Implementation of Integrated Flood Management System (IFMS) at Center for Urban Water (CUrW), Metro Colombo Urban Development Project (MCUDP)

Executive Summary - Status Report 2020 July

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http://pub.curwsl.org

This work has been carried out from July 2016 to June 2020 including the development of proposal by the consultant and the design and implementation supported by necessary research with the staff at CUrW. The names, specialization and the period each staff member worked is listed on next page. This document also serve as the consolidated handing over document at the end of consultancy contract. In addition to this document, each major workflow component will have documents covering (a) concept (b) user interface and (3) technical specifications,

July 30, 2020

1 Background

In 2012 the World Bank and the Government of Sri Lanka (GoSL) agreed upon a loan to support the government to reduce flooding in the Colombo Water basin under project termed Metro Colombo Urban Development Project (MCUDP). Flood control measures include construction of two micro tunnels, establishment of three pumping stations to facilitate rapid discharge from the Colombo drainage canal system, widening of existing drainage canals and construction of control gates to flush canal water from the river discharge, which also could be used to compartmentalize flood prone areas to reduce flood risk. Under the project, establishment of an Integrated Flood Management System (IFMS) has been proposed to operate the flood control facilities considering the rainfall conditions and the flooding potential. The physical infrastructure and the unit to carry out this activity came to be referred to as Real Time Control (RTC) within the project management unit.

For the preparation and development of the RTC system for Colombo, **a consultant was to be selected to develop the lay-out of the system, to study the institutional setting, and to prepare the specifications for development, implementation, operation and maintenance of the system**. This will include the equipment, hardware, software and recommendations on staffing and training needs.

During the development of Real Time Control Center (RTC) proposal, the scope of the RTC was expanded in view of the need to assess short-term and long-term flood risks for the Colombo Metropolitan to safeguard investments and to ensure sustainable urban development. In addition to assisting and managing flood control, the center needs to provide environmental services and information for integrated water management in the city.

1.1 Real Time Control Center Proposal

The proposal for the establishment of RTC was submitted by the consultant to MCUDP in January 2017 and after review and modification in discussion with the World Bank Team the RTC proposal was finalized in March, 2017 and adopted as RTC proposal in April 2017 (RTC proposal, April 17, 2017, pp 80, [**rtc-prop**])

The objectives of the original Real Time Control Center were modified as ,

1. Develop an integrated flood control and water management information system
2. Provide Flood Early Warning support for the Metro Colombo.
3. Develop optimal operational rules for the flood control facilities such as pumps and storage facilities considering also the potential storage and use of water to make a pleasant urban environment.
4. Assess current and evolving future water related risks to Megapolis from urban development as well as climate change.

With a full time consultant joining the MCUDP PMU, it was decided to set up the RTC internally. Accordingly the above tasks have bene internalized and are implemented by the MCUDP under PMU.

1.2 The Scope and activities

The following is a description of scope and the activities planned to achieve the above objectives;

1. Development of a rainfall data integration system, using existing sources such as satellite rainfall observations, numerical weather forecasts and observations from rain gauges

2. Setting up rainfall monitoring stations for the metro Colombo area

3. Setting up water level monitoring gauges in canals/rivers/ponds and establishment of canal flow measurement system

4. Establishing communication links from the monitoring devices to the flood control and water management center

5. Developing a flood forecasting system comprising of rainfall integration, hydrological forecast model, hydro-dynamic model for inundation forecasting.

6. Developing a decision support system using all inputs to calculate the best operation of gates and pumps and setting up a SCADA control system for real time operation of the pumps

7. Establishment of a center for data integration, information dissemination and providing water management services for Metro Colombo

8. Setting up a system for continuous research and development to assess evolving risks due to urbanization and climate change and propose remedial measures.

1.3 Sustainability

Sustainability of the System is a major consideration addressed in the development stage. A sustained capacity development programme with the collaboration of educational and research institutions in the country, especially with the University of Moratuwa and the University of Peradeniya , support for continuous R & D, fostering collaboration among of academia and the line agency professionals are some of the key concerns addressed together with the development of the RTC. A program to enable center staff to obtain M.Sc. (Eng) or M.Sc based on the work done at the center will be implemented.

Maintenance of the System in the future require diversification of its activities beyond disaster management. Integrating urban water management with flood control, Catering to Megapolis development needs; Risk Assessment, Cost benefit analysis are some of the areas the centre will be engaged in.

1.4 Inter-agency collaboration

Discussions were carried out with Irrigation Department, Sri Lanka Land Reclamation and Development Corporation , Meteorology Department, National Building Research Bureau, Survey Department, World Bank team on climate resilience impact project, Disaster Management Centre, and International Water Management Institute to understand their role and challenges with regards to flood control and water management in the Kelani Basin and the Metro Colombo area.

2 Implementation Strategy

2.1 Colombo System and Major Stakeholders

The Kelani River basin where Colombo City is located is the second largest river basin in Sri Lanka and is located between Northern latitudes of 6 47' - 7 05' and Eastern longitudes of 79 52' - 80 13'. The River originates about 2250 m above mean sea level and passes 192 km through four districts of the country namely, Nuwara-Eliya, Kegalle, Gampaha, and Colombo before it reaches to the Indian Ocean. The basin area is about 2230 km^2. The basin can be considered consisting of two distinct sub basins, the upper basin which is mountainous and the lower basin which is below Hanwella, has plain features. The basin receives about 2400 mm of annual average rainfall. The river flow, which mostly depends on the season, and the three operational reservoirs, is an average of $25m^3/s$ in dry periods and ranges between 800m3/s and 1,500 m^3/s during rainy seasons ([**mir2009**]).

The Kelani River is fed by several tributaries. The Wak-Oya, Seethawaka River, Gatahatta Oya, Kehelgamu Oya, Maskeliya Oya, and Gurugoda Oya drain the upper basin while Attanagalu Oya, Maha Ela, and Pallewela Oya drain the lower basin. Moreover, the Kelani River is utilized for producing hydropower, with the use of Mausakelle, Castlereigh, and Lakshapana reservoirs.

Although Colombo City basin is part of the Kelani River Basin, but is protected from river overflow from a series of bunds and gates. Thus the catchment for consideration in the RTC design is limited to the Metro Colombo Drainage Basin shown in Figure(1). City flooding occur due to high intensity rainfall within the catchment that cannot be drained adequately. There are two major challenges in reducing risk in Colombo.

1. The City drainage depends on outfalls to Kelani River as well to the sea as shown in Figure (2). The Kelani river outfalls cannot function when the Kelani river flows are high. Of the 8 major extreme rainfall events during the past 32 years, 4 have coincided with high Kelani River water levels. (s 2 and 3).

2. The terrain is extremely flat and flooding occurs locally before drainage even with pumps become effective. Thus, high density rainfall measurements as well as rainfall forecasting is extremely important to prepare for extreme events. Radar raingauges would be ideal for such applications but are not available at present.

Considering the above following strategy is adopted for the RTC.

- Forecast Kelani River water levels using a hydrological model to anticipate in advance river conditions that would affect discharge to Kelani

- Assess areal distribution of rainfall using a dense rain gauge network in the basin. Use numerical weather forecast to anticipate rainfall in the Kelani basin 1-2 days in advance. Verify models and forecasts using satellite based rainfall estimates.

- Carry out extensive risk assessment case studies to improve preparedness for anticipated rain events.

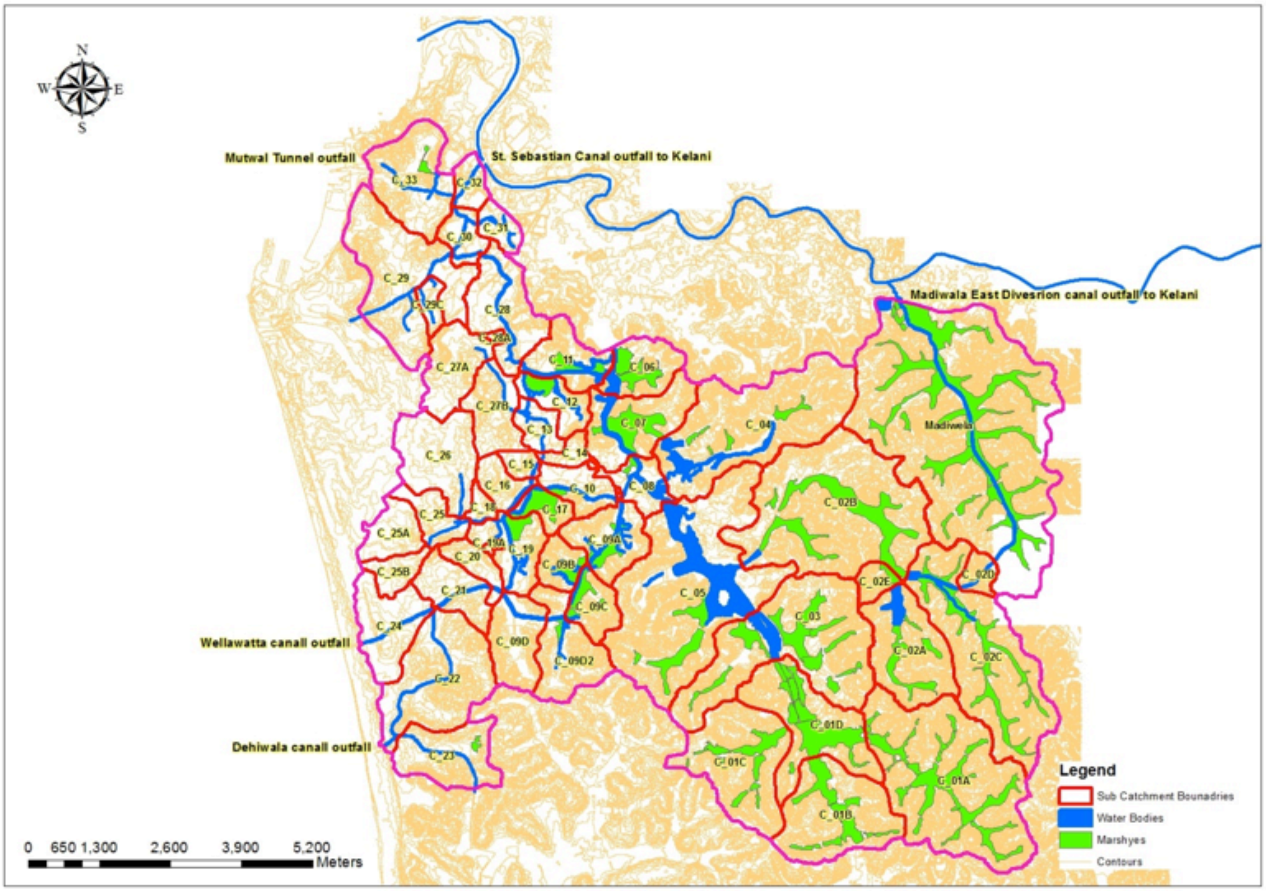


Fig. 1: Metro Colombo Drainage Basin

The schematic view of the three major components of the Colombo flood control system is shown in figure (3). The major components related to monitoring, modelling and control in the basin are shown in figure (4).

