METEOROLOGICAL AND HYDROLOGICAL SERVICES IN SRI LANKA

A REVIEW

ABSTRACT

A World Bank Report on the current status of meteorological and hydrological services in Sri Lanka, the need for modernization and a preliminary investment plan

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1. Aim of Report

The objective of this report is to provide the basis for an investment project to strengthen the capacity of the Department of Meteorology, the Department of Irrigation, the National Building Research Organization, and the Disaster Management Centre to meet their shared obligations to minimize loss of life, livelihoods, and property due to hydro-meteorological and related hazards in Sri Lanka. The main focus of the report is on how the Department of Meteorology and the Hydrology Division of the Department of Irrigation can improve their services to the Disaster Management Centre and National Building Research Organization, and how the latter two organizations can make optimum use of these services to the benefit of the Sri Lankan community.

This report includes:

i) A capacity assessment of the Department of Meteorology, Department of Irrigation, National Building Research Organization and Disaster Management Centre to provide and communicate forecasts and warnings of the impact of hydro-meteorological hazards;
ii) Users' needs for improved meteorological and hydrological services;
iii) Lessons learned from recent disasters;
iv) Preliminary investment plan.

The report is based on interviews and discussions with staff from each of the agencies; discussions with the Ministry of planning; existing project proposals, and discussions with colleagues at the World Bank and World Meteorological Organization.

The World Bank team comprised Vladimir Tsirkunov (GFDRR Hydromet); Suranga Sooriya Kumara Kahandawa (World Bank SAR); Geoff Love (Consultant); Bruce Stewart (Consultant); and David Rogers (Consultant). The principal authors of the report are Dr David Rogers, Dr Geoff Love and Mr Bruce Stewart. The team would like to thank the staff of the Department of Meteorology, Department of Irrigation, Disaster Management Centre, and National Building Research Organization for the frank and open discussions that contributed to the development of this report.

2. Findings and Recommendations

Summary

The World Bank team (the Team) visited the Government of Sri Lanka's (GoSL) Department of Meteorology (DoM), Disaster Management Centre (DMC), National Building Research Organisation (NBRO) within the Ministry of Disaster Management and the Hydrology Division (HD) of the Irrigation Department (ID). The Team was tasked to determine and address any deficiencies in these institutions with respect to their capacity to meet their mandated responsibilities to provide timely, accurate and useful forecasts and warnings of hydrological and meteorological hazards to prevent or minimize disasters. The operations during, and the impact of, a tropical depression on 16 May 2016 served to highlight many of the issues.

On 15 May 2016 Sri Lanka was hit by a tropical depression that moved northward, away from Sri Lanka, and intensified to become Tropical Storm Roanu. By 16 May this event had caused widespread flooding and landslides in 22 out 25 districts in the country, destroying homes and submerging entire villages. More than 150 people were killed or missing, the majority due to a landslide in Aranayake, Kegalle District, which devastated three villages. An estimated 500,000 people were affected by this disaster, including at least 21,484 people who were displaced from their homes. As a result of the floods and landslides, 623 houses were completely destroyed and more than 4,400 homes were damaged. Colombo was the worst affected District in the country with over 155,000 people affected by the floods; this was mostly as a result of large numbers of people living on reclaimed, marsh land that is highly susceptible to flooding. According to Government estimates, 25,000 to 30,000 businesses, mostly small enterprises, were impacted by the disaster. The post-disaster needs assessment preliminary findings indicate damage and losses exceed US$572 million.

The DoM warned that heavy rains around 150 mm were expected in some places, especially in the Southern and Eastern parts of the country as the disturbance that persisted to the South-east of Sri Lanka was likely to develop into a depression and move closer to the country. Although the Department issued a severe weather advisory, the lack of quantitative precipitation estimates (QPE) and limited skill in estimating rapid onset flooding, resulted in flood warnings being issued after the event had started to have a serious impact. This increased the need for rescue and left people ill-prepared for subsequent landslides, which caused most of the deaths. Overall the severity of the storm was underestimated with the DMC warning of torrential rains creating a minor flood situation in the country (Daily Mirror, 16 May 2016).

Most flooding in Sri Lanka occurs when heavy rain falls in the upper catchments of the river basins. This allows the HD a long lead-time in estimating the likelihood and level of flooding downstream. Heavy rain was widespread on 16 May both in the upper catchment of the rivers and downstream resulting in conditions more closely resembling a rapid onset flood.

River flood forecasts and warnings are the responsibility of the ID because these floods are most commonly associated with stream flow. Flash floods and landslides are more closely coupled with the actual rainfall. Without accurate, high-resolution gridded rainfall information, it is impossible for the DoM to provide adequate forecasts and warnings of the likelihood of flash floods or for the HD to provide sufficiently accurate inundation forecasts. This also limits the ability of the NBRO to provide longer lead time warnings of landslides.

By coupling gridded rainfall information with vulnerability and exposure data, where available, the DMC, HD and NBRO would be able to provide a more targeted and timely response for communities and sectors most at risk.

The shortcomings, highlighted in the following sections, must be addressed with some urgency to minimise the loss of life and livelihoods and significant economic disruption caused by possibly more frequent and intense hydrological and meteorological hazards in the future. Without such action, Sri Lanka will continue to suffer avoidable loss of life, livelihoods and property.

Institutional Structure

1. Investment in Meteorological and Hydrological Services

Findings:

***Finding 1.1** — In comparison with other developing and developed countries, Sri Lanka's investment in its National Meteorological and Hydrological Services (NMHSs) is low. Most NMHSs are funded in the range 0.01 to 0.05 percent of GDP with a global average of 0.02 percent of GDP. Return on investment of well-equipped NMHSs is estimated to be 10:1 globally.*

***Finding 1.2** — The investment in the Sri Lanka DoM is 0.002 percent of GDP, which is ten times below the global average. It is this low level of investment that has constrained the DoM in meeting its national public good obligations.*

***Finding 1**.3 – Social and economic data related to the benefits of modern meteorological and hydrological services to the Sri Lanka society and the economy is very limited.*

Recommendations:

***Recommendation 1.1** — Global good practice suggests that a country needs to invest between 0.02 – 0.03 percent of GDP to ensure effective and sustainable meteorological and hydrological services to support economic development and minimize the adverse impacts of hydro-meteorological hazards. Taking into account that Sri Lanka is a very vulnerable country facing a broad range of high intensity hazards, adequate protection of society should at least lead to a near-term significant increase of current funding for DoM and Hydrology Division of the ID.*

***Recommendation 1.2** — This level of investment should be applied in the first instance to provide sufficient operating and maintenance funds to sustain capital investments in observing and forecasting systems. In this regard, Recommendation 3.1 should be implemented as a high priority.*

***Recommendation 1.3** — Current arrangements for cost-recovery from aeronautical meteorological services provided to civil aviation should be reviewed. In many countries, consistent with ICAO recommendations, these funds are returned directly to the National Meteorological Service to offset operating costs. Such a practice would also provide transparency to the aviation industry regarding the utilization of these charges. In this regard, Recommendation 3.2 must be implemented as a high priority.*

***Recommendation 1.4** — An analysis of the ongoing operational budgetary requirements for the Hydrology Division should be undertaken to ensure that it is able to sustain the improvements made into the future and provide Sri Lanka with the operational flood forecasting and warning services it requires and deserves.*

***Recommendation 1.5** – A detailed social and economic benefit study should be undertaken as a part of any future modernization effort. This study would help to support an increase in investment to sustain improved meteorological services.*

2. Human Resources

Findings:

Finding 2.1 *— A typical modern hydro-meteorological service has a well-qualified (bachelor and higher degree level) leadership and professional group of meteorologists, hydrologists and IT specialists that comprises around 60% to 65% of the organisation's workforce. Such a group is essential for the hydro-meteorological organization if it is to succeed in delivering high quality information services that meet client needs in a timely fashion.*

Finding 2.2 *— The DoM has around 12.5% of its workforce with bachelor or higher degrees while the Hydrology Division of the ID has 5 hydrological engineering positions supported by 58 technical officers and 110 gauge readers to undertake their work (i.e., 3% of its workforce in the leadership/professional cadre). It was noted that at current remuneration levels the DoM and ID have difficulty in recruiting and retaining young, well qualified professional and technical staff.*

Finding 2.3 *— DMC and NBRO have limited skills in interpreting meteorological and hydrological forecasts. Therefore, they are limited in how they use current meteorological and hydrological forecasts and warnings.*

Recommendations:

Recommendation 2.1 *— Work force planning needs to address the urgent requirement of the DoM to evolve from manual data collection focused organisation with a low level of service delivery and client focus to become automated data collection organisation with a clear focus on efficient and responsive information service delivery. This will require changing the staff composition from a large pool of un- and semi-skilled staff to a smaller pool of vastly more productive professional staff properly supported with the appropriate IT environment. The evolution should be done over 5 to 10 years in consultation with the staff and their unions. It is expected that this process will lead to substantial culture and work practice change within the DoM.*

Recommendation 2.2 *— Work-force planning analysis should be undertaken for the Hydrology Division, taking into account the advances that will be achieved through the World Bank projects and the needs and requirements of the users of the Hydrology Division services flowing from these advances.*

Recommendation 2.3 *— New opportunities for staff development and capacity building with higher education departments within Sri Lanka should be explored.*

Recommendation 2.4 *— Hydrology Division staff should be trained in the application and use of distributed hydrological modelling and the use of quantitative precipitation forecasts (in association with the DoM).*

Recommendation 2.5 *— Training opportunities for DoM staff, especially in the use of modern forecasting methods, should be accelerated.*

Recommendation 2.6 *— DMC staff should be trained to interpret and apply meteorological and hydrological forecasts so that there is suitable expertise within the DMC operations.*

Recommendation 2.7 *— NBRO staff should be trained to interpret and apply meteorological and hydrological forecasts so that there is suitable expertise within the NBRO operations.*

3. Physical Resources and Institutional Strengthening

Findings:

Finding 3.1 *— Modern hydro-meteorological agencies are more capital intensive than many elements of government as they require equipment such as automatic weather station networks, weather radars, advanced computing systems, high volume data storage capability, broad bandwidth telecommunications, expensive computer software licences and the like. Operation and maintenance of such infrastructure imposes significant ongoing costs which cannot be met by the existing budget of the DoM.*

Finding 3.2 *— Furthermore, it is noted that the DoM is projected to move from cash-based accounting to accrual-based accounting methods in 2017. Were the DoM to have an up-to-date, accurate assets register in place such a move would highlight the depreciation expense currently faced by the Department and enable it to be resourced to meet this expense, unfortunately this is not the case. It has no such assets register and little progress has been made in creating one due to limitations in available staff.*

Finding 3.3 *— The DoM does not have a Quality Management System (QMS), which is required for compliance with the International Civil Aviation Organisation's (ICAO) directive for the provision of aeronautical meteorological services.*

Recommendations:

Recommendation 3.1 *— As a matter of urgency the DoM should establish an accurate, comprehensive and fully audited assets register. The planning for ongoing operation of DoM should reflect the current depreciation expense to be met, and the likely future growth of this expense as the Department transforms from an old style weather service focused on observation collection service to a modern high quality service provider of weather forecasts, warnings and related information.*

Recommendation 3.2 *— The DoM should, with the assistance of the World Meteorological Organization, implement a QMS. A national plan for the improvement of the provision of meteorological services to aviation should be developed.*

4. Project management capacity

Finding:

Finding 4.1 *— There is limited capacity to support a transformative project to improve the capabilities of the DoM and HD.*

Recommendations:

Recommendation 4.1 *— A project to increase the capacity and capabilities of the DoM and HD should involve a system integrator (SI) firm, which would design and build the integrated systems on behalf of the clients. If a turn-key approach is used, the SI would be responsible for the selection and integration of all equipment and systems, and may play an initial role in supporting operations and services.*

Recommendation 4.2 *— Any development activities should be linked to the existing project management unit and other related on-going projects.*

Observing, forecasting, communication and IT infrastructure

5. Historical Data

Finding:

> ***Finding 5.1*** *— A readily accessible, historical, digital database of hydrological and meteorological parameters is urgently required for the development of a range of warning and forecast services related to extreme weather and flood events that impact all sectors of the Sri Lankan economy. This is also needed for effective infrastructure planning. Much of the historical data required to build such a database are contained in paper-based records held by the DoM. These paper records include autographic records of rainfall and conventional synoptic observations. For some parameters these record extend as far back as 1861, and all are unique and irreplaceable. The current rainfall intensity, frequency and duration data used for the design of hydrological structures such as bridges and culverts is based on data recorded to the late 1980s and needs to be updated.*

Recommendations:

> ***Recommendation 5.1*** *— A "data rescue" activity be undertaken to digitize the paper-based archives held by DoM (and others) and to install the resultant digital data in a database accessible to other groups dealing with natural disasters including (but not limited to) the Disaster Management Centre and the Hydrology Division of the ID. Priority should be given to digitising the chart records from the DoM's pluviographs.*

> ***Recommendation 5.2*** *— The digital database of all hydrological and meteorological data should be routinely updated with quality controlled real-time data from all available automatic weather station networks currently operating in Sri Lanka. Care will need to be taken to identify within the database the originating network of the data (meta-data) so that users have a basis for determining the quality characteristics of the data they are accessing and using.*

> ***Recommendation 5.3*** *— The Hydrology Division should digitize the remainder of the data held on paper records and incorporate them into the Aquarius HMIS.*

6. Real Time Data and Information Access

Finding:

> ***Finding 6.1*** *— The activities of a number of Sri Lankan government agencies, for example, the landslide warning services of the Landslide Research and Risk Management Division of the National Building Research Organization and flood warning services of the Hydrology Division of the Irrigation Department identified the requirement for ready access to real-time data and short-range forecasts, especially precipitation estimates (on varying time scales) in order for them to provide better services to the community.*

Recommendations:

> ***Recommendation 6.1*** *— Arrangements should be made for the DoM to obtain ongoing access to relevant ECMWF NWP data sets (Euro 42,000 per year). Access to these data sets would provide an immediate contribution in support of real-time gridded data inputs to enable the production of impact-based forecasts and warnings.*

> ***Recommendation 6.2*** *— The Hydrology Division should implement improved distributed hydrological modelling (in cooperation with the Climate Resilience Improvement Program (CRIP-1) advances) to enable better forecasts of floods in Sri Lanka, incorporating the use of forecast/predicted rainfall estimates to be provided*

by the DoM. This capability should be extended beyond the 10 basins covered by CRIP-1 on a priority basis.

Recommendation 6.3 *— Nowcasting and short-range forecasting and verification methods should be introduced into the operations of the forecast office of the DoM. A new forecasting facility is also needed.*

Recommendation 6.4 *— The DoM, ID and DMC should work together to develop real-time gridded products as input to models linked to Geographical Information Systems. This would provide more focused areal information on potential hazards, incorporating local data sources, and enable linkages with vulnerability information enabling DMC to issue impact-based forecasts and warnings.*

Recommendation 6.5 *— Based on the above activities, more targeted services, include mobile applications, with increased lead-time for meteorological and hydrological warnings and the introduction of impact-based warnings within the Disaster Management Centre should be developed. Also, improved presentation of warning information through electronic media should be implemented.*

Recommendation 6.6 *— Real-time data and information should be shared openly to ensure their effective use. Public access should be implemented with arrangements to protect the integrity and security of the data and the database that holds it.*

Recommendation 6.7 *— The Hydrology Division should work with the DMC to ensure that impact-based flood forecasts and warnings can be issued for the benefit of the impacted communities.*

7. Observing networks

Findings:

Finding 7.1 *— The Japan International Cooperation Agency (JICA), through its project with the DoM for Improving of Meteorological Observation, Weather Forecasting and Dissemination in the Democratic Socialist Republic of Sri Lanka, has already installed 38 automatic weather stations. The World Bank, through its Dam Safety and Water Resources Planning Project, is deploying another 183 automatic weather monitoring stations included in an expansion of the water resources monitoring network.*

Finding 7.2 *— Not all installed automatic weather stations are functional, nor are the data derived from functional automatic station always being used for their intended purposes. There are issues relating to the telecommunications systems as well as concerns about the accuracy due to lack of calibration or significant differences when the automatic weather station data are compared against calibrated instruments*

Finding 7.3 *— A number of other projects have installed automated rainfall monitoring networks (e.g. the NBRO for use in warning of landslides), whilst other projects under consideration are proposing the installation of additional automatic weather stations.*

Recommendation:

Recommendation 7.1 *— The risks of such an approach (that is, uncoordinated automatic weather station networks) are incompatible networks, challenges in integrating the data sources, and possibly duplication of sites. Future projects involving the installation of automatic weather stations should be evaluated against a stock-take and analysis of the existing instruments that establishes an agreed national approach to the integration of the relevant networks. This activity should also include the establishment of agreements for the free and open exchange of data, including meta-data, from all stations.*

8. Totality of observation systems

Finding:

> ***Finding 8.1*** *— A modern meteorological service optimizes its overall observation system by incorporating a mix of surface-based and atmospheric observations with the use of remotely sensed data to establish an observation system that meets their service delivery needs. This includes the use of satellite and radar derived data along with in-situ observations such as surface-based networks, upper-air networks and the global Aircraft Meteorological DAta Relay (AMDAR) programme, amongst others. This system optimization ensures that a fit-for-purpose integrated observation is maintained and operated in an economically efficient and effective manner.*

Recommendation:

> ***Recommendation 8.1*** *— The DoM should undertake a study to determine and define the fit-for-purpose, composite observation system that will meet the existing and future needs of Sri Lanka for its meteorological and climatological services.*
>
> ***Recommendation 8.2*** *— The Hydrology Division should work with the DoM in rationalizing the surface-based hydro-meteorological automatic weather stations.*
>
> ***Recommendation 8.3*** *— The NBRO should work with the DoM in rationalizing the surface-based rain gauge network.*

Service Delivery

9. Demand for Meteorological and Hydrological Services

Findings:

> ***Finding 9.1*** *— There is a strong demand for better meteorological and hydrological services evidenced by the responses from disaster management, water management, hydropower, agriculture, health and other clients following the impact of the 16 May 2016 flood event and related landslides. The meteorological and hydrological services have limited capacity and capability to provide quantitative information to guide timely decision making in disaster management. This resulted in avoidable losses of life and critical resources (e.g. in the health sector, industries etc.).*
>
> ***Finding 9.2*** *— As a result of the perception that the 16 May event was poorly forecast and the warnings were inadequate, the roles of the DoM, ID and the DMC were criticized.*
>
> ***Finding 9.3*** *— It is a critical, sovereign function of government to provide adequate warning services for hydro-meteorological hazards. This requires, timely, accurate and geographically specific information about the impact of the hazard on the population and economy originating from an authoritative government agency. Increasingly, private sector service providers are challenging this authority by providing various warning-related products and services independent of government. This can introduce confusion if different observing techniques are used and may lead to contradictory warning-related information being disseminated.*
>
> ***Finding 9.4*** *— There is a need for a more comprehensive understanding of user needs across all sectors.*
>
> ***Finding 9.5*** *— More actionable forecast and warning information is required.*

Recommendations:

> ***Recommendation 9.1*** *— A systematic and sustainable improvement in forecasting and warning services is required within both the DoM and the Hydrology Division that*

makes full use of the products and services that are available from the World Meteorological Organization's (WMO) centres and more advanced NMHSs, as a first step to upgrading the national observing and forecasting infrastructure. The Global Flood Alert System (GFAS) and the Global Flash Flood Guidance System (GFFGS) are two examples of systems that exist to support NMHSs' forecasters.

Recommendation 9.2 *— In order to re-establish trust in warning services and to ensure appropriate public response to warnings, the DoM and Hydrology Division, in consultation with the DMC, should implement ways to acceleration the adoption of currently available international products to quickly improve their basic services. This could be achieved through partnerships with other public institutions or with private sector meteorological service providers.*

Recommendation 9.3 *— Improvements in warnings services should be accelerated to reduce the threat of independent providers challenging the sovereignty of the national warning services. This would be an interim solution, while the longer term transformative investment is in development.*

Recommendation 9.4 *— More extensive and inclusive user-oriented workshops should be introduced to ensure current user requirements are addressed adequately.*

Recommendation 9.5 *— Impact-based forecast and warning services should be implemented by the DMC in collaboration with DoM, ID and NBRO. Initially this should be piloted in regions where there is sufficient vulnerability and exposure data. A program to be implemented by the DMC to collect and collate exposure and vulnerability data, prioritizing high hazard areas.*

Recommendation 9.6 *— Climate services should be introduced to address the growing need for climate-related information in all sectors.*

***Recommendation 9**.7 — Partnerships should be developed with other public institutions or with private sector meteorological service providers where they provide opportunities to improve warning services.*

10. Improved working relationships

Findings:

Finding 10.1 *— A number of key government agencies, including the DoM, the ID and the DMC, must work in close cooperation if forecasting and warning services are to be fully effective. The forecasting and warning system is only as strong as its weakest link. Roles and responsibilities of each agency must be sufficiently well defined to avoid miss-understandings during severe weather related events. It was found that miss-communications had occurred in recent events, such as, for example different forecasts from different sources.*

Finding 10.2 *— A weather-related forecasting and warning service is one necessary element of a floodplain management programme and current initiatives, such as the World Bank financed Climate Resilience Improvement Project for Sri Lanka, are providing essential information (e.g. digital elevation data) and capabilities (e.g. floodplain mapping) that are required to support Integrated Flood Management.*

Recommendations:

Recommendation 10.1 *— Formal roles and responsibilities within the forecasting and warning system must be agreed and respected. Approaches and techniques to improve interagency communication should be implemented, such as, for example, the establishment of daily situation reports, holding of weekly briefings, and dedicated forecasting and warning teams prior to, and during, severe weather* *related events. A dedicated joint warning desk, as well as centre-to-centre video linkage should be considered. The aim should be an authoritative and consistent message going to the media and the community from all involved agencies.*

Recommendation 10.2 *— To ensure that Sri Lanka achieves full benefits from externally funded projects, formal communication mechanisms should be established involving all stakeholders. This should enable the sharing of information (e.g. digital elevation data) and capabilities derived from the projects and a consistent approach to addressing nationally relevant issues, such as flood management.*

11. National Strategy for Weather, Climate and Hydrological Services

Findings

Finding 11.1 *— There is no user driven, long-term national strategy for meteorological and hydrological services. The absence of such a strategy is reflected in the ad hoc approach and proliferation of independent observational networks and incomplete coordination of activities related to water and climate activities*

Recommendation:

Recommendation 11.1 *— Develop, routinely review, and update as necessary, a national strategy for the provision of weather, climate and hydrological services, including national observing systems, forecasting systems and warning systems, and national climate services. It should have an implementation plan supported by realistic resource allocation. This should involve all relevant ministries, stakeholders and users.*

Brief Project Description

Based on the findings and recommendations, it is proposed that a project aimed at strengthening the capacity and capability of the DoM, the Hydrology Division of the ID and the DMC is developed that would provide forecasts and warnings of the main hydro-meteorological hazards, which impact Sri Lanka. By improving the meteorological forecasts from the DoM, weather- and climate-sensitive sectors would be provided with better access to higher quality information to make more informed and reliable decisions. The project will also increase the capacity and capability of the Hydrology Division to provide operational flood forecasts. It would also enable the DMC and NBRO provide more timely and accurate information on the impacts of hydrological and meteorological hazards.

It is proposed that the project will have three interrelated components. ***Component A*** will focus on institutional strengthening; ***Component B*** will focus on modernisation of the observing, forecasting and communications systems infrastructure; and ***Component C*** will focus on enhancing service delivery. It is intended that the project will improve the capabilities of the DoM, the NBRO, and the DMC, and the Hydrology Division of ID. All weather-, climate- and hydrologically-sensitive sectors and the public in general will benefit from the improved services.

The estimated cost of the project is **$20'780'000**, which will be included in the Climate Resilience Improvement Project Phase II.

Project Activities

	Activity	Institutions	Ref. to Recommendations .
A	**Institutional Strengthening, Capacity Building and Project Management**		
A.1	***Institutional strengthening***		

	Activity	Institutions	Ref. to Recommendations .
A.1.1	Develop and update national strategy for weather, climate and hydrological services	DoM, HD	11.1
A.1.2	Workforce Planning	DoM , HD	2.1. 2.2
A.1.3	Develop asset register and introduce modern accounting methods	DoM	3.1
A.1.4	Introduction of Quality Management System (QMS)	DoM	1.3, 3.2
A.1.5	Working together - improve inter-department operational relations (video conferencing, meetings, workshops)	DoM, ID/HD, DMC and other departments/ agencies	9.2, 10.2
A.1.6	Working with others - twinning with advanced NMHSs, operational support centres (WMO initiatives (SWFDP, FFG), NMHSs, WMO regional centres)	DoM, HD	9.1
A.2	***Training and Capacity Building***		
A.2.1	Professional training, retraining, staff development (including fellowships)	DoM, HD, DMC	2.3, 2.4, 2.5, 2.6
A.2.2	Working with customers/users - implement training activities (workshops, roundtables, etc.)	DoM, HD, all users	9.4
A.3	***System design, operate, transfer and project management***		
A.3.1	Systems design and integration	DoM	4.1, 1.1, 1.2, 1.4
A.3.2	Project Management	ID (CRIP)	4.2
B	**Modernize the Observing, forecasting and communication systems infrastructure**		
B.1	***Modernize observing system infrastructure***		
B.1.1	Develop optimum composite observation network design?	DoM, HD and other agencies/partner s	7.1, 8.1
B.1.2	Data recovery	DoM, HD	5.1
B.1.3	Rehabilitation of existing observing network (funds to repair/replace existing equipment)	DoM, HD	7.1
B.1.4	Upgrade of observing system at Colombo international airport	DoM	1.3
B.2	***Modernize the data, communication and IT systems***		
B.2.1	Data management systems for weather and climate- and hydrological data (servers, software, web access, social media, etc.)	DoM	5.2
B.2.2	Communications system for forecast and warning dissemination (telecommunications - internet and mobile/smartphone, bandwidth)	DoM, HD	6.4
B.3	***Improve numerical weather prediction system and hydrological forecasting system***		
B.3.1	Access to ECMWF products	DoM	6.1
B.3.2	Introduction of Operational Forecast verification	DoM	6.3
B.3.3	Develop Distributed hydrological modelling	HD	6.2
B.3.4	High Performance Computer (for data assimilation, nowcasting and short-range forecasting, hydrological modelling)	DoM, HD, DMC	6.3
B.4	***Construct and furbish offices and facilities***		
B.4.1	New DoM building for forecast operations	DoM	6.3
C	**Enhance Service delivery systems**		
C.1	***Climate Services***		
C.1.1	Digital library of climate-relevant information for Sri Lanka (Climate database including web-based open access)	DoM	6.6
C.1.2	National framework for climate services - support for sectoral working groups	DoM, and relevant groups	9.4, 9.6
C.13	Develop Agricultural Climate Service	DoM, DoA, ID	9.4, 9.6
C.2	***Support DMC operations***		
C.2.1	Develop and implement a joint forecast and warning service desk (collocated with DMC)	DMC, DoM, ID, BRO	10.1

	Activity	Institutions	Ref. to Recommendations .
C.2.2	Develop and pilot impact-based forecast and warning services (including access to gridded products, GIS info, etc.)	DMC, DoM, ID, BRO	6.4, 6.5, 6.7, 9.5
C.3	***Enhance weather services to sectors (health, agriculture, tourism, transport, etc.)***		
C.3.1	Development of specialized services to sectors including mobile applications and web-based services	DoM	9.4, 9.5, 9.6
C.3.2	Introduction of user satisfaction surveys	DoM	9.4

There is a need to provide better access to high resolution, digital data from global numerical weather prediction centres as a matter of urgency, and in advance of a longer term investment. Therefore, it is recommended that an interim project focused or early phase of the investment, focus on making higher quality rainfall data available in form that can be accessed and used operationally by each of the participating organisations. This early effort is estimated to cost approximately $230,000. This would address recommendation 9.3.

