktop application of WEB-CRA

This desktop application will be connected to the centralized database server of WEB-CRA over internet. The figure below shows the layout of the proposed solution.

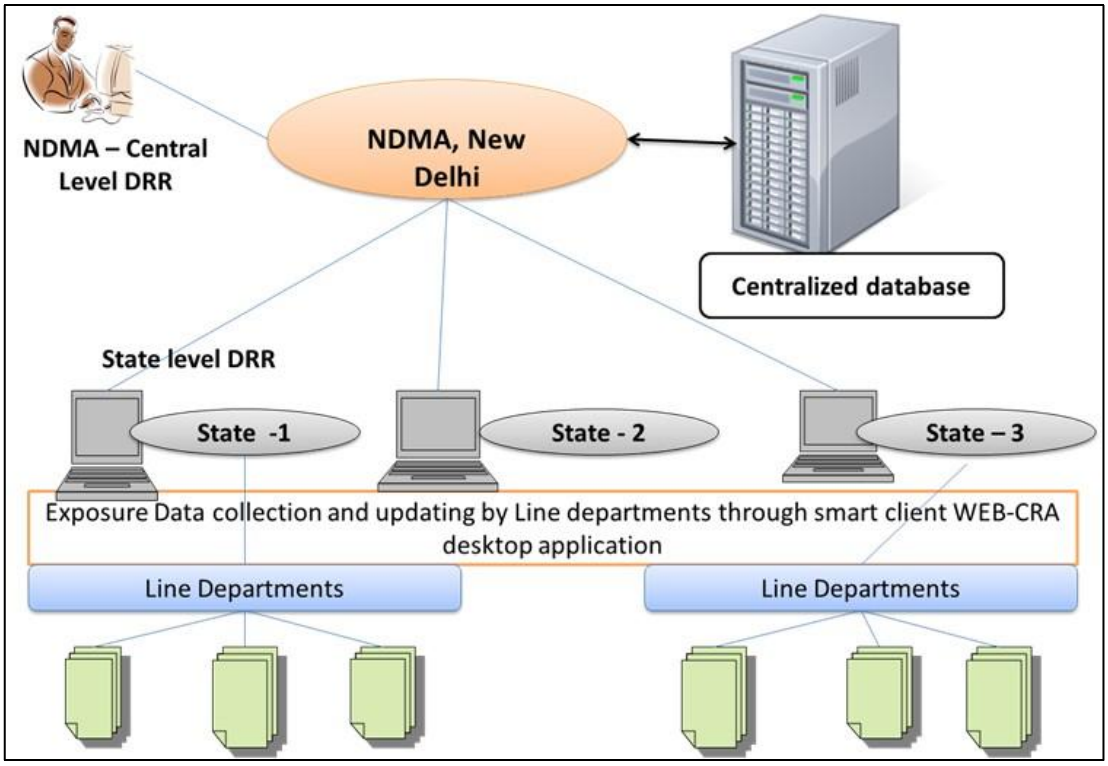


Figure 2-21: Layout of the proposed WEB-CRA desktop smart client application

WEB-DCRA App - Android based mobile phone application

RMSI proposes a mobile-based WEB-DCRA application that will provide the below mentioned functionalities on smart-phones:

1. Simple registration process to receive alerts in case of an impending disaster event like SMS and pre-recorded voice alerts regarding potential for impact, what they can do to reduce losses, etc.

Figure 2-22: Sample user interface (Mobile application) for WEB-DCRA App

1. "I AM SAFE" feature: By clicking 'I AM SAFE' button, the system will send SMS alert to predefined numbers. This will help the user's relatives to know that the user is safe and considerable efforts will be saved in searching for people.
2. Crowd Sourcing feature to get feedback from people who want to submit information related to events such as:

    - Status of flooding
    - Approximate wind speed, surge height
    - Damage descriptions
    - Need to be evacuated
    - Need Emergency Medical help" etc.

WEB-DCRA APP will also be developed using Open Source Technologies for mobile development. Android SDK will be used as the development platform, and PostGre/PostGIS will be used to store data on mobile device. The Android SDK provides the tools and APIs necessary to begin developing applications on the Android platform using the Java programming language.

Figure 2-23 depicts technical architecture of the Android platform-based mobile application.

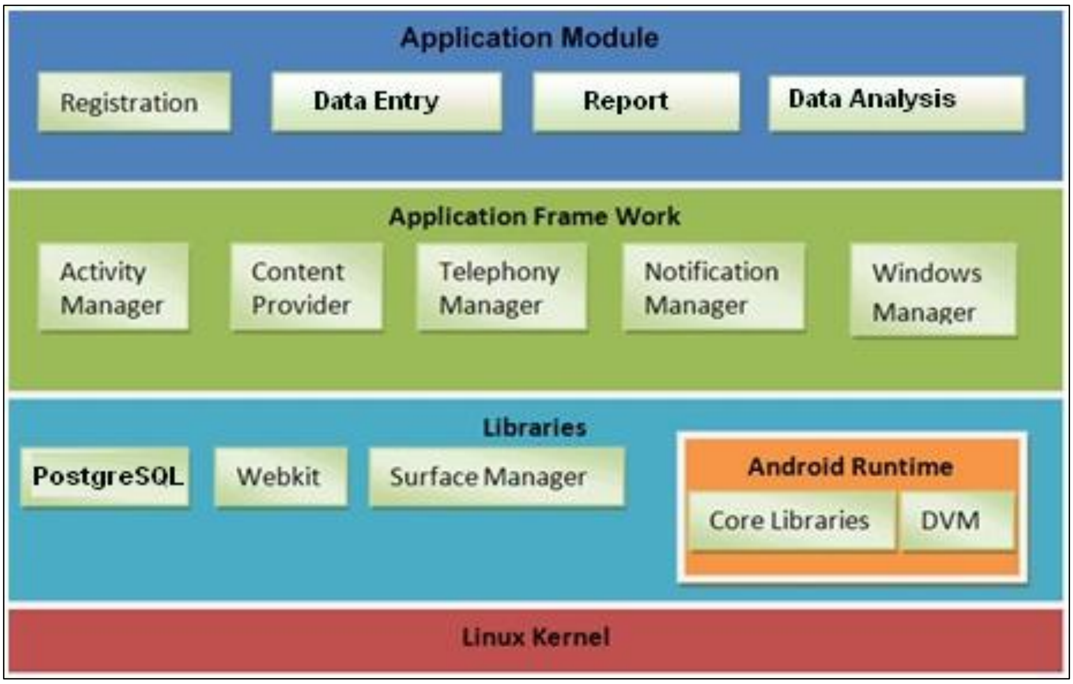


Figure 2-23: Android Architecture

The Android OS can be referred to as a software stack of different layers, where each layer is a group of several program components. Together it includes operating system, middleware and important applications. Each layer in the architecture provides different services to the layer just above it. Android is a Linux-based operating system for mobile devices such as smart-phones and tablet computers. The Android NDK (Native Development Kit) is a toolset that embeds components, which make use of native code in the Android applications. Android applications run in the Dalvik virtual machine. The NDK allows implementing parts of the applications using native-code languages. Hence, RMSI proposes to develop modules (described below) on the above application framework.

2.7.3 PROPOSED PHYSICAL ARCHITECTURE WEB-CRA

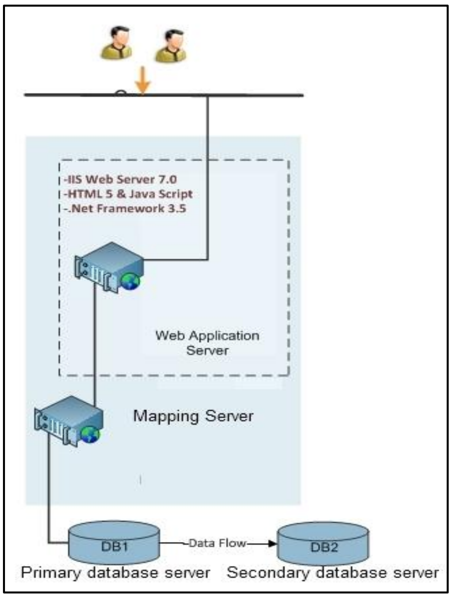


Figure 2-24: Schema showing physical architecture

Security

Integrated Authentication and Authorization

The authentication strategy will be implemented for the security and reliability of the web applications. Since the presentation and business layers are deployed on the same machine, resources will be accessed based on the original caller's Access Control List (ACL) permissions. The services will be secured by authenticating users, taking advantage of the features of the underlying development platform. Secure protocols such as Secure Sockets Layer (SSL) will be used during Basic authentication or when credentials are passed as plain text. Message-level security mechanisms supported by the WS* standards (Web Services Security, Web Services Trust, and Web Services Secure Conversation) will be implemented with SOAP messages.

The authorization strategy will provide the security and reliability to the web applications. Resources will be protected by applying authorization to callers based on their identity, account groups, roles, or other contextual information. For roles, the granularity of roles will be minimized as far as possible to reduce the number of permission combinations required. Role-based authorization will be implemented for business decisions, resource-based authorization for system auditing.

The authentication, authorization, and profile provider web service will provide security services to the web applications with central web based management application to manage users, roles, and users in roles.

Audit Trail

The audit trail mechanism will track all changes to the systems underlying data so that an auditor can examine these at any later point in time.

For each database table that requires an audit trail, another table will be created that will have the exact same schema as the parent table with four additional fields:

3. AuditID - a primary key, IDENTITY field
4. Deleted - a bit field that defaults to 0 that indicates if the record has been deleted.
5. CreatedOn - a date time field that defaults to the current date and time.
6. CreatedBy - a field that records who changed the data.

A trigger will be created on the parent table for UPDATE and INSERT that inserts the contents from the inserted table into Audit table.

Similarly, a trigger on parent table will be created for DELETE that inserts the contents from the deleted table into Audit table, putting in a value of 1 into the audit table's Deleted field.

Passwords Encryption

For Password Encryption, development framework's inbuilt support for encryption will be utilized. The following encryptions are part of the development framework such as Hashing, and Symmetric and Asymmetric Encryption.

The Hash based encryption will be implemented by adding a salt (unique string) to every password before hashing it. Hash based encryption is optimized for speed.

Database Mirroring

The proposed deployment will consist of database mirroring. Database mirroring maintains two copies of the single application database and will reside on different server instances of PostGRES/PostGIS Server Database Engine.

Out of the two databases, one database server instance will serve the database to clients (the primary server). The other secondary instance will act as a hot or warm standby server (the mirror server), depending on how it is configured as well as the state of the mirroring session. The database mirroring provides a hot standby server that supports quick failover without any loss of data from committed transactions when a database mirroring session is synchronized. When the session is not synchronized, the mirror server is typically available as a warm standby server (with possible data loss). The technology, which will be used to develop the proposed application, is given in Table 2-5.

Table 2-5: Technological details - Open Source Technology

Technology	Description
PostGreSQL (Database Server)	PostgreSQL is a powerful, open source object-relational database system. It has more than 15 years of active development and a proven architecture that has earned it a strong reputation for reliability, data integrity, and correctness. It runs on all major operating systems, including Linux, UNIX (AIX, BSD, HP-UX, SGI IRIX, Mac OS X, Solaris, Tru64), and Windows. It is fully ACID compliant, has full support for foreign keys, joins, views, triggers, and stored procedures (in multiple languages). It includes most of SQL:2008 data types, including INTEGER, NUMERIC, BOOLEAN, CHAR, VARCHAR, DATE, INTERVAL, and TIMESTAMP. It also supports storage of binary large objects, including pictures, sounds, or video. It has native programming interfaces for C/C++, Java, .Net, Perl, Python, Ruby, Tcl, ODBC, among others, and exceptional documentation.
Geoserver	GeoServer is an open source software server written in Java that allows users to share and edit geospatial data. Designed for interoperability, it publishes data from any major spatial data source using open standards. GeoServer is the reference implementation of the Open Geospatial Consortium (OGC) Web Feature Service (WFS) and Web Coverage Service (WCS) standards, as well as a high performance certified compliant Web Map Service (WMS). GeoServer forms a core component of the Geospatial Web.
Geowebcache	GeoWebCache is a Java web application used to cache map tiles coming from a variety of sources such as OGC Web Map Service (WMS). It implements various service interfaces (such as WMS-C, WMTS, TMS, Google Maps KML, Virtual Earth) in order to accelerate and optimize map image delivery. It can also recombine tiles to work with regular WMS clients.
Apache Tomcat (Web Server)	Apache Tomcat is an open source software implementation of the Java Servlet and JavaServer Pages technologies. The Java Servlet and JavaServer Pages specifications are developed under the Java Community Process. Apache Tomcat powers numerous large-scale, mission-critical web applications across a diverse range of industries and organizations.