2.2 Functions of the System

The main functions of the system are identified as

1. Monitoring: Rainfall and river levels; street inundations
2. Collection: Integration of data from different sources; Point data and Gridded data
3. Simulation and forecasting

Tab. 1: Colombo Floods Associated with Heavy Rains

Date	Rainfall (mm)/d
17^{th}May 1981	194
4^{th}June 1992	494
20^{th}April 1999	285
21^{st} November 2005	270
17^{th}November 2009	207
$12^{th}$to $18^{th}$of May 2010	503
10^{th}November 2010	440
16^{th}May 2016	260

Tab. 2: Kelani High Water Level Events

Date	Kelani Water Level at Northlock (m.MSL)
15^{th} July 1984	1.60
6^{th} July 1989	2.80
4^{th} November 1990	1.52
1^{st} June 1991	1.50
5^{th} June 1992	1.55
15^{th} October 1992	1.61
17^{th} September 1997	1.70
22nd November 2005	1.72
1st June 2008	1.80
17^{th} May 2010	1.60
19^{th} May 2016	2.24

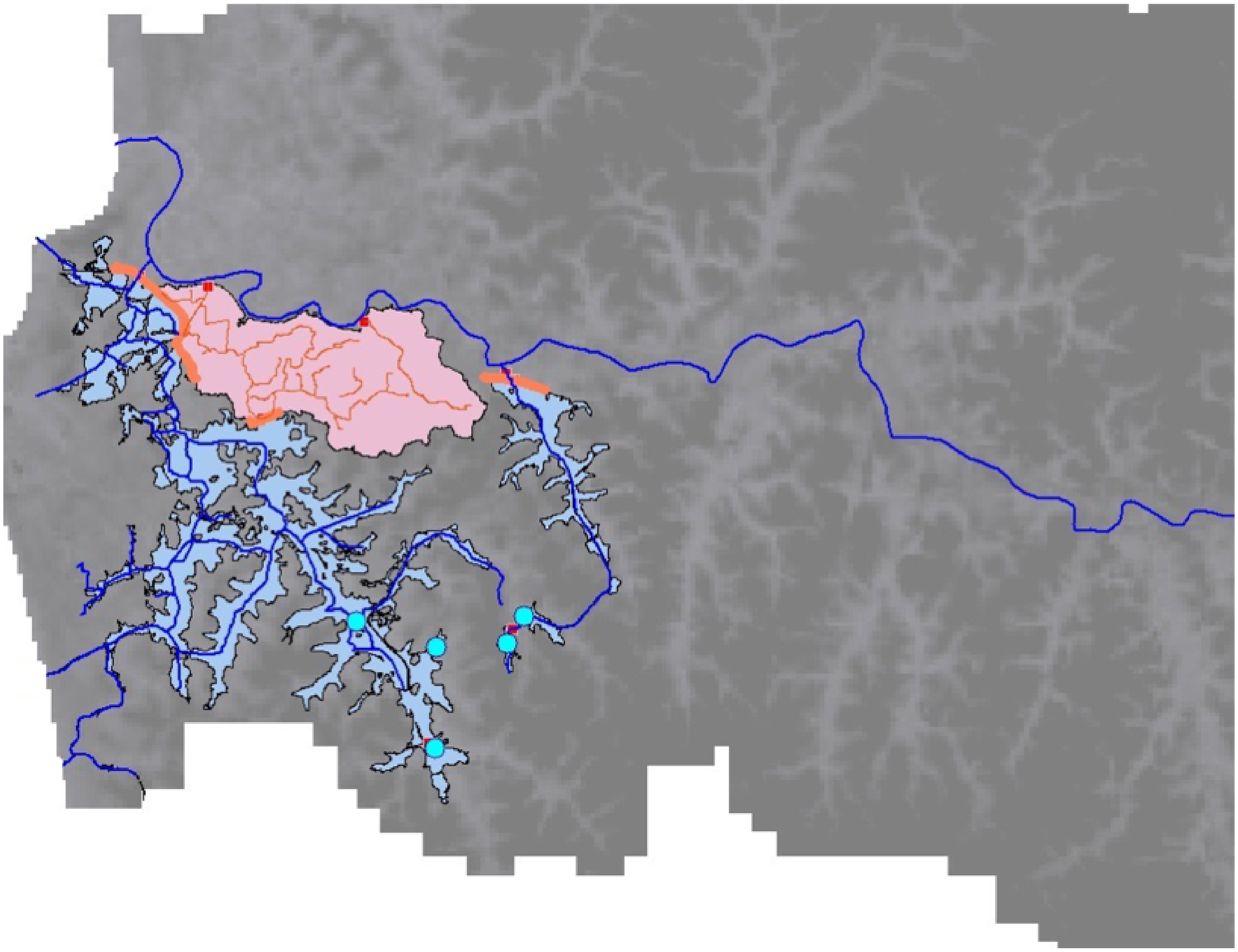


Fig. 2: Colombo 1:50 yr flood risk map

4. Real time dissemination and RT Control
5. Short and long term risk assessment

Most of the above would need continuous Research and Development, thus a continuous interaction with research communities in the country as shown in figure (5).

2.3 System Services for Stakeholders

The system is designed to consist of three units that deal with data integration, needs assessment and flood control and water management target identification related to rainfall, catchment hydrology and urban water respectively. Based on this input information three types of analysis and simulations would be carried out to provide

1. Real time forecasting to assist flood risk reduction
2. Operation of control structures

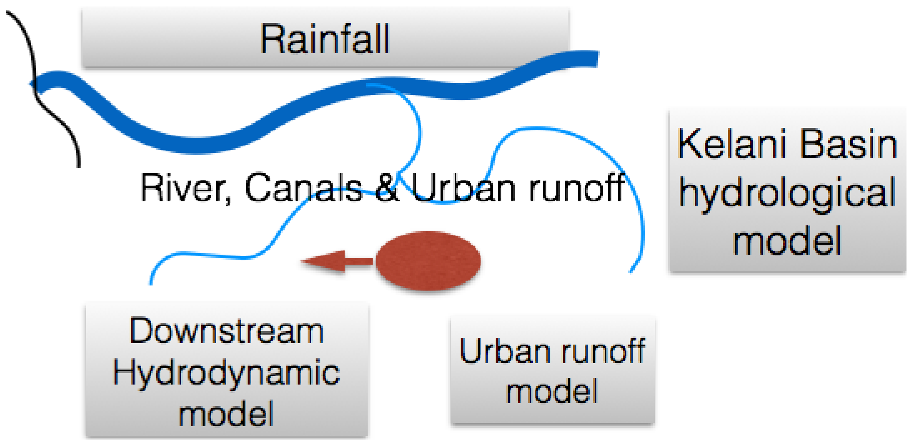


Fig. 3: Schematic view of the Colombo Flood Control System

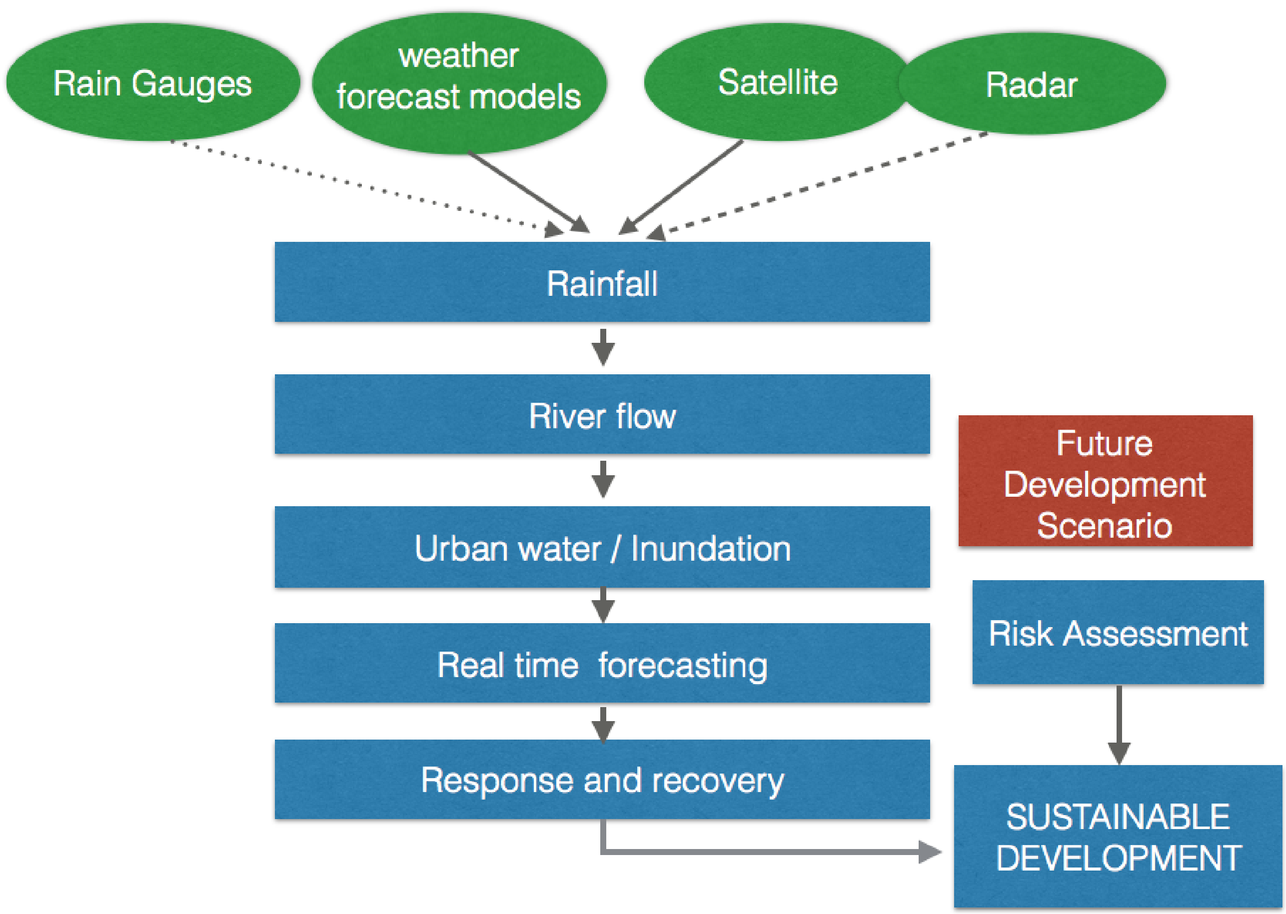


Fig. 4: Major components of the Colombo Flood Control and Water Management System

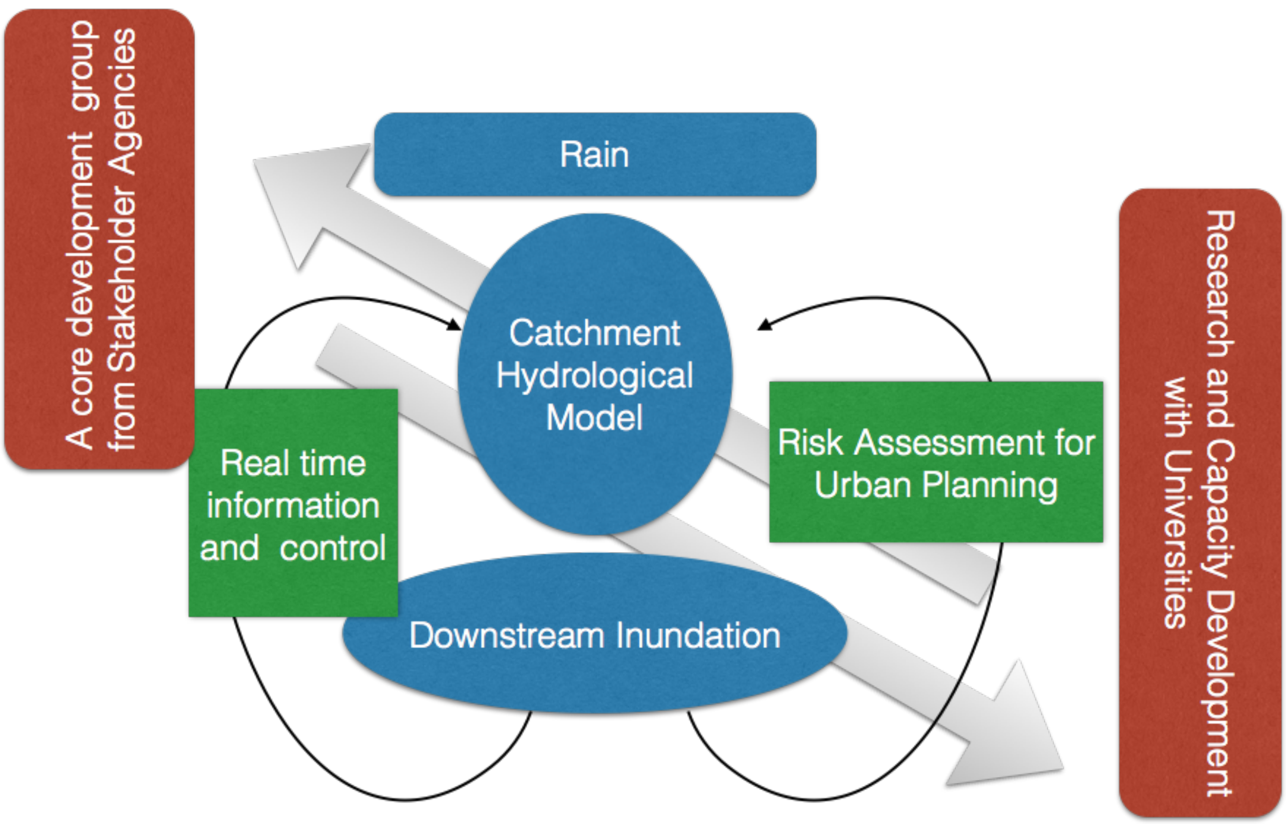


Fig. 5: Provisions for R&D needs to be built in to the system

3. Scenario analysis to develop optimal strategies for flood control. Short and long term risk assessment to support development planning

The system will provide information to the following specific constituents:

1. Government Agencies involved in risk reduction
2. Local governments
3. Academia and Professionals in R&D
4. Civil Service Organizations
5. Private Sector
6. Public

Collaboration of stakeholder organizations involved in flood and water management in the whole Kelani Basin, and in particular Metro Colombo Area is essential to address flood control and water management successfully in the basin. Several meetings were organized to develop this collaboration among the major stakeholder agencies. The system description and the stakeholder involvement is shown in figure (6).