3. Strategic Context

Country Context

Sri Lanka is a lower-middle-income country with a per capita GDP of US$ 3,811 (2014) and a population of 20.5 million. Growth over the past decade has been strong, averaging 6-7 percent per year, and has resulted in significant poverty reduction. Absolute poverty declined from 22.7 to 6.7 percent from 2002 to 2012/13 while per capita consumption of the bottom 40 percent grew at 3.3 percent a year, as compared to 2.8 percent for the total population. Since 2009, however, consumption and income inequality have been increasing. Roughly one quarter of the Sri Lankans remain nearly poor, as defined by living above the national poverty line (about US$ 1.5 but below US$ 2.50 per day (2005 PPP terms). Living standards of the near-poor are closer to those of the poor than those living above US$ 2.50. Sri Lanka has comfortably surpassed most of its Millennium Development Goals. Primary school enrolment is near universal, while secondary and tertiary enrolment has substantially increased. Maternal and infant mortality rates are at very low levels, and life expectancy at 74 years has been above its regional peers for over a decade.

Following the end of the civil war in 2009, investment in reconstruction and new infrastructure, including with World Bank support, and increased consumption have delivered a strong economic peace dividend. The non-tradable sectors and public sector investments have been the main drivers of this growth that has led to higher labour demand and employment. Sri Lanka is also undergoing a structural transformation away from agriculture, which now accounts for 10 percent of GDP towards industry (32.5 percent) and services (57.5 percent) with associated productivity growth and accelerating urbanization. However, this transformation is progressing relatively slowly with 30 percent of the labour force remaining in agriculture. More recently, Sri Lanka has undertaken renewed efforts in governance reforms and political reconciliation to secure long-term peace. Notwithstanding the post-conflict environment, Sri Lanka's economic policies over last ten years have been inward-looking with an increasing degree of protectionism and anti-export bias. This has prevented the country from: capitalizing on comparative advantage and exports; attracting domestic and foreign investments to foster technology transfer; and generating new sources of innovation driven growth and employment.

The country's fiscal landscape is challenging. In 2014, a widened deficit and a slowdown in growth increased the fiscal deficit to 5.7 percent and the public debt to 71.8 percent, as a share of GDP, marking a slight reversal of the fiscal consolidation path of the post-conflict period. The fiscal budget for 2016 presented to Parliament projected a deficit of 6.0 percent of GDP for the years 2015 and 2016. The Government presented its economic policy in November 2015 that includes as priorities the generation of one million job opportunities, enhancing income levels, developing the rural economy, and creating a wide and a strong middle class. It proposed fiscal consolidation through increasing revenue collection, reforms of state owned enterprises, and enhanced trade and foreign investment. The economic development in Sri Lanka at the same time exposes livelihoods and property to natural disasters both individually and collectively (Figure 1.1).

Sectorial and Institutional Context

Climate-related hazards pose a significant threat to economic and social development in Sri Lanka. Extreme variability of rainfall and droughts is already a defining feature of Sri Lanka's climate. Climate projections indicate an increasing rainfall trend in the wet zone and a decreasing rainfall trend in the dry zone, meaning that the risks associated with water-related hazards are likely to increase.

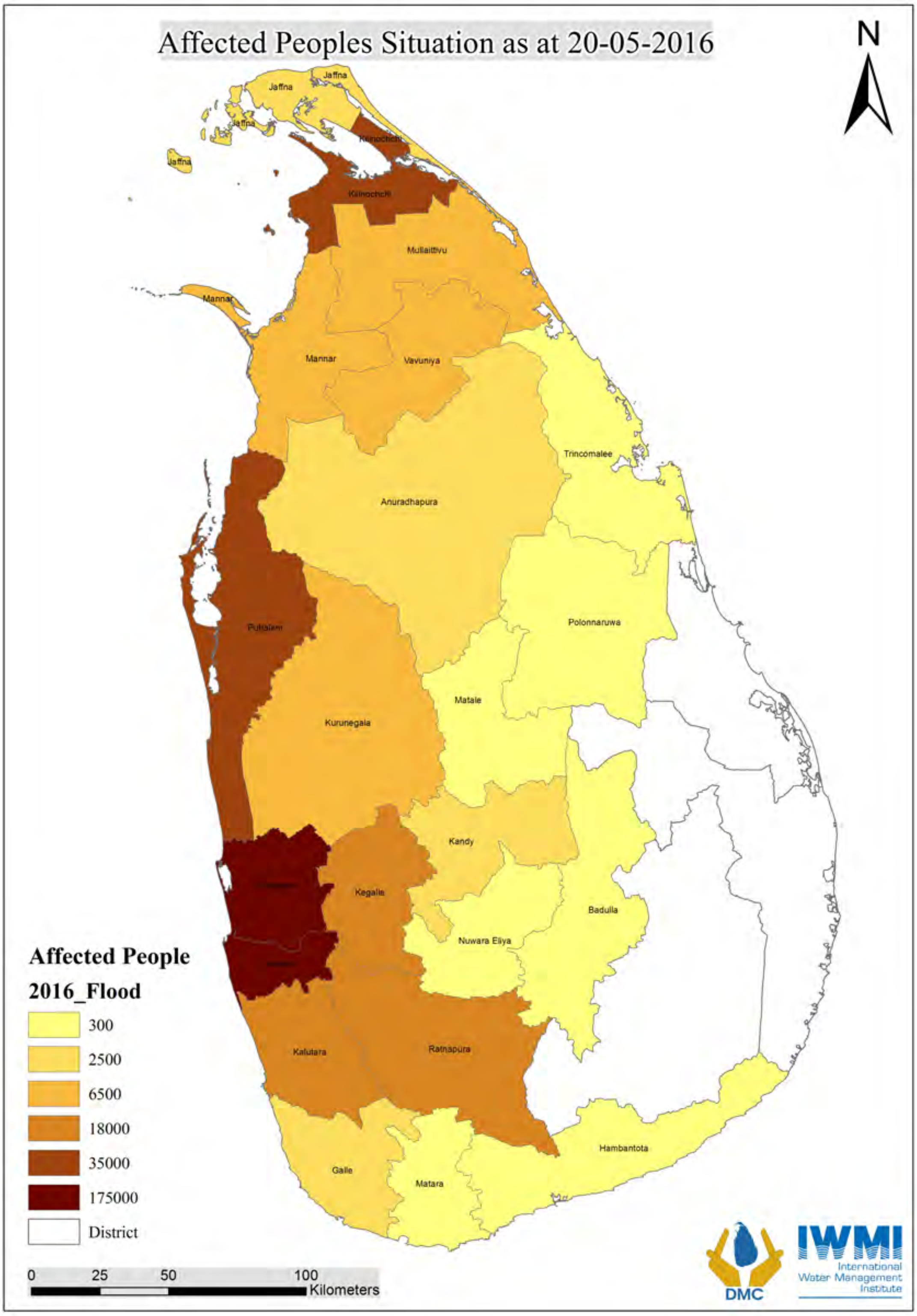


Figure 1.1 People affected by May 2016 Flood by District (source DMC and International Water Management Institute)

Annual average fiscal loss associated with disasters is estimated to be already in excess of US$380 million, but disaster losses can significantly exceed this amount in a given year. In 2011, floods affected more than a million people in the Northern, North Central and Eastern provinces and caused more than US$600 million in direct damages. Floods in 2012 affected nearly a half a million people and the December 2014 floods affected 1.2 million people.

Each of these events severely impacted the agriculture sector, destroying crops, livestock and agricultural infrastructure, and the road infrastructure. The floods and landslides of December 2014 affected 22 out of the 25 districts in the country, killed 39 people and damaged more than 25,000 houses. The rapid damage assessment conducted by the National Planning Department (NPD) revealed that direct damages to public assets were US$155 million, including an estimated damage of US$65.4 million to irrigation and flood control infrastructure and an estimated damage of US$85 million to the road infrastructure. Provincial roads suffered the most of the damages, especially in Uva Province, amounting to US$ 70.6 million.

On 15 May 2016 Sri Lanka received extremely heavy rainfall from a tropical depression that moved northward, away from Sri Lanka, and intensified to become Tropical Storm Roanu. This tropical depression caused widespread flooding and landslides in 22 out 25 districts in the country, destroying homes and submerging entire villages. More than 190 people killed, the majority due to a landslide in Aranayake, Kegalle District, which devastated three villages. An estimated 301,602 people were affected by this disaster, including at least 21,484 people who were displaced from their homes. As a result of the floods and landslides, 623 houses were completely destroyed and more than 4,400 homes were damaged. Colombo was the worst affected District in the country with 190,349 people affected by the floods; this was mostly as a result of large numbers of people living on reclaimed, marsh land that is highly susceptible to flooding. According to Government estimates, 25,000 to 30,000 businesses, mostly small enterprises, were impacted by the disaster. The post-disaster needs assessment preliminary findings indicate damage and losses exceed US$572 million.

The DoM warned that heavy rains around 150 mm were expected in some places, especially in the Southern and Eastern parts of the country as the disturbance that persisted to the South-east of Sri Lanka was likely to develop into a depression and move closer to the country. Although the Department issued a severe weather advisory, the lack of quantitative precipitation estimates (QPE) and limited skill in estimating rapid onset flooding, resulted in flood warnings being issued after the event had started to have a serious impact. This increased the need for rescue and left people ill-prepared for subsequent landslides, which caused most of the deaths. Overall the severity of the storm was underestimated with the DMC warning of torrential rains creating a minor flood situation in the country (Daily Mirror, 16 May 2016). This event is described in detail in Section 7 and Annex 4.

Most flooding in Sri Lanka occurs when heavy rain falls in the upper catchment of the river basins. This allows the HD a long lead-time in estimating the likelihood of flooding downstream. Heavy rain was widespread on 16 May both in the upper catchment of the rivers and downstream resulting in conditions more closely resembling a flashflood.

River floods forecasts and warnings are the responsibility of the ID because they are most commonly associated with stream flow. Flash floods and landslides are more closely coupled with the actual rainfall. Accurate, high-resolution gridded rainfall information is needed for the entire country. This would enable the DoM to better forecast and warn of the likelihood of flash floods and would enable the Hydrology Division to provide more precise inundation forecasts. Coupled with vulnerability and exposure data, where available, the DMC would be able to provide a more target and timely response for communities and sectors most at risk.

4. The Need for Improved Meteorological and Hydrological Services in Sri Lanka

A present there is very little data available to support a detailed analysis of the social and economic benefits of improved meteorological and hydrological services. What is known is largely anecdotal and related primarily to loss of property associated with flooding and loss of life and livelihood disruption associated with landslides. The latter being responsible for the largest loss of life related to a meteorological event.

Recommendation 1.5

A detailed social and economic benefit study should be undertaken as a part of any future modernization effort. This study to help to support an increase in investment to sustain improved meteorological and hydrological forecast and warning services.

The absence of significant user input into meteorological and hydrological operations also reflects the limited engage of all stakeholders in a national strategy. The Team recommends that a national strategy be developed.

Recommendation 11.1

Develop, routinely review, and update as necessary, a national strategy for the provision of weather, climate and hydrological services, including national observing systems, forecasting systems and warning systems, and national climate services. It should have an implementation plan supported by realistic resource allocation. This should involve all relevant ministries, stakeholders and users.

The post-disaster needs assessment estimates damage and losses due to May 2016 event in excess of US$572 million with over 90% of the losses sustained by the private sector. The combined losses due to major floods since 2010 is in excess of US$1.077 billion. For comparison, the cost of recovery from the 2004 Tsunami was US$1.6 billion, the cost of recovery from the 2016 floods is estimated at US$1.024 billion. The largest damage and losses due to the May 2016 event occurred in the social sector – housing, land and settlements, health and nutrition, and education (Table 4.1). Landslides were the largest cause of the loss of lives, while the health sector was mostly impacted by flood damage to medical stores. The latter being largely avoidable losses.

Sectors	Damages (LKR m)	Losses (LKR m)	Total Effect (LKR m)	Total Effect (US$ m)
Housing, Land and Settlements	LKR55,822	LKR256	LKR56,078	US$382.47
Health and Nutrition	LKR479	LKR119	LKR597	US$4.07
Education	LKR620	LKR13	LKR633	US$4.32
Total -Social Sectors	LKR56,920	LKR388	LKR57,308	US$390.86

Table 4.1 Losses and damages due to May 2016 flood by social sectors (from PDNA)

Damage and losses in productivity-related sectors was estimated at US$125 million (Table 4.2)

Sectors	Damages (LKR m)	Losses (LKR m)	Total Effect (LKR m)	Total Effect (US$ m)
Food Security, Agriculture, Livestock, Fisheries	LKR2,372	LKR1,203	LKR3,575	US$24.38
Trade and Industries	LKR12,235	LKR2,544	LKR14,779	US$100.80
Productive Sectors	LKR14,607	LKR3,747	LKR18,354	US$125.18

Table 4.2 Losses and damages due to May 2016 flood by productivity sectors (from PDNA)

A future role for the DoM and the HD would be in educating farmers and fishers on climate adaptation strategies through a dedicated agriculture climate service and overall greater engagement with users to understand their needs and to identify the benefits to be obtain from future services.

It is notable that the PDNA following the May 2016 event does not identify a role for either the DoM or ID to provide more effective meteorological and hydrological services to those at risk, apart from providing recent rainfall intensities and strengthening local level elements of early warning systems.

There is the potential to use meteorological and hydrological information about the past, present and future to improve infrastructure planning and management in both the public and private sectors.

Recommendation 9.4

More extensive and inclusive user-oriented workshops should be introduced to ensure current user requirements are addressed adequately.

Recommendation 9.6

Climate services should be introduced to address the growing need for climate-related information in all sectors.

Recommendation 10.2

To ensure that Sri Lanka achieves full benefits from externally funded projects, formal communication mechanisms should be established involving all stakeholders. This should enable the sharing of information (e.g. digital elevation data) and capabilities derived from the projects and a consistent approach to addressing nationally relevant issues, such as flood management.

5. Institutional Reviews

The Team had several meetings with the staff of the DoM, DMC, NBRO and the Hydrology Division (HD) of the ID to identify and address any deficiencies in these institutions with respect to their capacity to meet their mandated responsibilities to provide timely, accurate and useful forecasts and warnings of hydrological and meteorological hazards. The institutional reviews provide the foundation for a World Bank financed project to strengthen the capabilities of the DoM and related organizations to minimize the adverse impacts of meteorological and hydrological hazards on the population of Sri Lanka.

Organization of Meteorological and Hydrological Services

How disaster management, meteorological services and hydrological services are set up varies from country-to-country. In some countries, meteorology and hydrology are co-located within a single service, in others, including Sri Lanka, operational meteorology is housed within a single organization, while operational hydrology and water resources assessment activities are shared among several departments. Typically, the closer these activities are aligned, the more effective the warning services for flood-related are, given that flood forecasts require both meteorological and hydrological inputs. In most countries, the meteorological, hydrological, earthquake and landslide warning services are integrated fully into the central operations of the meteorological service or in some cases, the disaster management's emergency operations centre.

Governments are beginning to encourage joint warning centres, such as the Flood Forecasting Centre in the United Kingdom, which is operated by the Met Office and Environment Agency; the Shanghai Multi hazard Early Warning Centre, which is operated by the Shanghai Meteorological Service on behalf of the Shanghai municipal government; and the Flood Forecasting and Warning Service of the Bureau of Meteorology in Australia. The United Kingdom has also created a natural hazards partnership, which brings together the Met Office, the Environment Agency, the Health Protection the Cabinet Office and at least nine other agencies to provide a single cohesive picture of the potential impact of environmental hazards by using predictive tools, made possible by pooling data and information from each of the partners.

In Sri Lanka, these warning services remain separate; although the DMC is responsible for communicating warnings. There is the potential, however, to make significant progress to improve multi hazard early warning services.

Department of Meteorology

Introduction

The DoM was established on 1st October 1948, around the time that colonial rule of Ceylon ended and the independent state of Sri Lanka was created. The taking of meteorological observations in Sri Lanka, and the provision of meteorological advice by the government of the day, date back to around 1850. The Surveyor General of Sri Lanka from 1866-1883, established meteorological stations on an island-wide basis. In 1907, with the founding of the Colombo Observatory at the present site of the current DoM headquarters, meteorological work in Sri Lanka assumed a more scientific orientation. The first Superintendent of the Colombo Observatory was the Assistant Surveyor General.

The DoM in Sri Lanka is currently an agency within the Ministry of Disaster Management (MoDM). Among the Duties and Functions of the MoDM are[1]:

1. Formulation of policies, programs and projects, monitoring and evaluation in regard to the subject of disaster management, and those subjects that come under the purview of Departments, Statutory Institutions and Public Corporations under the Ministry
2. Coordination and management of activities in relation to mitigation, response, recovery, and relief in natural and man-made disasters
3. Formulation of National Disaster Management Plan and National Emergency Operation Plan based on national policies
4. Initiation and coordination of foreign aided projects for disaster mitigation, response and recovery
5. Liaison with ministries, government institutes and agencies, private institutes, and local and foreign nongovernmental organizations to ensure timely execution of above activities
6. Promotion of housing construction with technical standards to withstand environmental hazards
7. Encourage research and development into appropriate technology for housing and construction sectors
8. Meteorological surveys and research
9. Forecasting of natural disasters and sensitizing relevant sectors regarding them
10. Coordination of awareness programs on natural disasters and man-made disasters
11. Implementation of measures for rescue operations during natural and man-made disasters
12. Coordination of international humanitarian relief service programs
13. Matters relating to all other subjects assigned to Institutions under the Ministry
14. Supervision of the Institutions listed under the Ministry

MoDM Duties and Functions 8 and 9 are carried out by the DoM and currently the following activities are undertaken in doing this[2]: (1) the provision of meteorological, climatological and limited astronomical services, including the taking, storing and managing a range of meteorological observations (2) the provision of early warning services with regard to meteorological hazards and tsunamis, (3) contribution to technical activities on climate change, and (4) undertaking staff training and research in matters relating to meteorology.

Staffing

The DoM currently has a staffing level of 364 persons (Table 1). 12.5% of these staff have three-year university degrees or higher level of qualifications. A number of staff have master's degree level qualifications but there are no staff members with doctorate level qualifications. The great bulk of DoM staff are working at the secondary or primary level and have no university education.

The World Bank team noted that advanced meteorological services generally have around 60% or more staff with university degrees and also have a reasonable number of staff with

[1] Gazette Extraordinary of the Democratic Socialist Republic of Sri Lanka – 21.09.2015, Pg. 17.
[2] http://www.disastermin.gov.lk and from discussions with staff.

doctorates in leadership positions in the technical areas. For the DoM to transition from an agency focused on data collection and the issuance of synoptic forecasts and warnings, to an information service meeting the needs of a diverse range of clients by providing high resolution in space and time warnings, forecasts and climatological advice, then there needs to be a managed transition to a more highly qualified, more productive, but likely smaller work force. Opportunities should be explored to work with local universities to develop courses that would enable staff of DoM who participate in those courses more easily contribute to the evolving modern DoM.

Recommendation 2.1

Work force planning needs to address the urgent requirement of the DoM to evolve from manual data collection focused organisation with a low level of service delivery and client focus to become automated data collection organisation with a clear focus on efficient and responsive information service delivery. This will require changing the staff composition from a large pool of un- and semi-skilled to staff to a smaller pool of vastly more productive professional staff properly supported with the appropriate IT environment. The evolution should be done over 5 to 10 years in consultation with the staff and their unions. It is expected that this process will lead to substantial culture and work practice change within the DoM.

Recommendation 2.3

New opportunities for staff development and capacity building with higher education departments within Sri Lanka should be explored.

The DoM currently spends about 60% of its budget on staff salaries and allowances (Table 5.1 & Table 5.3) which the World Bank team considered to be around the percentage that is typical of other national meteorological and hydrological services.

Staffing of DoM as of 21 July 2016			
Staff Level	**Approved Staffing**	**Existing Staffing**	**Total Cost of the Approved Staffing (LKR/yr)**
Senior Level **Administrators, Meteorologists and Engineers**	54	47	25,103,514
Tertiary Level **Senior Met Officers, Communications Officers, and Telecoms Tech Officers**	29	8	13,055,064
Secondary Level **Admin Assistants, Met Observers, IT Tech Assistants, and Met Communications Officers**	238	194	73,580,352
Primary Level **Drivers, Carpenters, Mechanics, and Helpers**	139	115	29,201,100
TOTAL	460	364	140,940,030

Table 5.1: The Approved and Existing staffing levels of DoM. The cost of the approved staffing level is indicative only. As will be seen in the discussion of the DoM budget, "emoluments, allowances and overtime payments" change substantially the actual cost of staff.

Budget

The DoM total budget must be considered in two parts. Firstly, there is 2015 when the GoSL injected LKR 250,000,000 (approx. US$ 1.667M) into the DoM's Capital Expenditure (Table 5.2) to "improve capability to minimize the impact of frequent weather hazards". This was a very significant funding boost and roughly equals the DoM's annual recurrent expenditure (Table 5.3). The 2015 fund injection has enabled the DoM to access, process and store numerical weather prediction and analysis products, in image format, from a number of major centres. These products have been used to good effect to improve synoptic scale analysis and forecasting on 1 to 5 day timescales. The funding injection has also assisted in improving the DoM's capability to distribute forecast and warning information to emergency services and the media.

Secondly, there is the more usual budgetary situation in the years preceding and following 2015 in which Recurrent Expenditure is between LKR 185,000,000 and LKR 190,000,000 (US$1.3M) while Capital Expenditure is around LKR 50,000,000 (US$135,000) resulting in a total level of financing of DoM around LKR 320,000,000 (US$ 2.1M) –Table 5.4.

The Team noted that in comparison with other developing and developed countries, Sri Lanka's investment in DoM is low. Most national meteorological and hydrological services are funded in the range 0.01 to 0.05 percent of GDP with a global average of 0.02 percent of GDP. The GoSL investment in DoM is 0.0026 percent of GDP[3], which is ten times below the global average. It is this low level of investment that has constrained the DoM in meeting its national public good obligations.

DoM Capital Expenditure (LKR x 1000)			
ITEM	**2015**	**2016**	**2017**
Building Rehabilitation	7,500	7,000	7,350
Asset Acquisition	21,000	4,000	3,860
Capacity Training	3,500	3,000	3,200
Meteorological Equipment	15,000	11,200	10,000
Awareness Training	1,000	1,000	1,100
Improve Extreme Weather Forecasting	250,000	-	-
GoSL/Japan Investment	50,000	37,000	12,000
TOTAL	348,000	63,200	37,410

Table 5.2: DoM Capital expenditure. Revised budget for 2015, budget estimate for 2016 and budget projection for 2017.

Recommendation 1.1

Global good practice suggests that a country needs to invest between 0.02 – 0.03 percent of GDP to ensure effective and sustainable meteorological and hydrological services to support economic development and minimize the adverse impacts of hydro-meteorological hazards. Taking into account that Sri Lanka is a very vulnerable country facing a broad range of high intensity hazards, adequate protection of society should at least lead to a near-term significant increase of current funding for DoM and Hydrological Division of the Department of Irrigation.

Recommendation 1.2

This level of investment should be applied in the first instance to provide sufficient operating and maintenance funds to sustain capital investments in observing and forecasting systems. In this regard, **Recommendation 3.1** should be implemented as a high priority.

The DoM does not have in place an up to date assets register so it was difficult for the World Bank team to assess whether the level of capital expenditure in the relevant sub-categories in Table 2 matches the rate of depreciation of the DoM's assets. The team was advised that

Recommendation 3.1

As a matter of urgency the DoM should establish an accurate, comprehensive and fully audited assets register. The planning for ongoing operation of DoM should reflect the current depreciation expense to be met, and the likely future growth of this expense as the Department transforms from an old style weather service focused on observation collection service to a modern high quality service provider of weather forecasts, warnings and related information.

there is a planned move for DoM from cash to accrual accounting in 2017 and considers that given the current state of the assets register it is difficult to see how it can make this transition, accordingly it recommends that priority be given to establishing an accurate assets register as soon as possible. Should the annual depreciation expense of the DoM's assets in 2017 exceed LKR 14,300,000[4] (approx. $US 95,000) then it will be clear that the DoM is in an unsustainable situation with regard to its support for the assets needed for it to carry out its functions in the medium- to long-term.

In the longer term, an investment supported by the World Bank and other donors of around LKR 1,500,000,000 (US$ 10M) in assets such as radars (15-year lifetime), computers (5 year lifetime) and software (3 year lifetime) the DoM may have an unfunded depreciation expense (on current budget projections) of around LKR 150000000 (US$ 1M) per year. If sustainability of the DoM's upgraded capability is to occur the GoSL will need to fund the DoM's Capital Expenditure at a level closer to the norm found for other national meteorological and hydrological services that exists around the World.

DoM Recurrent Expenditure (LKR x1000)			
ITEM	**2015**	**2016**	**2017**
Personal Emoluments	**182,238**	**189,500**	**190,800**
Salaries & Wages	84,000	86,500	87,800
Overtime & Holiday Allowance	14,150	13,000	13,000
Other Allowances	84,088	90,000	90,000
Travelling Expenses	**2,000**	**2,000**	**2,100**
Supplies	**10,442**	**10,650**	**11,180**
Maintenance	**13,750**	**11,350**	**11,860**
Services	**38,400**	**38,450**	**40,150**
Transfers	**8,350**	**8,850**	**8,920**
TOTAL	255,180	260,800	265,010

Table 5.3: DoM Recurrent expenditure. Revised budget for 2015, budget estimate for 2016 and budget projection for 2017.

The DoM, along with most other national meteorological services provides services to domestic and international aviation. The services to domestic aviation are entirely regulated

[4] In 2017 the projected budget allocates a total of LKR 14,300,000 to the three items that would be expected to fund replacement/rehabilitation of depreciating assets: Building Rehabilitation, Asset Acquisition and Meteorological Equipment (Table 2).

by the GoSL, however the services to international aviation are regulated through *Annex 3 of the International Civil Aviation Organization (ICAO) Convention*. Section 2.1 of Annex 3 specifies that: "The objective of meteorological service for international air navigation shall be to contribute towards the safety, regularity and efficiency of international air navigation". One key set of ICAO recommendations relates to the requirement that States providing meteorological services have in place, by November 2012, an ISO 9000 compliant quality management system (see Box 1). The DoM does not have a compliant quality management system in place and should take steps to correct this deficiency.

Recommendation 3.2

The DoM should, with the assistance of the World Meteorological Organization, implement QMS. A national plan for the improvement of the provision of meteorological services to aviation should be developed.

Box 1

Extracted from Section 2.2 of ICAO Annex 3

2.2.3 **Recommendation. —** *The quality system established in accordance with 2.2.2 should be in conformity with the International Organization for Standardization (ISO) 9000 series of quality assurance standards and should be certified by an approved organization.*
Note.— The International Organization for Standardization (ISO) 9000 series of quality assurance standards provide a basic framework for the development of a quality assurance programme. The details of a successful programme are to be formulated by each State and in most cases are unique to the State organization.

2.2.4 **Recommendation. —** *The quality system should provide the users with assurance that the meteorological information supplied complies with the stated requirements in terms of the geographical and spatial coverage, format and content, time and frequency of issuance and period of validity, as well as the accuracy of measurements, observations and forecasts. When the quality system indicates that meteorological information to be supplied to the users does not comply with the stated requirements, and automatic error correction procedures are not appropriate, such information should not be supplied to the users unless it is validated with the originator.*
Note.— Requirements concerning the geographical and spatial coverage, format and content, time and frequency of issuance and period of validity of meteorological information to be supplied to aeronautical users are given in Chapters 3, 4, 6, 7, 8, 9 and 10 and Appendices 2, 3, 5, 6, 7, 8 and 9 of this Annex and the relevant regional air navigation plans. Guidance concerning the accuracy of measurement and observation, and accuracy of forecasts is given in Attachments A and B, respectively, to this Annex.

2.2.5 **Recommendation. —** *In regard to the exchange of meteorological information for operational purposes, the quality system should include verification and validation procedures and resources for monitoring adherence to the prescribed transmission schedules for individual messages and/or bulletins required to be exchanged, and the times of their filing for transmission. The quality system should be capable of detecting excessive transit times of messages and bulletins received.*
Note.— Requirements concerning the exchange of operational meteorological information are given in Chapter 11 and Appendix 10 of this Annex.

2.2.6 **Recommendation. —** *Demonstration of compliance of the quality system applied should be by audit. If nonconformity of the system is identified, action should be initiated to determine and correct the cause. All audit observations should be evidenced and properly documented.*

The ICAO framework for international aviation also expects that contracting States (such as Sri Lanka) will recover associated costs of service provision. The ICAO Convention specifies that charges to be paid by international civil aviation should be based on the principles contained in Article 15 of the Convention on International Civil Aviation (Doc 7300) and ICAO's Policies on Charges for Airports and Air Navigation Services (Doc 9082). Detailed guidance for determining the costs of aeronautical meteorological service is provided in the Manual on Air Navigation Services Economics (Doc 9161). Among the many recommendations is one that calls for the meteorological service charge to be included in the nationally levied air navigation charge and that the Contracting State should make internal arrangements for the separation of the amounts to be paid to the agencies that provide air navigation and meteorological services.