Experimental Phase

Before exposing WEB-CRA to target users, a team of key experts nominated by client and RMSI experts will work together to analyze the outcomes of the WEB-CRA for about 18 months by considering real cyclone risk assessment and related product development, finalizing the interactive map viewer platform, protocol development for warning etc.

Quality Assurance

RMSI is a CMMI certified organization and follows a very robust and detailed process to ensure quality of the development.

System Testing - The objective of system testing exercise is to validate that the software built conforms to functional and non-functional requirements specified Software Requirement Specifications so that it works as expected. Thus, software testing ensures the quality of product built.

To ensure that adequate effort is made towards producing quality software, a separate team for system testing comprising of full-time test engineers will be formed. Iterative builds will be released to testing team.

RMSI will carry out the following activities in this step:

Test Case Preparation: The purpose of preparing test cases is to have a documented way of validating specified functionality in a structured and exhaustive manner. Test case preparation will involve the following activities:

- Study of Software Requirement Specifications document
- Documenting test cases detailing the steps to carry out to validate specified functionalities
- Review of test cases to ensure adequate coverage

Test Environment Preparation: The output of this step will be a well-isolated environment suitable for system testing.

Test Case Execution and Defect Tracking: This step involves performing the actual testing of the system and includes performing the following activities: Test site links, execute test cases to test Business logic and functional requirements, Test overall site, Test template with target browsers, and Logging of defects found in a defect tracking tool and assignment of defects to appropriate developer for rectification. The output of this step will be a test report giving details on defects validated and new defects found with their severity and priority.

Non-functional testing: The purpose of this step is to test whether the portal meets the non-functional requirements including response time, throughput and load. It may involve one or more of the following activities: Recording of test scripts, simulating load on system using the test scripts, and Taking measurements of response time. The output of this step will be test reports detailing the measurements recorded and identification of potential areas of bottlenecks.

User Acceptance Testing: The purpose of User Acceptance Testing is to establish whether the system developed meets the expectations of the system users or not. This will involve carrying out of following activities: Deployment of system at the operation environment for testing by its users, Execution of user acceptance test cases by the users, and Reporting of defects/issues by users and fixing of the same by RMSI. The output of this step will be issuance of acceptance certificate by the client.

2.8 Training and Capacity building support

RMSI team understands the importance of training and capacity building supports at all levels and hence devise an inclusive training program to ensure knowledge transfer, capacity building and project sustainability. As mentioned in Section 2.1, with the help of NDMA, we will be involving disaster managers from all the 13 coastal states/UTs from the inception phase of this assignment. Accordingly, RMSI team will map the key stakeholders, understand their requirements, capacity and will develop a detailed training and capacity-building plan. The training and capacity-building plan will include content, schedule and plan of actions for implementation and this will be finalized in consultation with NDMA.

Our proposition is to involve identified stakeholders from all the 13 States/UTs for training and capacity building:

- In key project activities including exposure data updating through the Web-CRA and its usage until Beta version of Platform (WEB-DCRA, Updated Web-CRA, Offline Exposure Management and Mobile APP).
- In testing once Beta version of the Platform is ready
- In national and state-level trainings and capacity building activities.

The training and capacity building activities will be carried out in a phased manner and at different levels. This will include 2 national level workshops and trainings and 14 State/UT level outreach trainings and workshops (twice in 7 identified and agreed locations in different States/UTs with the help of NDMA). The stakeholders for these activities will be carefully identified at two levels.

- Senior Officers from each State and UTs who will attend two high level workshops at NDMA in addition to Project Inception Meeting.
- Middle level officers (who have a basic background on DRR and who will be carrying out the operational activities in the various State/UTs), who will attend two trainings of two days each at NDMA (in the developmental phase of the project in consultation with NDMA) and two trainings during experimental phase through 14 State Outreach Trainings. This would provide opportunity to middle level officers to attend at least 4 trainings (2 at NDMA and 2 at State/UT levels as TOT (Training for Trainers), a total of 8 days training and hands on sessions) and participation in the model outputs' verifications through comparison of modeling outputs of live cyclone(s) and field outputs during the experimental phase of project. This approach will also ensure ownership among stakeholders in addition to capacity building and knowledge transfer.

The details of the training and capacity building and outreach activities are provided below.

2.8.1 National Level Workshops

The objectives of the national level workshops are to familiarize the key stakeholders at NDMA, National Agencies and Senior Level State Officials and key Middle Level State Officials on WEB-DCRA, Updated Web-CRA, Offline Exposure Management, and Mobile APP. The idea is to start with these selected audiences, make any suggested changes, and subsequently take it to a wider audience.

RMSI proposes 2 national workshops of 3 days each for this. While the first day workshop would cater to Senior Level Officials, the next two days training would be focused on Training of Trainers (ToTs).

Testing beta version of Platform: Once the beta version of the Platform (WEB-DCRA, Updated Web-CRA, Offline Exposure Management and Mobile APP) and their respective Technical User Guides are ready, RMSI in coordination with NDMA will conduct first 3 days National Level Workshop-cum-Training Program to present the functionalities and capabilities of the Platform to Senior Level Officers and Training and hands-on sessions to ToTs. The attendees of the 1-day workshop will be mostly policy makers and selected representatives from 13 States/UTs, NDMA, the World Bank, IMD, and any other stakeholders that NDMA would like to invite. The team will demonstrate the functionalities and the base data available in the system and its application.

The attendees of the 2 days ToTs will be trained on development of cyclonic disaster scenarios and assessment of vulnerability and risk assessment specific user cases based on some of the low-probability-high-impact events. As the stakeholders will have on-ground experience dealing with these past events, the specific use case scenarios of these events may be used for bench marking and verifying the capability and authenticity of the system. The team will explain the data layers involved in the analysis and their limitations if any for building the scenarios. The opinions and suggestions of the stakeholder will be documented and will be considered for finalization of the WEB-DCRA (Web and desktop versions) and App.

Demonstration of Platform: The second national workshop will be conducted in coordination with NDMA after we address the suggestions and recommendations of the stakeholders. Now the application will be ready for a wider audience accommodating the requirements and expectations of client and users. The same stakeholders invited for the first national workshop will be invited for this workshop and presented the risk atlas again to ensure that all the comments and suggestions have been addressed satisfactorily beforehand.

Second national level workshop: This national level workshop will be conducted as part of the closure session and demonstrating the fully operational Platform *(WEB-DCRA, Updated Web-CRA, Offline Exposure Management and Mobile APP)*. A larger audience including senior and middle level officers (participants of first national workshops), policy makers both at state and national level from all 13 States/UTs, other stakeholders like IMD, INCOIS, NRSC, NDMA, the World Bank will be invited. The team will explain the study in details and further present the WEB-DCRA (Web and desktop versions) and App. capabilities. The second and third day of the workshop would focus on hands on to ToTs. For this, we would form smaller groups in which the ToTs will have hands-on training sessions including demonstration of the software developed. RMSI team will actively support the groups in exploring and understanding the WEB-DCRA (Web and desktop versions) and App. capabilities.

The agenda for these two training and workshops will be designed carefully in consultation with NDMA. Key principle for developing the agenda would be to ensure active involvement of stakeholders and provide opportunities to stakeholders to contribute in finalizing the beta version and understand the capabilities in full potential.

RMSI will take the support of NDMA to identify and invite the stakeholders, required logistics for the participants, venue locations and facilities required for the workshop and trainings. RMSI will prepare presentation materials, handouts, workbooks, reference sheets etc. that will be provided to the participants during these trainings and workshops. These will not only facilitate the dissemination of the findings of the study but will also keep all the stakeholders informed so that they are at the same level of understanding regarding the processes/methodologies that will pave the way to develop a road map for Disaster Risk Reduction in all the 13 coastal State/UTs.

2.8.2 State Level Training

The objective of state level outreach is to provide comprehensive hands on training to as many state level stakeholders as possible on use of WEB-DCRA, Updated Web-CRA, Offline Exposure Management, and Mobile APP.

The state outreach trainings will be carried out twice in experimental phase (a total of 14 State Outreach trainings covering all the 13 States/UTs) starting from the demonstration of fully operational WEB-DCRA, Updated Web-CRA, Offline Exposure Management, and Mobile APP. The dates and schedules of these trainings will be decided in consultation with NDMA and concerned state stakeholders.

The broad outline of the training activities at the state level will follow the same agenda that will be followed in National Level trainings; however, the data discussion and analysis will be focused to the participating States/UTs. The use case scenarios demonstrated in Technical User Guides will also be considered with reference to that particular state. We propose a 2-day focused interactive Training Program with a total of 14 such Training Programs in different States/UTs. All the states will have separate sessions according to the category they are grouped into. The UTs will be invited to the nearest state for the sessions. However, this tentative plan will be further discussed with NDMA to see the modalities and feasibility of grouping 2 states together for outreach activities. It is logical to consider adjoining states, as it is essential for such states to coordinate between themselves for any mitigation and adaptation activities particularly for hazards like cyclone, which often have regional impact.

3 Deliverables and schedule for completion of tasks and services

RMSI team would adhere to the requirements of timelines for various deliverables as shown in the table below, however, deliverables time-line may get impacted due to delays in getting data from different organizations and delay in review and final acceptance process of the deliverables.

Table 3-1: Deliverables and Schedule

S. No.	Deliverables	Duration (from date of signing the contract)
1	Project Inception Report	2 weeks
2	Development of probabilistic risk assessment Maps/products for Cyclonic wind, storm surge and rainfall induced flooding and demonstrate them through interactive map viewer	3 months
3	1. Alpha version of • WEB-DCRA, • Updated Web-CRA, • Offline Exposure Management and • Mobile APP 2. Demonstration and Presentation to key stakeholders, 3. Draft Technical User Guide	5 months
4	Demonstration of Beta version of • WEB-DCRA, • Updated Web-CRA, • Offline Exposure Management and • Mobile APP	7 months
5	1. Fully Operational • WEB-DCRA, • Updated Web-CRA, • Offline Exposure Management and • Mobile APP 2. Closure Report	7 months
6	Experimental Phase	8 – 20 months
7	Training Workshops and Capacity Building activities	8 – 20 months

4 Work Plan

4.1 Work Schedule

S.No.	Project Tasks	Apr-18		May-18				Jun-18				Jul-18				Aug-18				Sep-18				Oct-18				Nov 18- Dec. 2019												
		W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20
1.0	**Project Management and Communication**																																							
1.1	Project initiation meeting																																							
1.2	Project Status Reports																																							
1.3	Project Management																																							
D1	**Inception Report**																																							
D1.1	Inception workshop - Stakeholder consultation																																							
D1.2	Data Review and gap analysis																																							
D1.3	Data collection																																							
D1.4	System requirement analysis																																							
D1.5	System specification and																																							
D1.6	Report 1: Inception Report			◆																																				
D2	**Development of probabilistic risk assessment Maps/products and display through interactive map**																																							
D2.1	Historical Data Analysis																																							
D2.2	Stochastic Event Set Generation																																							
D2.3	Hazard analysis																																							
D2.4	Exposure data enhancement																																							
D2.5	Vulnerability assessment																																							
D2.6	Probabilistic Risk Assessment																																							
D2.7	Generation of probabilistic risk assessment products																																							
D2.8	Integration into Web-CRA																																							
D2.9	Development of Offline verion for Exposure Management																																							
D2.10	Presentation of Probabilistic Risk Assessment Products													◆																										