2.4 Inter agency collaboration

- First Inter-agency meeting held on August 30, 2016 at Irrigation Ministry. Second on September 22^{nd} at Meteorology Dept.
- Discussed and agreed on the background papers
- Set up a steering committee of senior management that would meet once in 2 months (10 agencies at present):
- Set up a working group with nominations from concerned agencies (20 nominated at present).
- Identified agencies and major resource institutions for developing each of the major components of the system
- Identified and calibrated available models and systems to start setting up the information system
- Submitted a cabinet paper to setup a centre for flood forecasting and water management on October 12, 2016. Cabinet approved the paper on October 25, 2016.

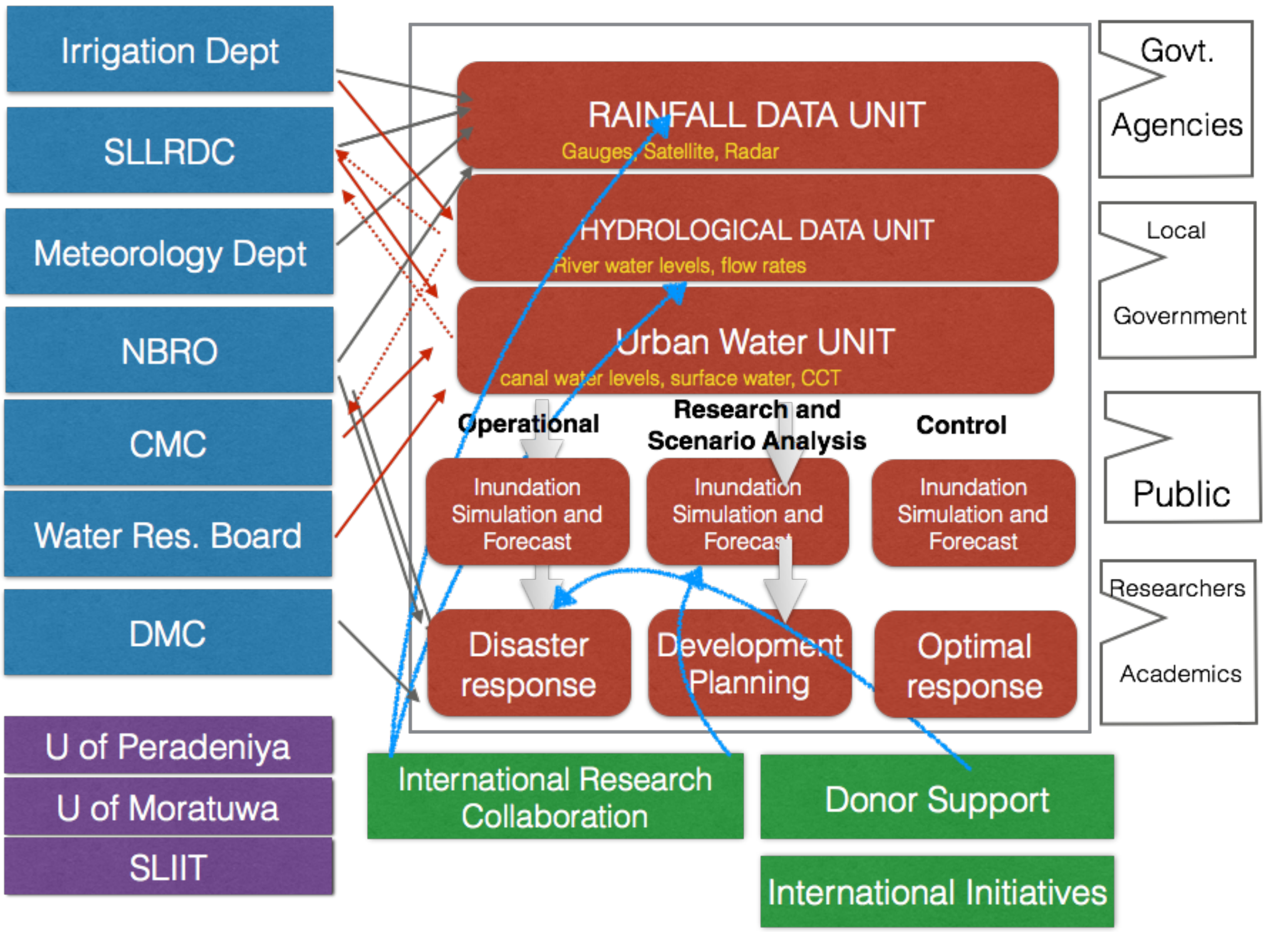


Fig. 6: System Implementation

2.5 Research Collaboration

- Established links with University of Moratuwa and University of Peradeniya to provide MSc. enrollment for Centre engineers. The program was implemented by the University of Moratuwa for the project.
- Established Graduate research projects implementation where the students worked for their final year projects as well as group research as collaborative work at the center as interns. Students from the University of Ruhuna, University of Moratuwa and the University of Peradeniya participated in this program.
- A meeting with education and private sector institutions was organized on 2^{nd} June, 2019. Representatives from University of Moratuwa, David Pieris Information Technology (DPIT), Lanka Hydraulic Institute Limited (LHI), Dialog Axiata and University of Ruhuna participated in the meeting and suggestions were made to extend their contributions in Measurement in Canals, Water quality monitoring, Economic aspects of disasters and School program on weather monitoring.

2.6 International Collaboration

- International Flood Initiative (WMO, UNESCO, UNISDR, UNU) endorsed the RTC-project as one of 7 demonstration projects to receive support from *Integrated flood and water management : (Seven countries are, Philippines, Sri Lanka, Pakistan, Indonesia, Malaysia, Vietnam, Myanmar)*
- Became a member of Global Alliance of Disaster Research Institutes (GADRI) of Disaster Prevention Research Institute (DPRI),, Kyoto University.
- Researchers from the University of Kyoto, Japan, Tshinghua University, China, IHE-Unesco, Netherlands visited and spent time at the center and carried out research works.

3 System Implementation - Current Status

In order to implement the activities within the scope defined above the Center is designed with the following five components.

1. The physical infrastructure of the center where monitoring and forecasting information is collected, analyzed and disseminated.
2. Modeling systems comprising of (a) Rainfall integration and forecasting system (b) Hydrologic and Hydro-dynamic forecasting for the observed and forecasted rainfall and (c) Risk assessment and Operational procedures estimation.
3. Computational environment consisting of servers for modeling information archiving, and dissemination through a web based content management system. The computational environment is set up in a cloud platform.

4. Monitoring and control system consisting of rain gauges, water level gauges and Scada control units for facility operations which provide real time information to the center

5. Stakeholder collaboration mechanism and outreach mechanisms.

The components of the center is shown in Figure (7).

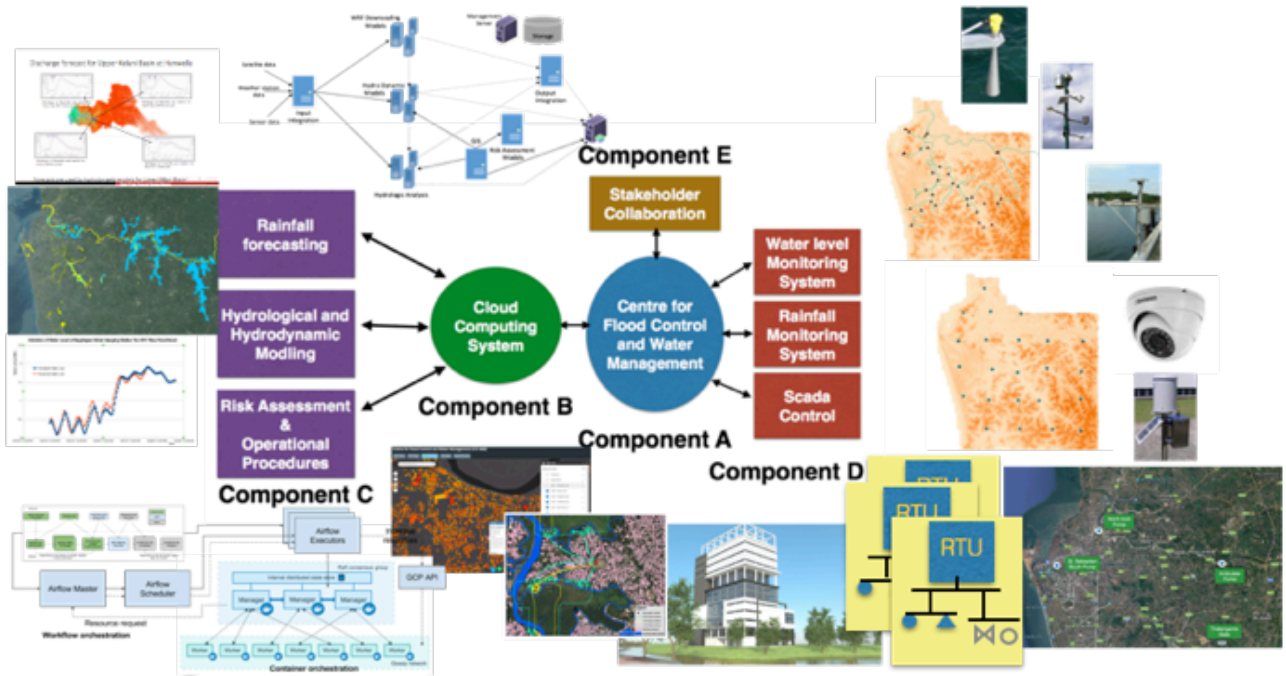


Fig. 7: Main Components of the system

The systems described above are already developed and are currently working smoothly. The current staff are capable of maintaining and operating the system as expected. However, they will not be able to make changes to the system architecture or carry out new development work and it would be necessary to get a higher level of expertise to guide and direct them if such a need arise. As of now the system automatically carry out the following tasks.

1. Collection of real time weather information (rainfall, temperature, wind speed, wind direction, humidity) monitored at 5 min intervals from 50 telemeter stations. 33 of the stations are located in schools

2. Monitor and collect water levels in 45 locations (9 currently operating and others are being installed)

3. Development of a weather forecasting system that use global GFS data to forecast rainfall for next two days. We run four models with different parameterizations that run in cloud servers 2 times a day.

4. Development of a data integration system that creates rainfall time series combining 1 and 3

5. Setting up hydrological models to forecast river water levels and canal water levels using 2 hydrological and 3 hydrodynamic models with inputs from 4 for rainfall and 2 for boundary and initial conditions. The hydrodynamic models provide the inundation extent and duration when discharges exceed canal carrying capacity.

6. Development of a data archiving, retrieval and display system for the items 1, 2, 3 and 5 outputs.

7. Created digital footprint of all buildings in Colombo categorized in to 10 use classes with methodologies developed to estimate structural and content damage to buildings as well as commercial losses when a flood occur.

8. Estimated and prepared digital map of night time population distribution in the city across the buildings.

9. Estimation of population at risk and potential economic loss from an anticipated extreme event calculated from 5 , 7 and 8.

10. Dissemination of all above information to all stakeholders through WWW with different user level access provision.

11. Operational sequences of pumps to reduce 9

12. Real time control of pumps and gates using a Central SCADA system. We have completed items 1 to 10 completely and item 11 is ongoing. Last component, 12, will be implemented once the pumping station installation is completed, expected in early next year to end of next year.

3.1 System Overview and Major Workflow Flowcharts

The above processes are carried out automatically through coupled workflows components. The workflows are actually designed as work-loops where each process is carried out continuously by independent work-flow-loop. The linkage among independent processes is achieved by rule-based work-flow connectors and the results are passed to downstream processes from upstream processes through database population and retrieval. Fault tolerance, load balancing and scaling in each process component is achieved through the services provided by Google Kubernetes and each work flow and their rule based connections are orchestrated using Apache Airflow, which is an open source platform created by Apache Software Foundation to programmatically author, schedule and monitor workflows.

The major workflows that constitute the system is schematically shown in the following sections. Once the system development is complete, it is envisaged to complete three documents for each major components of the system as;

1. Process/Workflow Concepts

2. User manual

3. Technical specifications

which are currently being documented.