Recommendation 1.3

Current arrangements for cost-recovery from aeronautical meteorological services provided to civil aviation should be reviewed. In many countries, consistent with ICAO recommendations, these funds are returned directly to the National Meteorological Service to offset operating costs. Such a practice would also provide transparency to the aviation industry regarding the utilization of these charges. In this regard, Recommendation 3.2 must be implemented as a high priority.

The World Bank team noted the very crowded nature of the forecasting and warning centre during a time of relatively benign weather and considered that the addition of further equipment and staff to deal with an extreme weather event could seriously impact on the smooth operation of the centre and recommended that consideration be given to a new, purpose build forecast and warning centre with dedicated space in the operational area for media briefings and the like, and for staff of other agencies such as the ID Hydrology Division or from the DMC to interact with key operational staff in the lead up to expected extreme weather events.

TOTAL DoM Expenditure (LKR x 1000)			
ITEM	2015	2016	2017
Recurrent + Capital	603,180	324,000	302,420
Domestic Funds	563,180	297,000	302,420
Foreign Grants	40,000	20,000	-
Reimbursable Foreign Grants	-	7,000	-

Table 5.4: Summary of DoM total financing with a breakdown between domestic and foreign funding sources. Revised budget for 2015, budget estimate for 2016 and budget projection for 2017.

Meteorological Networks Managed by DoM

The DoM maintains 20 meteorological stations that are staffed by trained meteorological observers (Figure 5.1). Surface observations are carried out at the standard times for synoptic observations (i.e. 0000, 0600, 1200 and 1800 UTC) and at the intermediate times (i.e. 0300, 0900, 1500 and 2100 UTC) are taken at: Anuradhapura, Batticaloa, Colombo, Galle (Figure 5.2), Hambantota, Katugastota, Katunayake, Nuwara Eliya, Puttalam, Ratmalana, Ratnapura, and Trincomalee. The following stations carry out surface observations at 0300, 0600, 0900, 1200 and 1500 UTC: Badulla, Bandarawela, Jaffna, Kurunegala, Maha Illupallama, Mannar, Pottuvil, and Vauniya.

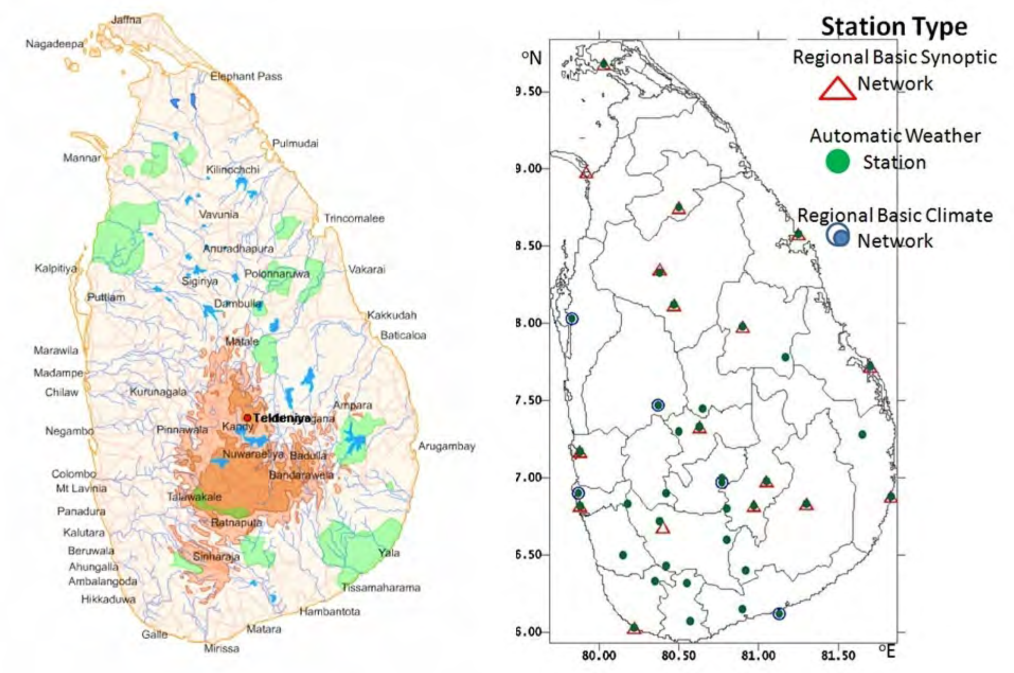


Figure 5.1: (a) Geographic map of Sri Lanka, (b) location of surface-based, meteorological observing stations.

Automatic Weather Stations

As a part of the Japanese International Cooperation Agency (JICA) funded project ("Improvement of Meteorological and Disaster Information Network") the DoM has, to date, installed 38 Automatic Weather Stations (AWS). The DoM national forecasting centre in Colombo used to receive the data from these JICA AWS every 10 minutes via a system of VSAT communications links. When the World Bank team visited Colombo these stations had not been received in the forecasting centre for 14 months due to upgrades to the VSAT communications system that Sri Lanka Telecoms had been not able to implement. Tendering for Internet-based communications was being planned in the expectation that the cost would be around half of the VSAT communications (or less). The World Bank team was advised that the ID automatic stream gauging networks utilize Meteosat communication free of charge and recommends that this communication option be explored for communication with the JICA AWS network.

Figure 5.2: Galle Meteorological Observing Station. The tall white pole is the JICA AWS (see discussion below) while the white boxes are Stevenson Screens housing traditional instruments.

The DoM has identified systematic biases in the temperatures reported by the JICA automatic weather station network due to the different heat capacity of the metal louvered housing to the JICA automatic weather station temperature sensor as compared to the heat capacity of a standard, wooden Stevenson Screen (Figure 5.3).

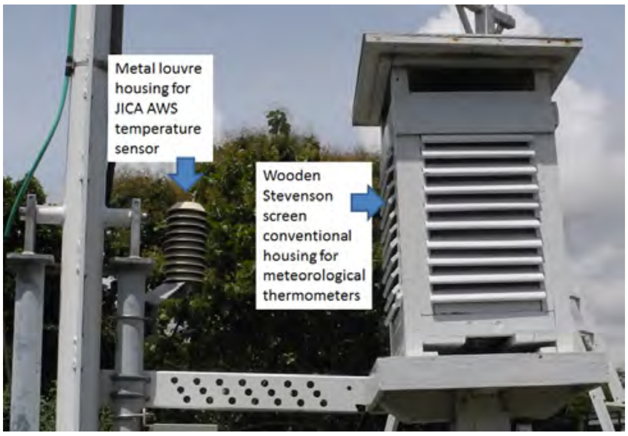


Figure 5.3: The JICA AWS and standard meteorological instrument intercomparison site in Colombo, Sri Lanka.

Prior to the loss of telecoms, the JICA automatic weather station data were available on a personal computer located in the Forecast and Warning Division of DoM but were rarely used because they were not plotted on the operational charts. While it is clear that because of instrumentation concerns the data were not fit for climatological use, the 10-minute real-time monitoring of rainfall and wind velocity makes them the only high temporal resolution data potentially available to forecasters and they are certainly fit for the purpose of monitoring severe weather events in locations around Sri Lanka. In fact, post analysis of an extreme event in November 2011 illustrated the value of these AWS data.

Communications should be restored to the JICA automatic weather stations as soon as possible, and arrangements should be made to give forecasters easy access to a real-time display of the data. In the future, should the DoM install an integrated forecaster workstation, the automatic weather station data should trigger some sort of alarm when wind speeds exceed critical levels such as the “Strong Wind” level of 25 knots and/or the “Storm Force” level of 34 knots.

There are a number of other automatic weather station networks operating in Sri Lanka including those in support of agro-meteorology, river gauging and dam monitoring. The DoM makes no use of the data from these stations for a variety of reasons including uncertainty as to the quality if the observations, cost and complexity of accessing the networks and even lack of knowledge as to the extent of the networks. While the data these other automatic weather station networks may not meet the standards for climate analysis they may provide crucial real-time data in extreme events which is of a far higher temporal and spatial resolution than the synoptic networks operated by DoM, and so assist greatly in the DoM warning processes.

Recommendation 7.1

The risks of such an approach (that is, uncoordinated automatic weather station networks) are incompatible networks, challenges in integrating the data sources, and possibly duplication of sites. Future projects involving the installation of automatic weather stations should be evaluated against a stock-take and analysis of the existing instruments that establishes an agreed national approach to the integration of the relevant networks. This activity should also include the establishment of agreements for the free and open exchange of data, including meta-data, from all stations.

Upper air, radar derived wind observations are taken at Hambantota in the extreme south, Puttalam in the west and Polonnaruwa in central Sri Lanka (Figure 5.4). Radar wind and radiosonde observations (upper-air observations that provide wind, temperature and pressure data up to a height of 20,000 metres or more) are taken only at Colombo (on the west coast) three days per week. Ideally the radiosonde would be launched twice daily (at 00 UTC and 12 UTC) however only three radiosonde flights per week are carried out because the cost of consumables (more than US$200 per radiosonde) precludes doing this.

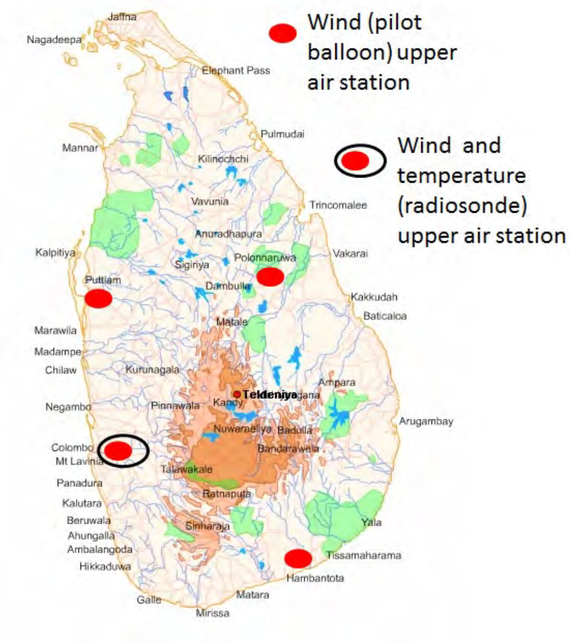


Figure 5.4: Location of DoM upper air observing stations.

The DoM currently only receives three-hourly synoptic data from its national networks. Such data are suitable for synoptic analysis and forecasting but will not meet the demands of mesoscale analysis and forecasting at the divisional secretariat level[5], the level at which communities need to be warned of impending extreme weather events and other natural hazards. Remote sensing satellite systems are currently mesoscale meteorological observations available for Sri Lanka. It is expected that in the future radar will supply additional remotely sensed data. Furthermore, real-time access DoM forecasters to the variety of AWS networks across the Sri Lanka that observe as frequently as every ten minutes would supply another important mesoscale data set. Currently, the most readily available meteorological data for forecasting and warning at the mesoscale/Divisional Secretariat are those derived from state-of-the-art numerical weather analysis and forecasting systems that incorporate a variety of satellite data from over, and adjacent to Sri Lanka. Centres operating state-of-the-art numerical weather analysis and forecasting systems include: The European Centre for Medium-range Weather Forecasting (ECMWF), The United Kingdom Meteorological Office (UK Met Office), The United States National Weather Service (US NWS). The foremost of these is the ECMWF, and the World Bank team recommends that the DoM seek access to the stream of digital products available from the ECMWF at a modest cost (around Euro 42,000 per annum) for use in a range vital, public good, forecasting and warning services.

Recommendation 6.1

Arrangements should be made for the DoM to obtain ongoing access to relevant ECMWF NWP data sets (Euro 42,000 per year). Access to these data sets would provide an immediate contribution in support of real-time gridded data inputs to enable the production of impact-based forecasts and warnings.

[5] There are 331 Divisional Secretariats in Sri Lanka, a country with a land area of 64,740 sq km. That is, on average a Divisional Secretariat covers around 200 sq km, or an area of a square bounded by sides of around 14 km in length.

To make best use of the stream of digital information from the ECMWF there may be a need to increase the DoM Internet bandwidth and there will certainly be a need to increase its in-house computing and data storage capacity. Furthermore, there will need to be a training program, led by scientists familiar with the capabilities of the ECMWF data, to enable the DoM staff to make best use of this extremely valuable information source.

Recommendation 2.5

Training opportunities for DoM staff, especially in the use of modern forecasting methods should be accelerated.

In addition to employing data from modern analysis and forecasting systems the DoM needs to re-consider its observing strategy. While the historical record at its synoptic sites is an impressive and invaluable one, higher resolution spatial and temporal data will be needed in the future for services that meet clients' needs at a community level. A modern national meteorological service optimizes its overall observation system by incorporating a mix of surface-based and atmospheric observations with the use of remotely sensed data to establish an observation system that meets their service delivery needs. This includes the use of satellite and radar derived data along with in-situ observations such as surface-based networks, upper-air networks and the global Aircraft Meteorological DAta Relay (AMDAR) programme, amongst others. This system optimization ensures that a fit-for-purpose integrated observation is maintained and operated in an economically efficient and effective manner. Such an observing system employing a diverse range of complementary technologies is often referred to as a composite observing system.

Recommendation 8.1

The DoM should undertake a study to determine and define the fit-for-purpose, composite observation system that will meet the existing and future needs of Sri Lanka for its meteorological and climatological services.

Data Storage and Analysis

Collecting meteorological observations is a costly undertaking that can only be justified when the benefits from the observations exceed the cost of taking them. The benefits from a meteorological observation accrue over time: the initial benefits are extracted when real time weather forecasts and warnings are based upon them, however most of the benefits come later as the observation is used in applications such as weather research, agro-meteorological decision making, solar and hydro-power energy studies, design studies for irrigation networks, dams, roadways, airports, office buildings and the like. The more an observation is used the greater the benefit derived as compared to the cost of taking it.

A prevailing data management philosophy in many developed countries is that as the tax payer has already paid for the collection of the data they should only have pay the incremental cost of accessing the data should they want to make use of it. Data can only be re-used in multiple applications if they are managed with a view to making them widely available at low cost. To make data widely and cheaply available they must be managed effectively, this requires that they be properly quality controlled before insertion into a well-structured, digital database, that can be accessed on-line and that has security measures that can give a high level of protection to data integrity.

Archives of DoM Surface and Upper Air Synoptic Data

The Data Archive Division of DoM is staffed by one meteorologist and three support staff. The Computer Division routinely enters the synoptic observations into CLIMSOFT climate database. In particular, the Division routinely enters daily values of rainfall, minimum and maximum temperature, and relative humidity. Wind speed and direction are also entered if requested. The record extends from 1869 to the present day (relative humidity entry commenced in 1996). The data are stored on a 200 GB SATA hard disc which has no back up. The Archive Division also has data in a legacy CLICOM system which requires a DOS operating system and a floppy drive to read data stored on the floppy discs. There is no on-line, external access to these data.

The Archive Division also manages the paper records that are created when an observer records his or her observation in a log book or when an analogue recorder, such as a pluviography, barograph or a sunshine recorder creates a chart.

The World Bank team estimated that the paper archives are stored on approximately 400 metres of shelving containing:

- Three-hourly synoptic observations at 23 stations, some commencing in 1860;
- Pilot balloon data;
- Pluviograph charts;
- Campbell-Stokes sunshine recorder strip charts;
- Barograph charts;
- Thermograph and hydrograph charts.

The archive room is air conditioned, the paper records are well labelled and are stored in an orderly fashion. The room is quite clean with a large table for working on. There is no fire extinguisher system (Figure 5.5).

Figure 5.5: The DoM archive room

The World Bank team recommends that efforts be made to digitize these data, commencing with those most needed for research into the climatology of extreme weather events, such as flood situations, and considers that the pluviography charts should be a priority.

The World Bank team also recommends a carbon dioxide fire extinguisher system be installed in the archive room as it is clear that an irreplaceable climate record would be lost in the case of fire.

Recommendation 5.1

A "data rescue" activity be undertaken to digitize the paper-based archives held by DoM (and others) and to install the resultant digital data in a database accessible to other groups dealing with natural disasters including (but not limited to) the Disaster Management Centre and the Hydrology Division of the Department of Irrigation. Priority should be given to digitising the chart records from the DoM's pluviographs.

Recommendation 5.2

The digital database of all hydrological and meteorological data should be routinely updated with quality controlled real-time data from all available automatic weather station networks currently operating in Sri Lanka. Care will need to be taken to identify within the database the originating network of the data (meta-data) so that users have a basis for determining the quality characteristics of the data they are accessing and using.

Recommendation 6.3

Nowcasting and short-range forecasting and verification methods should be introduced into the operations of the forecast office of the DoM. A new forecasting facility is also needed.

Recommendation 6.4

The DoM, ID and DMC Centre should work together to develop real-time gridded products as input to models linked to Geographical Information Systems. This would provide more focused areal information on potential hazards, incorporating local data sources, and enable linkages with vulnerability information enabling DMC to issue impact-based forecasts and warnings.

Recommendation 6.5

Based on the above activities, more targeted services, include mobile applications, with increased lead-time for meteorological and hydrological warnings and the introduction of impact-based warnings within the DMC should be developed. Also, improved presentation of warning information through electronic media should be implemented.

Recommendation 6.6

Real-time data and information should be shared openly to ensure their effective use. Public access should be implemented with arrangements to protect the integrity and security of the data and the database that holds it.

Daily Rainfall Data

The DoM operates a network of daily rainfall stations. The data set of daily rainfall commences with a small number of observations taken in 1869 and now includes 521 stations. Volunteer observers should check a simple rain gauge each day at 9am and telephone their observation of the rainfall amount the gauge contains to DoM in Colombo. The data provided by the rainfall observers are held on a hard disk attached to a personal computer. The daily rainfall data hard disk is backed up weekly. There is no external user access to these data. There are some concerns about the quality of the data, including the adherence to the uniform observing time, as there has been little or no training of the observers.

The standard rain measuring equipment that each observer should be using is a standard 5-inch diameter funnel, robust metal gauge, along with a glass measuring cylinder into which the daily precipitation is tipped for accurate measuring (Figure 5.6).

Staff of the DoM are aware of the proliferation of non-standard gauges with a 4-inch diameter and no rainfall measurement gradations for less than 50mm of rain marked on the gauge. These are lightweight plastic 4-inch gauges and so are likely to be blown over in extreme weather events and they do not come with a properly calibrated measuring cylinder. Observers are known to resort to purchasing inappropriate chemist shop style measuring devices to determine rainfall amounts less than 50 mm, furthermore, even using the standard measuring cylinder would give incorrect results because these are designed for use with 5 inch, not 4 inch gauges. Because the DoM does not have the resources to inspect all of its 521 rainfall observers it has no way of determining which observers are using which gauges and which measuring cylinders, and so it no longer has a real understanding of the quality of the rainfall information being provided to it.

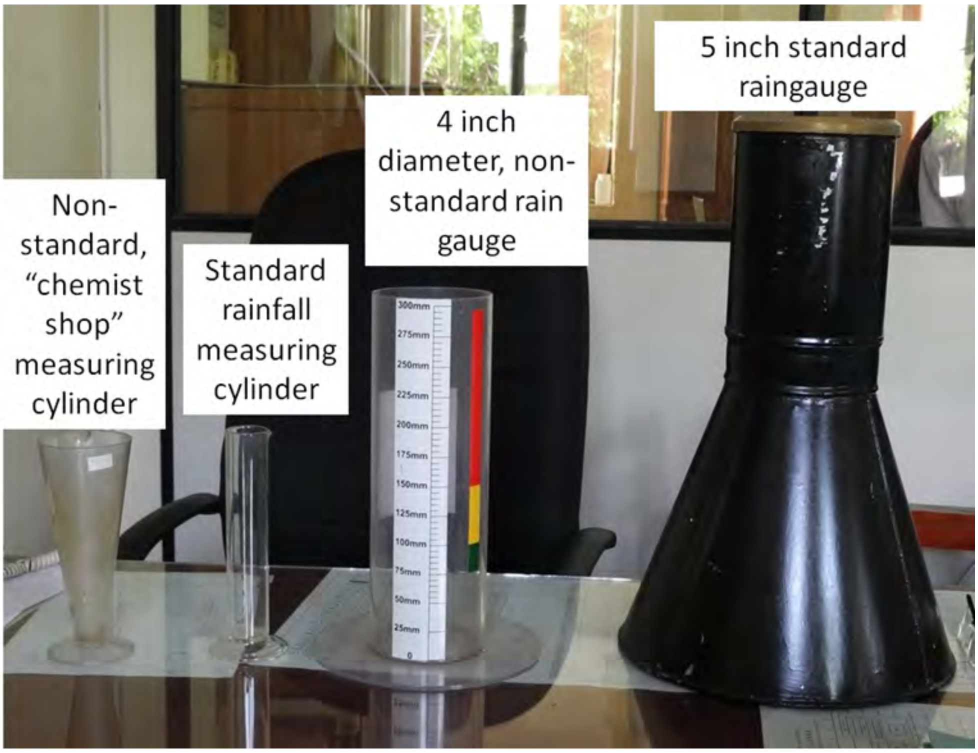


Figure 5.6: A description of the instruments involved in corruption of the Sri Lanka daily rainfall record held by DoM.

The DoM should carry out a review of the gauges and measuring cylinders currently being used be each observer in the network, identify those stations whose data has been affected by the issues described above and flag the suspect data accordingly in the digital records.

When a quality controlled data set is in place it should be placed in an on-line database with access managed in such a way as to recover cost of access and to safeguard the integrity and security of the data.

DoM and Private Sector Weather Services

There is some urgency to the improvement and enhancement of the services provide to Sri Lanka by the DoM to avoid direct competition from the private sector. The latter would be capable of exploiting its access to high quality international meteorological products and well-designed applications to offer an alternative to the DoM without, of course, the responsibility for warning services. Given the overall weakness of the DoM, a head-to-head competition with private weather services is undesirable.

Recommendation 9.3

Improvements in warnings services should be accelerated to reduce the threat of independent providers challenging the sovereignty of the national warning services. This would be an interim solution, while the longer term transformative investment is in development.

Department of Irrigation – Hydrology Division

Summary

The Hydrology Division of the Sri Lankan Department of Irrigation is in a state of transition, especially with respect to its flood forecasting and warning function. It is moving from a largely manual mode of operations with limited modelling (one dimensional) capabilities to a more automated environment, with improved data handling technology and with significantly improved modelling capabilities. However, the workforce remains strongly orientated towards technical expertise and continues to have a lack of professionally qualified staff. There are also concerns with respect to the ongoing funding being sufficient to ensure the sustainability of the new systems being installed and the new computing environment required to implement the new capabilities. Furthermore, a key element of improved flood forecasting and warning services will be the ability to incorporate better estimates of future rainfall that will become available through this project. Considerable efforts will be required to continue to improve the modelling capabilities of the Hydrology Division and ensure that the flood forecasts and warnings meet the identified needs of a wide ranging user community.

Functions of the Hydrology Division

The Hydrology Division, established in the late 1940's, is a specialized branch of the Sri Lanka Department of Irrigation. It is responsible for maintaining the hydrological information system of the country. However, the collection of hydro-meteorological data in major river basins started in 1924 with the establishment of a streamflow gauging station at Nagalagam Street on the Kelani River (Figure 5.7). The Director of Irrigation (Hydrology) is responsible for Administration, Financial Control and Management of the Hydrological Information System for Sri Lanka.

Figure 5.7 Kelani River at Nagalagam Street – Gauge Boards

The responsibilities and functions of Hydrology Division are as follows:

- Management of Sri Lanka's Hydro-Meteorological Information System (HMIS) and hydrological observation network including adding or removing stations as per the requirements and priorities;
- Management of the hydrological database and HMIS system with necessary improvements to meet the present and future requirements of Sri Lanka;
- Validation of hydrological and hydrodynamic models including collection of field

data and issuing flood forecasts regarding major rivers;

- Flood mapping including collection of required data and information related to major floods;
- Publishing periodic hydrological bulletins, manuals etc.; and
- Conducting research works and providing consultancy services for other agencies on their request.

Hydro-meteorological Networks

There are 103 major river basins in Sri Lanka which cover the 90 % of total land extent of the country as shown in **Annex 1**. The remaining 10% is situated along the coast and Jaffna peninsula and is covered by small watersheds.

Prior to 2015-16, the hydro-meteorological network (Table 5.5) was primarily manually operated with 35 principal stations reports at 1-hourly intervals by telephone.

	Number of Stations	Data Recording	Transmission	Interval of Recording	Data Period
Principal Stations	35	Manual	Telephone	1 Hour	Around 60 years
Peripheral Stations	40	Manual	Mail	Daily	Around 60 years

Table 5.5: Old Hydro-meteorological Data Collection and Transmission system

The World Bank, through its *Dam Safety and Water Resources Planning Project*, is supporting the Irrigation Department and the Mahaweli Authority of Sri Lanka (MASL) to deploy new automatic hydro-meteorological monitoring stations as an expansion of the water resources monitoring network (Table 5.6).

	Number of Stations	Data Recording	Transmission	Interval of Recording	Status
Phase I	122	Automated	Satellite (MeteoSat) GPRS	10 Minutes	Installation completed Data Processing and validation
Phase II	40	Automated	GPRS	10 Minutes	Planning and Design of installation

Table 5.6: New Hydro-meteorological Information System (HMIS)

The current HMIS comprises 122 stations (**Annex 2**) and includes a mix of streamflow, reservoir level, rainfall and meteorological data monitoring sites (**Annex 3**).

Data Storage and Analysis

Prior to 2015-16, the hydro-meteorological data collected by the Irrigation Department was stored in paper format and on Excel spreadsheets. The Hydrology Division has had some of the paper format hydrological record digitized, however some records remain in paper format. The approach to data storage and analysis could therefore be considered as rudimentary. As part of the World Bank *Dam Safety and Water Resources Planning Project,* the Aquarius software has been purchased and installed on the Hydrology Division’s servers.

The Aquarius Time-Series is software for water data management. It enables water resource managers to correct and quality control time series data, build better rating curves, and derive and report on water information in real-time to meet stakeholder expectations. Aquarius is continuously upgraded to support the latest industry best practices and technologies with a powerful, easy-to-use set of tools that centralize data management, simplify analysis, automate consistent workflows, and facilitate information sharing. The result is better insight into water data in less time.

Staffing

The Hydrology Division staff includes 5 Professional Officers (currently only 4 positions are filled), 58 Technical Staff (46 filled), 110 gauge readers and 15 other non-technical staff. That is, only 3% of the officers have professional qualifications. Their salaries (around LKR 55M (US$380k)) are paid directly by the ID.

Budget

The total annual budget for the Hydrology Division is LKR 74M (US$511k). Of this, the annual funding for operation and maintenance of the existing hydrometric stations (considered insufficient by the Director of Hydrology) is LKR 12M (US$83K). The Hydrology Division also receives additional funding of LKR 7M (US$48k) for special studies, training and purchase of new instruments.

Hydrological Modelling

Prior to 2015-16, the Hydrology Division had used basic hydrological modelling techniques such as flood routing (unit-hydrograph) and hydro-dynamic modelling (Mike 11). As part of Component 1 of the World Bank's *Climate Resilience Improvement Project (CRIP), Development of Basin Investment Plans* (Flood and Drought Risk Mitigation Investment Plans), and range of new modelling capabilities are being investigated, including, a basin-scale flood model, rapid direct rainfall 2D model with Green Ampt Infiltration (TUFLOW); Continuous Simulation Hydrological Model (SWAT); Event-based hydrological model (floods) (Unit-hydrograph, SCS Curve method); River Basin Model (water allocation model) (WEAP); Hydraulic/Hydrodynamic: 1D Channel Model (Flood Modifier (formerly ISIS); Two Dimensional Model for detailed out of bank modelling (Flood Modifier/TUFLOW).

As part of CRIP 1, these models will be applied to ten river basins in Sri Lanka (**Annex 4**).