S.No.	Project Tasks	Apr-18		May-18				Jun-18				Jul-18				Aug-18				Sep-18				Oct-18				Nov 18- Dec. 2019												
		W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20
D3	**Development of Alpha version of Web-DCRA/Decision Support Tool,**																																							
D3.1	Setting of communication protocal with IMD for data real time cyclone track and rainfall forecast and				■	■																																		
D3.2	Hazard model setup for live								■	■	■	■	■	■	■																									
D3.3	Hazard Analysis												■	■	■	■	■																							
D3.4	Impact Assessment														■	■	■	■																						
D3.5	Web-DCRA Development												■	■	■	■	■	■	■																					
D3.6	Adding Decision Support Capabilities to Web-DCRA																■	■	■	■																				
D3.7	DCRA App Development																■	■	■	■																				
D3.8	Demonstration and Presentation of Alpha Version																				◆																			
D4	**Demonstration of Beta version of Web-DCRA, DCRA App. And Offline Desktop Application for User**																																							
D4.1	Update Web DCRA based on Alpha version demo feedback																					■	■	■	■															
D4.2	Update DCRA App based on Alpha version demo feedback																					■	■	■	■															
D4.3	Demonstration of the Beta Version																									■	■													
D5	**Closure Report and fully operational Web-DCRA and offline Desktop version of**																																							
D5.1	Update the Web DCRA based on User Acceptance Testing																									■	■	■												
D5.2	Updated DCRA App based on User Acceptabce Testing																									■	■	■												
D5.3	Update Offline Desktop verion based on User Acceptance Testing																									■	■	■												
D5.4	Closure Report and fully operational Web-DCRA and offline Desktop version of Web-CRA																												◆											
D6	**Experimental Phase**																													■	■	■	■	■	■	■	■	■	■	■
D7	**Training and Workshops**																																							
D7.1	Creation of training modules																									■	■	■	■											
D7.2	National Workshops																													■							■			
D7.3	State Workshops																													■	■	■	■	■	■	■	■	■	■	■

4.2 Project Planning and Management

Key Features

As a first step, during the project initiation meeting, we will define the project communication protocol between RMSI and PMU-NCRMP by defining single point of contact on both the sides. The key activities under project management are further elaborated below.

1. **Project Initiation** - The Project Manager will undertake a detailed discussion during the project initiation meeting and finalize core team, and roles and responsibilities, and discuss the project plan with the PMU representatives.
2. **Development of Project Plan** - RMSI Project Manager will develop a project plan defining roles and responsibilities, communication protocol, key milestones, assumptions, constraints, task dependencies & budget; listing the anticipated risks and RMSI risk mitigation plan; project monitoring protocol including the monitoring team; project status reporting; quality objectives and management plan.
3. **Project Monitoring and Control -** The project monitoring procedure will be defined, in close consultation with the PMU-NCRMP, to regularly measure project progress and refurbish the execution plan, if required. The project monitoring team will consist of RMSI Senior Management, Project Manager, and key client representatives. This will aid in identification of problems and taking corrective action in a timely manner.
4. **Project Status Reporting -** RMSI team will undertake regular monthly project status discussions and subsequent reporting. Along with status reporting, the team will also maintain regular communication between RMSI and PMU-NCRMP, and within the project implementation team. The reports and other outputs generated as part of the project will be shared with the key stakeholders for review. While regular correspondence will be through e-mail, other modes of communication like teleconference, video-conference, and site visits will also be undertaken.
5. **Communication Plan**- The project team will follow a defined communication protocol to ensure regular communication with PMU-NCRMP. This will help us ensure prompt issue resolution, feedback attraction, monitoring and evaluation of the project against set targets, and refurbishment of work plan/ methodologies for effective implementation.
6. **Risk Management -** RMSI Project Manager will develop a project-specific strategy for identifying, analyzing and mitigating risks, and also set up an escalation mechanism with the client during project initiation meeting. This will consist of preparation of a list of anticipated risks and their sources; Prioritization and categorization; and Risk Mitigation Plan for major anticipated risks including contingency plans. A spreadsheet will be shared every month with the client highlighting all the risks faced and mitigation measures adopted.

4.3 Project Meetings

We propose the following meetings as part of our effective project implementation plan.

Name	Purpose	Location / Method
Project Initiation Meeting	• To identify the points of contact; and finalize the project approach, deliverables, work schedule, communication protocol, project team, roles, and responsibilities	PMU, NCRMP
State training workshops	• To demonstrate the web-DCRA and the app to state stakeholders • To share results of state-level assessment	States as discussed with PMU, NCRMP

Name	Purpose	Location / Method
National training workshops	• To share the assessment and result information and discuss the recommendations • To demonstrate the web-DCRA and the app	2 locations as discussed with PMU

5 Annexure 1

5.1 Annex 1: Cyclone and Storm Surge Modeling

The sections below present the details of the standard methodology followed for modeling cyclone and flood risk. The extent of sophistication implemented is only limited by the availability of data and literature for India. Every attempt will be made to increase the quality of results.

5.1.1 Methodology for Modeling Cyclonic Wind Hazard

Dynamic Storm Model: Surface winds associated with a tropical cyclone are derived using a dynamic storm model (Jelesnianski and Taylor). Meteorological inputs required by this model include positions of the cyclone, pressure drop, and radii of maximum winds at any fixed interval of times. The main component of the storm model is a trajectory model and a wind speed profile approximation scheme. The trajectory model represents a balance among pressure gradient, centrifugal, Coriolis, and surface frictional forces for a stationary storm. The model is being used for the computation of maximum wind at each grid point of the analysis area and retained these wind speeds for input to the surge model. The wind model is then calibrated and validated using available observed data related to important historical cyclones.

Cyclonic wind hazard assessment identifies and demarcates areas, which are exposed to strong winds associated with tropical cyclones. It provides information on the extent and wind speed to the cyclone prone areas for a range of wind magnitudes. Figure 5-1 explains the step-by-step approach to be adopted for cyclone hazard modeling.

Step 1	Step 2	Step 3
• **Storm Parameters Before Landfall** – Track (Lat, Long) – Pressure drop – Radius of maximum wind – Forward velocity – Duration of the storm	• **Wind Foot Print** – 250 m grid cells over area of interest – Simulate storm motion using time step process – Record maximum wind speed in each cell of the grid – Calibration	▪ **Hazard mapping** – Repeat step 2 for all storms – Generate wind hazard map

Figure 5-1: Steps for wind hazard assessment

Computing hazard footprints of wind Field: zonal statistics (geo-spatial technique) are applied on peak gust wind speeds to get an aggregated value at village level. Finally, wind hazard map at village level are prepared to identify strong wind prone extent delineation. A sample of computed maximum wind field (km/h) at district level is depicted in Figure 5-2. These kinds of maps would help the Disaster Management Authorities to develop short and long-term disaster management and vulnerability reduction action plans in respect to cyclones.

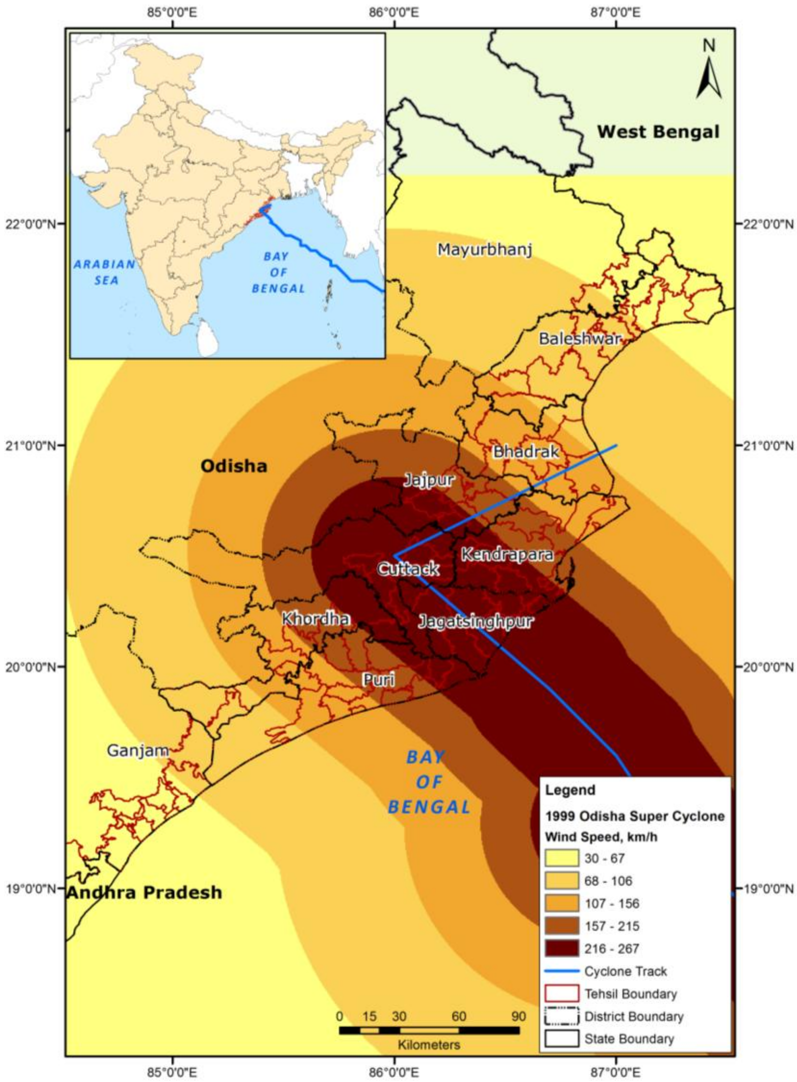


Figure 5-2: Sample of computed wind speed

5.1.2 METHODOLOGY FOR MODELING STORM SURGE HAZARD

Storm surge hazard modeling for NCRMP Phase-1 project was performed using the ADCIRC-2DDI hydrodynamic finite-element model. A finite-element mesh for the study area was constructed using the software package Surface Modeling System (SMS) (Westerink et al. 1994). The maximum surge height computed with the model was calibrated and validated against observed surge heights. The validated storm surge model was then applied for historical cyclone events that made landfall and the associated surge amplitude, velocity, and surge flood depths were computed accordingly. Finally, scenarios of storm surge flooding were prepared. These scenarios were then used to delineate the flood-prone extents along the coast. The storm surge hazard assessment framework adopted is shown in Figure 5-3.

A detailed description of the finite-element based hydrodynamic model ADCIRC-2DDI is available in Luettich et al (1992). The governing model equations comprise of the depth-integrated equations for mass and momentum conservation, subject to incompressibility, and Boussinesq, and hydrostatic pressure approximations. These equations are discretized in space using linear finite elements and in time by a finite-difference scheme. Water level along the open boundary was obtained from Le Provost tidal database and was represented by 13 tidal constituents (K_1, M_2, N_2, O_1, P_1, S_2, K_2, L_2, $2N_2$, MU_2, NU_2, Q_1, and T_2) based on

Finite Element Solution (FES) Version 95.2 (Le Provost et al. (1998). FES95.2 solutions are 0.5^0x 0.5^0 gridded versions of the full finite element solutions.