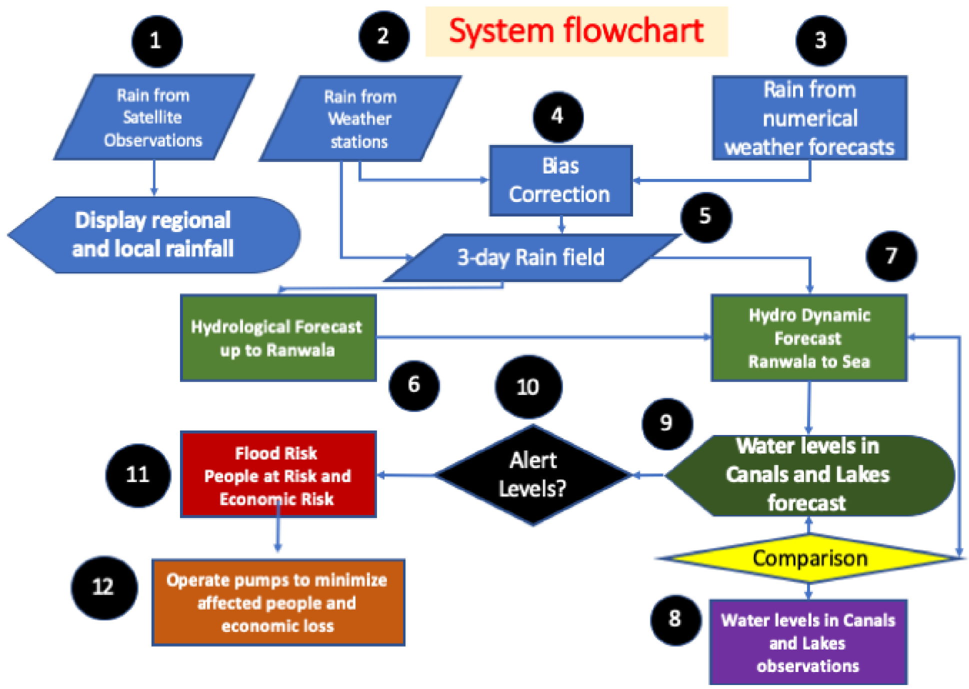


Fig. 8: System Overview

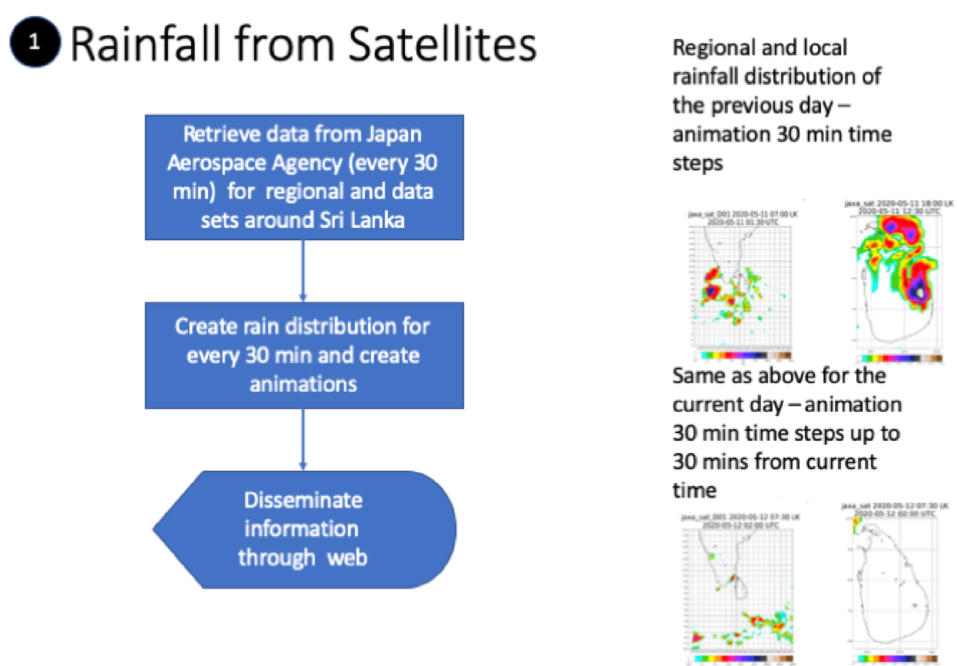


Fig. 9: Rainfall Estimation from Satellite

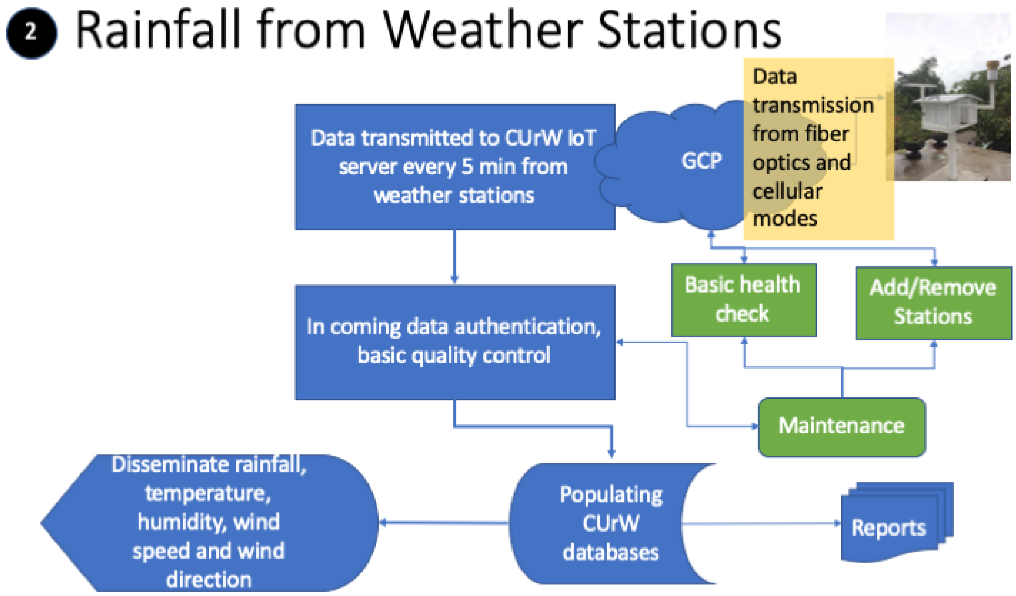


Fig. 10: Rainfall Observation from Weather Stations

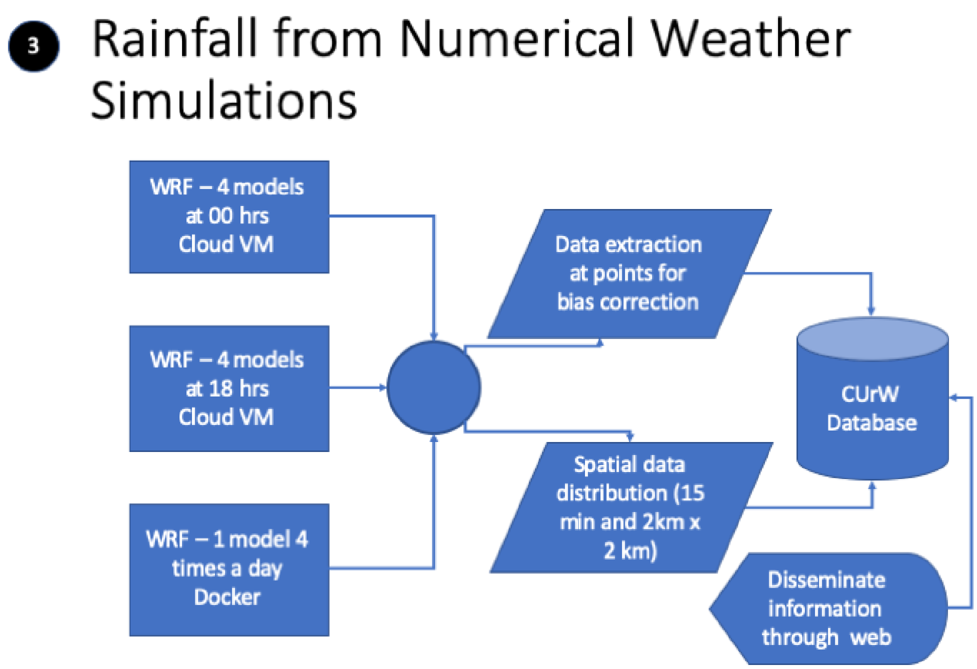


Fig. 11: Rainfall Estimation from Numerical Weather Forecasts using WRF model

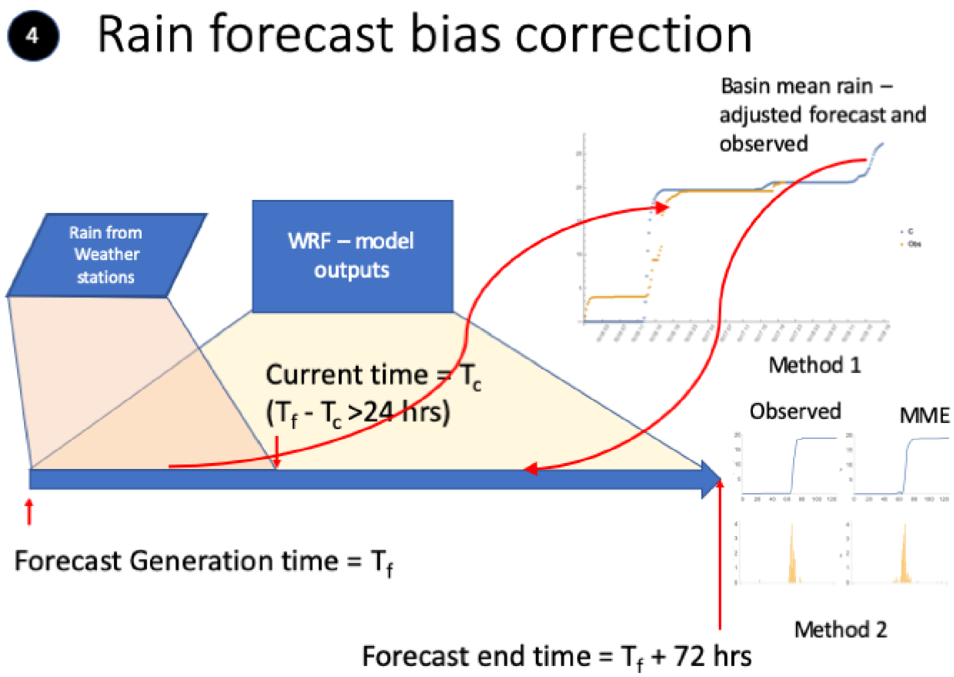


Fig. 12: Bias correction of Numerical Weather Forecasts

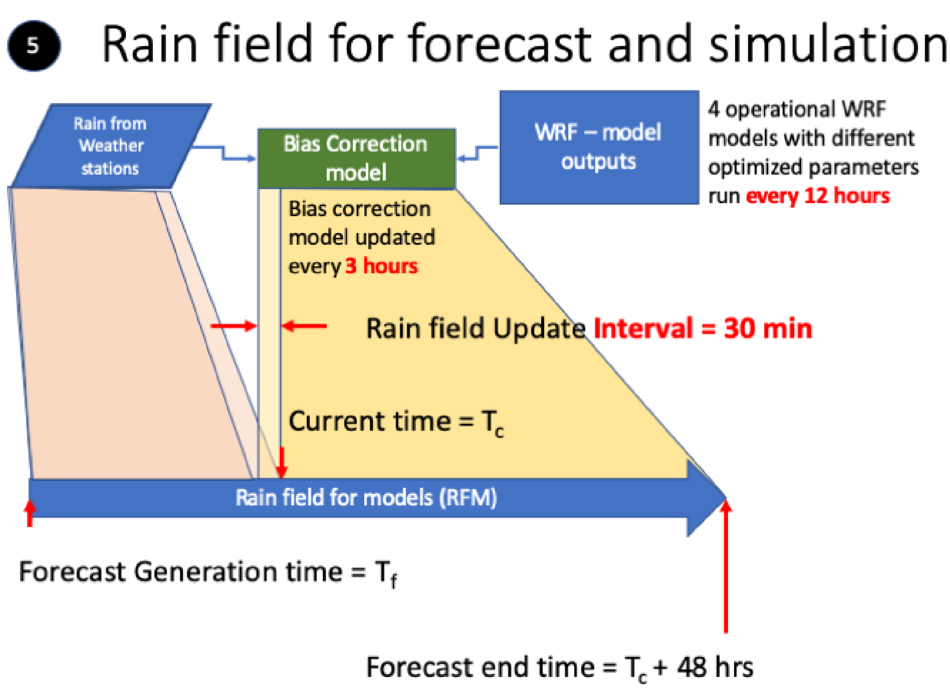


Fig. 13: Data Integration for Creating Rain Field for Flow forecasts and Simulations