Flood Forecasting and Warning

The current system for flood forecasting and warning in Sri Lanka involves using rudimentary hydrological and one dimensional hydraulic modelling to forecast the river height, based on river heights observed at up-stream stations. Based on these forecast heights and the information in Table 5.7, flood warnings are issued (Figure 5.8). Note that Table 5.7 is an example only and that similar information on flood levels is available for other sites on these rivers, and also for 12 other river basins. Warnings are issued to the media and the Disaster Management Centre

River Basin	Station Name	Flood Level Classification			
		Alert	Minor	Major	Danger
Kelani River	Nagalagam Street	1.22m	1.52m	2.13m	2.74m
	Hanwella	7m MSL	8m MSL	10m MSL	11m MSL
	Glencourse	15m MSL	16.5m MSL	19m MSL	22m MSL
Kalu River	Ratnapura	5m	5.75m	6.5m	
	Ellegawa	2m	3m	5m	
	Millakanda	3m	3.5m	4.5m	

Table 5.7: Example of flood level classification for two rivers

It should be noted that the Hydrology Division does not provide warnings for flash flood situations.

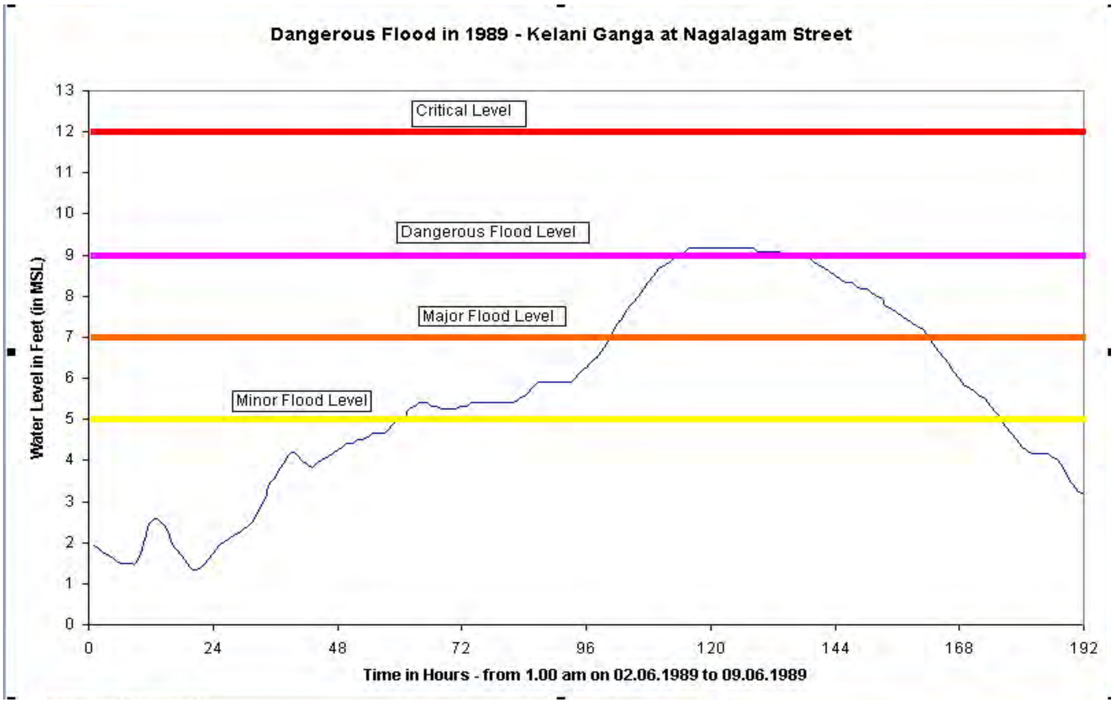


Figure 5.8 Flood Levels, Kelani River at Nagalagam Street, 1989 Flood

Internally, within the ID, when a flood is forecast, impacted groups (including the Division of Drainage and Flood Systems and the Division of Water Management) work together to manage the flood situation from the perspective of the ID.

The 15-16 May 2016 Event

The report by the Hydrology Division on the May 2016 flood event is contained in **Annex 5**. In essence, the spatial distribution and intensity of the rainfall was such that lead times for flood warnings for greater than 3-4 hours were not possible using the existing flood forecasting and warning capabilities of the Hydrology Division. The heavy rainfall covered the entire catchment in a relatively uniform fashion. The flood was dominated by the rainfall in the middle reaches of the catchment. The rapid rise of the floodwaters in the lower catchment was unexpected. (Figure 5.9, Figure 5.10)

Figure 5.9 Kelani Ganga Floods at Biyagama

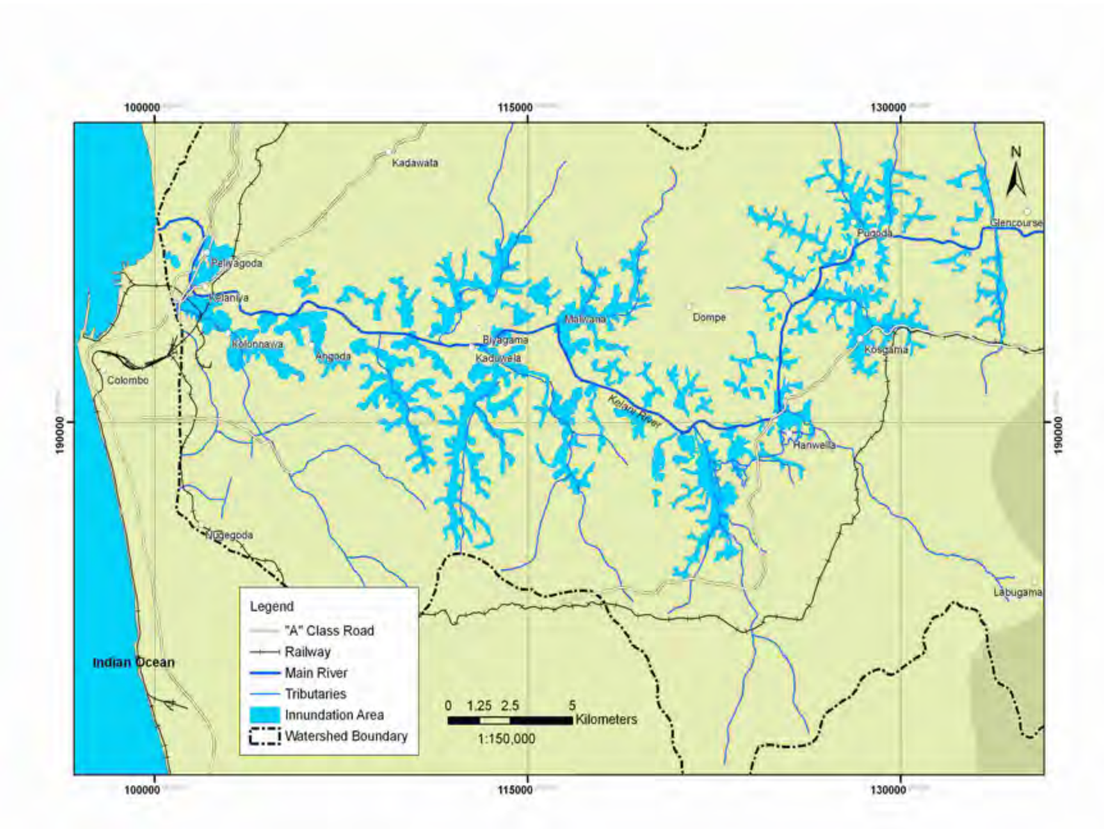


Figure 5.10 Flood Inundated Area in Kelani Ganga Basin

Discussion – Major Findings

The Hydrology Division of the ID is in a state of major transition, moving from a manual system of hydro-meteorological monitoring to an automated system, upgrading its information management system from Excel Spreadsheets to a full Hydro-meteorological Information System and implementing new modelling applications, including two dimensional and water resources allocation models.

Flood Forecasting and Warning

Prior to 2015-16, both the resources (staff and funding) and the technical capabilities (data access and modelling) meant that the flood forecasting and warning services provided by the Hydrology Division were rudimentary in nature. That is, there was adequate ability to forecast and warn of flood events that occurred as a result of rainfall in the upper catchments and rising river levels at the upper catchment streamflow monitoring sites. There was no capability to incorporate forecast rainfall in the flood forecasting and warning system. Also, responsibility for the provision of flash flood warnings appears to be uncertain and should reside with the DoM because flash floods occur very quickly in response to high intensity, localised rainfall events, which the DoM is best placed to observe/forecast ("nowcast").

Recommendation 6.2

The Hydrology Division should implement improved distributed hydrological modelling (in cooperation with the Climate Resilience Improvement Program (CRIP-1) advances) to enable better forecasts of floods in Sri Lanka, incorporating the use of forecast/predicted rainfall estimates to be provided by the DoM. This capability should be extended beyond the 10 basins covered by CRIP-1 on a priority basis.

Whilst the full impacts are yet to be felt, it is anticipated that the funding provided by the current World Bank projects will enable improved river flow and rainfall monitoring (in real-time) and improved modelling capabilities that may be applicable for flood forecasting and warning. However, it is noted that this will be confined to ten river basins in Sri Lanka (approximately 42% of the land area). Also, the extent to which forecast rainfall can be incorporated into models needs to be assessed as the CRIP-1 project continues.

Recommendation 2.4

Hydrology Division staff should be trained in the application and use of distributed hydrological modelling and the use of quantitative precipitation forecasts (in association with the DoM)

Recommendation 6.7

The Hydrology Division should work with the DMC to ensure that impact-based flood forecasts and warnings can be issued for the benefit of the impacted communities.

It is noted that whilst the Hydrology Division has identified alert, minor, major and danger flood levels for 14 river basins, there is little evidence to suggest that any detailed analysis has been undertaken to identify the impacts of these floods at the levels given and thus the ability to develop an impact-based warnings approach.

Observation Systems

It is noted that the Hydrology Division is operating real-time hydro-meteorological observing systems. It is essential that the Hydrology Division keep the DoM informed of all plans to establish weather related data collection platforms and that data from such systems be shared with all partner agencies.

Recommendation 8.2

The Hydrology Division should work with the DoM in rationalizing the surface-based hydro-meteorological automatic weather stations.

Data Management

The Hydrology Division is implementing a new Hydro-meteorological Information System (Aquarius). However, whilst the Hydrological Division has rescued some of its paper records, a considerable amount of paper records remain.

Recommendation 5.3

The Hydrology Division should digitize the remainder of the data held on paper records and incorporate them into the Aquarius HMIS.

Staffing

Whilst there are limited data available on the breakdown of professional versus technical officers in other national or regional hydro-meteorological services, the observed trends are increasing numbers of professional staff and an increasing number of technical staff with base three years degrees in areas such as water resources management. That is, with increasing automation, a move towards larger numbers of professionals (see Table 5.8 for a comparison of staffing levels between Sri Lanka and New Zealand). The ability of the Hydrology Division to gain from the advances that will come from the existing World Bank projects will to a large degree depend on the capabilities of the staff.

Recommendation 2.2

Work-force planning analysis should be undertaken for the Hydrology Division, taking into account the advances that will be achieved through the World Bank projects and the needs and requirements of the users of the Hydrology Division services flowing from these advances.

	Professional	Technical	Non-Technical	Administrative	TOTAL	Stations	Telemetry	% Professional	Stations/Staff	Operations Budget	Salary Budget	TOTAL	Budget/Station	Operations/Station
New Zealand	30	150	20	15	215	1500	100%	37	7.0	NZ$6.0M	NZ$12.0M	NZ$18.0M		
										US$4.3M	US$8.6M	US$12.9M	8600	2867
Sri Lanka	5	58	110	15	188	122		3	0.6	LKR 19MN	LKR 55M	LKR 74M		
										US$130K	US$380K	US$510K	4180	1066

Table 5.8 Comparison of staffing between Sri Lanka and New Zealand. Note New Zealand observations are 100% automated.

Funding

There is some concern that the operational funding base for the Hydrology Division will not be sufficient to ensure the sustainable operations of the new systems (both monitoring and modelling) being installed as part of the World Bank projects.

Recommendation 1.4

An analysis of the ongoing operational budgetary requirements for the Hydrology Division should be undertaken to ensure that it is able to sustain the improvements made into the future and provide Sri Lanka with the operational flood forecasting and warning services it requires and deserves.

Disaster Management Centre

Summary

The DMC was established under the National Council for Disaster Management in accordance with the Sri Lanka Disaster Management Act No. 13 of 2005. Currently the DMC functions within the Ministry of Disaster Management, which is also the parent Ministry of the DoM and NBRO.

Functions of the Disaster Management Centre

In collaboration with Ministries, Line Departments, Public Corporations, Provincial Councils, the Local Authority Administration, as well as District, Division and Grama Niladhari administration, DMC strives to achieve the following objectives:

- providing hazard and risk information to support proper disaster management decisions.
- formulating and implementing mitigation strategies to reduce future losses
- building capacity to respond quickly and effectively to disasters.
- Effective dissemination of early warning issued by relevant technical agencies
- Enabling competent Emergency Operations Management
- Managing post-disaster activities; and
- Improving community understanding of risks in order to enhance their resilience in the face of disasters.

The DMC coordinates and collaborates with all of the above stakeholders as well as the armed forces police, international and national NGOs in managing the total disaster risk management process in the country.

The activities of the DMC include directing, issuing guidelines, facilitating, coordinating, monitoring and where necessary directly implementing or enforcing activities related to the following:

- Disaster risk assessment, data collection, research & analysis
- Disaster management technology, mitigation & disaster risk reduction
- Early warning dissemination
- Emergency Operations in case of a disaster
- Preparedness planning (National, District, Division and Grama Niladhari levels
- Training, Education & Public Awareness
- Formulating and implementing National Disaster Management Plan and National Emergency Operation Plan
- Implementing, coordinating and monitoring activities related to hazard mapping, risk assessment, disaster mitigation, disaster preparedness, management of emergency operations and post-disaster activities

Emergency Operations Centre

The Emergency Operations Centre (EOC) is central to a coordinated and effective response to any emergency. The EOC operates on a 24x7 basis, coordinating all incident information on disasters and resources for management. It receives, analyzes, and displays information about incidents to enable decision-making. The EOC also finds, prioritizes, deploys, and tracks critical resources. It enhances decision making, communication, collaboration, and coordination. It is staffed with diverse personnel required for complex operations and as recommended in the revised Organizational Restructuring of DMC. The structure of the National EOC is shown schematically in Figure 5.11.

The EOC has mostly all of the necessary equipment with conference facilities and display systems. It comprises one full-fledged Operations Room, one Control Room that is 24X7 operational and one Communication Room to manage all communication equipment. In practice, the space appears quite limited and not easily expandable to accommodate new functions (Figure 5.12)

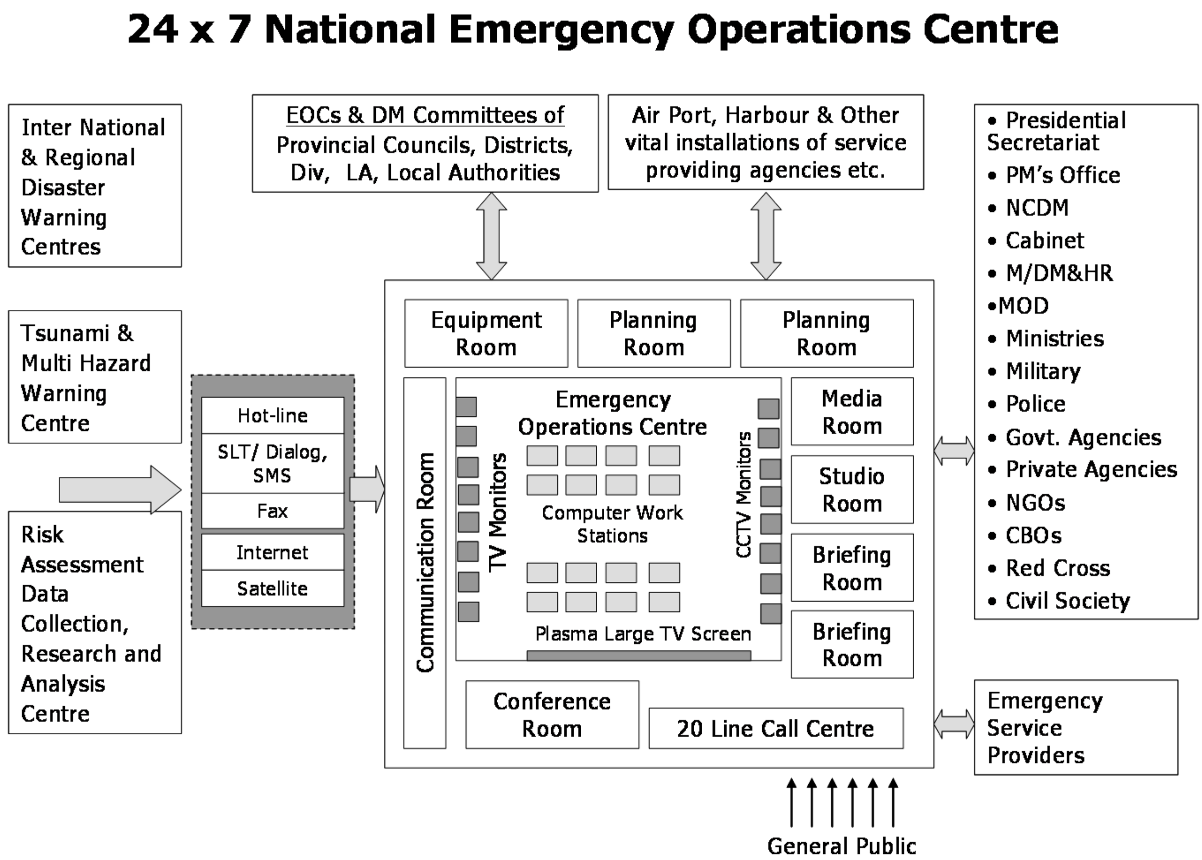


Figure 5.11 Workflow of the National Emergency Operations Centre

Figure 5.12 Emergency Operations Centre

Warning Dissemination

DMC is the main focal point responsible for coordinating and disseminating early warning, along with the relevant technical agencies and technical committees. The Multi Hazard Early Warning Dissemination Division of the DMC is in direct contact with all technical agencies responsible for hazards, and in instances of imminent disaster takes action to inform the responsible officers for onward communication to the sub-national levels and communities.

Its key responsibilities are:

- Maintaining and operating Early Warning Towers and other early warning dissemination equipment;
- Dissemination of Early Warning Messages and ensure the receipt at remote vulnerable villages;
- Co-ordination of donor assistance to strengthen capacity of technical agencies for early warning;
- Working out strategy and policy in the given area of activity;
- Initiating awareness on activities related to early warning among the various agencies and public;
- Guiding District Disaster Management Units in coordinating and implementing warning dissemination related activities in the Province, district, Local Authority, Division, Grama Niladhari and community levels.

Other responsibilities include:

- Establishing coordination with the local technical agencies responsible for forecasting different hazards;
- Establishing a reliable communication system (telephones, radio communication etc.) from technical agencies to the Emergency Operations Centre (EOC) and to Provincial / District Control Rooms directly or through (EOC)). Ensure redundancy by having alternative communication systems in place in case of breakdowns in the main system;
- Establishing communication system with media and ensuring dissemination of information through same;
- Creating awareness among communities and all concerned including Police on the communication system in use for early warning and what immediate actions to be taken, especially on rapid onset disasters.

Staffing

While the DMC appears to be appropriately staffed for its operational mission, it lacks technical skill in the areas of meteorology and hydrology to make full use of the services provided by DoM and ID.

Recommendation 2.6

DMC staff should be trained to interpret and apply meteorological and hydrological forecasts so that there is suitable expertise within the DMC operations.

Collaboration with other Agencies

Besides its mandated responsibilities to stakeholders, DMC is collaborating with other agencies on several projects intended to improve disaster management. The Climate Resilience Improvement Project (CRIP), supported by the World Bank, is being implemented through the Ministry of Irrigation and Water Resources Management with the objective of integrating disaster risk management. CRIP focuses on the geographical areas that have been impacted by recent major floods, landslides and droughts.

The Dam Safety & Water Resource Planning Project, which is being implemented in collaboration with Mahaweli Authority, ID, Ceylon Electricity Board, National water supply and Drainage Board, Water Resources Board, DoM, and DMC, aims to ensure safe, operationally efficient and risk minimized reservoir/ head works system with a safety monitoring system in place; a modern and efficient hydro-meteorological information system; and river basin based water development and management master plan addressing both surface and ground water.

A separate division has been established within the ID under the Director, Disaster Management for quick response and better coordination during flood and drought situations. Similarly, a Disaster Preparedness and Response unit has been established under Ministry of Health to enhance the quick response during emergency situation.

300 local government officials have been trained on mainstreaming DRR into local government sector, and 150 craftsmen have been trained on resilience construction.

A community participatory early warning and emergency response system was introduced to selected villages in Eastern and Southern part of the country under the Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES). This project facilitated the integration of tsunamic warning into a national early warning system and the creation of end-to-end strategy for warnings.

The National Building Research Organization

Summary

The National Building Research Organization (NBRO) was established under the Ministry of Local Government, Housing and Construction in March 1984. In February 2007, NBRO was brought under purview of the Ministry of Disaster Management & Human Rights. NBRO was formed by a cabinet decision and an Interim Management Committee (IMC) was established to guide and direct the administrative, financial and management functions of NBRO

The prime aim of the NBRO is to spread and promote culture of disaster mitigation, preparedness and safety through innovative disaster education, research and training by rendering highly specialized professional services at the cutting edge of science and technology (NBRO website).

Functions of the NBRO

The Services offered by the NBRO include:

- Geo technical and foundation engineering and soil investigation and testing
- Landslide related studies mitigation and slope stability measures, early warning and real time forecasting (Figure 5.13);
- Human Settlement Planning design of cost effective housing and training;
- Testing and quality control of construction materials, guidance and training to the industry;
- Environmental quality monitoring and advisories, Environmental Impact Assessments, Strategic Environmental assessments, Watershed Health Risk Assessments and Management, Monitoring air, water, waste water, soil. noise and vibration monitoring for environmental compliances;
- Total Consultancy services on Architectural, Structural, Engineering, and preparation of tender documents and tender Evaluation reports for building projects;
- Investigation of structural safety of buildings and associated structures;
- Research and development in the field of housing construction technology;
- Research and development on disaster mitigation;
- Research on, and provision of limited early warning services for, landslide hazard.

Figure 5.13 Landslide – Sri Lanka

Staffing

While the NBRO appears to be appropriately staffed for its operational mission, it lacks technical skill in the areas of meteorology and hydrology to make full use of the services provided by DoM and ID.

Recommendation 2.7

NBRO staff should be trained to interpret and apply meteorological and hydrological forecasts so that there is suitable expertise within the NBRO operations.

NBRO rainfall observations

NBRO operates its own independent network of rain gauges. It is recommended that NBRO work with DoM to rationalize the rain gauge network

Recommendation 8.3

The NBRO should work with the DoM in rationalizing the surface-based rain gauge network

Dissemination of meteorological and hydrological forecasts and warnings

In practice, and consistent with international norms established by the World Meteorological Organization, the responsibility for forecasting and early warning of meteorological and hydrological hazards is the responsibility of the DoM and the Hydrology Division of the ID, respectively. The distribution list of DoM originated "Bad Weather" Advisories and Warnings is given at **Annex 6**, and includes the President and senior government officials, DMC, Defence, the media and local government (via District Secretariats). In addition, the NBRO is responsible for landslide warnings. The utility of the information disseminated by DMC is, therefore, dependent on the quality and timeliness of the forecasts and warnings provided by DoM, ID and NBRO.

Recommendation 10.1

Formal roles and responsibilities within the forecasting and warning system must be agreed and respected. Approaches and techniques to improve interagency communication should be implemented, such as, for example, the establishment of daily situation reports, holding of weekly briefings, and dedicated forecasting and warning teams prior to, and during, severe weather related events. A dedicated joint warning desk, as well as centre-to-centre video linkage should be considered. The aim should be an authoritative and consistent message going to the media and the community from all involved agencies.

6. Existing Information Platforms

RiskInfo – Disaster Risk Information Platform

With the support of World Bank and GFDRR, DMC has developed Risk Info – an online Disaster Risk Information Platform (Figure 5.14). This is an open platform, which allows the open exchange of spatial data and information related to hazards, vulnerability and exposure. In addition, under the GFDRR supported Open Cities initiative the DMC has undertaken high resolution disaster exposure mapping in selected regions in Sri Lanka in pilot basis and the DMC is in the process of partnering with the other government agencies to scale up this initiative. In its first phase, the Sri Lanka Open Cities engagement mapped the city of Batticaloa, to better understand and visualize multi-hazard risks in this highly vulnerable city on the eastern coast. Within three months, all 30,000 buildings were mapped and visualized on a Web-based geospatial platform that can be used to understand the risk of floods, tsunamis, and storm surges. These data are accessible through www.riskinfo.lk .

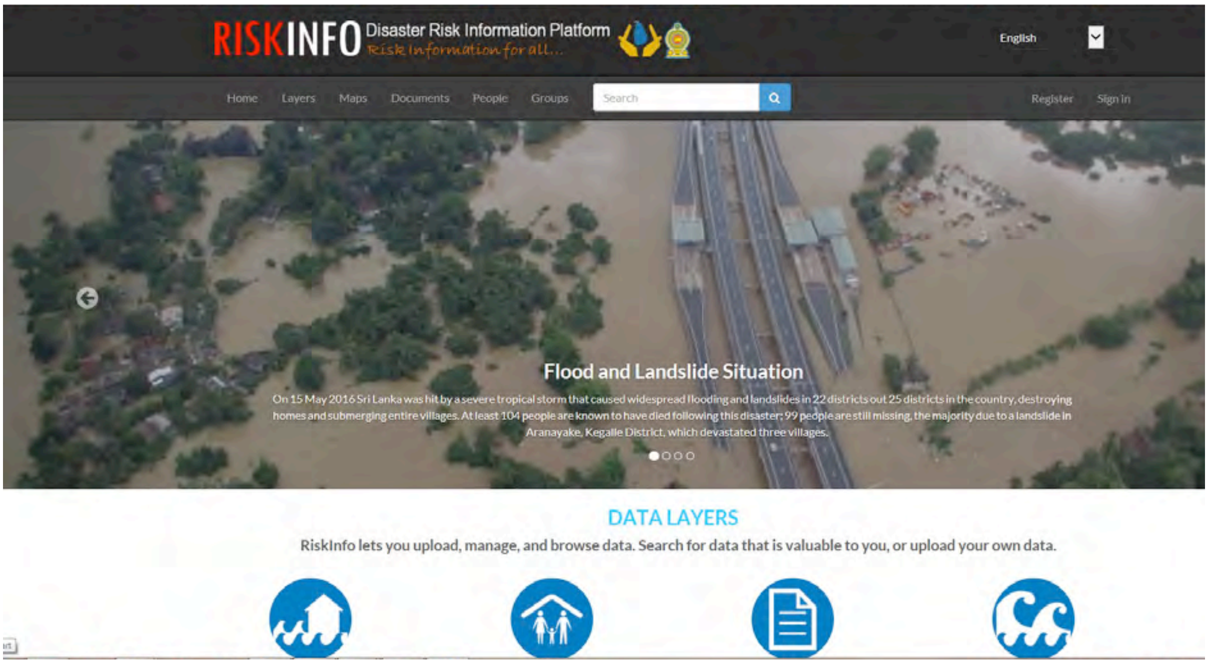


Figure 6.1 RiskInfo data sharing platform

The utility of this tool will increase as more data is incorporated in the platform. In particular, it would provide the basis for the development of impact-based forecasts and warnings.

Disaster Information Management System (DesInventar)

The Disaster Information Management System was developed by the DMC with the support of Disaster Risk Management Program of UNDP and the UNDP Regional Centre in Bangkok, to systematically collect, document and analyse data about losses caused by disasters. It is a tool that helps to analyse disaster trends and their impacts in a systematic way to provide better preventative and preparedness measures to reduce the impact of disasters on communities. The system has linked many different government organizations at the national and district levels to collect information related to disasters. However, the data base does not seem to be up to date.

7. Case Studies – Forecasting and Warning for Severe Weather Events

Introduction

The World Bank team's attention was repeatedly drawn to the flood disaster of 15 May, 2016 and measures that might be taken to mitigate a similar disaster in the future (Figure 7.1). The team understands the need to learn from this disaster and many of its recommendations have been framed based upon the experiences of this event. The team however notes that all disasters are different and that measures taken to mitigate the impact of one severe weather event should be such that they serve to mitigate the impacts of future events that will be different to the last one. To highlight how severe weather events can differ this section briefly contrasts two recent severe weather events that occurred in Sri Lanka.