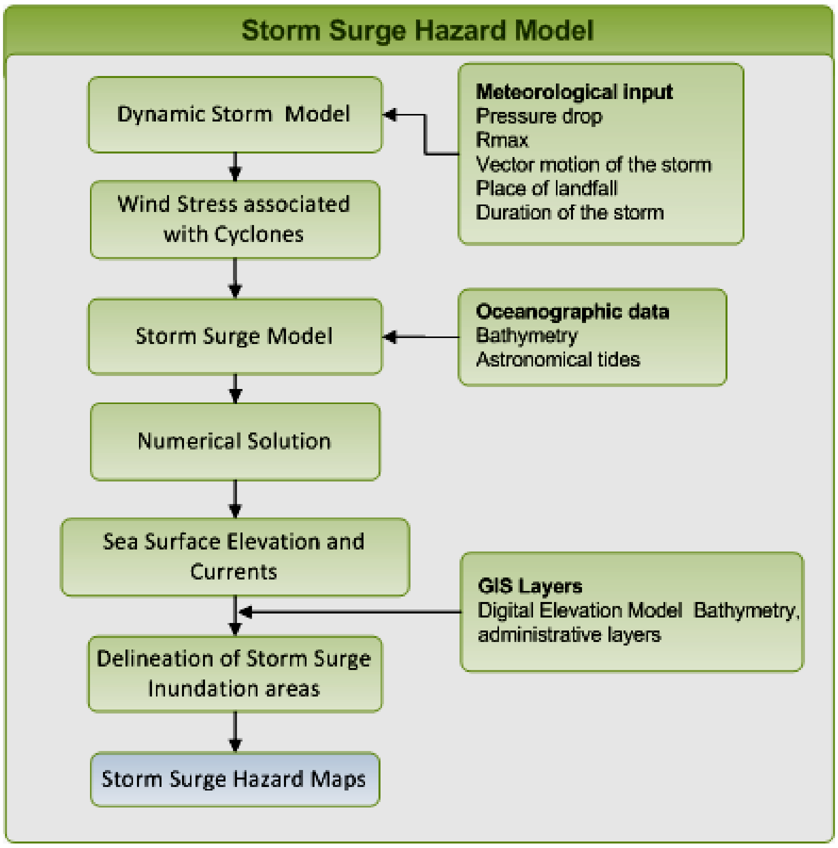


Figure 5-3: Framework of storm-surge hazard modeling

The ADCIRC model requires wind forcing as an essential input parameter. For this purpose, the wind fields computed using the dynamic storm model of Jelesnianski and Taylor were used. Further, the wind model provides the wind-fields and pressure gradient to the ADCIRC model. The conversion of pressure gradient to equivalent water column height was obtained through the transformation P/ρwg proposed by Blain et al. (1994). Finally, the wind stress and equivalent water column heights were linearly interpolated at each computational node of the finite element mesh used in the model.

The finite-element mesh for the study area was constructed using the Surface Modeling System (SMS) software package (Westerink et al. 1994). The program generated a grid with a low resolution in the deeper region, and high-resolution when approaching the coast. The node spacing was set to 100 m near the coast and about 20-30 km in the open ocean. The model mesh with variable grid resolution for Odisha is shown in Figure 5-4 and the mesh in zoomed area is depicted in Figure 5-5. The bathymetry and topography is shown in Figure 5-6. The landward boundary of the model is fixed from the coast based on 11m topo contour, presuming that the surge would never exceed 11m in this region. An explicit scheme is used in time discretization with a time step.

Storm surge hazard assessment identifies and demarcates areas, which are exposed to storm surge flooding. It provides information on the extent and depth of flooding for a range of events, which is the result of hazard assessment. This information is very useful to identify coastal stretches vulnerable to the impact of surge inundation. The sample output of ADCIRC for floodwater extent and depth in coastal area is shown in Figure 5-7.

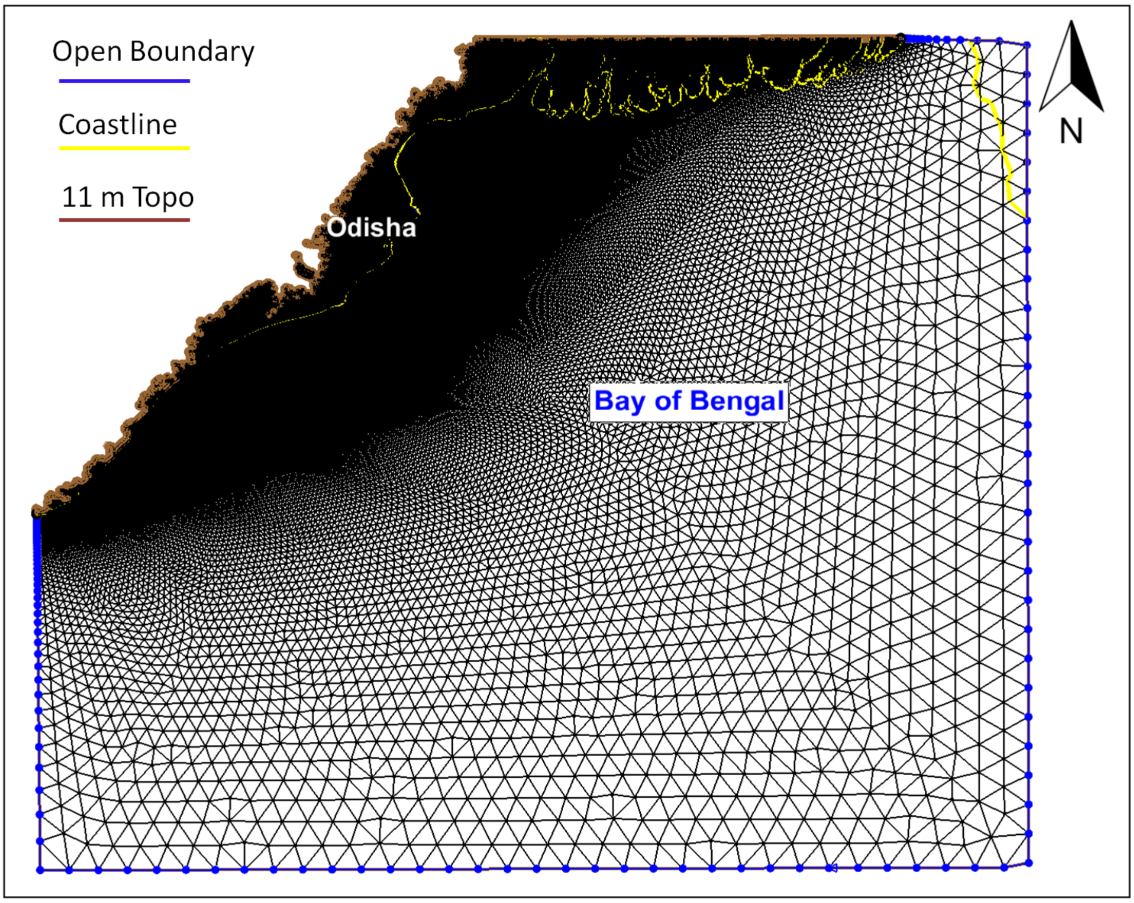


Figure 5-4: Sample of flexible unstructured mesh

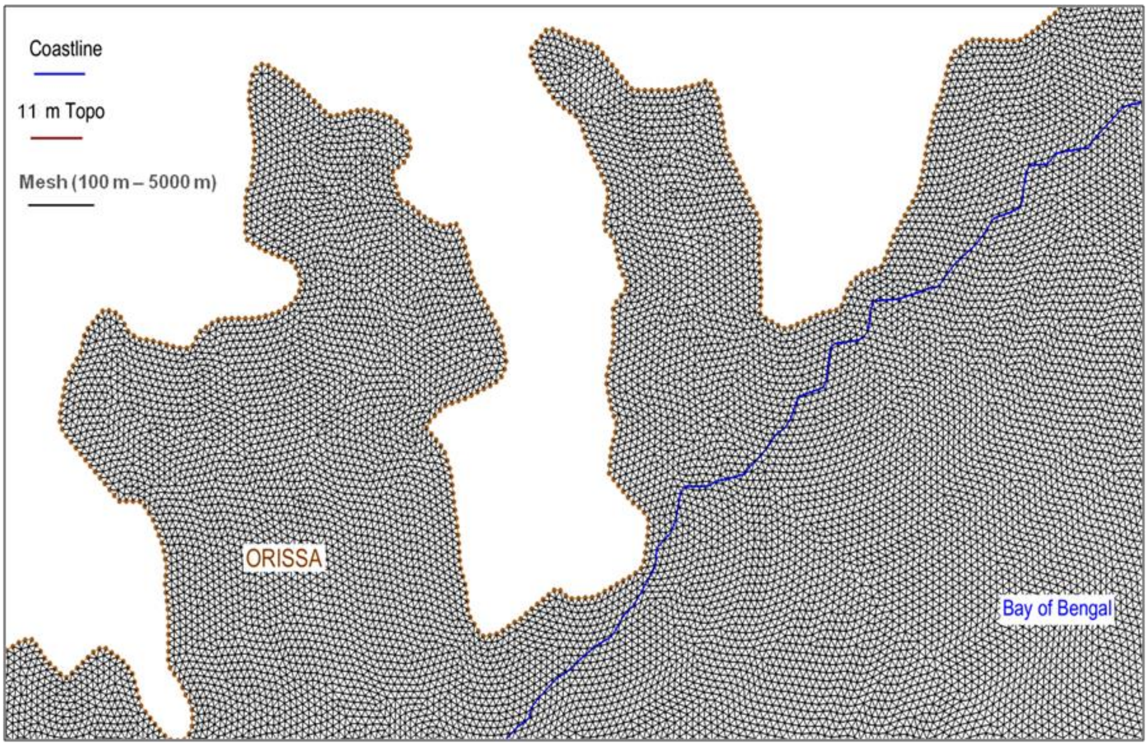


Figure 5-5: Enlarged view of above figure near Paradip coast

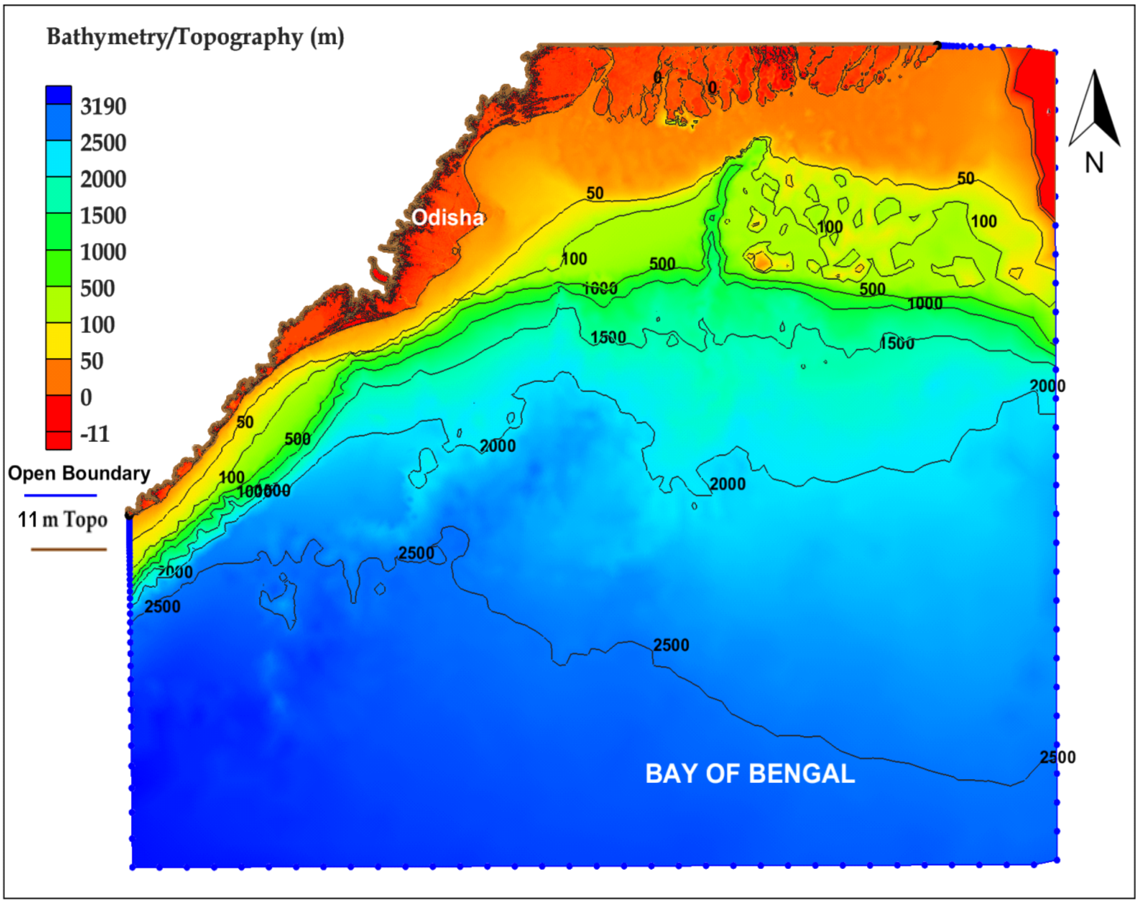


Figure 5-6: Sample of Bathymetry/Topography (m)