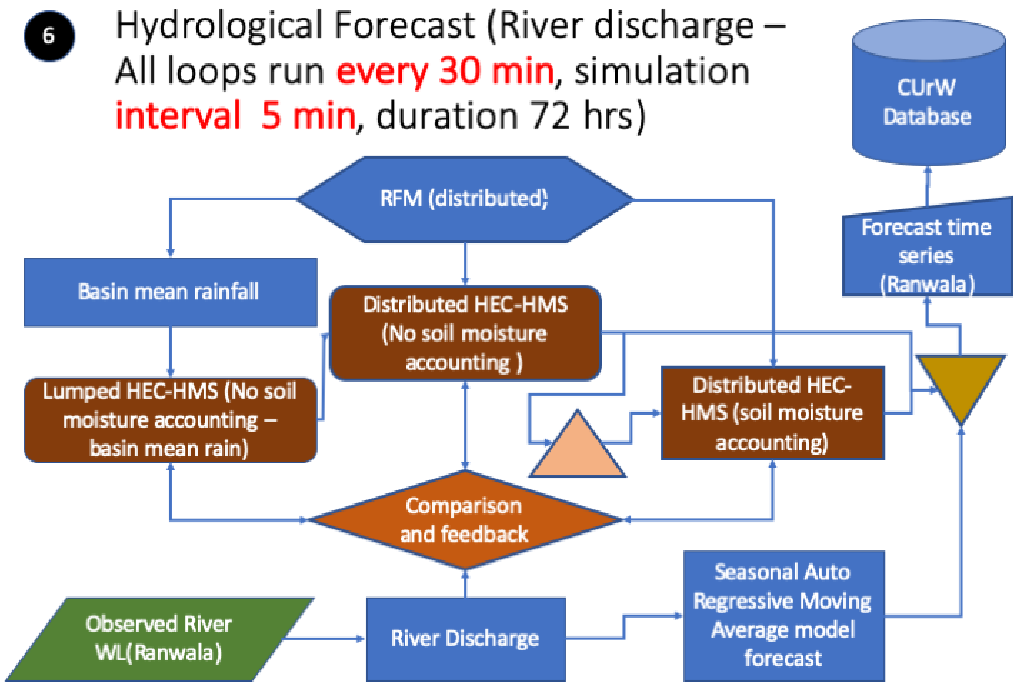


Fig. 14: Hydrological Forecast for Kelani Basin

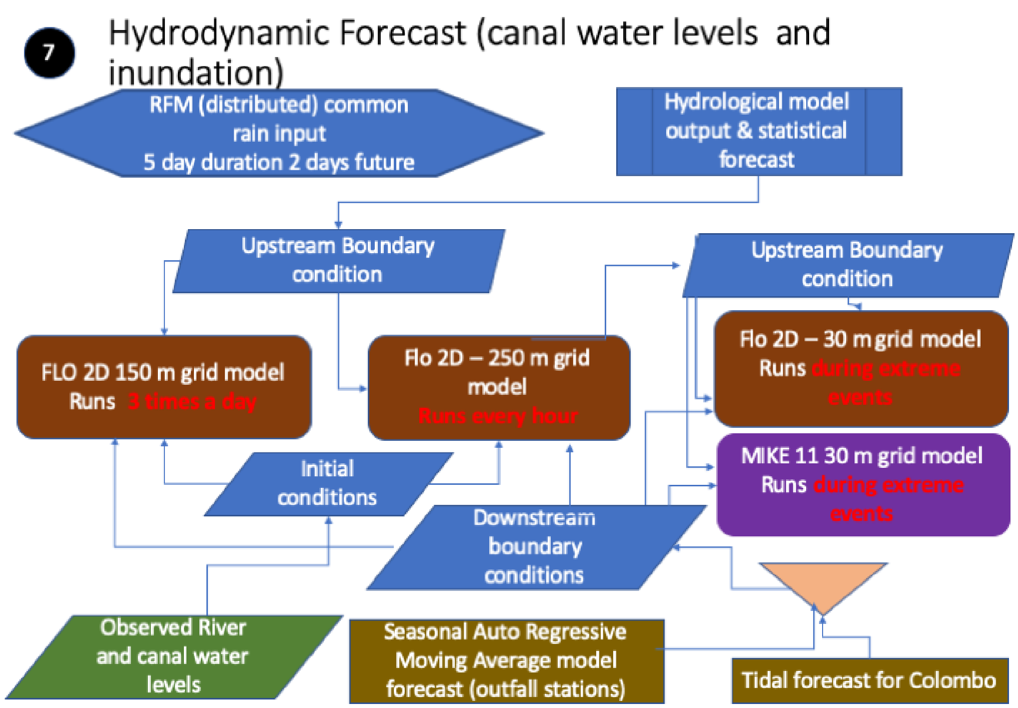


Fig. 15: Hydrodynamic Forecast for Colombo Basin

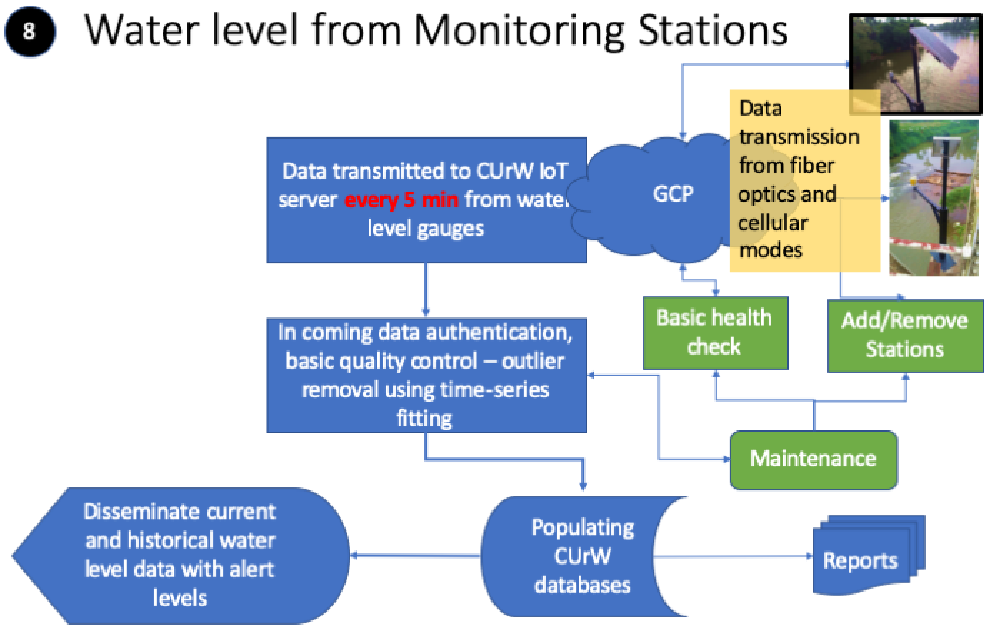


Fig. 16: Water Level Forecast Dissemination

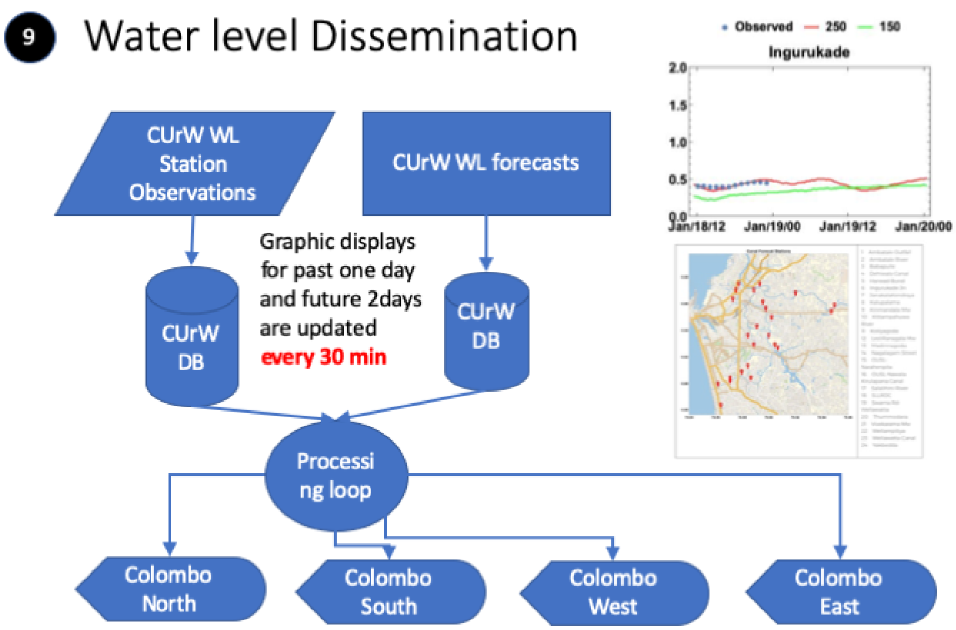


Fig. 17: Flood Alert Triggers

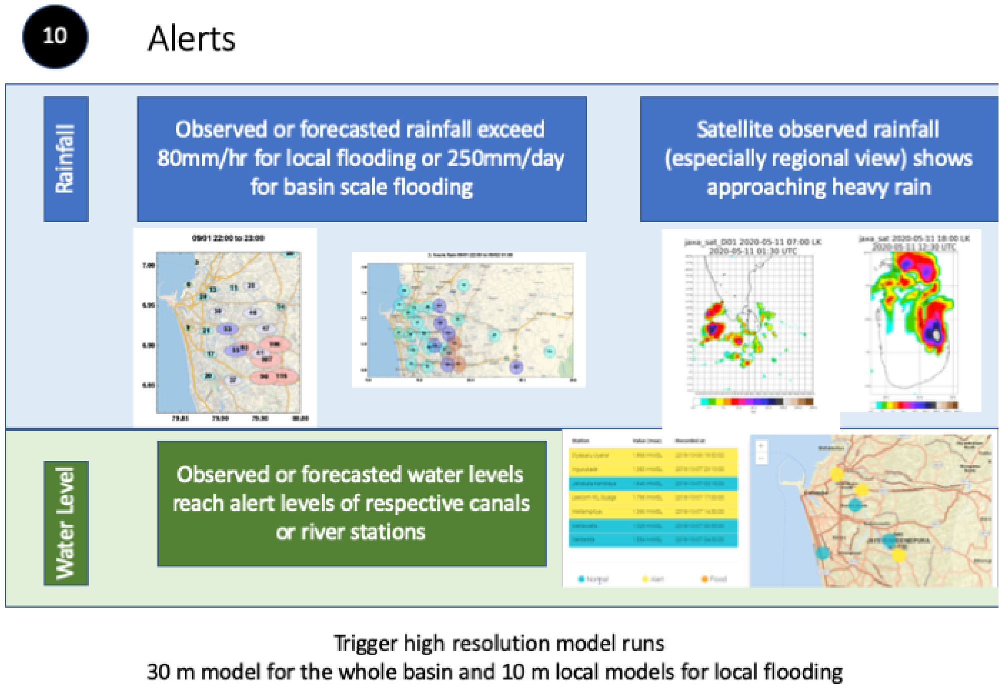


Fig. 18: Flood Risk Assessment

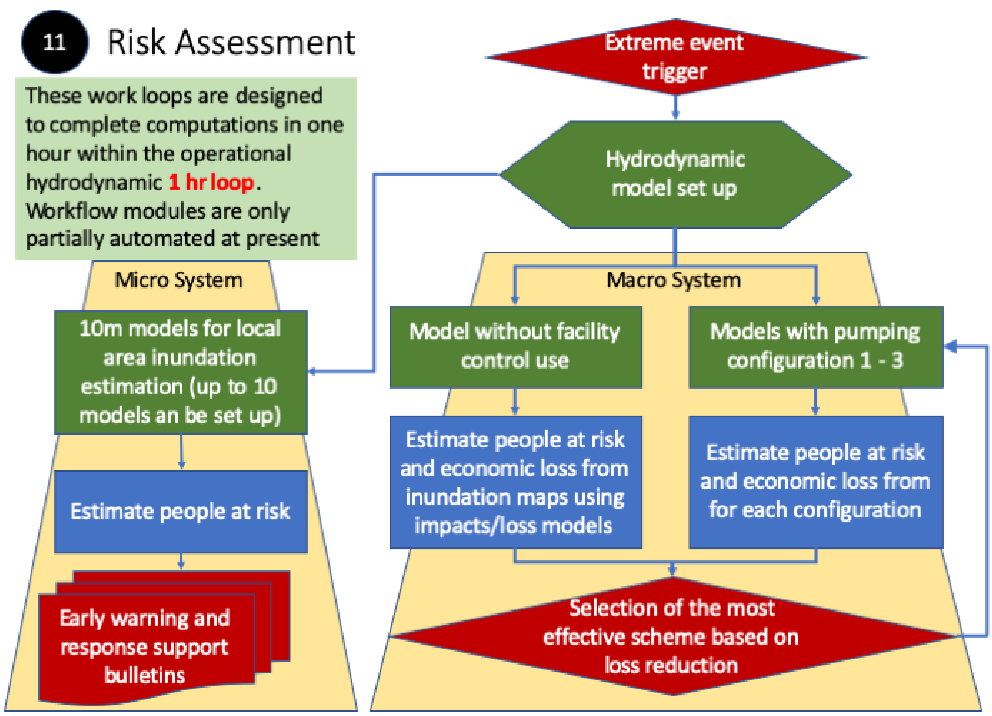


Fig. 19: Pump Operational Strategy

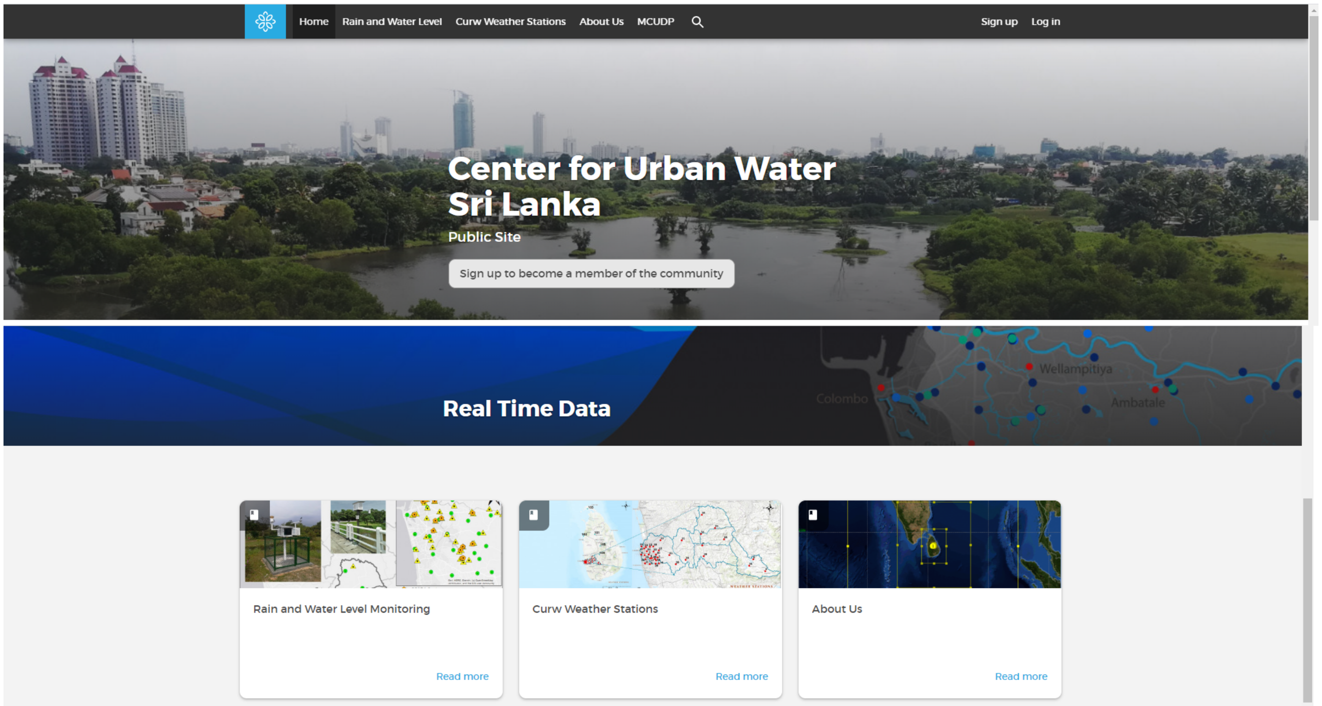
All of above development was carried out by local engineers, mostly fresh graduates who were trained in the center. About half of the staff are enrolled in MSc.Eng programs at the Moratuwa and Peradeniya Engineering faculties. The project accomplished all the above at very high financial efficiency as we designed and implemented IoT devices communication protocol and IoT platform at the center, thus removing the usually costly data processing component, cloud based servers eliminating a costly data/server center and system development by engineers directly recruited through a special service agreement with the University of Moratuwa. We can be really proud of our young engineers who produced these commendable results. In addition, during the last year (2019), 30 graduate students spent time in our center for their research and projects work. A considerable portion of the resources allocated under the World Bank Loan is set for education, research and development. The budget breakdown for this project is attached herewith. As can be seen the current status of RTC was achieved with only about 1.5 m USD which include all monitoring devices, consultancies and salaries over the 4 year period. The remaining amount of 3.17 m USD of the budget provided is mostly allocated for the ITC infrastructure for the building, additional monitoring equipment and central SCADA control system. In comparison the project to establish Hydro-meteorological Information System (HMIS) set up in Sri Lanka for a number of government agencies implemented over a period of 10 years covered only items 1, 2 and part of item 6 and did cost much more. A comparison of the that project with CUrW system based on available information online is provided in Table (**??**) and Table (**??**). This high efficiency is achieved due to the use of IoT devices, Cloud computing systems and the use of open source public domain software.