Figure 7.1: The rescue of an injured woman during the Sri Lanka floods of 25 November 2011. [Source: http://thewatchers.adorraeli.com/2011/11/28/severe-storm-hit-sri-lanka/]

Two Extreme Events

The south coast of Sri Lanka is located around latitude 6^{o}N which is 414miles/666km north of the equator. Over the warm tropical ocean between Sri Lanka and the equator seemingly weak tropical depressions can intensify and move northwards bringing heavy rain and at times high winds to Sri Lanka. Shipping to the south of Sri Lanka provides very few meteorological observations and so forecasters in the DoM must rely on satellite imagery and products from the advanced meteorological centres as to what weather systems are to their south and what their potential for development might be. Figure 7.2 shows the tracks of two tropical depressions that formed to the south of Sri Lanka, they will be called the May and November depressions, it should be noted that while the May 2016 depression ultimately intensified to become Tropical Cyclone "Roanu" and the November 2011 depression dissipated over India, at the time they affected Sri Lanka they were both only tropical depressions.

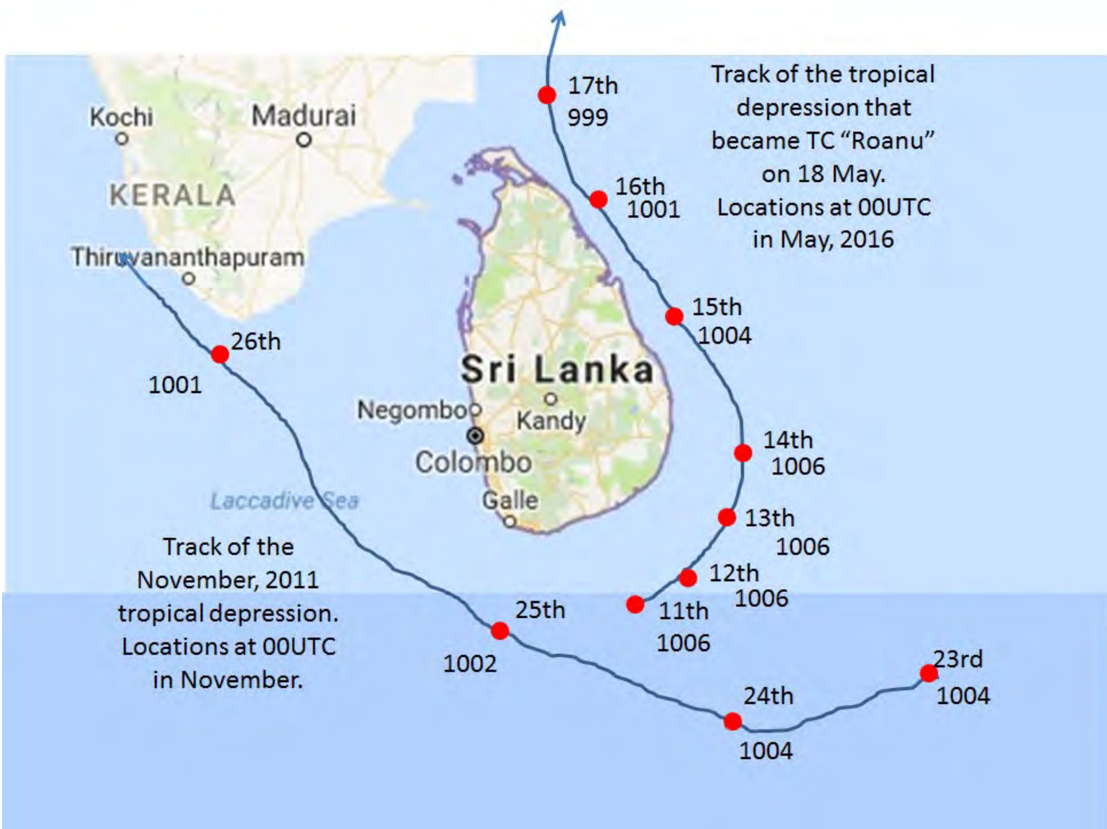


Figure 7.2: The approximate tracks of two tropical depressions that brought severe weather to Sri Lanka. The tracks are called "approximate" because, particularly in their early stages, the depressions are poorly defined in the surface pressure field and are most clearly seen in the winds field at 1000 to 2000m above sea level.

A brief review of the operations of the DoM during, and the impact of, the May 2016 and November 2011 tropical depressions serves to highlight many of the issues faced by the Sri Lanka emergency management system.

The Tropical Depression of November 2011

On 25 November 2011 Sri Lanka was affected by a tropical depression moving rapidly to the northwest off Sri Lanka's West coast (Figure 7.2). The high winds off the south coast, created on the northern quadrant of the depression moving rapidly to the northwest, devastated the local fishing fleet with 19 deaths reported. 43 fishermen were missing and a further 40 were hospitalized with injuries sustained in the high seas. 5,700 houses were damaged, 54,000 people were affected by the depression and 427 families were displaced. Flash flooding was reported in districts in the predominantly in the southern portion of Sri Lanka but also in central and norther districts (Figure 7.3).

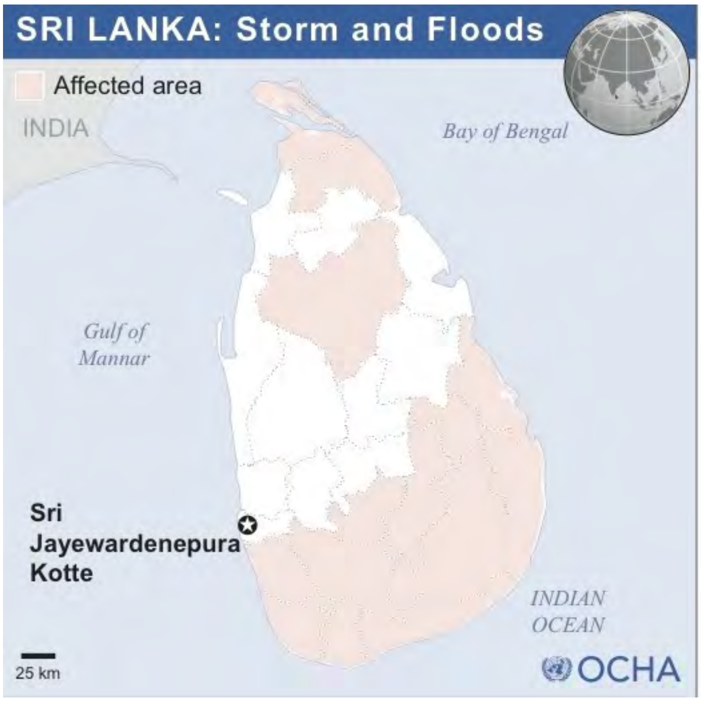


Figure 7.3: The United Nations Office for the Coordination of Humanitarian Affairs (OCHA) Situation Report of 27 November 2011 issued at 18.00 hours describing the areas of Sri Lanka affected by flooding.

On the 24th of November the DoM had issued a "Bad Weather Advisory" for heavy rains from the depression (Figure 7.4). Overall, the strong the winds associated with the depression were not anticipated nor was the sea state which saw 8m/25ft waves being reported 1 to 2 km from the shore. Throughout the event the DoM forecast and warning centre was inundated with telephone enquiries from the public and media and struggled to disseminate accurate and timely information in a rapidly developing situation.

BAD WEATHER ADVISORY VALID FOR THE NEXT 18 HOURS ISSUED AT 1600 HOURS, 24TH NOVEMBER 2011.

(Issued by Early Warning Centre of the Department of Meteorology)

Under the influence of low level disturbance rain or thunderstorms will continue in the Northern, Eastern, North Central, Uva, and Southern provinces. Heavy rains are also expected at some places.

(Duty Meteorologist)
(Department of Meteorology)

Figure 7.4: The Department of Meteorology Bad Weather Advisory of 24 November 2011

In 2011 the DoM forecasters did not have easy access to a wide variety of products from advanced centres, however is possible to retrospectively look at some of products that were being prepared but not available in Sri Lanka. In particular the Extreme Forecast Index (EFI) charts from the ECMWF provided indications of the developing situation (Figure 7.5). On the 22nd of November extreme wind was forecast for the 25th of November off the east coast of Sri Lanka with windy conditions confined to the coastal areas of the north coast as the depression accelerated towards the northwest, and heavy rain was forecast over the Eastern and central areas of the country. On the

23rd the forecast for the 25th had intensified the expected rainfall across the country to extreme in places and increased the area of extreme wind off the east coast with threatening conditions along the north coast.

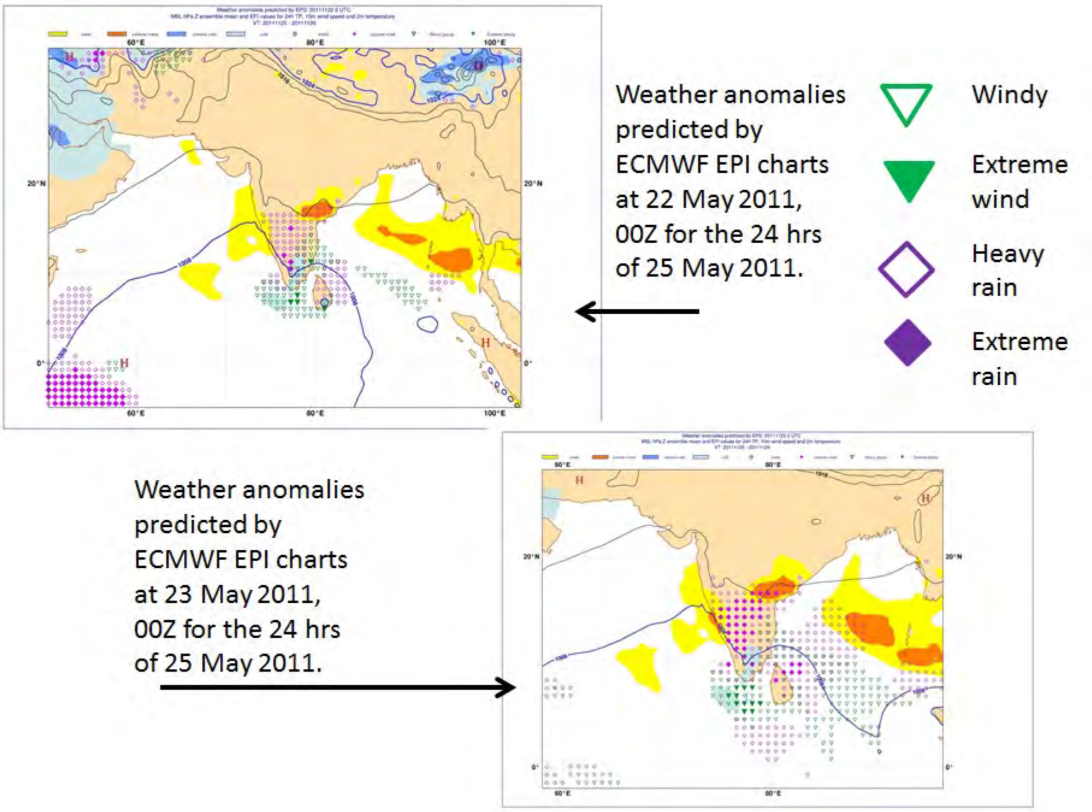


Figure 7.5: ECMWF Extreme Probability Index charts for Sri Lanka region 48 and 24 hours before the 25th of November depression affected the Island.

While the ECMWF products shown in Figure 7.5 were not available in Sri Lanka in November 2011, had they been available, and had the forecasters experience in the usage and a good level of confidence in their usefulness, they may have been emboldened to take a stronger line in their Bad Weather Advisory, perhaps issue the Bad Weather Warning one a day earlier and give stronger advice to Emergency Services and the Hydrology Division of the ID of the level of extreme precipitation being forecast – that is, an event in which the rainfall extreme was in the top 10% of rainfall events for the Island.

The Tropical Depression of May, 2016

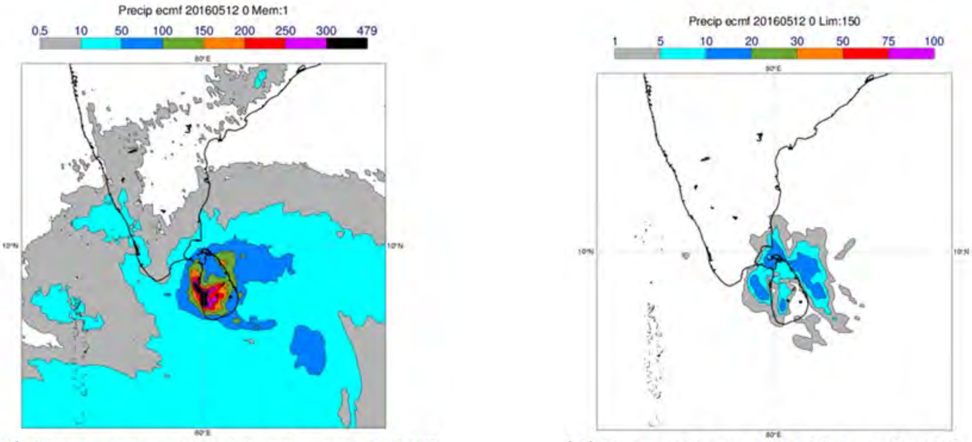
On 15 May 2016 Sri Lanka was hit by a tropical depression moving slowly northwards off the Sri Lanka's East coast (Figure 7.2). At 11 am (local time or 0530UTC) satellite imagery shows a major cloud band located over Sri Lanka (Figure 7.6). The slow movement northwards of the depression exposed much of Sri Lanka to prolonged heavy rainfall.

Station	Significant Daily Rainfall(mm) on 15th
KILINOCHCHI	373.2
Ethavetunu veva	337.4
Pulmudain(yan oya)	317.3
ODDU SUDDAN	295.0
WELLIPUNAM	286.7
Yatiyanthota	281.2
Undugoda	270.3
Elston	261.4
Parangiyavadiya	257.7
Colombo	256.9
Kalatuwawa	243.7
Negombo	237.0
ALAMPIL	230.9
Huruliveva	229.5
Palampoddar	228.2
Labugama	224.6
Moralioya	222.6
vakarai-Kaddumurivu	214.5
Rugam	213.5
Kirindiwela	212.5
Norton	201.5

Figure 7.6: Satellite image at 05.30 Local time (00 UTC) on 15 May, 2016 and the 24 hour rainfall totals recorded on 15 May for 21 stations.

By 16 May the depression had caused widespread flooding and landslides in 22 out 25 districts in the country, destroying homes and submerging entire villages. More than 150 people were killed or missing, the majority due to a landslide in Aranayake, Kegalle District, which devastated three villages. An estimated 500,000 people were affected by this disaster, including at least 21,484 people who were displaced from their homes. As a result of the floods and landslides, 623 houses were completely destroyed and more than 4,400 homes were damaged. Colombo was the worst affected District in the country with over 155,000 people affected by the floods; this was mostly as a result of large numbers of people living on reclaimed, marsh land that is highly susceptible to flooding. According to Government estimates, 25,000 to 30,000 businesses, mostly small enterprises, were impacted by the disaster. The post-disaster needs assessment preliminary findings indicate damage and losses exceed US$572 million.

On May 12 the DoM warned that heavy rains around 150 mm were expected in some places, especially in the Southern and Eastern parts of the country as the disturbance that persisted to the South-east of Sri Lanka was likely to develop into a depression and move closer to the country Figure 7.7(C). The ECMWF provides a number of ways to view a developing weather event, the most usual way is to look at the forecast from the highest resolution “deterministic” model. Figure 7.7(A) is the deterministic 24hour rainfall prediction issued by the ECMWF at 00UTC (05.30 local time in Sri Lanka) on 12 May 2016. This prediction is for rainfall totals of between 300mm and 479mm in areas along the west coast and in the highlands around Kandy with areas of lesser rainfall amounts around 150 mm to 250mm. In order to determine the likelihood (or probability) of this outcome the ECMWF runs an ensemble of forecasts at the time each deterministic model run is carried out. One 'ensemble forecast' consists of 51 separate forecasts made by the same computer model, all activated from the same starting time. The starting conditions for each member of the ensemble are slightly different, and physical parameter values used also differ slightly. The differences between these ensemble members tend to grow as the forecasts progress, that is, as the forecast lead time increases. The spread of the solutions between members of the ensemble allow for the computation of the probability of the forecast being realized at each geographic location (Figure 7.7(B)).



(A) 24-hour precipitation from ECMWF deterministic model for 15 May 2016, from model run 00Z - 12 May

(B) Ensemble probabilities of >150 mm/24h 15 May 00z – 12 May 00z

(C) **<u>SEVERE WEATHER ADVISORY FOR HEAVY RAINFALLS OVER THE COUNTRY AND SRROUNDING SEA AREAS.</u>**
<u>VALID FOR NEXT 24 HOURS, ISSUED AT 0900HRS, 12th May 2016.</u>
(Issued by Early Warning Centre of the Department of Meteorology)

Due to an atmospheric disturbance in the vicinity of Sri Lanka, cloudy skies and showery weather is enhanced over the country and surrounding sea areas.

Showers or thundershowers will occur at most places in the Eastern, Uva, Northern, North Central and Southern provinces.

Thundershowers will occur at most places elsewhere during the afternoon and night.

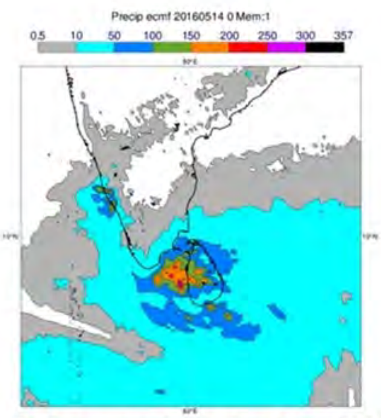
Very heavy falls (around 150 mm) are also likely at some places.

There may be temporary localized strong winds during thundershowers. General public is kindly requested to take adequate precautions to minimize damages caused by lightning activity.

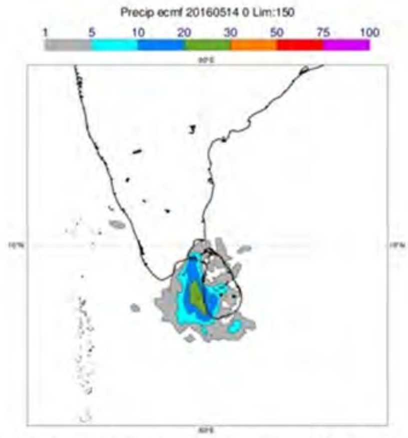
Figure 7.7: (A) and (B) Some output from the ECMWF deterministic and ensemble numerical weather forecast systems respectively for the Sri Lanka region issued at 00UTC (05.30 local time) on 12 May valid for the 24 hours commencing at 00.00 on the 25 May 2016. (C) The Severe Weather Advisory issued by the Department of Meteorology on 12 May 2016.

While the probability of occurrence of the extreme rainfalls seen in the deterministic run are only between 5% and 20% (Figure 7.7(B)), given their extreme nature they would have warranted a high level of warning had the forecasters been able to access to them. Furthermore, they would have provided quantitative rainfall data on a 9km grid scale for the island of Sri Lanka for input to early runs of the Hydrology Division flood forecasting models.

On 14 May, at 00UTC (05.30 local time) the ECMWF continued to show extreme rainfall in the vicinity of Sri Lanka, still with the highest totals off shore, and still with 24-hour rainfall totals expected on the 25th to be of the order of 150mm to 200mm in some districts with small areas of higher totals (Figure 7.8(A)). The probability for such totals had increased to be in the range 10% to 30% (Figure 7.8(B)).



(A) 24-hour precipitation from ECMWF deterministic model for 15 May 2016, from model run 00Z - 14 May



(B) Ensemble probabilities of >150 mm/24h 15 May 00z – 14 May 00z

(C) **<u>SEVERE WEATHER ADVISORY FOR STRONG WINDS AND HEAVY SHOWERS VALID FOR NEXT 12 HOURS COMMENCING FROM 11.30 HRS, 14th May 2016).</u>**

(Issued by Early Warning Centre of the Department of Meteorology issued at 1100 hrs)

The disturbance that persists to the South east of Sri Lanka is likely to intensify further and gradually develop in to a depression and likely to move closer to Sri Lanka affecting the weather over the country and surrounding sea areas.

Due to the active cloudiness associated with the above system, the possibility of sudden roughness of the sea areas associated with sudden increase of wind speed (up to 70-80 kmph) can be expected over the surrounding sea areas of the island.

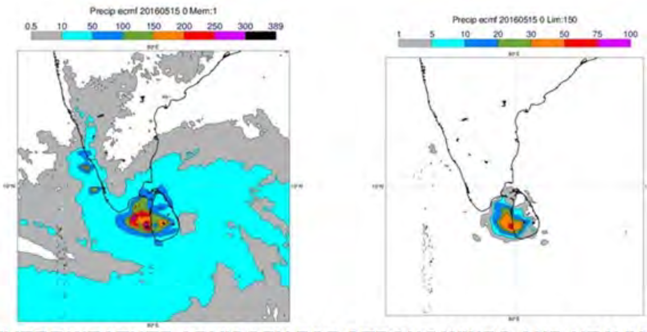
Very heavy rain falls are also likely at some places over the country and surrounding sea areas, particularly in the Southern and Eastern parts of the country.

Figure 7.8: (A) and (B) Some output from the ECMWF deterministic and ensemble numerical weather forecast systems respectively for the Sri Lanka region issued at 00UTC (05.30 local time) on 14 May valid for the 24 hours commencing at 00.00 on the 15 May 2016. (C) The Severe Weather Advisory issued by the Department of Meteorology on 14 May 2016.

Figures 7.9(A) and (B) are the confirming analyses from the ECMWF system that the developing severe weather system did impact Sri Lanka. While there is no independent way of knowing the rainfalls over the ocean to the west of Sri Lanka, the analysis in Figure 7.8(A) of a broad area of rainfalls with totals in the region of 150mm to 250mm, and small areas of even higher totals, looks very realistic when compared to the station rainfalls listed on Figure 7.5.

Although the DoM issued a severe weather advisory, the lack of quantitative precipitation estimates (QPE) and limited skill in estimating rapid onset flooding, resulted in flood warnings being issued after the event had started to have a serious impact. This increased the need for rescue and left people ill-prepared for subsequent landslides, which caused most of the deaths. Overall the severity of the storm was underestimated with the DMC warning of torrential rains creating a minor flood situation in the country (Daily Mirror, 16 May 2016).

(A) 24-hour precipitation from ECMWF deterministic model for 15 May 2016, from model run 00Z - 15 May



(B) Ensemble probabilities of >150 mm/24h 15 May 00z – 15 May 00z

(C) **SEVERE WEATHER ADVISORY FOR STRONG WINDS AND HEAVY SHOWERS VALID FOR NEXT 24 HOURS COMMENCING FROM 1100 HRS, 15th May 2016)**

(Early Warning Centre of the Department of Meteorology issued at 1100 hrs on 15th May 2016) 2016)

The disturbance in the Bay of Bengal to the South east of Sri Lanka has developed in to a low pressure area and now located over Batticaloa coast. It is likely to intensify further in to a depression and likely to continue affecting the weather over the country and surrounding sea areas. However it is expected to move away from Sri Lanka by Tomorrow towards India.

Showery and windy weather is expected to continue today and tomorrow over most parts of the island particularly Eastern, Northern and Southwestern parts of the country. Very heavy rain falls (more than 150mm) are also likely at some places.

Due to the active cloudiness associated with the above system, the possibility of sudden roughness of the sea areas associated with sudden increase of wind speed (up to 70-80 kmph) can be expected over the surrounding sea areas of the island. Intermittent showers/thundershowers will occur over surrounding sea areas of the country.

Naval and fishing communities are requested to be vigilant in this regard.

Figure 7.9: (A) and (B) Some output from the ECMWF deterministic and ensemble numerical weather forecast systems respectively for the Sri Lanka region issued at 00UTC (05.30 local time) on 15 May valid for the 24 hours commencing at 00.00 on the 15 May 2016. (C) The Severe Weather Advisory issued by the Department of Meteorology on 15 May 2016.

Lessons Learnt from the Recent Severe Weather Events

Most flooding in Sri Lanka occurs when heavy rain falls in the upper catchments of the river basins. This allows the Hydrology Division a long lead-time in estimating the likelihood of flooding downstream. Heavy rain was widespread on 16 May 2016 both in the upper catchment of the rivers and downstream resulting in conditions more closely resembling a rapid onset flood.

River floods forecasts and warnings are the responsibility of the ID because they are most commonly associated with stream flow. Flash floods and landslides are more closely coupled with the actual rainfall. One critical aspect of the May 2016 event was its timing. May 15 was a Sunday and the bulk of the heavy rains fell in the afternoon and evening hours. While the DoM operates seven days a week, 24 hours per day, flood forecasting is the responsibility of the Hydrology Division of the ID. This Division is staffed five days per week during business hours, though staff do work out-of-hours when emergencies require their services. For the Hydrology Division to have given early warning of the floods that were to come, it would need to have notified Emergency Services on Friday 13 May or at the latest Saturday 14 May. However, Hydrology Division would have required accurate, high-resolution gridded rainfall forecasts on Friday or Saturday which could then be used in flood forecast models to calculate estimates of the extent and severity of flooding. These estimates could, in turn, be used by the DMC along with their knowledge of community vulnerability to put in place response measures and by the NBRO and DoM to assess the likelihood of landslips and flash flooding.

The DoM does not yet have access to the digital output from the ECMWF modelling system which is prepared, twice daily, giving a wealth of information including quantitative precipitation estimates on a 9km grid across Sri Lanka with lead times up to one week. However, these data alone would not be sufficient, there would need to be in place support from trained, experienced meteorologists who could assess, and advise on the significance of the forecast information, most particularly on the meaningfulness of the low probability – high impact forecasts such as that which was available leading up to 15 May 2016. With such conditions in place Hydrology Division would need to be capable of running, in real time, operational flood forecasting models for Sri Lanka's major catchments using these forecast quantitative precipitation estimates. Finally, the output from the flood forecasting models, along with the precipitation estimates would need to be accessible to the Disaster Management Centre along with hydrological and meteorological support in their interpretation. The DMC, the DoM, NBRO and the Hydrology Division need to work to put these various elements in place so as to reduce to zero the avoidable losses in events like the November 2011 and May 2016 floods (Figure 7.10).

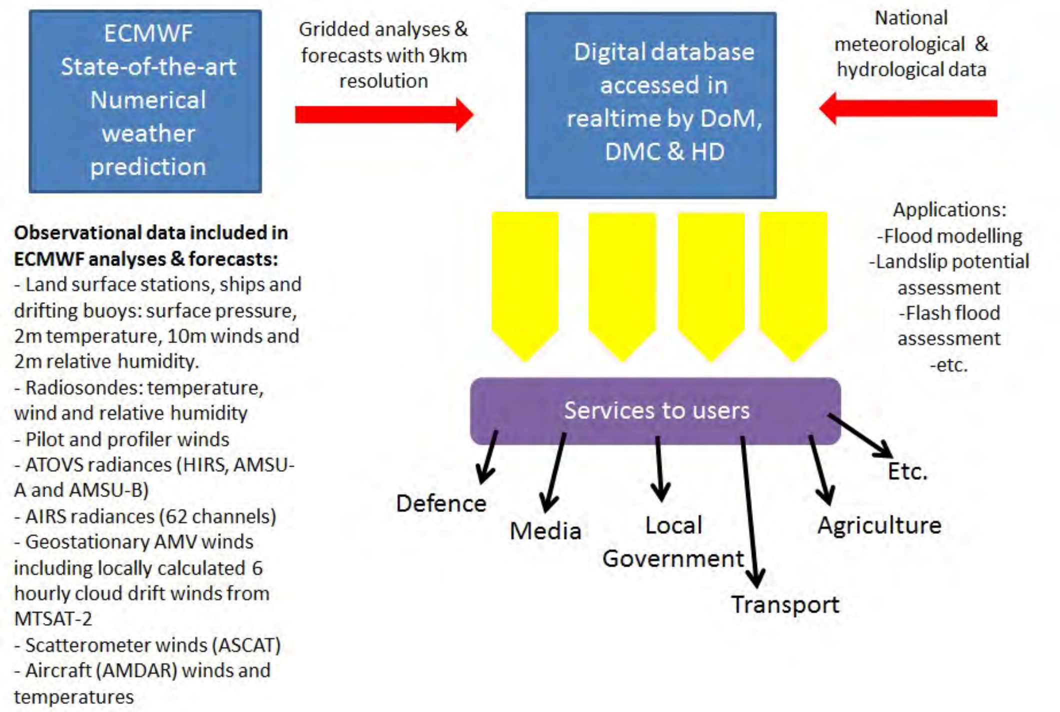


Figure 7.10: A schematic of the forecast and warning process for Sri Lanka.