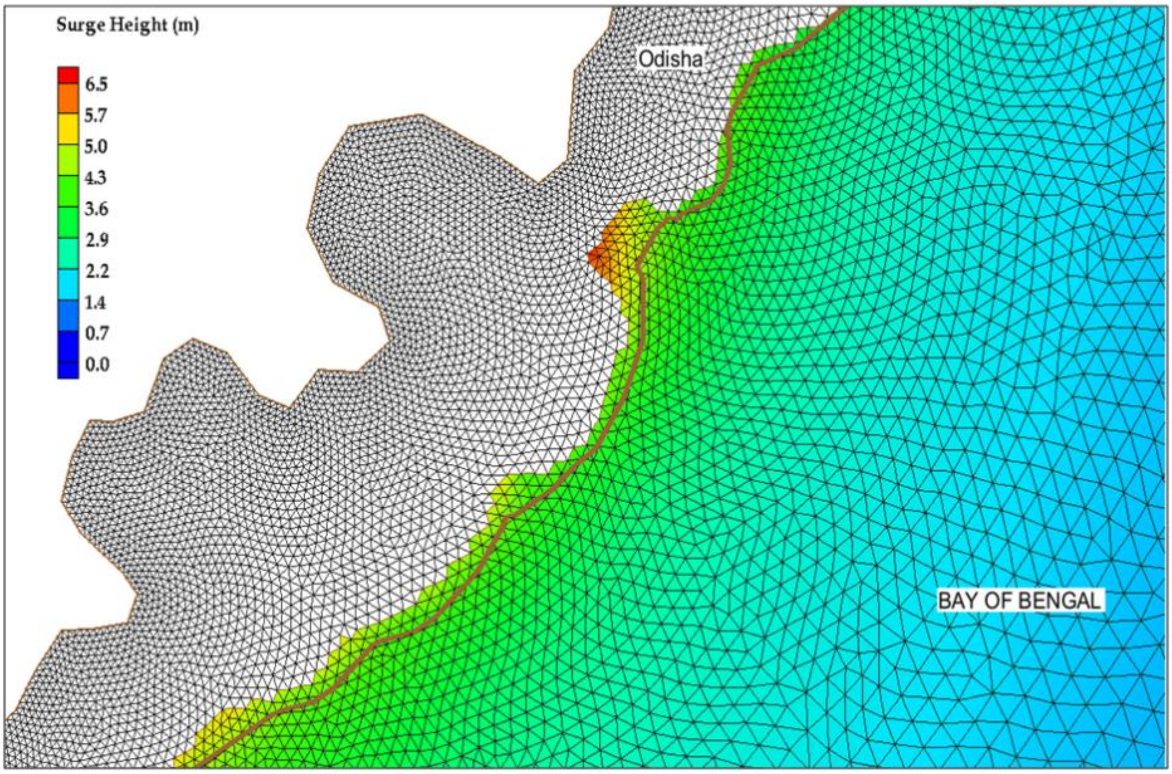


Figure 5-7: Sample of storm-surge flood extent and depth

5.2 Annex 2: Development of the hydrological model for all basins

This section provides the necessary theory for understanding the implementation of the hydrological modeling framework. It begins with a broad presentation of modeling components and continues with a more in-depth look into flood modeling and the hydrological assessment. The HEC-Real Time Simulation (HEC-RTS) model has been proposed for hydrological modeling and other components such as flood Inundation mapping and flood forecasting.

5.2.1 HEC-Real Time Simulation (HEC-RTS)

HEC-RTS is an all-inclusive system that picks up precipitation data, simulates a rainfall-runoff model, runs a hydraulic model and makes available inundation maps, stage and plots. Once the models have been calibrated and validated to reflect current hydro-meteorological conditions, they can be executed to produce forecasts of flood characteristics. This will assist the concerned agencies to evaluate the effects of their operating decisions in the near future. Reservoirs, bridges and other data from the field will be incorporated in the model to make it robust.

The ability of HEC-RTS is to forecast floods with a sufficient lead-time for early flood warning dissemination and take timely protection measures. This will also help in effectively undertaking flood mitigation measures and minimizing damage during floods in coastal cities. It will specifically address flood risk management and loss-of-life concerns in the coastal cities. The accuracy and strength of output will depend on the input data and will require cooperative working with other regional or national agencies. This model has already been tested for flood modeling in various large and small-scale river basins across the world.

Control and Visualization Interface (CAVI), is the graphical user interface of HEC-RTS. CAVI is the primary framework of HEC-RTS. Using CAVI, user configures watersheds/hydrological boundary, views and edits data and information, sets up and runs forecasts, and views results. CAVI provides the linkage between incoming data feeds, observed data, models, and computed data. The user oversees and controls the operation of the functional modules until model setup, calibration and validation. Once the model is validated, it will be automated to fetch the forecasted precipitation data and provide maps. Evaluation of quality of incoming data would be of prime importance for the modeling exercise.

The functions of CAVI are grouped into modules, corresponding to different water management tasks. These are the Data Acquisition Module, the Data Visualization Module, the Model Interface Module, and the Watershed Setup Module. Each has a specific set of commands that are accessed through menus, toolbars, scripts, and from the context menus associated with the schematic elements displayed in the interface. HEC-RTS allows the user to make short-term (typically a few days or weeks) forecasts of hydrologic conditions. It provides an integrated suite of generalized modeling programs that represent different hydrologic aspects of the watershed. HEC-RTS includes the following models listed in the sequence of execution:

1. HEC-HMS, a hydrologic rainfall-runoff model
2. HEC-ResSim, a reservoir flood operations simulation model
3. HEC-RAS, a river hydraulics model

Each of these programs can run independently but in HEC-RTS, they are combined to provide a comprehensive watershed forecast that includes river stages and flooding extents. The flowchart of HEC-RTS processes has been shown in Figure 5-8.

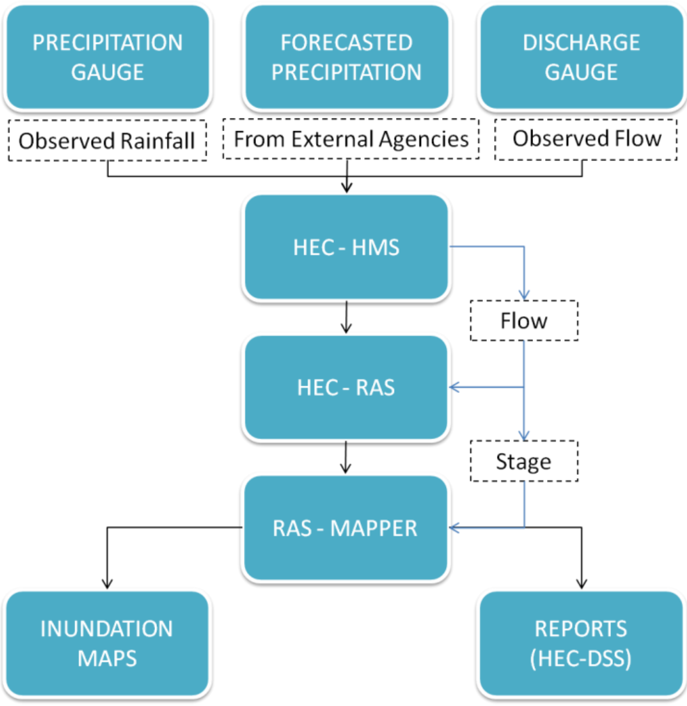


Figure 5-8: Flowchart for the HEC-RTS process

The initial step of any hydrological model is to organize the database inputs preparation, pre-processing of the datasets and model setup. A vital component in the initial stage of model development is meteorological data analysis. The analysis is required for a robust model, which after adequate calibration and validation, will produce desirable meteorological output that would subsequently serve as an input of the forecasting model. HEC-RTS utilizes Hydrological Modeling System (HEC-HMS), which simulates watershed response to precipitation. The hydrological modeling incorporates following steps:

5.2.2 Meteorological Analysis

The ultimate output of the present hydrological modeling framework is to incorporate the characteristics of the flood producing rainfall events. Therefore, a meteorological analysis will be undertaken. It includes: (i) analysis of rainfall records, (ii) review of historical storm duration and intensity to determine the critical storm duration and (iii) frequency analysis of historical records to determine rainfall volumes. The meteorological analysis evaluates the variation in rainfall across the study area and effects of features of the local geography, such as hills and water bodies on storm systems as they pass through an area. The meteorological analysis also explores the data discrepancy.

5.2.3 Hydrological Modeling – HEC-HMS

A hydrological model establishes flow behavior of the watershed or basin by converting the rainfall into runoff. In this project, the main aim of the HEC-HMS is to produce flood discharge by incorporating cyclonic extreme rainfall characteristics. The model often represents the spatial variability of the atmosphere and land surface characteristics that control the rainfall-runoff process. The hydrological model, prior to being employed for flow simulation, needs to be developed, calibrated, and validated.

This model will be applicable across a wide range of geographic areas for addressing a variety of project goals. Applications include large flood hydrology, as well as supporting small urban or natural watershed runoff modeling. To apply the model for a specific purpose and location, a model of the watershed is constructed by dividing the hydrologic cycle into manageable pieces, by constructing boundaries around the watershed of interest, and establishing appropriate geographic and other parameters in the model. The model provides completely integrated work environment, including a database, data entry utilities, computation engine, and reporting tools, with a graphical user interface. To develop the model for a particular use and location, the following steps are generally implemented:

- Basin delineation using high resolution Digital Elevation Model (DEM) and river network creation of basin model (including all elements such as sub-basins, channels and reservoirs) and estimation of physical loss, routing and transformation parameters (for each sub-basin element)
- Addition of time-series data (for various meteorological parameters) and setting control specifications (for running the model)
- Calibration and validation
- Interpretation of flows at critical locations