The major proprietary software/models purchased for this project for forecasting is only the FLO-2D software, while it is planned purchase MIKE 11, both of them to be used for hydrodynamic modeling. Mathematica, MATLAB and ArcGIS were purchased for data processing. All these software are on perpetual licenses, meaning there are no additional annual payments to be made. The two major open source software used for the forecasting are the Weather Research and Forecast (WRF) for weather forecast and HEC-HMS for hydrology. The major open source utility programs used are MQSQL and Mongo databases and Apache, Nginx, Flask Platform and NodeJS web servers. Programing is done mainly in Python and Mathematica. All components in the system including IoT platform, data integration routines, adaptors for transferring upstream module outputs to downstream process module inputs, and workflow automation were coded in house during this development period and are unique to the CUrW system. Thus, the continuous mentoring of staff is essential for the regular maintenance of system as well as for R&D to achieve the potential of the center and its sustainability.

The unique service agreement with the Moratuwa University helped to get excellent young engineers through whom we could carry out the necessary R&D work as well. The university collaboration has proved that if is possible to develop a productive eco-system among Government, Academia and Industry to support national development programs providing a platform for innovation and development using new technologies and IT services. The present type of collaboration, without a doubt will support the advancement of the higher education sector of the country. Details of some of these activities carried out are listed under the chapter **Collaboration with Local Universities**

CUrW Website (http://pub.curwsl.org)

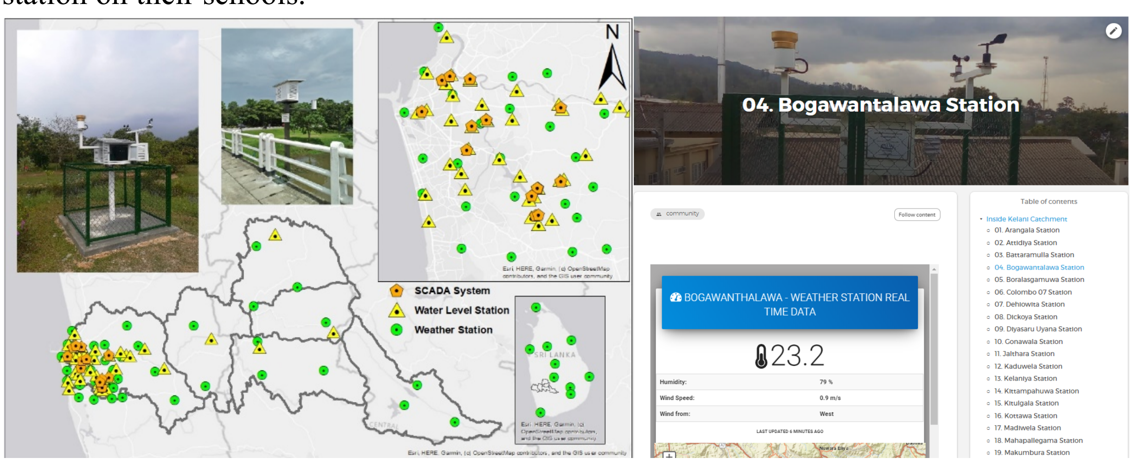
A website which is open for the stakeholders to view and download data from the CUrW is now available at http://pub.curwsl.org/.



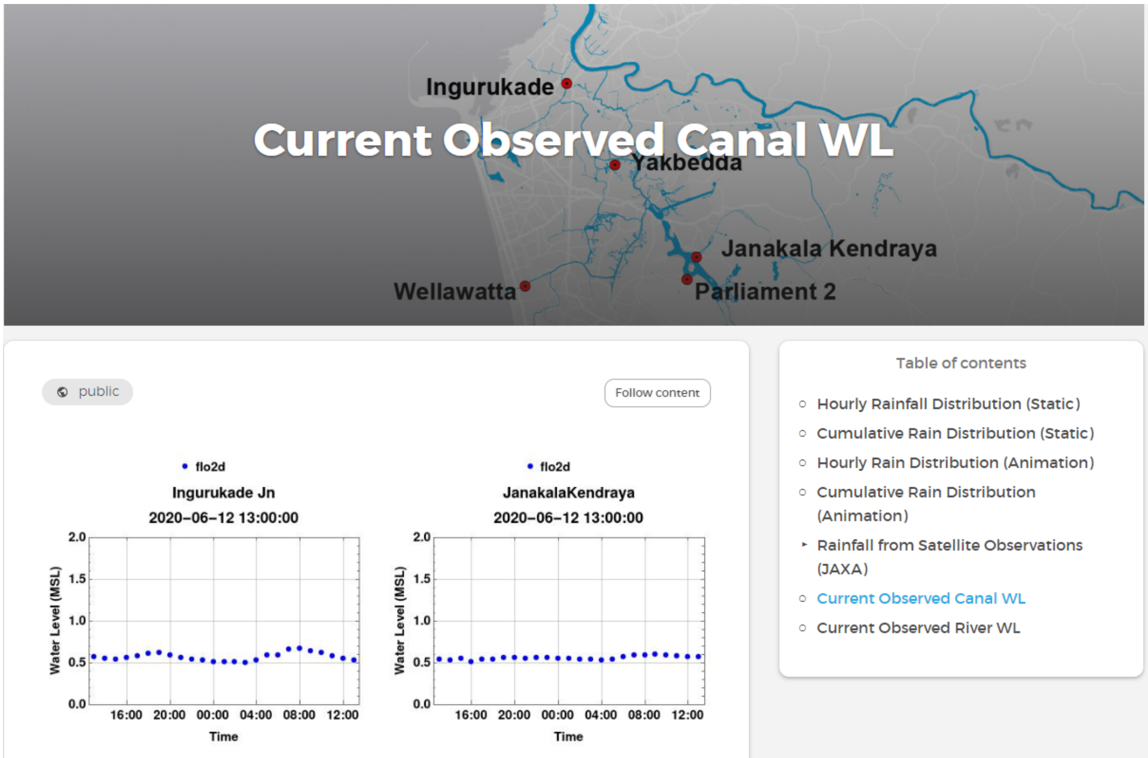
The website basically contains the following real-time information.

Observed data

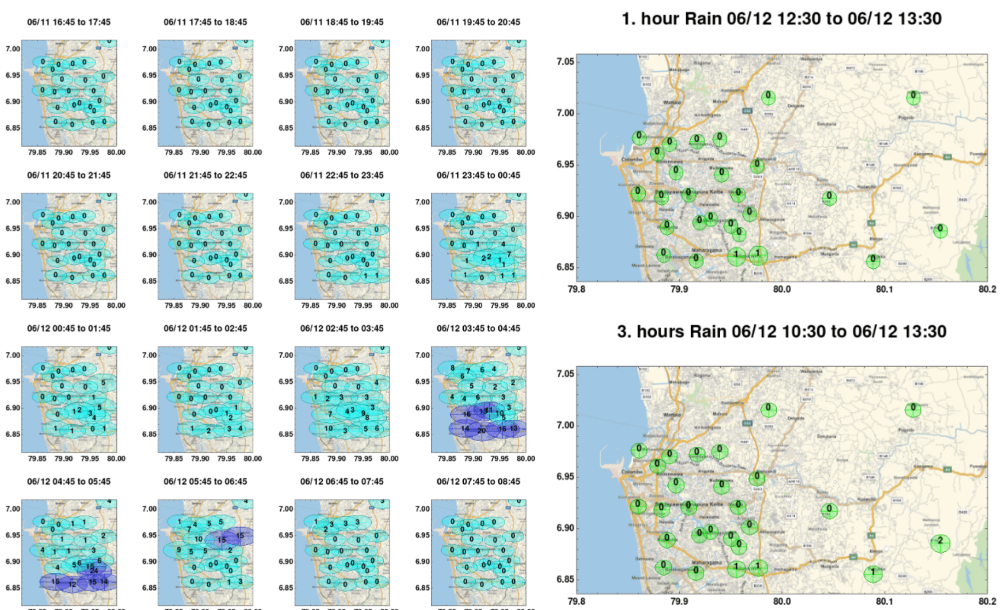
1. Observed weather (precipitation, temperature, humidity, wind directions and velocities) at 5 minutes interval at island-wide weather stations. Most of these weather stations are installed in schools, where a web link will be given to the schools to view data from the station on their schools.