In summary then, the forecasting and warning system is only as strong as its weakest link, for it to become more the effective the DoM, the ID, NBRO and the DMC, must work in close cooperation. Roles and responsibilities of each agency must be sufficiently well defined to avoid miss-understandings during severe weather related events. It was found that miss-communications had occurred in recent events, such as, for example different forecasts from different sources. Perhaps more importantly each agency needs to have regular discussions with concerning their requirements for support from its partners and adjusting their expectations having due regard to each agencies resources and the state of the science and technologies at their disposal.

Recommendation 9.1

A systematic and sustainable improvement in forecasting and warning services is required within both the DoM and the Hydrology Division that makes full use of the products and services that are available from the World Meteorological Organization's (WMO) centres and more advanced NMHSs, as a first step to upgrading the national observing and forecasting infrastructure. The Global Flood Alert System (GFAS) and the Global Flash Flood Guidance System (GFFGS) are two examples of systems that exist to support NMHSs' forecasters.

Recommendation 9.2

In order to re-establish trust in warning services and to ensure appropriate public response to warnings, the DoM and Hydrology Division, in consultation with the DMC, should implement ways to acceleration the adoption of currently available international products to quickly improve their basic services. This could be achieved through partnerships with other public institutions or with private sector meteorological service providers.

Recommendation 9.7

Partnerships should be developed with other public institutions or with private sector meteorological service providers where they provide opportunities to improve warning services.

8. Impact-Based Forecast and Warning Services

A weakness in weather and hydrological warnings is the focus on the phenomena rather than the impact of the phenomena, which result in disseminating information that is difficult to understand and interpret for the non-specialist. Moving beyond traditional meteorological and hydrological forecasts and warnings is the purpose of Impact-based forecast and warning services. For example, impact-forecasts emphasize what the weather will *do* rather than what the weather will *be*. For floods, the emphasis shifts from warnings of water level thresholds to the expected impact on those at risk. Moving beyond weather and hydrological forecasting requires effective partnerships with many different government agencies, as well as volunteer organizations and non-governmental organizations. In the case of Sri Lanka, this framework has already been established; therefore, it is a relatively small step to develop an impact-based forecast and warning system within the DMC. Data sharing arrangements are already in place and the DMC is mandated to disseminate hydrological and meteorological warnings.

Impact-based forecasting and warning services focus on translating weather and hydrological hazards into sector- and location- specific impacts, and the development of sectorial responses to mitigate those impacts. Landslide warnings are in practise already impact-based warnings, since the warning depends on rainfall, slope, soil saturation, among other factors, including the exposure of communities. By focusing on impacts, it is expected that those exposed to a particular hazard will have a better understanding of the risk and will more likely take appropriate action.

Successful implementation depends on close working relations among all stakeholders and close cooperation between DMC, NBRO, ID and DoM for access to up to date, real-time information. Success is predicated on the DoM having access to the best available weather prediction guidance from numerical models to generate timely, accurate and specific meteorological forecasts and for ID to generate timely, accurate and specific hydrological forecasts. This is often the most challenging, but increasingly possible as higher resolution numerical weather predictions become available from the WMO global production centres and the WMO Regional Specialized Meteorological Centres (RSMCs), which are tasked to support NMHSs. This can be taken a step further nationally if the country has the capacity and capability to run very high resolution models (better than 2km resolution), which incorporate assimilation of local data from radar and other observing systems. If this is not possible reliance on the global and regional centres may be a sufficient first meaningful step.

While not essential for the successful implementation of impact-based forecast and warning services, it is highly desirable to develop a map-based warning system, which divides the country into a convenient grid and uses colours to represent warning levels within each of the grid boxes. This approach was initially developed by MétéoFrance and has been adopted Europe-wide through the MeteoAlarm portal. Other countries are following this example, which enables stakeholders to visualize at-a-glance the geographical extent and type of warning. Updated frequently, warnings evolve during the course of the event and in response to actions taken to mitigate risks. This tool can be used to display meteorological warnings and sector-specific impact-warnings. It also highlights the importance of common colour-coding for specific levels of risk regardless of the hazard, impact or sector. This way a better “feeling” for risk is established across all sectors. RiskInfo is a suitable platform to create such a warning system.

By focusing on forecasts, the lead time for warnings can be substantially increased. This would permit DMC to develop new protocols for hazard response with the expectation that disasters could be significantly mitigated or avoided all together. In the case of landslides, early evacuation would be possible reducing risk of loss of life.

Recommendation 9.5

Impact-based forecast and warning services should be implemented by the DMC in collaboration with DoM, ID and NBRO. Initially this should be piloted in regions where there is sufficient vulnerability and exposure data. . A program to be implemented by the DMC to collect and collate exposure and vulnerability data, prioritizing high hazard areas.

9. Proposed Project – Impact-based Multi-Hazard Early Warning Services

The team's analysis and recommendations highlight the need to improve basic meteorological and hydrological forecasting services of the DoM and Hydrology Division of the ID. In particular, the absence of quantitative, gridded rainfall information limits the ability of the DMC and NBRO to provide consistent early warnings of the impact of rapid onset floods and landslides, respectively.

The recommendations highlight the need for an overhaul of the DoM with an extensive modernization program aimed at improving the overall capacity of the service. A more narrowly focused effort on improvements in flood modelling and forecasting is proposed for the ID. Delivery of improved services also requires new capabilities with the DMC and NBRO, which improve their capacity to utilize weather, water and climate information to provide actionable forecasts and warnings of the impact of hazards. This requires new skills and better coordination among the agencies involved.

Project Description

The objective of this project is to improve the quality of weather, climate and hydrological information and services in Sri Lanka. The project will increase the capacity of the DoM and ID to provide information and services for disaster risk management, water resources management, agriculture, transport, and other sectors. The proposed project will be a component of the CRIP II and should build on the experience of CRIP I utilizing the existing project management.

The role of the DoM includes observing and understanding weather and climate phenomena and providing meteorological services in support of national needs, including disaster management, water resources management, transportation safety, food security, sustainable development and promoting capacity building. Its primary clients for severe weather information are the Disaster Management Centre, National Building Research Organization and the Hydrology Division of the ID. The role of the latter is to provide flood forecasts and warnings and support water resource management and dam safety, among other responsibilities. The DMC supports emergency operations and communicates warning information through various channels to ensure an effective response to minimize loss of life and property. The NBRO also has a critical role in the prevention of losses due to landslides, which are one of the main causes of loss of life due to rainfall related hazards.

The DoM faces the most difficult challenge to modernize its capabilities because of its very low level of base support for operations and maintenance, and a workforce that needs to rapidly develop new skills to use modern observing, forecasting and service methods. The other agencies are to varying degrees constrained, although ID faces challenges in recruitment and retention of skilled engineers.

The DoM and ID participate in a number of internationally funded programs and activities, most of which are related to developing weather, climate and flood early warning systems. There are opportunities to build on these activities to enhance national capacity. There are several donor-supported projects, which will be complemented by this project. At the same time, there is a need to rationalize the observational networks operated by the different agencies to ensure their compatibility and utility. JICA is in the process of developing a Doppler radar network for DoM, which comprises two radars and a network of automated weather stations. This will substantially improve real-time rainfall estimates. DoM will need to integrate these and other observational networks into a numerical forecasting system.

One approach is to use a systems integrator to design and build the modernized systems, and if necessary to support the operation of the system until such time as the agencies have increased their skills.

Recommendation 4.1

A project to increase the capacity and capabilities of the DoM and HD should involve a system integrator (SI) firm, which would design and build the integrated systems on behalf of the clients. If a turn-key approach is used, the SI would be responsible for the selection and integration of all equipment and systems, and may play an initial role in supporting operations and services.

Recommendation 4.2

Any development activities should be linked to the existing project management unit and other related on-going projects.

The Component will improve the quality of the services provided by DoM, ID, DMC and NBRO by providing to varying degrees (a) stronger institutional frameworks, (b) modern observing and forecasting infrastructure, and (c) enhanced service delivery.

A preliminary budget estimate is in **Annex 7**.

Sub-Component A – Institutional Strengthening, Capacity Building and Implementation Support

This subcomponent aims to create a national strategy for weather, climate and hydrological services, which engages all users; address workforce issues; modernize accounting methods at DoM, introduce a quality management system; improve the operational working relations among the among the key agencies responsible for hazard and impact warnings; strengthen working relations with other more advanced meteorological and hydrological services; develop an extensive training program for both providers and users of services; and support the system design, integration and project management.

A.1 Institutional strengthening, which includes: 1.1) developing and updating the national strategy for weather, climate and hydrological services including remaining current with new solutions for the production and delivery of services, taking account of the changing capacity of partner agencies, and the evolving needs of the public and private sector consumers; 1.2) workforce planning, including assessing the current staffing levels and evolving requirements of the DoM and ID in the future to accommodate the increasing use of technology to produce and deliver services to enable the organizations to evolve from largely data gathering services to information providing services. For DMC and NBRO, this would focus on building skills to make full use of the new levels of services provided by DoM and ID; 1.3) Develop an asset register and introduce modern accounting methods with the aim of justifying and quantifying the level of support needed for the operations and maintenance of the DoM as it acquires new technologies; 1.4) Introduce a quality management system (QMS) in DoM. Initially, this will be required by ICAO for the provision of aeronautical meteorological services, but may be extended to all aspects of the DoM since it will show that the organization is operating to an identified standard giving consumers more confidence in the value-for-money services it provides; 1.5) Working together focuses on improving the operational relations among the various agencies through video conferencing, meetings, workshops and establishing a common platform among the agencies for the delivery of warning services; Working with others focuses on establishing long-term operational relations with more advanced National Meteorological and Hydrological Services and related WMO specialized centres. Twinning arrangements would enable forecasters, for example, to reach out to other centres for guidance ahead of potentially life-threatening hazards according to agreed standard operating procedures.

A.2 Training and capacity building, which includes: 2.1) professional training and retraining of staff including long-term university level courses to ensure that DoM, ID, DMC and NBRO have the skills to exploit the latest tools for weather, hydrology and impact-based forecasts and warnings; and 2.2) working with customers/users, including understanding the evolving needs of users, helping users understanding the limitations of current services, and identifying potential new or improved services.

A.3 Systems design and integration, component management and monitoring, which includes: 3.1) detailed design of DoM systems, hydrological modelling and integration with the operational platforms of the DMC and NBRO, procurement, support for implementation and operational support to DoM. This component may be tendered as a turn-key[6] solution given the limited capacity of the DoM to absorb the subcomponents of the system quickly; and 3.2) project management, monitoring, reporting and evaluation of subcomponents A, B and C. This task will be carried by the CRIP PMU.

Sub-Component B – Modernize the Observing, Forecasting and Communication Systems Infrastructure

This sub-component focuses on improving the DoM meteorological and ID hydrological analysis and objective forecasting systems. It aims to upgrade the objective forecasting platform with access to the best available numerical weather prediction (NWP) products and hydrological models, and the means to visualize and overlay all relevant data and information expected within modern meteorological and hydrological forecasting offices. The sub-component will rationalize the observing networks, and upgrade the data communication and IT systems. Local NWP will focus on the gap between real-time observations and the forecasts available from global and regional centres. This will increase the utility of the radar and real-time surface data by assimilating them into a nowcasting and very short-range forecasting system. It will allow for future development of local NWP and hydrological modelling as human capacity is increased. The Sub-Component has four parts:

B.1 Modernize Observing System Infrastructure, which includes 1.1) developing the optimum composite observation network for the country with the participation of all organizations wishing to share and exchange data to mitigate the risks of extreme meteorological and hydrological events. The composite observation network plan will be an integral component of the national strategy (A.1.1); 1.2) Data recovery or rescue, including the digitization of paper-based archives held by the DOM and ID. Priority will be given to the DoM's chart records from pluviographs. The data base will also include current digital data from automated stations; 1.3) Rehabilitation of the existing observing network is necessary, including upgrading of communications systems with existing automated weather stations operated by DoM; and 1.4) Upgrading of the observing system at Colombo International Airport to international standards. This work may be carried out by other development partners, so close cooperation is needed.

B.2 Modernize the Data Communication and IT Systems, which includes: 2.1) data management systems for weather and climate data, including computer servers, software, web access, and social media; and 2.2) communication systems for forecast and warning dissemination including visualization tools, broadband communication, intranet, smartphone applications, and common, shared systems among DoM, ID, NBRO and DMC.

B.3 Improve numerical weather prediction system and hydrological forecasting system, which includes: 3.1) access to ECMWF products, including ensemble products and digital data, the amount of data that can be used in the operational system will depend on internet bandwidth and will

[6] We define turn-key as a project that consists of a single tender, which include a set of subprojects under the coordination of the main contractor

improved by B.2.2. Training (A.2.1) will focus on building forecaster skills to maximize use of ECMWF products; B.3.2 forecast verification will focus on quantifying forecast uncertainty and using this information to improve the reliability of decision tools; B.3.3 Improved distributed hydrological modelling will be implemented by the Hydrology Division (in cooperation with CRIP-1 advances) to enable better forecasts of floods in Sri Lanka, incorporating the use of forecast/predicted rainfall estimates to be provided by the DoM. This capability should be extended beyond the 10 basins covered by CRIP-1 on a priority basis; and 3.4) High performance computing (HPC) including servers data access, suitable for data assimilation, nowcasting, short-range numerical weather prediction and hydrological modelling. This system will be a shared facility to support production of objective forecasts and impact-based forecasts.

B.4 Construct and Furbish Offices and Facilities, which includes: 4.1) construction of a new DoM building for forecast operations. This may also include facilities joint forecast operations to support DoM, NBRO, and ID.

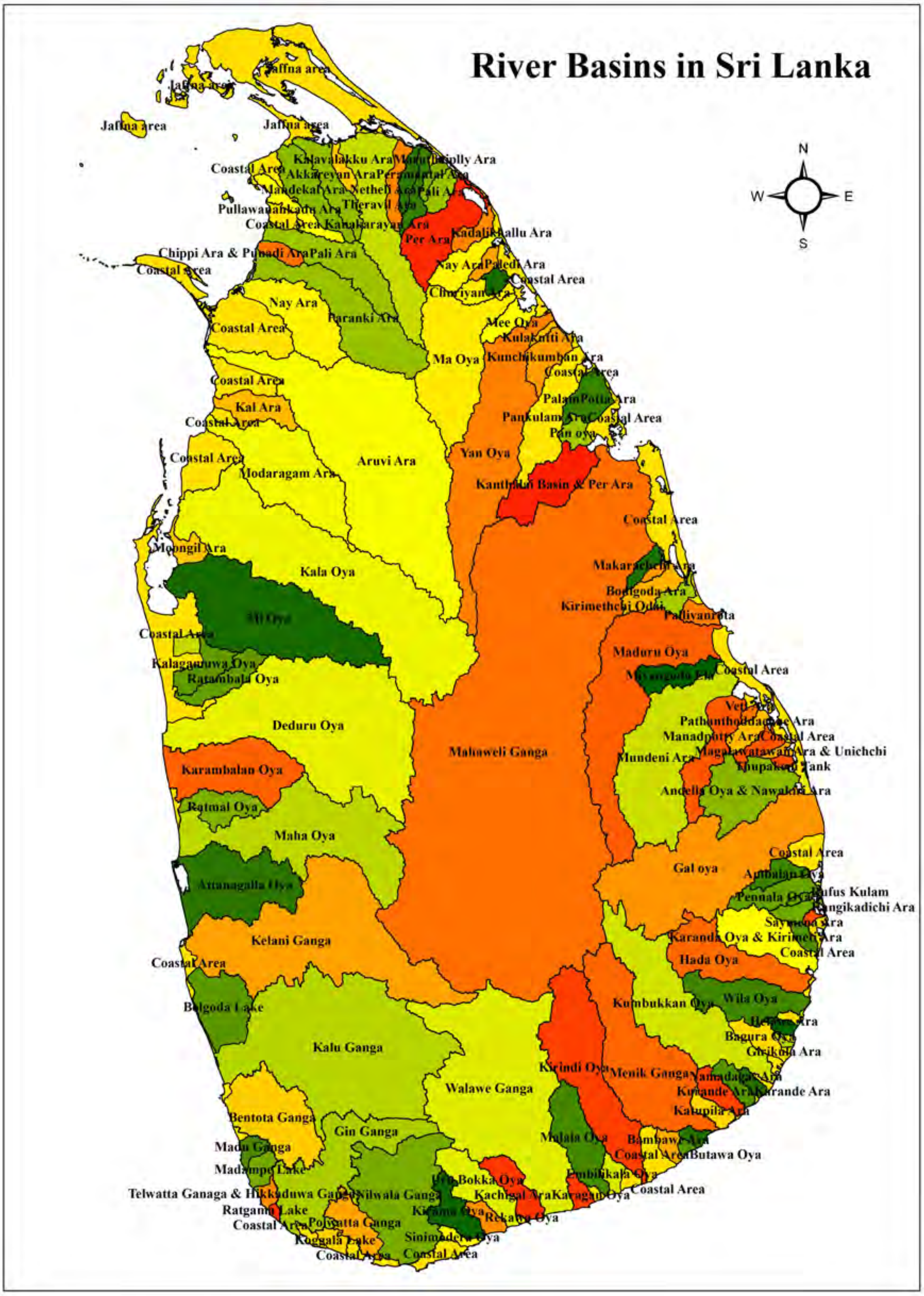
Sub-Component C – Enhance Service Delivery Systems

C.1 Climate Services, which includes: 1.1) The development of a digital library of climate-relevant information for Sri Lanka. The climate data base would include the data rescued (B.1.2) as well as data from non-meteorological and hydrological sources. The database would be hosted by B.2.1; National Framework for Climate Service, including support for sectoral working groups and sharing of all climate data (C1.1) among stakeholders and the development of tools to use these climate data; and 1.3) the development of an agriculture climate advisory service (ACAS) to provide critical, timely and reliable agro-climate and weather information to the agricultural sector, including the development of an ACAS portal (software and hardware developed in B.2.1. This would be developed in close cooperation with Department of Agriculture. Training would be included in A.2.1.

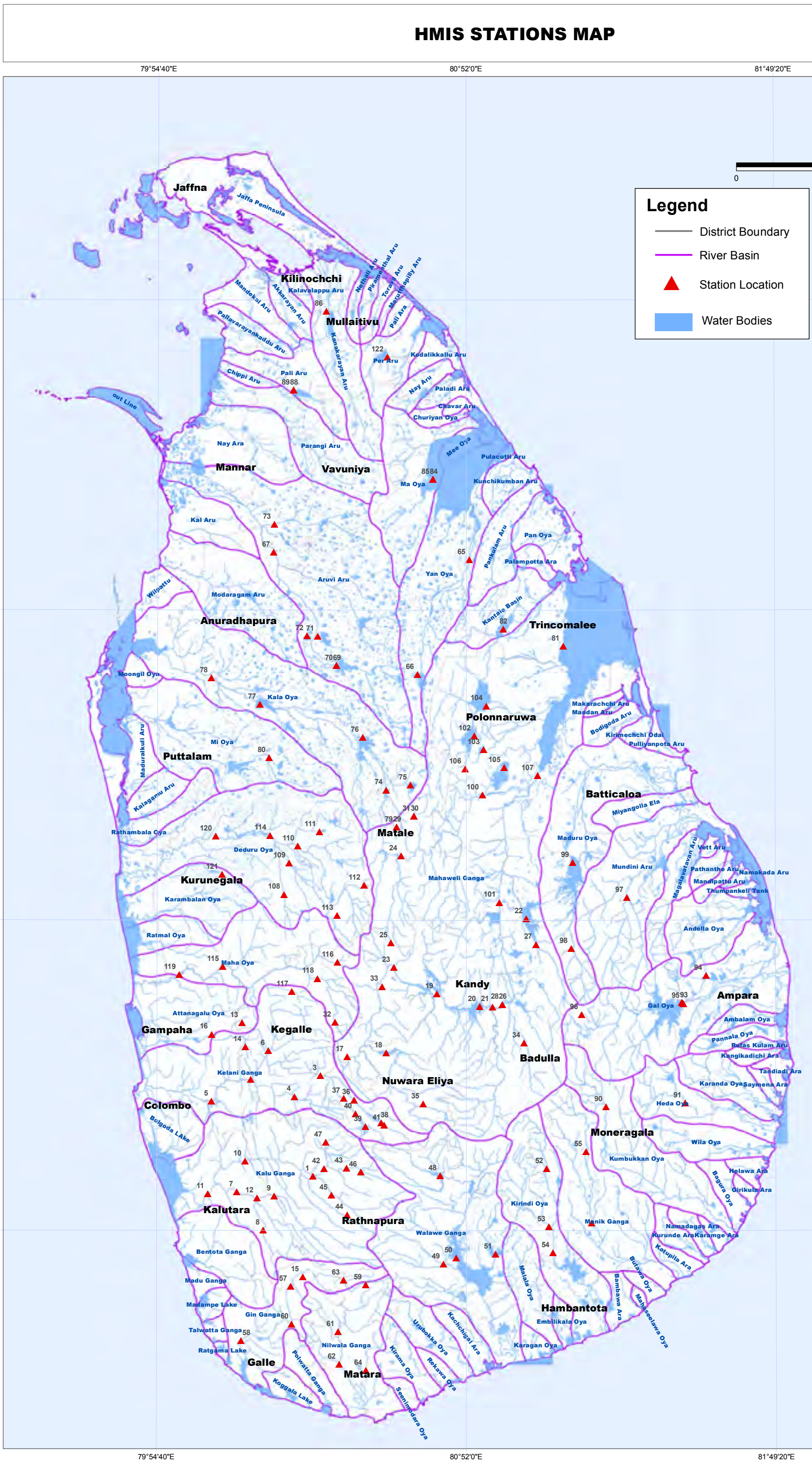
C.2 Support DMC operations, which includes: 2.1) developing and implementing a joint forecast and warning service desk collocated with DMC as a part of the EOC. This would mirror facilities in DoM, ID and NBRO; 2.2) Develop and pilot expanded end-to-end early warning systems based on impact-based forecast and warning in a limited number of high risk areas (initially). This includes DMC developing SOPs, warning protocols and signals based on combining hazard forecasts, vulnerability data and exposure data. This will be possible when gridded rainfall data are available (B.3.1).

C.3 Enhance weather services to sectors (health, agriculture, tourism, transport, etc., which includes: 3.1) developing specialized services to sectors including mobile phone applications and web-based services; and 3.2) developing and operationalizing assessments of forecast utility through public and sector specific surveys.

10. Annex 1 River Basins of Sri Lanka



11. Annex 2 Hydrological Management Information System (HMIS) Stations



No	Staton	River Basin
1	RATHNAPURA	KALU GANGA
2	AVISSAWELLA(GLENCOURSE)	KELANI GANGA
3	KITULGALA	KELANI GANGA
4	DERANIYAGALA	KELANI GANGA
5	HANWELLA	KELANI GANGA
6	RUWANWELLA	KELANI GANGA
7	MILLAKANDA	KALU GANGA
8	MAGURA	KALU GANGA
9	KUKULE DIVERSION	KALU GANGA
10	HALWATURA	KALU GANGA
11	ANGURUWATHOTA	KALU GANGA
12	PARAGODA BRIDGE	KALU GANGA
13	ALGAMA	ATTANAGALU OYA
14	CHESTERFORD	ATTANAGALU OYA
15	AVITHTHAWA	BENTARA GANGA
16	DUNAMALE	ATTANAGALU OYA
17	NAWALAPITIYA	MAHAWELI GANGA
18	KOTMALE RESERVOIR	MAHAWELI GANGA
19	VICTORIA RESERVOIR	MAHAWELI GANGA
20	RANDENIGALA RESERVOIR	MAHAWELI GANGA
21	RANTEMBE RESERVOIR	MAHAWELI GANGA
22	ULHITIYA RESERVOIR	MAHAWELI GANGA
23	POLGOLLA DIVERSION	MAHAWELI GANGA
24	BOWATHENNE RESERVOIR	MAHAWELI GANGA
25	UKUWELA	MAHAWELI GANGA
26	MINIPE RB T'BASIN CANAL	MAHAWELI GANGA
27	ULHITIYA INLET CANAL	MAHAWELI GANGA
28	MINIPE LB CANAL	MAHAWELI GANGA
29	LENADORA	KALA OYA
30	KALUNDEWA (HURULU)	KALA OYA
31	KALUNDEWA	KALA OYA
32	ARANAYAKE	MAHA OYA
33	PERADENIYA	MAHAWELI GANGA
34	THALDENA	MAHAWELI GANGA
35	CALSEY-MAHAELIYA R/F	MAHAWELI GANGA
36	NORTON BRIDGE RESERVOIR	KELANI GANGA
37	LAXAPANA RESERVOIR	KELANI GANGA
38	CASTLEREIGH RESERVOIR	KELANI GANGA
39	MAUSAKELLE RESERVOIR	KELANI GANGA
40	CANYON RESERVOIR	KELANI GANGA
41	NORWOOD	KELANI GANGA
42	MALWELA	KALU GANGA
43	BANAGODA	KALU GANGA
44	WATAPOTHA	KALU GANGA
45	DELA	KALU GANGA
46	BATEWELA	KALU GANGA
47	ASHOKA ESTATE(R/F)	KALU GANGA
48	SAMANALA WEWA	WALAWE GANGA
49	TIMBOLKETIYA	WALAWE GANGA
50	UDA WALAWE RESERVOIR	WALAWE GANGA
51	MAW ARA TANK	WALAWE GANGA
52	WELLAWAYA	KIRINDI OYA
53	KUDA OYA	KIRINDI OYA
54	TANAMALWILA	KIRINDI OYA
55	BUTTALA BRIDGE	MENIK GANGA
56	WEHERAGALA RESERVOIR	MENIK GANGA
57	TAWALAMA	GIN GANGA
58	BADDEGAMA	GIN GANGA
59	DENIYAYA BRIDGE	GIN GANGA
60	UDUGAMA	GIN GANGA
61	PITABEDHARA	NILWALA GANGA
62	AKURESSA BRIDGE	NILWALA GANGA
63	LANKAGAMA	GIN GANGA
64	SAPUGODA	NILWALA GANGA
65	HOROWAPATANA	YAN OYA
66	HURULUWEWA RESEVOIR	YAN OYA
67	KAPPACHCHI	MALWATHU OYA
68	NACHCHADUWA RESERVOIR	MALWATHU OYA
69	NACHCHADUWA (LB CANAL)	MALWATHU OYA
70	NACHCHADUWA (RB CANAL)	MALWATHU OYA
71	NUWARAWEWA RESERVOIR	MALWATHU OYA
72	TISSAWEWA RESERVOIR	MALWATHU OYA
73	MENIK FARM	MALWATHU OYA
74	DAMBULUOYA RESEVOIR	KALA OYA
75	KANDALAMA RESERVOIR	KALA OYA
76	KALAWEWA RESERVOIR	KALA OYA
77	RAJANGANA RESERVOIR	KALA OYA
78	NEELA BEMMA	KALA OYA
79	DAMBULU OYA RIVER	KALA OYA
80	GALGAMUWA	MI OYA
81	ALLAI KANTALE	MAHAWELI GANGA
82	KANTALE RESERVOIR	KANTALE ARU
83	PADAWIYA TANK	MA OYA
84	PADAWIYA (LB CANAL)	MA OYA
85	PADAWIYA (RB CANAL)	MA OYA
86	IRANAMADU TANK	KANAKARAYAN AR.
87	VAVUNIKULAM TANK	PALI ARU
88	VAVUNIKULAM (RB)	PALI ARU
89	VAVUNIKULAM (LB)	PALI ARU
90	NAKKALA	KUMBUKKAN OYA
91	SIYAMBALANDUWA	HEDA OYA
92	Senanayaka Samudraya Res (Gal Oya)	GAL OYA
93	GAL OYA (LB1)	GAL OYA
94	GAL OYA (LB2)	GAL OYA
95	GAL OYA (RB)	GAL OYA
96	BIBILE	GAL OYA
97	MAHA OYA	MUNDENI ARU
98	PADIYATALAWA	MADURU OYA
99	MADURU OYA RESERVOIR	MADURU OYA
100	ANGAMEDILLA	MAHAWELI GANGA
101	HEMBARAWA	MAHAWELI GANGA
102	MINNERIYA RESERVOIR	MAHAWELI GANGA
103	GIRITALE RESERVOIR	MAHAWELI GANGA
104	KAUDULLA RESERVOIR	MAHAWELI GANGA
105	PARAKRAMA SAMUDRA RES.	MAHAWELI GANGA
106	DIYABEDUMA(EMYE)	MAHAWELI GANGA
107	MANAMPITIYA	MAHAWELI GANGA
108	MASPOTHA BRIDGE	DEDURU OYA
109	AMUNUGAMA BRIDGE	DEDURU OYA
110	ETILIYAWELA	DEDURU OYA
111	MA ELIYA	DEDURU OYA
112	DINIMINIYATENNA	DEDURU OYA
113	DAISY VALLEY GROUP	DEDURU OYA
114	RIDI BENDI ELA	DEDURU OYA
115	GIRIULLA	MAHA OYA
116	MOLAGODA	MAHA OYA
117	HATARLIYADDE	MAHA OYA
118	BOLAGAMA BRIDGE	MAHA OYA
119	BADALGAMA	MAHA OYA
120	MORAGASWEWA	DEDURU OYA
121	Nugawela	
122	Mulhaniykaddu Kalam (MTK)	