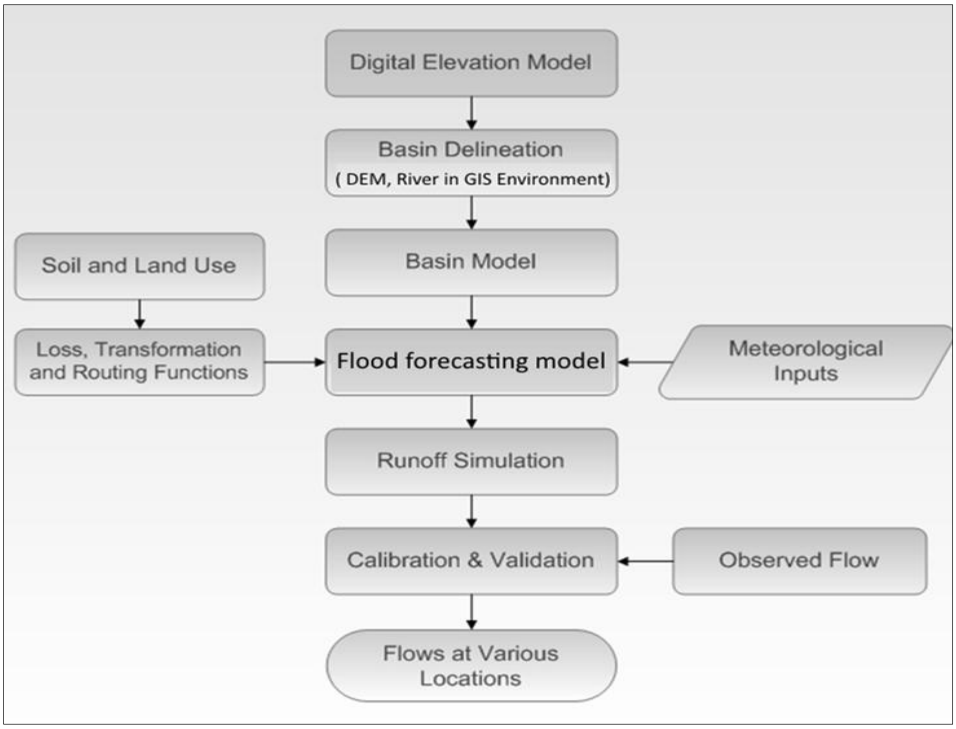


Figure 5-9: Flowchart for hydrological modeling

The flowchart in Figure 5-9 explains the systematic approach to be adopted for hydrological modeling. The DEM will be the primary input to the hydrological model for boundary delineation and deriving other hydrological characteristics such as slope, stream network, flood plain etc. The DEM represents the topographical characteristics of the area. The meteorological datasets such as daily rainfall, minimum and maximum temperature etc. will be used as input parameters. For model calibration and validation, observed discharge/flood discharge will be required. The observed discharge during historical time is available at Central Water Commission (CWC) New Delhi and for few stations, the observed discharge can be downloaded freely from the India Water Resources Information System (India-WRIS). RMSI will ensure that the proposed model allows the user to select from a number of methods to represent flood flow characteristics based on the extreme rainfall events. Flood flows estimated in the hydrologic analysis provide input to the hydraulic analysis.

5.2.4 Calibration/Validation – Hydrologic Modeling

The hydrologic model calibration and validation process is intended to ensure that the model parameters are well set to reflect the physical nature of entire study area. A good fit in this case indicates a robust simulation, which can be used with reasonable confidence. A poor fit, on the other hand, indicates low confidence. Model calibration consists of changing values of model input parameters in an attempt to match field conditions within some acceptable criteria. This requires that field conditions at a site be properly characterized. For calibration and validation of flood discharges resultant from cyclonic extreme rainfall, observed flood discharge will be used. To test the flood discharge simulation capability of HEC-HMS, the popular and globally accepted efficiency criteria such as Nash-Sutcilffe Efficiency (NSE) (NSE; Nash and Sutcliffe 1970) and coefficient of determination (R2) (Krause et al. 2005) will be used. Their formulations are described below:
NSE is defined as,

$$NSE = 1 - \frac{\sum_{I=1}^{N}(X_I - Y_I)^2}{\sum_{I=1}^{N}\left(X_I - \overline{X}\right)^2}$$

where xi and yi are the observed and model-simulated discharged values at flow gauge site at time i respectively, and $\bar{x}$ is the mean observed value. The NSE values can range from - ∞ to 1, with higher values indicating a better agreement of the model results with the observations.
R^2 can be defined as,

$$R^2 = \left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})\,(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^{\,2}} - \sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^{\,2}}}\right)^2$$

where O and P are observed and predicted values respectively. It is the squared ratio between covariance and multiplied standard deviations of the observed and simulated values. Range of R squared lies between 0 and 1. Value of zero means no correlation while one depicts dispersion of simulation is equal to that of observation. If the values approach 1, the model predictions are considered perfect.

5.3 Annex 3: Development of flash flood model for all coastal cities

A coastal flood, as the name suggests, occurs in areas that lie on the coast of a sea, ocean, or other large body of open water. It is typically the result of extreme tidal conditions caused by severe weather or by abnormally high precipitation events.

Storm surge produced by high winds from cyclones push water onshore - is the leading cause of coastal flooding and often the greatest threat associated with a tropical storm. In this type of flood, water overwhelms low-lying land and often causes devastating loss of life and property.

The severity of a coastal flood is determined by several factors, including the strength, size, speed, and direction of the storm. The onshore and offshore topography also plays an important role. To determine the probability and magnitude of a storm surge, coastal flood models consider this information in addition to data from historical storms that have affected the area, as well as the density of nearby development. Fluvial or riverine flooding, occurs when excessive rainfall over an extended period of time causes a river to exceed its capacity. The damage from a river flood can be widespread as the overflow affects smaller rivers downstream, often causing dams and dikes to break and swamp nearby areas.

The severity of a river flood is determined by the amount of precipitation in an area, how long it takes for precipitation to accumulate, previous saturation of local soils, and the terrain surrounding the river system. A pluvial, or surface water flood, is caused when heavy rainfall creates a flood event independent of an overflowing water body. One of the most common misconceptions about flood risk is that one must be located near a body of water to be at risk. Based on the projected and real time rainfall based generated flood discharges during the various cyclonic events, the boundaries of the flood plains will be determined by using HEC-RAS.

5.3.1 PLUVIAL FLOODING

Higher energy storm events such as cyclone with extreme rainfall intensities produce "pluvial" flooding and flash floods. Combination of pluvial flooding, flooding from small urban watercourses and groundwater flooding are collectively called surface water flooding. Pluvial flooding, as a result of extreme rainfall event due to their storm characteristics, accumulate large amount of water over the ground before it enters a natural or man-made drainage system. Pluvial flooding is associated with short duration (up to 3hrs) high intensity rainfall. The pluvial flooding includes different dynamic processes such as flow paths and ponding, steepness, barriers to flow, wetness, permeability and antecedent soil conditions. {luvial flooding will be incorporated in the present framework by incorporating real time and forecasted storm induced extreme rainfall events. The time of concentration and time lag factors are crucial in hydrodynamic flood routing to incorporate the effect of pluvial flooding, in case of storm induced rainfall events over coastal cities.

5.3.2 HYDRAULIC MODELING – HEC-RAS

HEC-RAS is an integrated software suite with HEC-RTS. It can calculate water surface profiles for both steady and unsteady, gradually varied flows for a full network of natural and constructed channels. Unsteady 2-D flow simulation will be adopted for this study. The model comprises of channel and floodplain geometry, which is defined by a series of cross-sections or transects together with hydraulic structures such as bridges, weirs, and levees. The basic computational procedure is based on the solution of the two-dimensional energy equation. Energy losses are evaluated by friction, expansion, and contraction losses. The momentum equation is utilized in situations where the water surface profile is varying rapidly. The situations include a mixed flow regime.

Model Setup

A review of historical storm flood events is undertaken to define the worst and most widespread flood events. The most important part of flood risk identification and assessment is the flood-prone area (extent) delineation; assess its intensity and magnitude. Flood-prone areas are those areas subject to inundation with regular frequency. The determination of flood prone area requires considerable collation of historical storm event data, field survey data, accurate digital elevation data and flood discharge data, and number of cross-sections located throughout the coastal streams. Proposed flood inundation methodology is presented in the flowchart below (Figure 5-10):

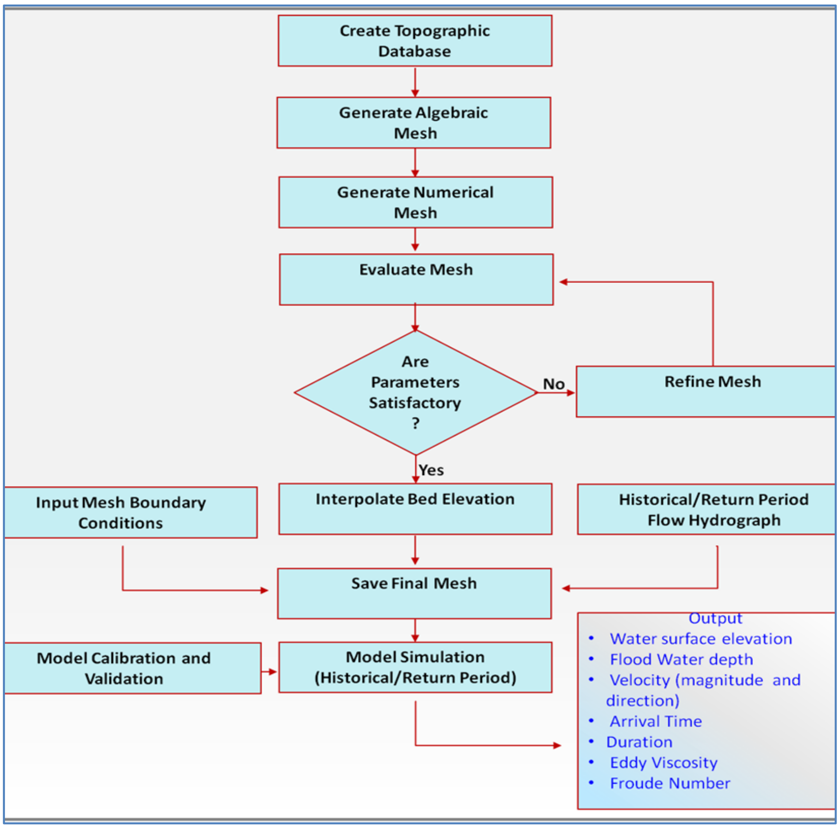


Figure 5-10: Methodology of flood inundation modeling

RMSI will use open source GIS or ESRI GIS environment to generate input file for storm induced flood inundation model containing geometric attribute data from a high resolution Digital Elevation Model (DEM) such as SRTM DEM (30 m resolution). Additional hydrodynamic parameters include hydraulic roughness coefficients (Manning's n) for channels, floodplains, and hydraulic structures, and contraction and expansion coefficients that are input to the model. The hydraulic parameters are estimated using GIS and land use land cover datasets. The channel slopes is estimated using DEM. The channel and flood plain roughness parameters are estimated using land use land cover datasets.

For initialization of the model, the parameter detail are obtained from manual computation, literature survey and standard global values. Boundary conditions comprise flow input hydrographs and downstream boundary hydrographs or specific flow conditions. The cross section details are used to extract the coastal river course and topography. The elevation information is modified with available surveyed cross sections wherever required.

An integrated Hydrological-Hydraulic modeling will be performed for all coastal cities. The parametric consideration will be accounted as per the available historical detail of cyclone storm events. Detailed hydraulic analysis requires an inventory of drainage conveyance structures, and topographic mapping of flood plain areas. In addition, site and aerial photographs, historical high water marks from past floods, and anecdotal flood observations would serve to guide a detailed hydraulic analysis.

A quality check exercise is carried out for this information. Once the quality checks are done, these data are implemented in the flood-forecasting model.

Flood Inundation/Extent Mapping

Flood extent and flood depth maps will be generated by flood inundation model in GIS environment. Flood plain boundaries and inundation depth data sets will be generated from exported cross-sectional water surface elevations. The results of hydraulic modeling are in the form of flood extent maps. Depth will be available for all the critical areas and other areas as required. HEC-DSS (Data Storage System) will be used to store all the incoming and resulting data. Flood extent mapping is done using RAS Mapper. RAS Mapper uses the topographic data along with land use and soil data and user-provided accurate cross section data, if available, to create a terrain. This terrain is used to model extents of flood.

Flood Forecasting

There are many ways in which recently observed storm flood flows and extreme rainfall data can be used for updating forecasts and various updating procedures are available. They differ in detail or in their mode of operation, but essentially, they provide the hydrological simulation model with feedback information from the most recently observed flows to estimate errors and thereby improve the accuracy of forecasts. The updating procedures can either be continuous, that is, they are applied at each time step, or periodic, which involves periodic recalibration of the model.