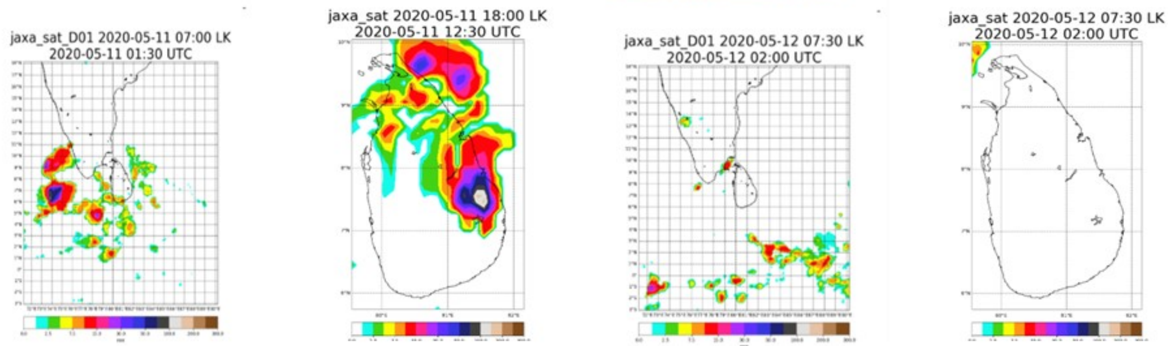
2. Observed water levels at canals and river - selected water level gauges based in Colombo (most of them covering the Kelani basin)



3. Hourly Rainfall distribution and cumulative rainfall distribution static maps for the recent 1, 3 and 6 and 24 hours

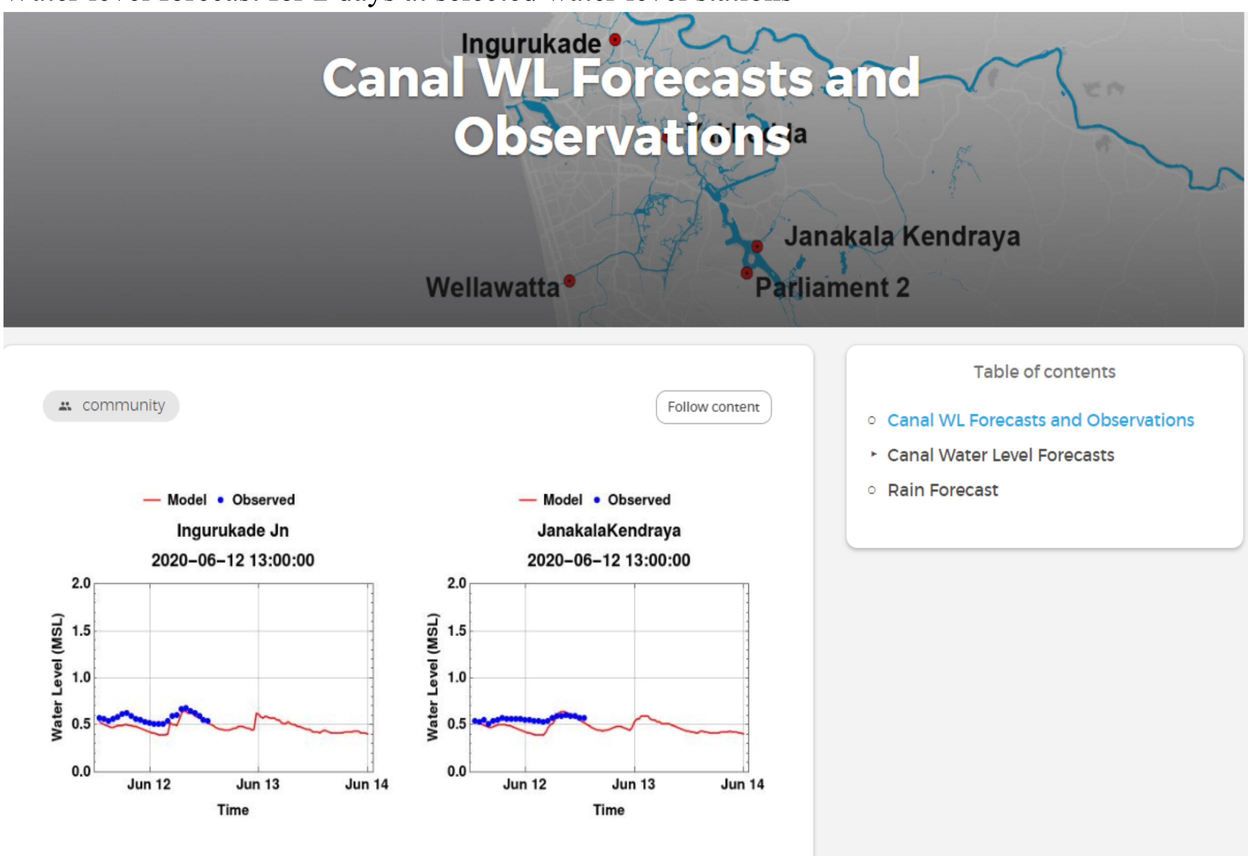


4. Hourly Rainfall distribution and cumulative rainfall distribution dynamic maps (animated) for the recent 1, 3 and 6 and 24 hours
5. Rainfall from Satellite Observations (JAXA) - dynamic maps for the regional rains and rainfall in Sri Lanka for the current date and yesterday.

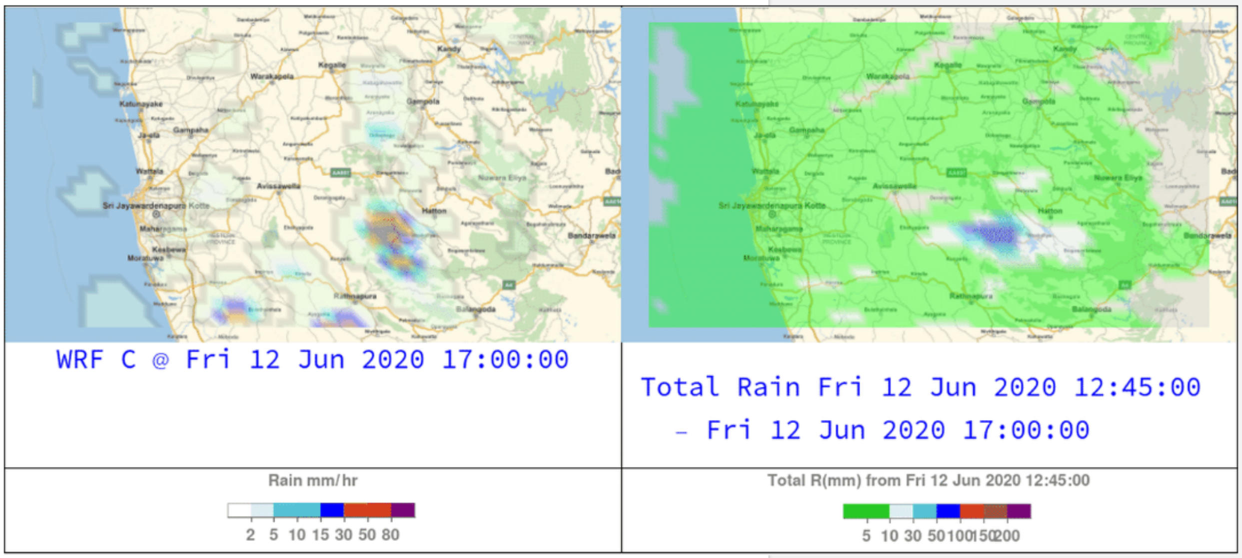


Forecasted data

6. Water level forecast for 2 days at selected water level stations

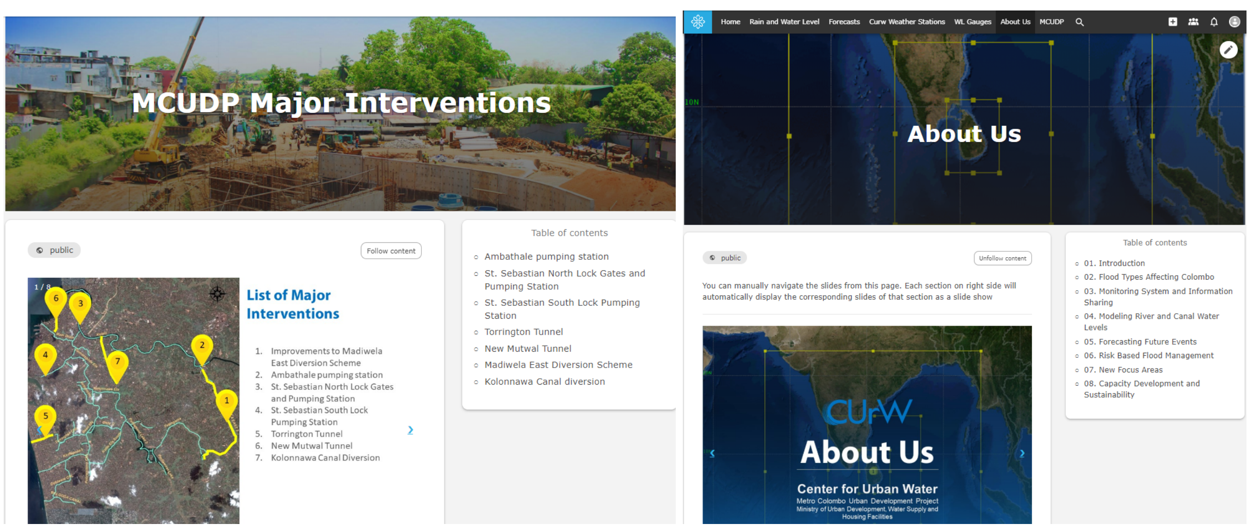


7. Rainfall forecast for the next day



It should be noted that some of these data is accessible for the registered users (which will be made available through a data dissemination agreement) while some other data is publicly available.
In addition, the website contains information about the interventions that are being carried by the MCUDP, for the flood management and flood controlling purposes.

Center Activities



Furthermore, the website contains information about the function of the CUrW, which include 8 sections starting from Introduction, Flood Types Affecting Colombo, Monitoring Systems and Information Sharing, Modeling River and Canal Water Level, Forecasting Future Events, Risk Based Flood Management, New Focus Areas, Capacity Development and Sustainability.

Furthermore, the website will contain information about the collaborations with the local universities, the school network and the industry partners, who may benefit from the data and the disseminations.

4 Other Services

The real time observations of rainfall and water levels are open and currently available to anyone who register on the system through the interface provided. A detailed exposure database has been compiled to rapidly evaluate potential flood damage to promote appropriate flood risk reduction investment. This database also include commercial exposure to facilitate pre-disaster damage and loss estimations as well.

In addition to the operational forecasts and observation data the center currently provide computational and design support for other MCUDP activities such as assessment of effectiveness of MCUDP interventions, economic justification of Pumping station at Ambathale, Micro drainage design for urban flood control (Saunders place underground storage, Tertiary drains for Torrington, Retention design using Diyasaru Uyana, etc.). In addition with the CMC we carried out urban stormwater management facility implementation design including onsite retention and infiltration systems for pilot studies. It will also provide environmental services for wetland management and landuse planning support, etc., in the future. Some of the studies carried out by the center and issued reports are on,

- Policy paper for actions to be taken to mitigate adverse impacts on water sector due to climate change
- Analysis of rainfall data and deriving IDF curves for Metro Colombo (Appendix 03)
- Design Example of Infiltration/Retention system for Urban Water Retention (Appendix 04)
- Evacuation center planning with example (Appendix 05)

5 The Center Building

The establishment of the center was approved by **cabinet paper no. 16/2143/724/085** on the 2016-10-25. The construction of the building was approved on 2017/05/02 by the cabinet decision on **paper no. 17/0819/715/011**. This approval was given after deliberation in a parliamentary committee meeting and the name for the center *Center for Urban Water* was adopted as a followup of this meeting outcome to separate the scope of activities from other institutions, especially activities of the Irrigation Department that deal with flood control in river basins.

The Center Building is an important component of the RTC design to ensure the sustainability of the institution in the long run as well as to leverage the investment in the Real Time Control Center to evolve in to an important R&D center for the country. It is very difficult to make a Flood or Disaster Early Warning System sustainable by itself. This is because they deal with high impact low frequency events, sustained support for system maintenance and continuous research and upgrading is difficult the long unused period between extreme events even though annual benefits would exceed annual required expenditure. This has been learnt through numerous failed experiences from the early cyclone shelters in Bangladesh in the 90s to Flood Early warning systems established in many Asian countries such as the Philippines, Thailand, etc. Thus, tobe sustainable, these systems should have provisions and avenues to be used in the day to day operations in the city and expand and diversify as technological centers supporting different needs of the society. CUrW was envisaged to address integrated water management, following the successful operation and implementation of the systems such as *The Dutch Flood Protection Program (DFPP)* which provides a framework for collaboration and joint operation of flood protection and regional water authorities and the *Surface Water Modeling Centre (SWMC)* of Bangladesh, etc. Its scope can expand from the current focus on Colombo Urban Storm Water management to cover the urban storm water management of the whole island. This approach has also been recommended in the chapter *Road Map for Disaster Risk Reduction* in the 2017 JICA study report ([**jica-rep-2017**]). In addition, it is very important to reduce the *Awareness Gap* about flood risks among citizens and the Center can play a vital role in bridging this gap. The public awareness raising is very important to achieve flood risk reduction in Colombo metropolitan area. The present flood control facilities depend heavily on pumping water out of the city to the Kelani River and Sea. However, due to very low gradient of the catchment the flow towards these outlet would not be adequate to sustain sufficient water levels in canals to operate the pumps continuously. Thus it will become necessary to retain storm runoff within the catchment for a short period of time to reduce the peak discharges so that the limited conveyance can manage the storm drainage without causing inundation. This storage would have to come from distributed local storages as described in the infiltration facility design outlined in Appendix 04.