12. Annex 3 Hydrological Stations

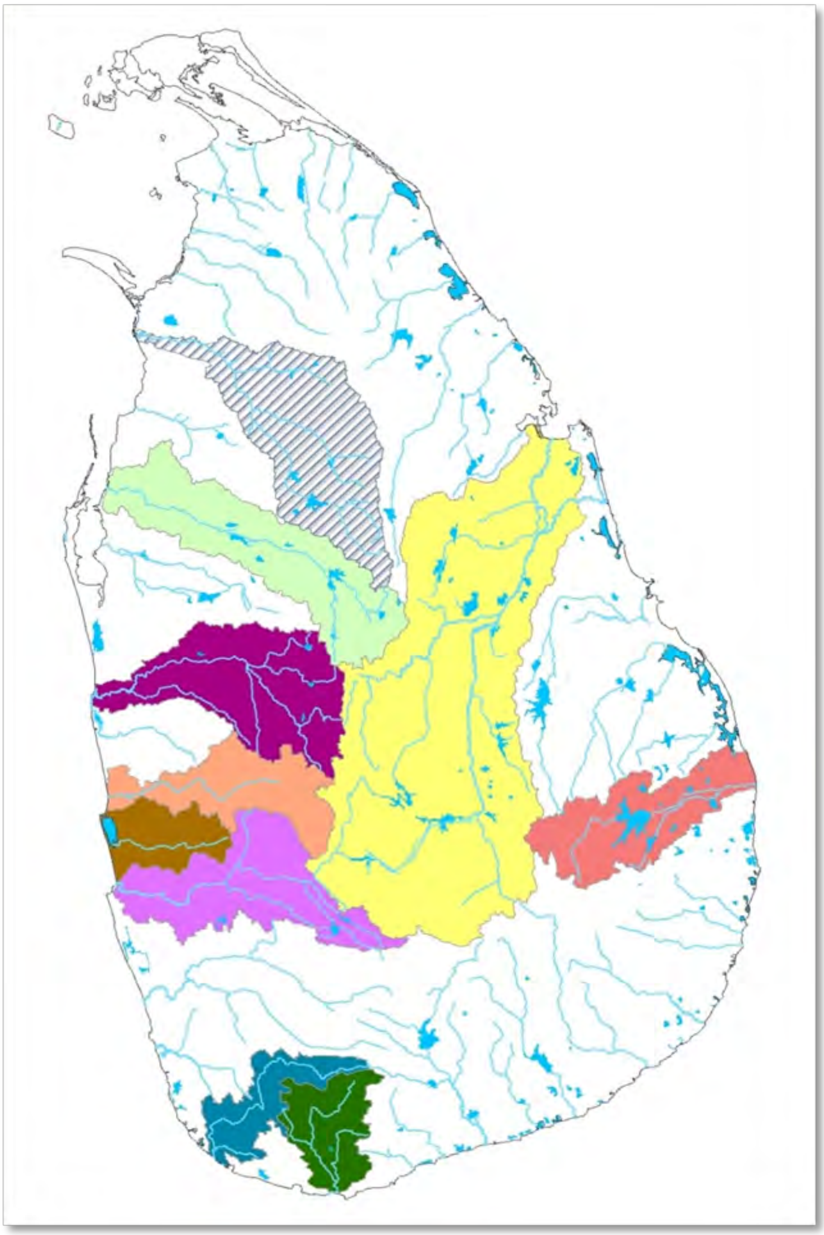
No	STATION CODE	Site	Station	Latitude	Longitude	Operating Base City	River Basin	RB No.	Instrumentation
1	003HD007		RATHNAPURA	6.679	80.395	COLOMBO	KALU GANGA	3	QLP
2	001HD003		AVISSAWELLA (GLENCOURSE)	6.978	80.203	COLOMBO	KELANI GANGA	1	QLP
3	001HD011	6	KITULGALA	6.989	80.418	COLOMBO	KELANI GANGA	1	QLP
4	001HD010	5	DERANIYAGALA	6.924	80.338	COLOMBO	KELANI GANGA	1	QLP
5	001HD002	1	HANWELLA	6.91	80.082	COLOMBO	KELANI GANGA	1	QLP
6	001HD006	4	RUWANWELLA	7.067	80.257	COLOMBO	KELANI GANGA	1	QLP
7	003HD002	9	MILLAKANDA	6.631	80.16	COLOMBO	KALU GANGA	3	QLP
8	003HD009	14	MAGURA	6.513	80.242	COLOMBO	KALU GANGA	3	QLP
9	003CE001	121	KUKULE DIVERSION	6.618	80.276	COLOMBO	KALU GANGA	3	QLP
10	003HD003	10	HALWATURA	6.726	80.186	COLOMBO	KALU GANGA	3	QLP
11	003HD004	11	ANGURUWATHO TA	6.625	80.071	COLOMBO	KALU GANGA	3	QLP
12	003HD019	23	PARAGODA BRIDGE	6.612	80.223	COLOMBO	KALU GANGA	3	QLP
13	103HD003	81	ALGAMA	7.152	80.176	COLOMBO	ATTANAGALU OYA	103	P
14	103HD004	82	CHESTERFORD	7.078	80.186	COLOMBO	ATTANAGALU OYA	103	P
15	004HD001	25	AVITHTHAWA	6.369	80.364	COLOMBO	BENTARA GANGA	4	QLP
16	103HD001	TBA	DUNAMALE	7.116	80.082	COLOMBO	ATTANAGALU OYA	103	QLP
17	060HD007	49	NAWALAPITIYA	7.048	80.501	KANDY	MAHAWELI GANGA	60	QLPE
18	060MA011	95	KOTMALE RESERVOIR	7.06	80.621	KANDY	MAHAWELI GANGA	60	LP
19	060MA009	93	VICTORIA RESERVOIR	7.242	80.778	KANDY	MAHAWELI GANGA	60	LP
20	060MA008	92	RANDENIGALA RESERVOIR	7.202	80.91	KANDY	MAHAWELI GANGA	60	LPE
21	060MA007	91	RANTEMBE RESERVOIR	7.201	80.95	KANDY	MAHAWELI GANGA	60	LP
22	060MA001	85	ULHITIYA RESERVOIR	7.473	81.054	KANDY	MAHAWELI GANGA	60	LP
23	060MA010	94	POLGOLLA DIVERSION	7.322	80.645	KANDY	MAHAWELI GANGA	60	QLP
24	060MA006	90	BOWATHENNE RESERVOIR	7.666	80.667	KANDY	MAHAWELI GANGA	60	LP
25	060MA012	96	UKUWELA	7.399	80.636	KANDY	MAHAWELI GANGA	60	QLP
26	060MA014	98	MINIPE RB T'BASIN CANAL	7.208	80.98	KANDY	MAHAWELI GANGA	60	QL
27	060MA015	99	ULHITIYA INLET CANAL	7.393	81.084	KANDY	MAHAWELI GANGA	60	QLP
28	060MA016	100	MINIPE LB CANAL	7.208	80.98	KANDY	MAHAWELI GANGA	60	QLP
29	093MA006	113	LENADORA	7.755	80.653	KANDY	KALA OYA	93	QL
30	093MA007	114	KALUNDEWA (HURULU)	7.788	80.707	KANDY	KALA OYA	93	QL

No	STATION CODE	Site	Station	Latitude	Longitude	Operating Base City	River Basin	RB No.	Instrumentation
31	093MA008	115	KALUNDEWA	7.788	80.707	KANDY	KALA OYA	93	QL
32	102HD007	78	ARANAYAKE	7.153	80.463	KANDY	MAHA OYA	102	P
33	060HD006	TBA	PERADENIYA	7.264	80.608	KANDY	MAHAWELI GANGA	60	QLP
34	060HD008	TBA	THALDENA	7.09	81.047	KANDY	MAHAWELI GANGA	60	QLP
35	060HD013	52	CALSEY-MAHAELIYA R/F	6.902	80.735	NUWARA ELIYA	MAHAWELI GANGA	60	P
36	001CE002	117	NORTON BRIDGE RESERVOIR	6.914	80.522	NUWARA ELIYA	KELANI GANGA	1	LP
37	001CE001	116	LAXAPANA RESERVOIR	6.919	80.49	NUWARA ELIYA	KELANI GANGA	1	LP
38	001CE005	120	CASTLEREIGH RESERVOIR	6.844	80.606	NUWARA ELIYA	KELANI GANGA	1	LP
39	001CE004	119	MAUSAKELLE RESERVOIR	6.833	80.557	NUWARA ELIYA	KELANI GANGA	1	LP
40	001CE003	118	CANYON RESERVOIR	6.871	80.527	NUWARA ELIYA	KELANI GANGA	1	LP
41	001HD012	7	NORWOOD	6.836	80.615	NUWARA ELIYA	KELANI GANGA	1	QLP
42	003HD011	15	MALWELA	6.703	80.429	RATNAPURA	KALU GANGA	3	QLP
43	003HD013	17	BANAGODA	6.704	80.499	RATNAPURA	KALU GANGA	3	QLP
44	003HD017	21	WATAPOTHA	6.561	80.501	RATNAPURA	KALU GANGA	3	P
45	003HD006	12	DELA	6.621	80.452	RATNAPURA	KALU GANGA	3	QLP
46	003HD018	22	BATEWELA	6.693	80.543	RATNAPURA	KALU GANGA	3	P
47	003HD020	24	ASHOKA ESTATE(R/F)	6.784	80.435	RATNAPURA	KALU GANGA	3	P
48	0018CE001	122	SAMANALA WEWA	6.68	80.788	RATNAPURA	WALAWE GANGA	18	LP
49	018HD004	36	TIMBOLKETIYA	6.408	80.798	RATNAPURA	WALAWE GANGA	18	QLP
50	018MA001	83	UDA WALAWE RESERVOIR	6.428	80.837	RATNAPURA	WALAWE GANGA	18	LPE
51	018HD003	35	MAW ARA TANK	6.439	80.959	RATNAPURA	WALAWE GANGA	18	LP
52	022HD003	40	WELLAWAYA	6.703	81.117	RATNAPURA	KIRINDI OYA	22	QLP
53	022HD002	39	KUDA OYA	6.523	81.123	RATNAPURA	KIRINDI OYA	22	QLP
54	022HD001	38	TANAMALWILA	6.444	81.136	RATNAPURA	KIRINDI OYA	22	QLP
55	026HD004	41	BUTTALA BRIDGE	6.755	81.238	RATNAPURA	MENIK GANGA	26	QLP
56	026HD005	TBA	WEHERAGALA RESERVOIR	6.536	81.255	RATNAPURA	MENIK GANGA	26	QL
57	009HD002	27	TAWALAMA	6.34	80.327	GALLE	GIN GANGA	9	QLP
58	009HD001	26	BADDEGAMA	6.173	80.174	GALLE	GIN GANGA	9	QLP
59	009HD003	28	DENIYAYA BRIDGE	6.345	80.558	GALLE	GIN GANGA	9	QLP
60	009HD004	29	UDUGAMA	6.223	80.33	GALLE	GIN GANGA	9	QLP
61	012HD004	32	PITABEDHARA	6.201	80.473	GALLE	NILWALA GANGA	12	QLP
62	012HD002	31	AKURESSA BRIDGE	6.1	80.477	GALLE	NILWALA GANGA	12	QLPE
63	009HD005	TBA	LANKAGAMA	6.359	80.49	GALLE	GIN GANGA	9	P

No	STATION CODE	Site	Station	Latitude	Longitude	Operating Base City	River Basin	RB No.	Instrumentation
64	12HD007	TBA	SAPUGODA	6.081	80.559	GALLE	NILWALA GANGA	12	QLP
65	067HD001	53	HOROWAPATANA	8.578	80.878	ANURADHAPURA	YAN OYA	67	QLPE
66	067MA001	102	HURULUWEWA RESEVOIR	8.225	80.718	ANURADHAPURA	YAN OYA	67	LPE
67	090HD001	62	KAPPACHCHI	8.602	80.272	ANURADHAPURA	MALWATHU OYA	90	QLP
68	090MA003	105	NACHCHADUWA RESERVOIR	8.252	80.467	ANURADHAPURA	MALWATHU OYA	90	LPE
69	090MA004	106	NACHCHADUWA (LB CANAL)	8.252	80.467	ANURADHAPURA	MALWATHU OYA	90	QL
70	090MA005	107	NACHCHADUWA (RB CANAL)	8.252	80.467	ANURADHAPURA	MALWATHU OYA	90	QL
71	090MA001	103	NUWARAWEWA RESERVOIR	8.343	80.409	ANURADHAPURA	MALWATHU OYA	90	LP
72	090MA002	104	TISSAWEWA RESERVOIR	8.344	80.376	ANURADHAPURA	MALWATHU OYA	90	LP
73	090HD003	63	MENIK FARM	8.687	80.275	ANURADHAPURA	MALWATHU OYA	90	QLP
74	093MA003	110	DAMBULUOYA RESEVOIR	7.869	80.621	ANURADHAPURA	KALA OYA	93	LP
75	093MA004	111	KANDALAMA RESERVOIR	7.885	80.696	ANURADHAPURA	KALA OYA	93	LP
76	093MA002	109	KALAWEWA RESERVOIR	8.032	80.548	ANURADHAPURA	KALA OYA	93	LP
77	093MA001	108	RAJANGANA RESERVOIR	8.133	80.23	ANURADHAPURA	KALA OYA	93	LP
78	093HD001	64	NEELA BEMMA	8.215	80.08	ANURADHAPURA	KALA OYA	93	QLPE
79	093MA005	112	DAMBULU OYA RIVER	7.755	80.653	ANURADHAPURA	KALA OYA	93	QLP
80	095HD001	65	GALGAMUWA	7.968	80.259	ANURADHAPURA	MI OYA	95	QLP
81	060HD011	50	ALLAI KANTALE	8.313	81.169	TRINCOMALEE	MAHAWELI GANGA	60	QLPE
82	061MA001	101	KANTALE RESERVOIR	8.364	80.983	TRINCOMALEE	KANTALE ARU	61	LP
83	069HD001	54	PADAWIYA TANK	8.825	80.766	VAVUNIYA	MA OYA	69	LPE
84	069HD002	55	PADAWIYA (LB CANAL)	8.825	80.766	VAVUNIYA	MA OYA	69	QL
85	069HD003	56	PADAWIYA (RB CANAL)	8.825	80.766	VAVUNIYA	MA OYA	69	QL
86	081HD001	57	IRANAMADU TANK	9.344	80.435	VAVUNIYA	KANAKARAYAN AR.	81	LPE
87	086HD001	59	VAVUNIKULAM TANK	9.101	80.333	VAVUNIYA	PALI ARU	86	LPE
88	086HD002	60	VAVUNIKULAM (RB)	9.101	80.333	VAVUNIYA	PALI ARU	86	QL
89	086HD003	61	VAVUNIKULAM (LB)	9.101	80.333	VAVUNIYA	PALI ARU	86	QL
90	031HD001	42	NAKKALA	6.893	81.3	AMPARA	KUMBUKKAN OYA	31	QLP
91	036HD001	43	SIYAMBALANDUWA	6.905	81.544	AMPARA	HEDA OYA	36	QLPE
92	044HD001	44	Senanayaka Samudraya Res (Gal Oya)	7.214	81.534	AMPARA	GAL OYA	44	LPE

No	STATION CODE	Site	Station	Latitude	Longitude	Operating Base City	River Basin	RB No.	Instrumentation
93	044HD002	45	GAL OYA (LB1)	7.213	81.537	AMPARA	GAL OYA	44	QL
94	044HD003	46	GAL OYA (LB2)	7.297	81.609	AMPARA	GAL OYA	44	QL
95	044HD004	47	GAL OYA (RB)	7.211	81.539	AMPARA	GAL OYA	44	QL
96	044HD005	TBA	BIBILE	7.177	81.225	AMPARA	GAL OYA	44	P
97	052HD007	TBA	MAHA OYA	7.538	81.365	AMPARA	MUNDENI ARU	52	QLP
98	054HD001	TBA	PADIYATALAWA	7.381	81.193	AMPARA	MADURU OYA	54	QLP
99	054MA001	84	MADURU OYA RESERVOIR	7.646	81.198	POLONNARUWA	MADURU OYA	54	LP
100	060HD003	48	ANGAMEDILLA	7.853	80.919	POLONNARUWA	MAHAWELI GANGA	60	QLP
101	060HD012	51	HEMBARAWA	7.523	80.971	POLONNARUWA	MAHAWELI GANGA	60	QLP
102	060MA004	88	MINNERIYA RESERVOIR	8.035	80.894	POLONNARUWA	MAHAWELI GANGA	60	LP
103	060MA002	86	GIRITALE RESERVOIR	7.994	80.922	POLONNARUWA	MAHAWELI GANGA	60	LP
104	060MA005	89	KAUDULLA RESERVOIR	8.128	80.931	POLONNARUWA	MAHAWELI GANGA	60	LP
105	060MA003	87	PARAKRAMA SAMUDRA RES.	7.939	80.986	POLONNARUWA	MAHAWELI GANGA	60	LPE
106	060MA013	97	DIYABEDUMA(E MYE)	7.933	80.865	POLONNARUWA	MAHAWELI GANGA	60	QLP
107	060HD001	TBA	MANAMPITIYA	7.913	81.089	POLONNARUWA	MAHAWELI GANGA	60	QLP
108	099HD002	66	MASPOTHA BRIDGE			KURUNEGALA	DEDURU OYA	99	QLP
109	099HD004	68	AMUNUGAMA BRIDGE	7.644	80.321	KURUNEGALA	DEDURU OYA	99	QLP
110	099HD005	69	ETILIYAWELA	7.697	80.348	KURUNEGALA	DEDURU OYA	99	QLP
111	099HD007	71	MA ELIYA	7.74	80.415	KURUNEGALA	DEDURU OYA	99	P
112	099HD008	72	DINIMINIYATEN NA	7.576	80.553	KURUNEGALA	DEDURU OYA	99	P
113	099HD009	73	DAISY VALLEY GROUP	7.483	80.469	KURUNEGALA	DEDURU OYA	99	P
114	099HD010	75	RIDI BENDI ELA	7.729	80.262	KURUNEGALA	DEDURU OYA	99	QLPE
115	102HD004	76	GIRIULLA	7.325	80.116	KURUNEGALA	MAHA OYA	102	QLP
116	102HD005	77	MOLAGODA	7.338	80.47	KURUNEGALA	MAHA OYA	102	P
117	102HD006	78	HATARLIYADDE	7.248	80.33	KURUNEGALA	MAHA OYA	102	P
118	102HD008	79	BOLAGAMA BRIDGE	7.288	80.409	KURUNEGALA	MAHA OYA	102	QLP
119	102HD001	TBA	BADALGAMA	7.301	79.982	KURUNEGALA	MAHA OYA	102	QLP
120	099HD011	TBA	MORAGASWEW A	7.727	80.094	KURUNEGALA	DEDURU OYA	99	QLP
121			Nugawela	7.6092	80.1134			**99**	**QLP**
122			Mulhaniykaddu Kalam (MTK)	9.203	80.624			75	LPE

13. Annex 4 10 CRIP Basins



14. Annex 5 - Hydrological Report on the Kelani River Flood in May 2016

(edited by authors)

1. River Basin Information

The Kelani is a one of major river systems in Sri Lanka. It takes the seventh place in respect of its extent of watershed, 2340 km^2. However, it is third with respect to water resources aspect (4225 MCM average annual discharge) due to abundant rainfall in the catchment. The river originates from the central hills near Adam's peak and traverses about 145 km through the south-western slopes of the Island to reach the sea near Colombo.

The Kelani catchment is entirely situated in the wet-zone of the country. The average annual rainfall of the catchment varies from 5700 mm in the upper catchment to 2300 mm in the lower basin. Major portion of the rainfall is received during the South-West monsoon period. However the catchment remains wet throughout the year since it receives considerable amounts of rainfall during the North-East monsoon and inter-monsoonal periods.

Owing to the heavy rainfall and the steep terrain of the upper catchment, the lower basin of the Kelani River is subjected to heavy floods. The Flood plain is formed below Glencoures gorge which is about 53 km upstream of the sea outfall. Below Hanwella (about 35 km from sea), the flood plain becomes wider following the flat landscape.

1.1 Developments in the Kelani River basin

The Kelani River starts at the confluence of two tributaries, Kehelgamu Oya and Maskeli Oya at the upstream of Kithulgala. These two tributaries contribute to a significant part of hydroelectric production of Sri Lanka by housing two major reservoirs (Maussakele and Castlereagh), three ponds (Noorten, Canyon, Laksapana) and five power stations. Castlereagh and Noorten have been constructed across Kehelgamu Oya while Maussakele, Canyon and Laxapana were constructed on the Maskeli Oya. In the lower reaches, some more tributaries connect to the Kelani River, out of which the most significant are Wee Oya at Yatiyantota, Gurugoda Oya at Ruwanwella and Seethawaka Ganga at Avissawella. So far there are no storage reservoirs constructed on these tributaries.

The Wak Oya connects to the Kelani River further downstream where the confluence is situated just above Hanwella hydrometric station. Kalatuwawa and Labugama reservoirs have been constructed on the upper reaches of Wak Oya. Those two reservoirs have been constructed purely for the purpose of domestic water supply to the capital city, Colombo.

Lower basin of the Kelani River has been protected against minor floods by construction of levees across the lower tributaries and the depressions either side of the main river. These levees prevent river water entering to the protected areas during floods. Storm water evacuation from these areas is mainly done by the gravity outlets. Therefore the basin drainage has to wait until the river stages fall and discharge through gravity outlets is possible. These schemes have been constructed in a different stages beginning from 1920s to suit the conditions prevailed (mainly for agriculture purpose) at the time of construction. These areas became populated gradually and the protection given is insufficient for the present conditions.

In addition to above there are some major flood protection and drainage schemes constructed for the purpose of protection of Colombo city and suburbs from the Kelani River floods. The level of protection of these areas is fairly high but most of the facilities provided by the schemes have deteriorated due to a variety of reasons.

1.2 Influence of the reservoirs on flooding

Castelreigh (43,830 acft) and Maussakele (93,000 acft) reservoirs regulate the inflows from the Kehelgamu Oya and Maskeli Oya to some extent. The Influences of Noorten, Canyon and Laksapana ponds are negligible, however the Gurugoda Oya and Seethawaka Ganga contribute a large amount of water to the river during flood periods.

The water from the upper catchment of Wak Oya is regulated to some extent by the domestic water reservoirs Kalatuwawa and Labugama. Impact of all these reservoirs on the Kelani River flooding is positive since they retard the flood wave and attenuate the peak floods to some extent.

2. Hydrometric Network on the Kelani River

Seven hydrometric Stations on the Kelani River are operated at 1 hr intervals by Hydrology Division. All seven stations are equipped with manual rain gauges which record rainfalls at the same interval. There are some other rainfall stations located at the upper catchments of the tributaries to record daily rainfalls by different organizations. Locations of all the stations are shown on the River Basin Map (Fig. 1) and some important parameters are tabulated in Table 1.

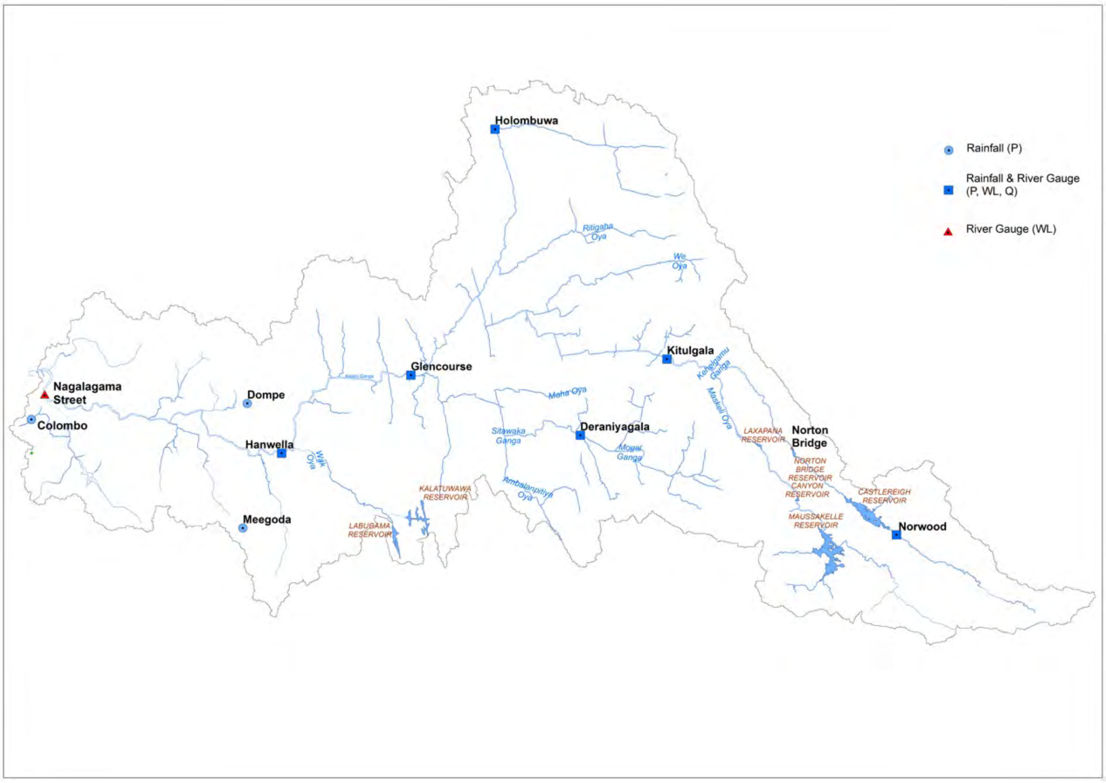


Figure 1. The Kelani River Basin Map

	Station Name & Implementing Agency	Location (X *N)	Type of data collected
1	Noorwood (ID)	182'051*182'230	Record water levels and rainfalls at 1 hour intervals. Rating curves are available to convert water levels to discharge. All six stations are maintained by the Hydrology Division of Irrigation Department.
2	Holombuwa (ID)	143'948*220,765	
3	Kithulgala (ID)	160,270*198'922	
4	Deraniyagala (ID)	152'036*191,688	
5	Glencourse (ID)	135'963*197'396	
6	Hanwella (ID)	123'689*189,980	
7	Nortenbridge (CEB)	172,111*190,453	Record 1 day Rainfalls by Ceylon Electricity Board

8	Castelreigh (CEB)	177,105*185797	
9	Maussakele (CEB)	175,140*182,642	
10	Canyon (CEB)	172,680*185,725	
11	Laxapana (CEB)	168,936*190,719	
8	Nagalagam Street (ID)	101,112*195,586	Hydrology Division records Water Level at 1 hr interval. No rainfall data collected.
8	Colombo (Met.)		Record continuous Rainfalls by the DoM.