For flood forecasting, the real time and forecasted precipitation data, available from different sources, will be used for flood forecasting. Three-hourly real time precipitation data and 3 to 5 days forecasted precipitation dataset are available at different agencies that will be used for flood forecasting. The integrated hydrological-hydrodynamic modeling framework HEC-RTS will be able to provide flood detail in advance by utilizing real time and forecasted dataset. The tentative flowchart of flood forecasting module has been shown in Figure 5-11.

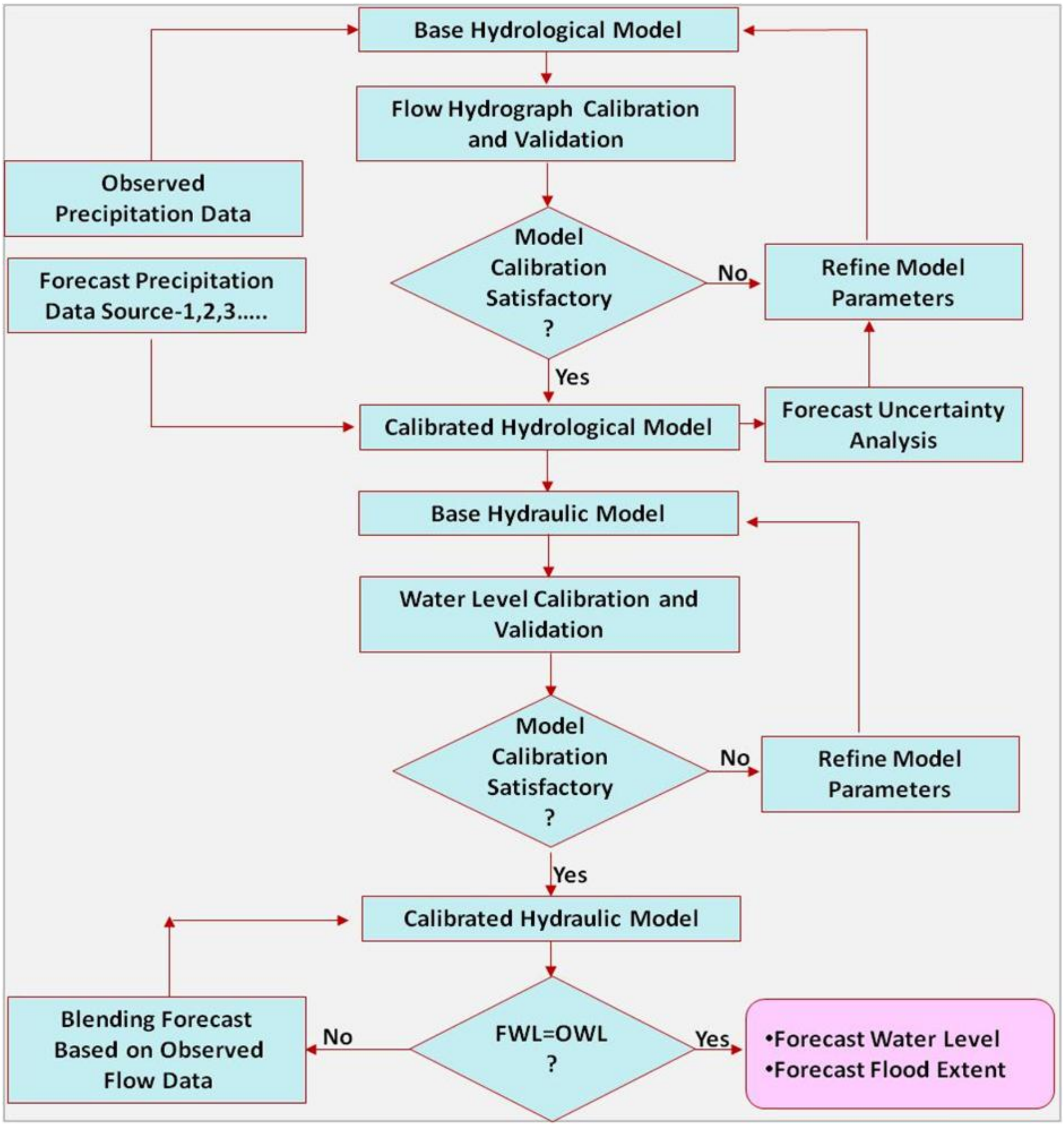


Figure 5-11: Flowchart for uncertainty reduction in flood forecasting modeling

A flood forecasting system is a complex system, which consists of many different components, and each of these components can contain, to some extent, an uncertainty. Analyzing the uncertainties in flood forecasting, and quantifying and propagating them through the system can help gain more information about the different sources of uncertainty that are likely to affect the forecasts.

These issues bring several challenges to the study of flow forecasting uncertainty such as:

- Quantification of impact of different sources of uncertainty on the quality of flood forecasts
- Identify which sources significantly affect flood forecasts among all sources of uncertainty that stem from different components of the modeling system
- Which methods can be used to efficiently quantify and propagate those uncertainties through a forecasting model
- Finally, which measures should be used to evaluate the uncertainty quantification and their impact on the quality of the forecasts?

The uncertainties related to flood forecasting can be broadly categorized into the following types:

- The uncertainty related to various modeling components, the initial moisture conditions, initial hydrological conditions (precipitation data), model parametric uncertainties, which are acknowledged as important sources of uncertainty in hydrological modeling and forecasting
- The uncertainties from precipitation data (real time precipitation, which is used for real time flow simulation and forecast precipitation used for flow forecasting).

Calibration/Validation – Hydraulic Modeling

An independent sample of storm events will be used to calibrate and validate the Flood forecasting model in terms inundation depth and extent. Protocol followed for calibration and validation of model would be:

Subjective Assessment: Visual inspection is a fundamental approach to assess model performance in terms of its behavior. Systematic behavior like over or under prediction and dynamic behavior like timing, rising and falling limb, base flow etc. of the model will be identified in the initial stages of calibration using this approach, which will extend till model validation.

Objective Assessment: This approach requires the use of mathematical estimates of error between observed and simulated flood depths. Nash-Sutcliffe Efficiency (NSE) and R square correlation would be employed as a mathematical measure of how well the simulation fits in the available observations.

Hydraulic Model will be calibrated with the available flood footprints, which are available with government agencies, on the internet as well as satellite images from global data. The development of hydraulic models across a large floodplain requires a rigorous calibration process to ensure that the hydraulic model accurately reproduces the observed flood behavior. The calibration process consists of systematically comparing observed flood behavior within the study area against the hydraulic model's reproduction of that behavior. This process generally incorporates comparisons between simulated flood levels and observed flood levels. This can also be done by comparing the areas of inundation from historical event with simulated flood extents from the model.

RMSI will apply the required approach of flood extent and/or depth measurements (spatial distribution) for particular events. Global mapping agencies, such as the Dartmouth Flood Observatory (DFO), and government agencies record the behavior of historical flood events and provide footprints of recent floods. Indian Meteorological Department (IMD) has historical storm event datasets, which will be utilized for the validation of the flood inundation maps. The real time high flood marks will be used to calibrate and validate the hydraulic model for the flood event.

Outputs Expected

As HEC-RTS model is a suite of models, each model gives an output for every forecast simulation. These model outputs can be broadly classified into four categories as follows:

Meteorological forecast pre-processor (MFP) Output

MFP provides step-by-step distribution and visualization of real-time and forecast precipitation. In place of manually entered precipitation forecasts, MFP permits the modeler to incorporate a sequence of QPF (quantitative precipitation forecast) values into an MFP alternative from an external source. In addition, the MFP provides a combined summary of the real time and forecast precipitation together.

HMS Output

The HEC-HMS model gives the output flood hydrograph at the concerned storm affected area by delineating the area into defined hydrological boundaries. It summarizes the global and element summary tables to include information on peak flow, total volume, and other variables. It will provide the necessary flood hydrograph information for hydrodynamic components.

RAS Output

The main outputs of the HEC-RAS models are stage, flood hydrographs, and flood extent maps of the storm affected areas. HEC-RAS detailed output is available in graphical and tabular formats. It allows the modeler to view water surface profiles, general profile, flood hydrographs, detailed tabular output at any location, and summary tabular at many flood-affected areas.

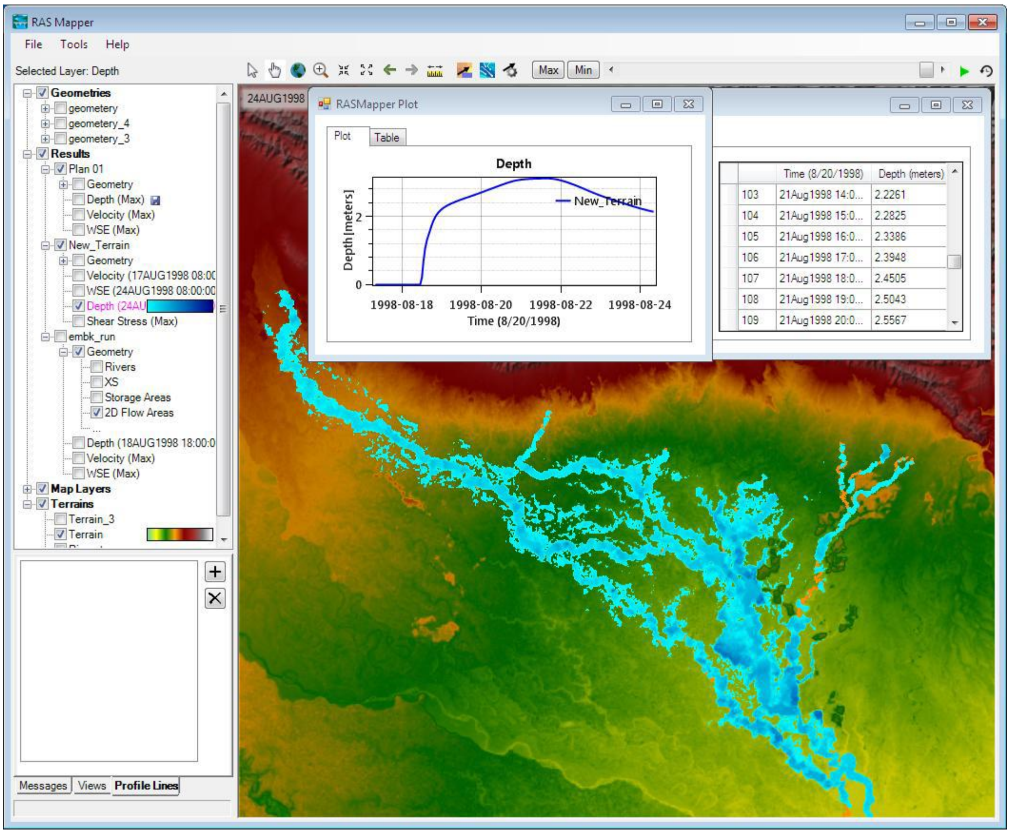


Figure 5-12: A sample screenshot of RAS output for Rapti river

The RAS Mapper tool in HEC-RAS enables the modeler to visualize the flood inundation areas. Computed model results can be displayed dynamically on the fly. A sample of RAS output flood map for Rapti River has been shown in Figure 5-12.

HEC-RTS Output

Additionally, HEC-RTS provides detailed outputs for various components of the hydrological and hydraulic systems that are accessible within the HEC-RTS interface. The flood extent maps of different simulation steps and storm durations can also be generated. The display of graphical plots and output summaries depends on the decision about which models have been chosen for configuring HEC-RTS.

5.4 Annex 4: Vulnerability Analysis

The methodology for Vulnerability Analysis for Phase 2 will be the same as followed by the team in NCRMP Phase 1 with required tweaking if needed. The details are given in the sections that follow.