Table 1. Rainfall Stations presently functioned in the Kelani Catchment.

3. Historical Floods

Colombo floods have been categorized based on the water levels at the river gauge at Nagalagam Street which has been maintained from 1830s. The floods above 7 ft MSL at Nagalagam Street are considered as major floods. Summary of information on historical major floods, as available at the Hydrology Division, is presented below (Table 2).

Year & Month	W.L. Max. ft	Year & Month	W.L. Max. ft	Year & Month	W.L. Max. ft
1837	13.5	1928 July	9.08	1942 July	8.17
1872	11.9	1930 May	10.91	1947 August	12.85
1891	9.8	1930 Oct.	9.83	1952 May	8.25
1904	9.9	1933 May	9.95	1955 Oct.	8
1906	10.8	1936 May	9.43	1966 Sept.	8.67
1913	11	1937 May	10.33	1966 Oct.	9
1922	12.6	1939 May	9.35	1967 Oct.	9.17
1925	11.5	1940 May	11	1971 Sept.	7.33
				1989 Jun	9.2

Table 2. Historical Floods Recorded at Nagalagam Street.

Out of those historical floods, most of the information with respect to 1989 flood has been recorded by the Hydrology Division. After 1989 no major flood had occurred in the lower Kelani basin until the recent flood in May 2016.

4. Flood in May 2016

The recent flood is the most severe hazard recorded after the 1989 flood. Some of the dominant features of this flood are discussed below.

4.1 Extreme Rainfalls Caused Flooding

A Bad Weather Warning was issued by the DoM on 14 May 2016 stating heavy storms (above 150 mm) will be expected covering the North Western and the Western parts of the country. Hydrology Division used to monitor the hourly water levels and the rainfalls from the following stations are recorded as depicted in Table 3.

Station	Rainfall mm								Total RF mm
	13th May	14th May	15th May	16th May	17th May	18th May	19th May	20th May	
Castlereigh(CEB)	6.20	15.60	137.50	116.30	72.00	15.80	68.20	11.60	443.2
Norton(CEB)	20.90	11.70	201.50	200.50	109.40	12.10	77.00	47.00	680.1
Maussakelle(CEB)	6.00	14.50	155.00	82.00	84.50	19.50	62.30	7.00	430.8
Canyon(CEB)	30.50	13.00	179.20	187.50	87.10	22.90	64.00	12.10	596.3
Laxapana(CEB)	20.60	12.00	158.50	167.90	129.10	12.70	78.50	20.20	599.5
Norwood	11.80	37.70	86.00	35.40	68.60	17.10	45.00	2.70	304.3
Kitulgala	23.10	32.90	336.90	70.00	66.90	51.60	138.70	21.90	742.0
Deraniyagala	142.60	22.80	355.50	91.70	69.40	58.20	144.30	14.30	898.8
Holombuwa	37.80	16.60	201.60	88.70	101.30	10.30	40.30	11.10	507.7
Glencourse	60.40	16.10	225.80	78.00	73.70	26.60	108.90	1.40	590.9
Hanwella	7.00	11.60	160.70	17.90	48.70	9.30	108.30	1.30	364.8
Colombo(ID)	2.60	82.60	217.40	7.60	13.40	1.70	10.10	0.00	335.4
Colombo(MET)	2.80	76.40	256.90	26.00	19.50	0.90	9.80	0.80	393.1

Table 3. Daily Rainfalls throughout the Flood Period

According to above, only Deraniyagala had recorded high rainfall above 100 mm on 13th May (before the event). The next day, there were no significant rains in the upper catchment but the lower basin (Colombo) experienced heavy rains (around 80 mm). However the entire catchment was saturated before experiencing torrential rainfall in the evening of 15th Sunday. Deranigala recorded the highest one day rainfall (355.5 mm) on 15th May and the same location recorded the highest 8 day total rainfall (898.8 mm) during the flood period. The entire catchment experienced heavy and long duration rainfalls during the flood period.

4.2 Flood Levels

Noorwood station reached minor flood level at 12.00 hour on 15th may 2015. That prevailed only for 7 hours and became normal by the 18th hour of the same day. This minor flooding did not have much influence on the Kelani River flooding since it was located upstream of Castelreigh reservoir.

The entire river below Kithulgala remained at normal stages up to 18th hour (6 pm) of 15th May. Kithulgala reached minor flood level at 17th hour of 16th May and remained for 14 hours but never reached to major flood level during the flood event.

Deraniyagala recorded the highest rainfall during the flood period, but the flooding was limited to 7 hours of minor flood situation and 2 hours at major flood level. Accordingly, the Kelani upper catchment was not badly affected by 2016 May flood. The flood was mainly dominated by the rainfalls of the middle parts of the catchment and the lower basin.

A middle reach tributary of Gurugoda oya (at the elevation of about 50 m MSL) and the entire catchment below Avissawella were severely affected by the flood. A detail record of flood levels and the periods of inundation is presented in Table 4 below.

	Minor Flood				Major Flood			
Station	Level m MSL	From …	To	Period hr	Level m MSL	From …	To	Period hr
Nagalagam St.	1.52	7 hr 16th	18 hr 22nd	155	2.13	13 hr 18th	13 hr 21st	73
Hanwella	8.48	4 hr 16th	12 hr 21st	128	10	21 hr 16th	5 hr 19th	57
Glencourse	16.76	24hr 15th	17 hr 18th	65	19.81	17 hr 16th	17 hr 16th	1
Holombuwa	47.91	15 hr 15th	8 hr 18th	65	49.43	24 hr 15th	12 hr 16th	12
Deraniyagala	79.00	24 hr 15th	6 hr 16th	7	79.61	2 hr 16th	3 hr 16th	2
Kithulgala	55.73	17 hr 16th	6 hr 17th	14	57.72	-	-	-
Noorwood	1099.76	12 hr 15th	18 hr 15th	7	1099.91	-	-	-

Table 4. Recorded Flood Level at the different stations and periods of Inundation

The torrential rainfall causing floods occurred in the night of 15th May and the highest intensity was recorded at about 24 hours. Entire basin up to Nagalagam Street was flooded within 7 hours causing severe damages to lowlands either side of the river.

5 Analysis of Flood

The floods are normally classified as flash floods if the response time (time between the rainfall and the flood) is less than 6 hours. It is not possible to use hydrological or hydrodynamic models to forecast flash floods with adequate lead time. Flash floods are characterized by high peaks and low durations of inundation. Floods in the upper reaches of the Kelani catchments are generally flash floods.

The floods in the lower reach (below Avissawella) are more critical due to large areas of spreading and longer durations of inundation. Furthermore, these areas are highly developed and densely populated.

In past experience, the Kelani Floods are mainly dominated by the torrential rainfalls of the upper catchments while the lower basin is experiencing fair weather. During these situations there is sufficient time to forecast flood peaks and put in place precautions to minimize damages. During the recent flood Hydrology Division was trying to forecast the flood levels with mathematical models and also by river routing methods. In both cases, Glencourse station (53 km away from the outfall) was taken as the upper boundary. However the time lag (travel time of the flood wave) between Glencourse and Hanwella (only 4 hours) and also from Hanwella to Nagalagam street (3 hour) were hardly sufficient to give effective forecasts. This condition is clearly visible in the Figure 5. The main reason behind this was the nature of spatial distribution of the rainfall on this particular occasion. The entire catchment received relatively uniform and heavy rainfalls and the floods were mainly dominated by the rainfalls of the middle reach.

5.1 Comparison of the recent flood with the historical flood 1n 1989

5.1.1 Rainfall Pattern

Since the catchment area and the duration of flood were fairly large, rainfall periods of 8 days were selected for the comparison of two events. The weighted average rainfalls of the catchments above Glencourse, Hanwella and Nagalagam street hydrometric stations were selected for the comparison.

Catchment	Year	Day 01	Day 02	Day 03	Day 04	Day 05	Day 06	Day 07	Day 08	Total mm
Glencourse	2016.0	49.1	22.1	238.3	91.7	82.3	30.8	93.3	13.0	620.7
	1989.0	125.1	32.0	10.5	122.2	188.4	87.0	76.2	27.6	669.1
Hanwella	2016.0	47.1	20.8	231.5	85.1	79.1	28.9	95.9	11.0	599.4
	1989.0	107.2	27.6	12.5	113.6	174.4	81.0	67.3	23.7	607.5
Nagalagam Street	2016.0	39.4	22.9	224.0	73.1	71.7	24.8	92.4	9.2	557.5
	1989.0	91.0	23.2	16.1	114.9	158.6	76.7	57.3	20.9	558.9

Table 5. Weighted Average Rainfall of Catchments above Glencourse, Hanwella and Nagalagam Street

Table 5 reveals that the one day maximum rainfalls (shaded values) show higher values in the recent flood but the 8 day totals are comparable (the "Total" column). This is clearly shown in the following charts (Figure 3 and 4).

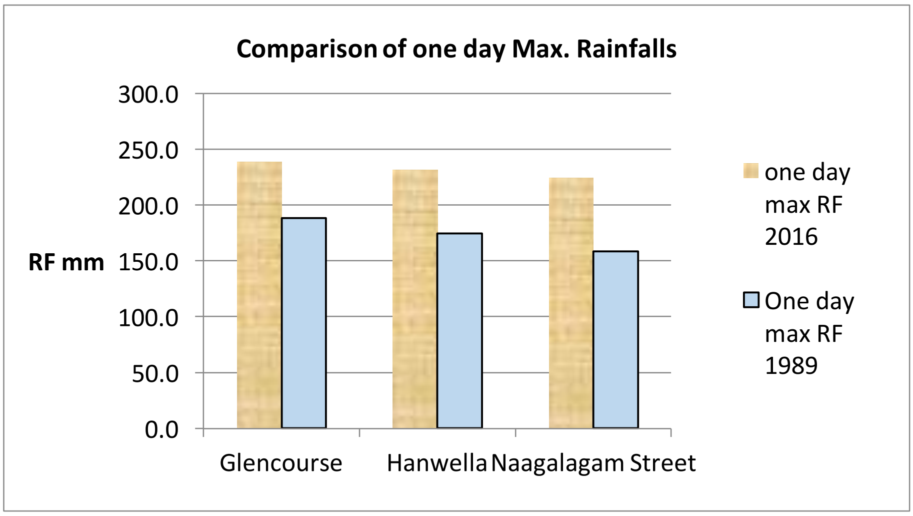


Figure 3. Comparison of One Day Maximum Rainfalls of Different Catchments.

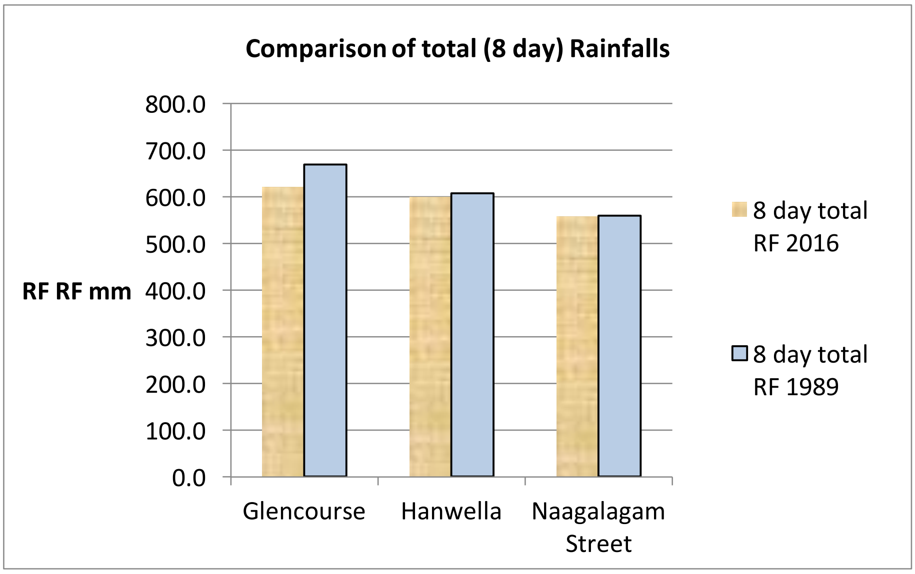


Figure 4. Comparison of Total Rainfalls of the different Catchments.

5.1.2 Characteristics of the Flood Hydrographs

When comparing the flood waves of two extreme events, the following characteristics of hydrographs are of prime importance.

1. Peak Discharge or Water Level
2. Time to peak discharge (or Water Level) at each station
3. Durations of flood at each section.

The above characteristics are clearly shown from the two figures below.

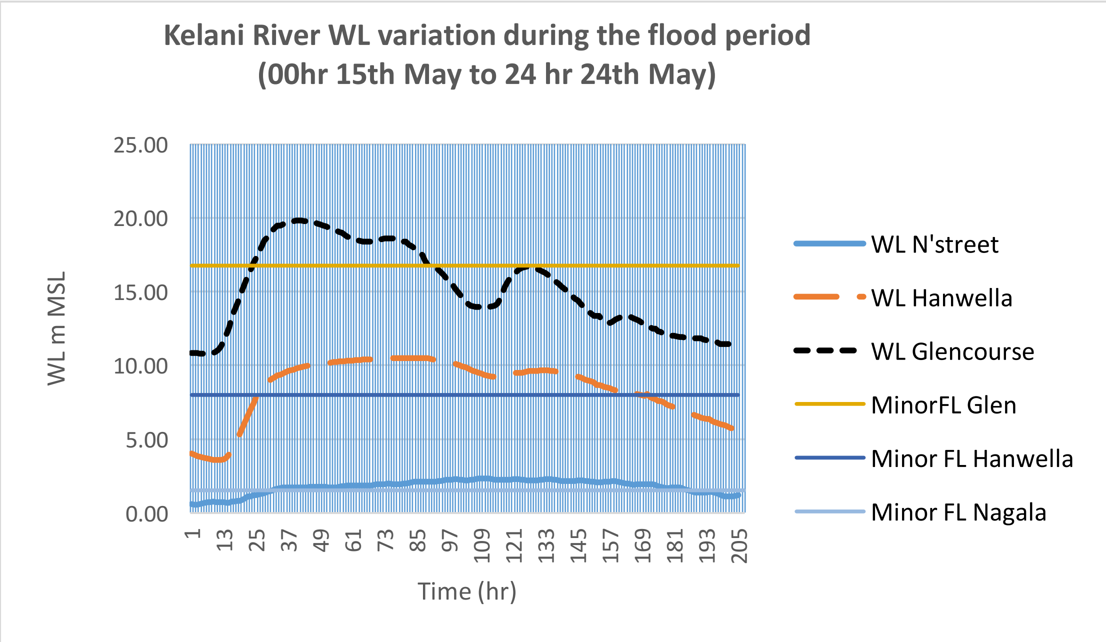


Figure 5. Water Level Variation of Three Stations during 2016 Flood

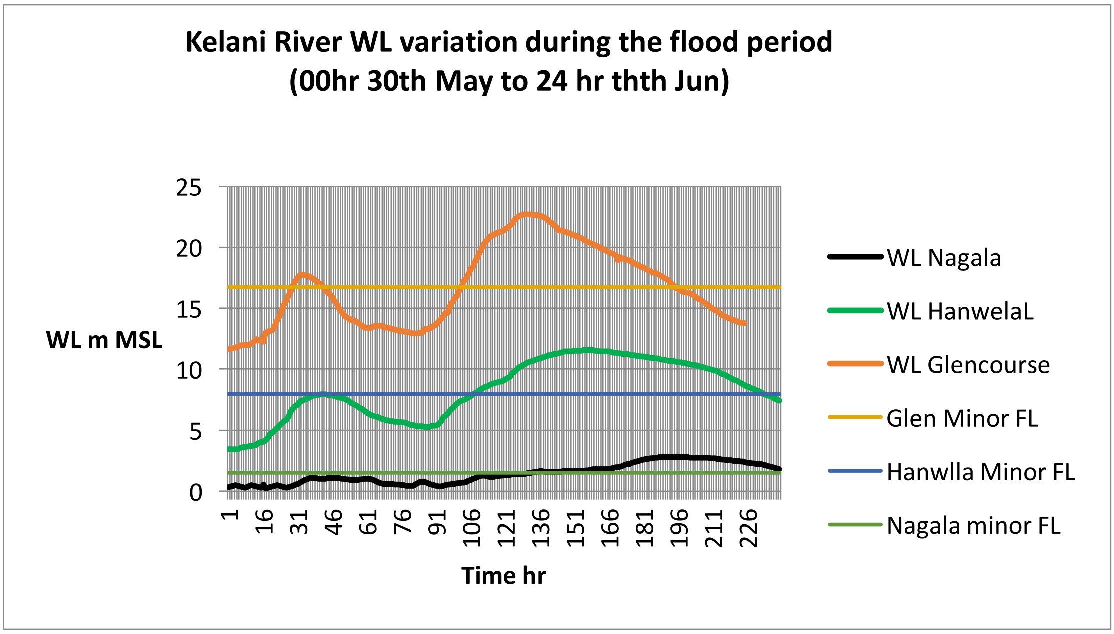


Figure 6. Water Level Variation at Three Stations during 1989 Flood.

Comparison of the Characteristics of 2016 Flood with 1989 Flood

2016 May Flood	1989 May/ June Flood
Low Peaks	High Peaks
Early Peaks	Late peaks
Longer durations	Short durations
Rainfall distributed throughout the catchment	Rainfall concentrated in the upper catchment
Very short alert periods	Longer alert periods
No sufficient time to forecast and warning	Ample time for forecast and warning
Heavy damages	Comparatively less damages

6. Flood Frequency Analysis

Hourly records of water levels are available for fairly long periods with respect to all hydrometric stations on the Kelani River. The graphical method of Gumbel EV1 distribution was used to carry out the frequency analysis using annual maximum rainfalls. Return periods of the two floods (2016 and 1989) at three main stations (Glencourse, Hanwella and Nagalagam Street) were analysed and presented in the Table 5 below.

Hydrometric Station	Data Period	2016 flood	1989 Flood
Glencourse	46years	10 year	50 year
Hanwella	42 years	10 year	25 year
Nagalagam Street	55 years	15 year	50 year

Table 5. Recurrence intervals of two floods

7. Conclusions and Recommendations

Mitigation of flood hazards is addressed in two different approaches, namely structural and non-structural measures. Structural measures provide solutions to protect certain areas from flooding by means of embankments, diversions and detention reservoirs etc. while the non-structural measures focused on lessening the damages by flood forecasting, early warning and evacuation of people and the properties from the vulnerable areas. Apart from those two approaches, adaptation to natural conditions by changing living styles and livelihoods, designing buildings and infrastructure facilities suitable for flood prone areas (elevated structures, floating structures) etc., can also be used. When considering highly developed and densely populated areas like Kelani River basin, a combination of all these approaches would be most appropriate.

The existing Kelani flood protection schemes were developed from early 1920s to late 1950s to protect the low lying areas adjacent to the river against river floods by construction of series of levees along the river. Evacuation of storm water from the interior catchments of the protected areas was mainly done through the use of gravity outlets. These schemes operated successfully for a long period except on few occasions when overtopping or failure of flood bunds was experienced.

Therefore, first priority should be given to the rehabilitation and modernization of existing flood protection schemes. The protection levels of original schemes may be insufficient for the present conditions since most of the agricultural areas at that time have been converted to residential areas with urbanization and increase of population. The levels of protection should be increased to manage floods with a 50 year return period (which is comparable) to 1989 flood. Further, storm water evacuation by gravity outlets is also problematic in the cases long duration floods. Therefore pumping facilities should be provided, in addition to gravity outlets, for evacuating storm water quickly from the protected areas.

Non-structural measures such as flood forecasting and early warning is also helpful in minimizing damages to properties. However, this method doesn't help much in the cases of flash floods similar to the recent flood. Nevertheless, it can be adopted very effectively in the cases similar to 1989 flood in which the flood is mainly dominated by the rainfalls of upper catchment and there is enough time for warning and evacuation. Even in the cases of flash floods, this method can be adopted effectively by running hydrological models with the forecasted rainfalls by meteorological models. The uncertainty of such forecasts will highly affect the model results.

Adaptation to flood situations by changing land use pattern, structures, lifestyles and livelihoods etc., can also be applied for the flood mitigation. This solution is somewhat costly when compared to other methods and should not be adopted for the areas where poor people are living. Such areas can be allocated for commercial purposes such as hotel projects and recreational areas etc. Optimum care should be taken to minimize environmental hazards that can be the result of such developments.

15. Annex 6 Distribution List for "Bad Weather" Advisories and Warnings

No	DESTINATION	FAX NO
01	MET Office - Katunayka Airport (CMB)	0112252721
02	MET Office – Maththala Airport (HRI)	0472031485*
03	Disaster Management Centre	0112670079/25*
04	Emergency Operation Centre(DM ministry)	0112665702
05	Central Disaster Response	0112867971
06	President Office	0112681419
07	President Investigation Unit	0112354573
08	Disaster Investigation Unit	0112354573
09	Prime Minister Office	0112753310/454
10	Ministry of Fisheries	0112334168*
11	Department of Fisheries	0112431448*
12	National Building and Research Organization	0112502611
13	National Aquatic Resources Research and Development Agency	0112546475
14	Information Department	0112514753
15	Government Information Centre (1919)	0112473696*
16	Coast Guard	0412254752*
17	Colombo Dockyard (pvt) Limited	0112329479*
18	Master Drivers (pvt) Limited	0112451507*
19	Police Communication Centre	0112854918
20	IGP Help Desk	0112472757
21	Police IG comd gr	0112854925
22	Police Navy Camp	0112472794*
23	Sri Lanka Navy Headquarters	0112441454*
24	Sri Lanka Navy - Trincomalee	0262220046/7166
25	Sri Lanka Navy - Mullikulam	0322260565
26	Sri Lanka Navy - Rangala	0112432929
27	Sri Lanka Navy - Kalpitiya	0322260594
28	Sri Lanka Navy - Galle	0912245954
29	Sri Lanka Navy - Panama	3137471
30	Sri Lanka Navy - Kankasanthurai	0212222816
31	Sri Lanka Air Force Headquarters	0112343969
32	Sri Lanka Air Force – Rathmalana	0112638118
33	Sri Lanka Air Force – Katunayaka	0112441044
34	Sri Lanka Air Force – Hingurakgoda	0272246063
35	Army Headquarters	0112434862
36	Welikanda Army Camp	0272259126
	District secretariat	
37	Colombo	0112369142
38	Jaffna	0212222355
39	Batticaloa	0652222435
40	Mannar	0232222232
41	Polonnaruwa	0272225578
42	Ampara	0632222130

No	DESTINATION	FAX NO
43	Puttalam	0322265543
44	Vauniya	0242222234
45	Trincomalee	0262222305
46	Kurunagala	0372222134
47	Kandy	0812233186
48	Monaragala	0552276025
49	Mathara	0412222233
50	Anuradhapura	0252222235
51	Hambanthota	0472220247
52	Galle	0912222972
53	Rathnapura	0452222140
54	Kaluthara	0342222635
	Television Stations and Radio Stations	
55	Sri Lanka Broadcasting Cooperation	0112698576*
56	Sri Lanka Rupawahini Cooperation	0112580134*
57	Independence Television Network	0112774421*
58	Lakhanda	0112774801
59	Hiru	0112346875*
60	MTV	0112838392*
61	TNL	0112501683
62	FM 99	0112544585
63	ALAI FM	0112691136
64	Rangiri	0662283603
65	V FM	0112814784
66	Sirasa/ Shakthi	0114792733
67	Vetri FM	0112304386
68	One Sri Lanka	0112851007
69	Metro News	0112323841
70	Ran FM	0112564262
71	Swarnavahini	0112507417
72	Sri FM	0112573453
73	Derana	0112506226
74	Isura FM	0112805742
75	News Alert	0112821786
76	Vasanthan	0112775110*
77	Buddhist Channel	0112689306
78	CBO Radio	0112424249*

16. Annex 7 Preliminary Project Scope and Cost Estimate

	Activity	Organization(s)	Cost Estimate	Type of Activity
A	**Institutional Strengthening, Capacity Building and Project Management**		**$7'750'000**	
A.1	***Institutional strengthening***		**$1'450'000**	
A.1.1	Develop and update national strategy for weather, climate and hydrological services	DoM, ID	$200'000	Consultancy (Systems Integrator -- SI)
A.1.2	Workforce Planning	DoM	$200'000	Consultancy (SI)
A.1.3	Develop asset register and introduce modern accounting methods	DoM	$100'000	Consultancy (SI)
A.1.4	Introduction of Quality Management System (QMS)	DoM	$150'000	Consultancy (SI)
A.1.5	Working together - improve inter-department operational relations (video conferencing, meetings, workshops)	DoM, ID; DMC and other departments/agencies	$500'000	Consultancy (SI)
A.1.6	Working with others - twinning with advanced NMHSs, operational support centres	WMO initiatives (SWFDP, FFG), NMHSs, WMO regional centres	$300'000	consultancy, travel
A.2	***Training and Capacity Building***		**$4'000'000**	
A.2.1	Professional training, retraining, staff development (including fellowships)	DoM	$2'500'000	Non-consulting services (NCS), travel, fees
A.2.2	Professional training, retraining, staff development (including fellowships)	ID	$750'000	NCS, travel, fees
A.2.3	Professional training, retraining, staff development (including fellowships)	DMC	$500'000	NCS, travel, fees

	Activity	Organization(s)	Cost Estimate	Type of Activity
A.2.4	Working with customers/users - implement training activities (workshops, roudtables, etc.)	DoM, all users	$250'000	NCS, Consultancy
A.3	***System design, operate, transfer and project management***		**$2'300'000**	
A.3.1	Systems design and integration		$2'000'000	Consultancy (SI)
A.3.2	Project Management		$800'000	Consultancy
B	**Modernisation of the Observing, forecasting and communication systems infrastructure**		**$8'230'000**	
B.1	***Modernisation of the observing system infrastructure***		**$2'100'000**	
B.1.1	Develop optimum composite observation network design	DoM, ID and other agencies/partners	$100'000	Consultancy (SI)
B.1.2	Data recovery	DoM, ID	$500'000	goods, consultancy (SI)
B.1.3	Rehabilitation of existing observing network (funds to repair/replace existing equipment)	DoM, ID	$500'000	Goods, civil works?
B.1.4	Upgrade of observing system at Colombo international airport	DoM	$1'000'000	goods, works, consultancy (SI)
B.2	***Modernisation of the data, communication and IT systems***		**$1'000'000**	
B.2.1	Data management systems for weather and climate data (servers, software, web access, social media, etc.)	DoM	$500'000	Goods
B.2.2	Communications system for forecast and warning dissemination (telecommunications - internet and mobile/smartphone)	DoM, ID	$500'000	Goods

	Activity	Organization(s)	Cost Estimate	Type of Activity
B.3	***Improve numerical weather prediction system and hydrological forecasting system***		**$2'130'000**	
B.3.1	Access to ECMWF products	DoM	$230'000	Goods?? (access to data)
B.3.2	High Performance Computer (for data assimilation, nowcasting and short-range forecasting, hydrological modeling)	DoM, ID	$1'900'000	Goods
B.4	***Construction and furbishment of offices and facilities***		**$3'000'000**	
B.4.1	New DoM building for forecast operations	DoM	$3'000'000	Consultancy (architecture, design) Works
C	**Enhancement of Service delivery systems**		**$4'800'000**	
C.1	***Climate Services***		**$2'500'000**	
C.1.1	Digital library of climate-relevant information for Sri Lanka (Climate database including web-based access)		$500'000	Consultancy (SI)
C.1.2	National framework for climate services - support for sectoral working groups		$1'000'000	Consultancy (SI)
C.1.3	Agricultural Climate Service		$1'000'000	Consultancy (SI)
C.2	***Support of DMC operations***		**$1'300'000**	
C.2.1	Develop and implement a joint forecast and warning service desk (collocated with DMC)	DMC, DoM, ID, BRO	$300'000	Goods

	Activity	Organization(s)	Cost Estimate	Type of Activity
C.2.2	Develop and pilot impact-based forecast and warning services (including access to gridded products, GIS info, etc.)	DMC, DoM, ID, BRO	$1'000'000	Consultancy (SI)
C.3	***Enhancement of weather services to sectors (health, agriculture, tourism, transport, etc.)***		**$1'000'000**	
C.3.1	Development of specialized services to sectors including mobile applications and web-based services	DoM	$1'000'000	Consultancy (SI)
		TOTAL	**$20'780'000**	