Modeling vulnerability of a system to natural hazards involves establishing a relationship between the potential damageability of critical exposure elements and different levels of local hazard intensity for the peril of interest. Physical vulnerability refers to the degree to which an asset would undergo damage or be destroyed in a hazardous environment caused by catastrophic events. Social vulnerability refers to the incapability of people, organizations, and societies to endure adverse impacts from disasters to which they are exposed. The vulnerability assessment will involve quantifying the damage susceptibility of each asset class with respect to hazard parameters of each peril.

Damage susceptibility associated with a given level of hazard is measured in terms of a mean damage ratio (MDR) defined as the expected proportion of the monetary value of repair needed to bring back the facility to pre-event condition, over the replacement value of the facility, as a consequence of the hazard. The curve that relates the MDR to the hazard is called a vulnerability function. Vulnerability functions shall be developed for various assets for different perils, using analytical/synthetic and statistical methods complemented with expert engineering or heuristic judgment based on local and/or international experiences.

5.4.1 PHYSICAL VULNERABILITY ASSESSMENT

Development of physical and social vulnerability functions for all the 13 States/UTs will be mainly, but not solely, based on damage data from historical events. An analytical approach complemented by engineering analyses along with expert judgment based on national/international experience will help in developing vulnerability functions with sound reasoning and these two approaches will also fill the gaps in the available damage data for various historical events. Figure 5-13 presents a flow chart indicating the interface between different components of vulnerability development. Proposed methodology for developing the vulnerability functions uses the three different approaches i.e., damage statistics of the past events, analytical/synthetic and or engineering studies and the international experience. The following tasks constitute the methodology:

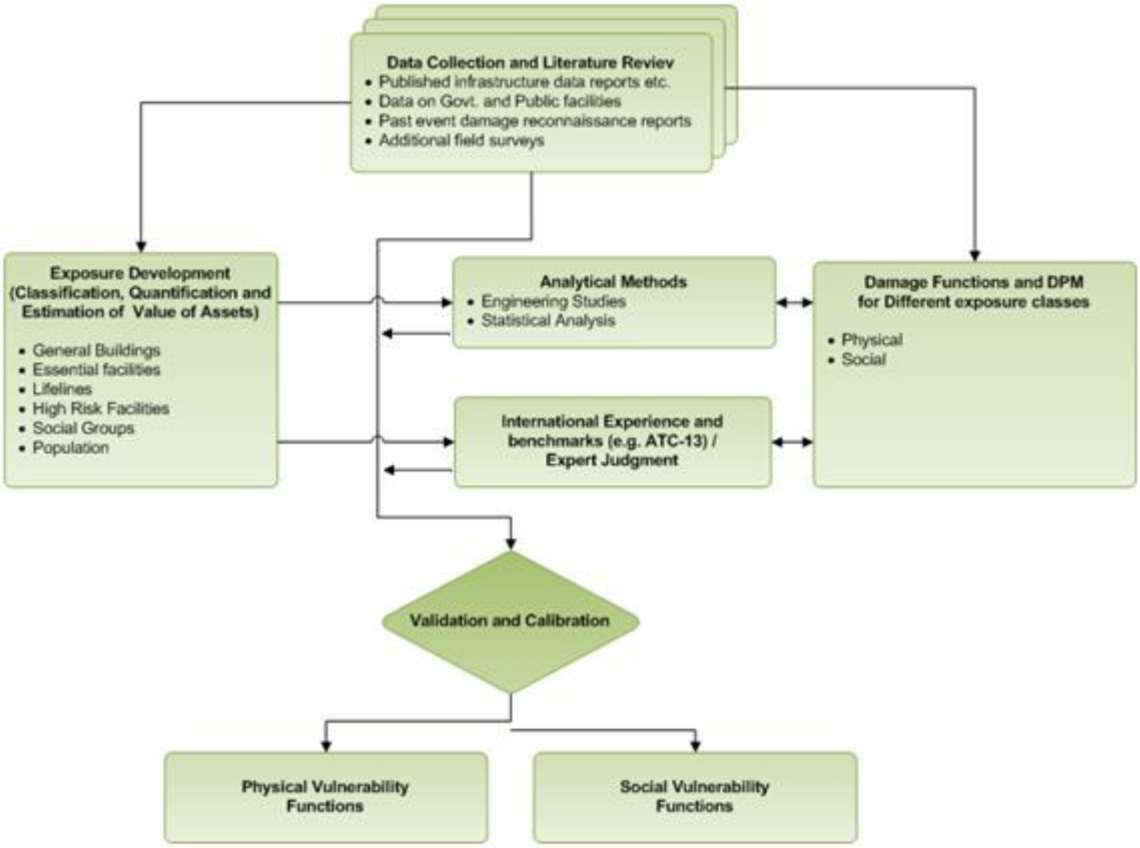


Figure 5-13: Vulnerability Functions' Development Methodology

5.4.2 Data Collection and Literature Survey

Locality-specific damage data in terms of quantity and extent of damage shall be collected for historical events wherever available. This data, in general, is collected in a variety of text and descriptive formats. They will be digitized by way of engineering interpretation of damage states and repair strategies.

Building stock in the region is to be reviewed and categorized into meaningful classes of typical buildings. Note that the classification, in general, can be different for different hazards. As a result, a super set of all classifications may be made and used.

Building-specific data (and other coverage types such as Contents, and Time Element) shall be collected with emphasis on vulnerability parameters such as material of construction, gravity and lateral resisting systems, age (to include practice and code enforcement), roof-material, height (in form of number of stories), shape (in matters of cross-section), design characteristics (both architectural and structural), maintenance levels (including upgrades to codes), reconstruction and retrofitting/mitigation measures, wherever possible.

Special emphasis will be given for collection of mortality rates, hospitalization by gender, age, physical condition, treatment, need for hospitalization, etc. during historical events. In addition to this, efforts will be made to capture historical disaster information about number of people looking for shelter by age, gender, income, and duration, etc. In addition, efforts will be made to understand the infrastructure in all the cyclone prone districts of the 13 States/UTs.

Literature survey shall be undertaken to extract and compile useful information on building, contents, time element (including additional living expenses, business interruption, and down time) infrastructure and social damage and vulnerability in the region. This shall include resources such as technical papers, historical event damage reports, building code provisions (and degree of its enforcement), studies on social impact of disasters, gender behavior and needs, etc. Note that data will also be adopted into the study for regions with similar infrastructure and building performance, if available, for purpose of enhancing the statistical convergence.

Information on damage mechanisms and behavior of different coverage classes in the region during past historical events; construction and design practices; code provisions and compliance levels; maintenance levels and regional trends, if any, shall be collected.

5.4.3 Relevance of Data Collection and Literature Survey

Building occupancy, such as residential, commercial, educational, governmental, or industrial, could be a factor when determining degree of damage to buildings and contents, incurred by cyclone and associated hazards. Note that building code provisions differ based on occupancy type to account for different loadings and performances.

Building material type, such as masonry or concrete, light or heavy (flat or sloping) roof material, is a factor when determining the damageability, repair, or type of debris, which will be generated after the hazardous event.

Building structural characteristics such as gravity and lateral resisting systems, height or number of levels, cross-sectional configuration, etc., also are a factor when determining how much damage a building will sustain during a hazardous event, as well as the repair strategies.

All the above information will be captured as part of data collection and literature review to understand the treatment given to these subjects in prior studies. These will be supported by surveys. All surveys conducted will be based on statistical approaches that not necessarily cover each and every block in the coastal parts of the country, but will use samples of different regions.

Vulnerability functions for buildings, critical facilities, and infrastructure will be developed using the above approach to estimate the vulnerability due to cyclone and associated hazards. The above approach will also be used for estimating the social vulnerabilities. This approach is very similar to the ones used in various open source models like HAZUS, CAPRA and GEM. The developed vulnerability functions would be compared with corresponding functions in the above open source models to improve the performance of the developed vulnerability function.

The agricultural vulnerability of the crops to cyclone and associated hazards involves developing a relationship between crop production and hazard parameter or wind speed, rainfall, locality, intensity, frequency and duration.

5.4.4 Social Vulnerability Assessment

Indicator identification and social survey: Social vulnerability is partly an outcome of aspects of social setup that influence or shape the susceptibility of various factions of the society to disasters and drive their ability to respond. It is, however, crucial that social vulnerability is not considered as a function of exposure to hazards alone, but also the sensitivity and resilience of the society to prepare, respond and recover from disasters. Therefore, it is the combination of the mentioned two factors that drives the MDR for social vulnerability.

Social vulnerability is a culmination of economic, demographic, and housing characteristics that influence a community's resilience to environmental hazards. The major components of vulnerability are well-being, livelihood resilience, skills awareness, social security and social awareness. RMSI would employ a two-pronged approach to assess the social vulnerability of the different communities across the study area:

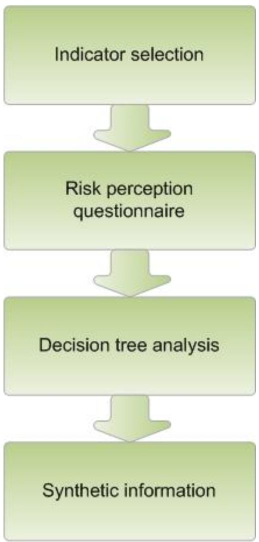
SoVI (Social Vulnerability Index): is a scientific approach using the secondary data available with the various administrative units and departments of the Government.

Community Assessment sample survey: analysis of primary data collected through sample surveys conducted at different levels.

Social Vulnerability Index (SoVI): In an effort to scientifically assess social vulnerability under the Hazard Vulnerability and Risk assessment (HVRA) exercise, RMSI intends to use the Social Vulnerability Index (SoVI) to quantify the social vulnerability in a comparative metric that facilitates the examination of the differences in social vulnerability among the different geographical units. SoVI would prove valuable to the lower administration units and state administration in planning and decision-making as it would graphically illustrate the geographic variations in social vulnerability by reflecting the uneven capacity of preparedness and response. This will also indicate the differential ability of recovery across the geographical units.

The proposed steps under SoVI:

- The secondary data available with the departments related to gender, ethnicity, class/income group etc. will be used to derive the input variables (as shown in) to calculate and generate the vulnerability index.
- The variables will be normalized as either percentages, per capita values or density functions
- Accuracy of the data sets will be verified using descriptive statistics
- Z score standardization will be used to standardize the input variables
- Principal component analysis (PCA) will be performed with the appropriate component selection to reduce the tendency for a variable to load highly on more than one factor



- Parameters will be set to extract the factors and then examine those to determine the broad influence on social vulnerability
- The scores will be calculated for the vulnerability components applying the positive and negative cardinality as per requirement.
- The SoVI scores will be mapped using objective classification illustrating areas of high, medium and low social vulnerability.

Community Assessment Sampling Survey: RMSI would involve a four-step methodology to measure the vulnerability of individuals within households. The individuals will be selected using appropriate sampling techniques. Samples will be selected in high, medium, and low hazard zones to get a real representation for the study area.

In order to select a representative sample, three main criteria can be chosen:

- Administrative units
- Hazard proneness
- Demography

1. Indicator Selection: This would involve Literature Review, Development of selection Criteria and selection of Vulnerability Indicators
2. Risk perception questionnaire: The development of the questionnaire would be based on asking participants to rank the vulnerability of ten hypothetical individuals, where vulnerability is defined as ‘a person’s ability to recover’, to various natural hazard impacts.
3. Decision Tree Analysis: Decision trees are a schematic way of representing alternative sequential decisions and the possible outcomes from these decisions. The analysis begins by placing all the data, in this case the results from the risk perception questionnaire, into a decision tree analysis program and ends with the establishment of high vulnerability classes.
4. Synthetic Information: This step in the methodology provides the opportunity to apply decision tree rules to a spatial area in order to analyze the vulnerability of individuals within a household in a real community.

The four-step methodology outlined is intended to be integrated into a broader risk assessment.

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