Another very important need for the country is to build an eco-system where higher education and government institutions can work together in solving development challenges with the participation of the Private Sector. Thus, the Center Building has been designed to address educational needs on urban floods for citizens, educational resources for schools and as a resource and research hub for higher education, in addition to its primary function as a control center for the Colombo Flood management as a collaborative endeavor among the relevant stake holders. The concepts and experiences of Disaster Management Center of Shanghai, China, the Emergency Management Center of Queensland, Australia, the Hydro and Agro Informatics Institute (HAII), of Thailand, the Public Information dissemination video wall design of Queensland University Technology, etc., influenced the design of the Center building.

The structural and architectural designs were completed and the building is currently nearing completion. The IT components have been designed in RTC and will be funded by the world bank loan component of the project. The construction was originally expected to be completed by mid 2018, which had been continuously delayed and now the date is set up as early 2021.

The following usage of the building is planned.

1. Ground floor: Will mainly serve as a public outreach area where public can visualize current state of water in the basin, past flood mechanisms, spatial distribution of flood risks and potential losses, educational information related to urban storm water management though a video wall and other information outlets. This public utility space can be used by the SLLDC for conducting seminars on its programs and awareness raising. The concepts of video wall for dissemination is shown in Figure(20). Several potential company proposals were evaluated in setting up the video wall. After consideration of the available construction quality, options for customization and ease of future changes, it was decided to carry out the construction and implementation as a direct supervision project and necessary procurement to be carried out for the study through the University of

Moratuwa, as was done for the real time monitoring equipment. The designs were carried out and screens and software are under procurement through the University, Ground floor will also provide facilities for emergency operation units, servicing areas for monitoring equipment and other facilities.

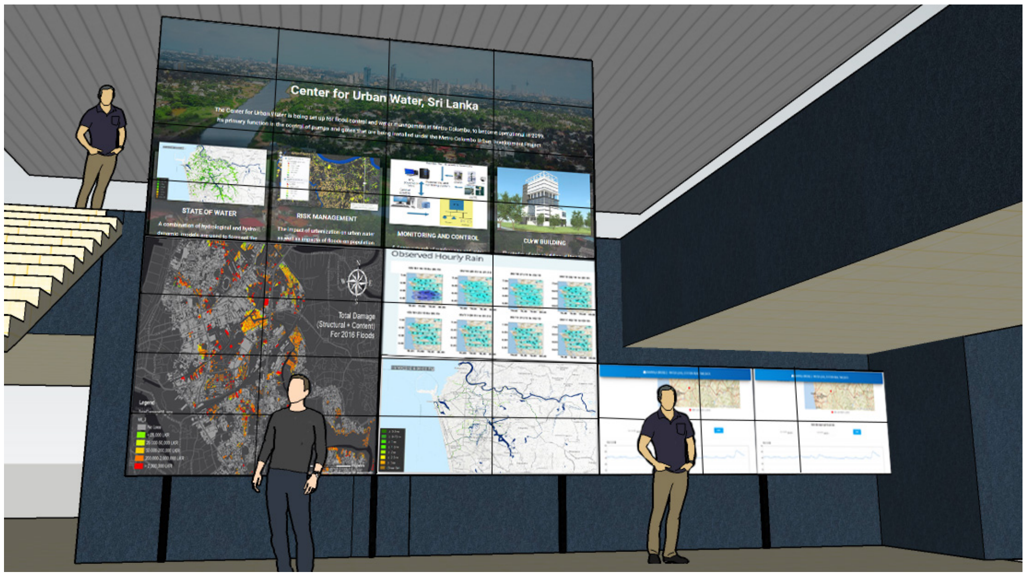
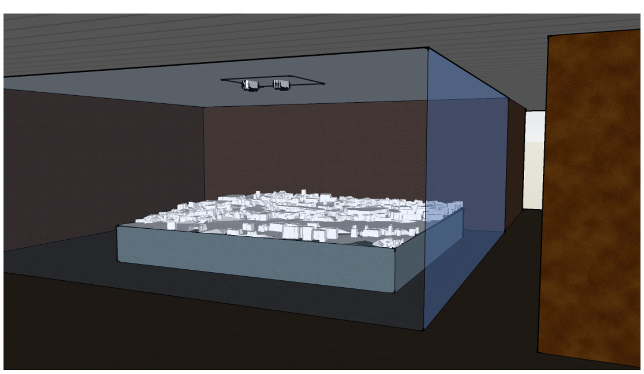


Fig. 20: Ground Floor proposed Public Video Wall

2. The reception will be located in the 1^{st} floor together with facilities to distributed data obtained from monitoring stations for the public. The main component located in the 1^{st} floor will be a physical model that will shown a 3D rendering of historical floods, possible future flood scenarios and impacts or effects of intervention measures. It is planned to achieve this by projecting the simulated or reconstructed video streams on a 3D rendering of the Colombo basin. The conceptual installation in the first floor is shown in Figure(21). The Figure(22a) shows the close up of 3D model planned to be printed using 3D printers, which also can be used to print maintenance components for the monitoring stations. A trail print of part of the basin around the parliament lake was carried out using a personal 3D printer as shown in Figure(22b)and testing of projection methodology has been carried out. The floor is expected to be used by schools and public. Currently 33 weather stations are placed in school premises that will be connected with fiberoptic lines that would also facilitate joint programs with the education sector as an important segment of society to promote disaster awareness and a resilient community.

3. 2^{nd} Floor will serve as the main control floor with data integration room, small precision temperature controlled unit for central SCADA, backup system and data archiving, decision making room and conferencing facilities. The main facilities of the floor are the information dissemination and conferencing facilities to be used in emergency situations or joint projects with stake holders. It will have two video walls, one for the information generated within and another for streaming information such as from TV and other real time monitoring with IP cameras as shown in Figure(23). The video wall frame design

Fig. 21: 1^{st} floor view of proposed 3D model for flood scenario projection



(a) 3D model

(b) A sample 3D print

has been carried out and is expected to be constructed at the Univeristy of Moratuwa, mechanical engineering workshop.

The remaining are of the floor, which constitute about half of the area, will be occupied by the Center staff and seconded officers from stakeholder communities engaged in development, maintenance and management of the center. The floor also has high level conferencing facilities for managing emergency situations. It is advised to get the services of professional emergency management service providers to come and conduct a few sessions on logistic management and effective information utilization in managing extremes. The emergency management center of Queensland, Australia has expressed willingness to conduct such training in Sri Lanka for the stakeholder organzations who would be using the Center facilities for flood risk reduction.

Fig. 23: 2^{nd} floor proposed video walls

4. $3^r d$ floor will provide facilities for environmental services that can be provided by partner institutions mainly focusing on dynamic real time data integration of weather/climate and water sector with other information such as transportation sector, tourism, etc. Its design was inspired by *Innovation Centers* established in various prefectures in Japan by local and central government to promote innovation and trans disciplinary collaboration. It is expected that private sector, universities both local and foreign would lease space to set up either long term or short term offices in this floor. The center can also engage in projects and programs utilizing its technical capacity and the information generated. For example, the emergency management center in Queensland, Australia, successfully bid and conducted organizational aspects of Commonwealth games held in Queensland.

   A test was carried out on such outreach activities during the initial lockdown period due to Covid-19 during the months of March and April 2020. Within the first week CUrW staff developed a real time Covid-19 situation tracker as shown in Figure(24) that was updated with real time data every hour. It was extended to contain neighborhood information a number of service categories as shown in Figures(25a, 25b and 25c). This database covered whole island. We also discussed with our private sector partners if these services can be extended to support back office analysis for essential services, but did not follow as that would deviate from our current function. However, this exercise demonstrated the numerous areas the center can rapidly mobilize resources and contribute technically to address issues of national interest.

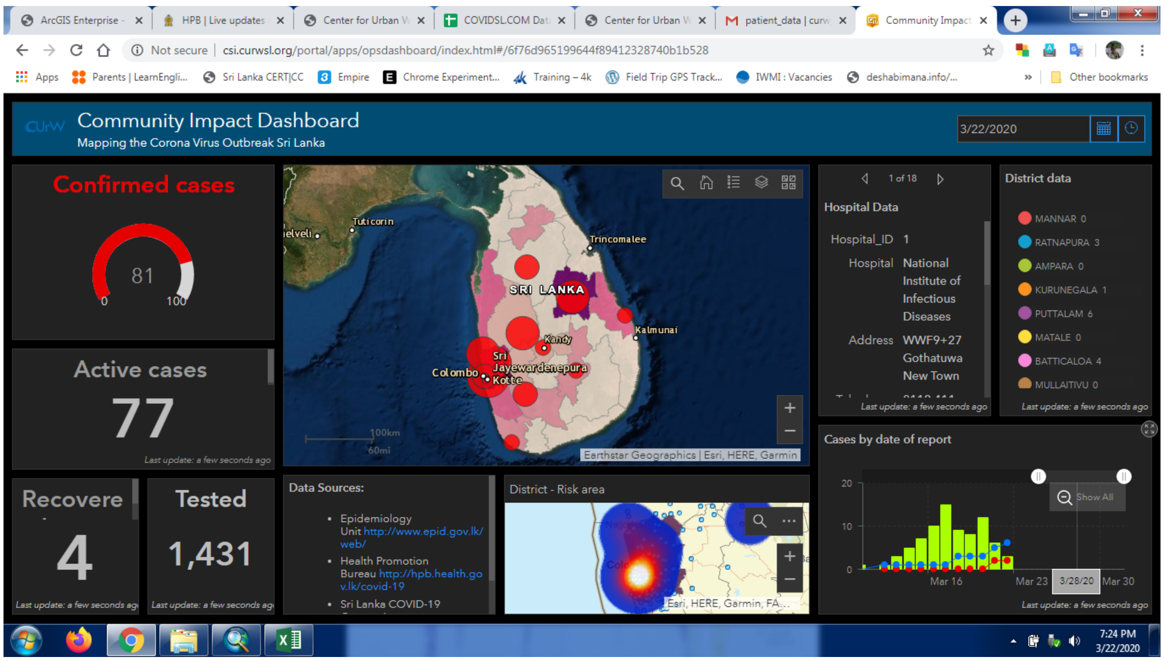
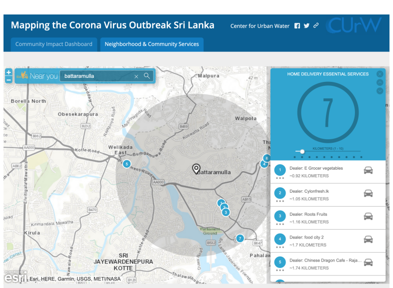
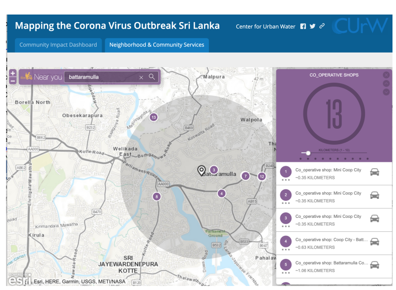


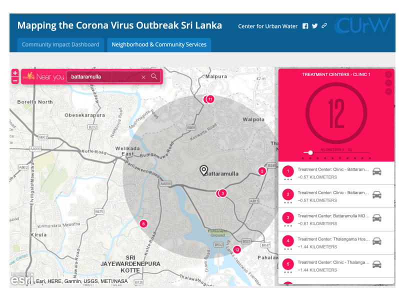
Fig. 24: Dashboard developed for realtime tracking of Covid-19 situation in Sri Lanka, March 20



(a) Neighborhood homedelivery services



(b) Neighborhood cooperatives



(c) Neighborhood treatment services

5. 4^th floor is reserved as a Research and Development floor, where researchers seconded from government institutions, postgraduate students from Universities in Sri Lanka as well as from abroad can study problems related to development and urban environment to

propose sustainable solutions. This floor will also be utilized for administrative activities, especially for enforcing policies related to urban drainage in partnership with Colombo Municipal Council and other relevant stakeholder organizations.

The detailed description of the building components related related to real time control is describe in the tender document of ITC services for the building. This is in tender at present.

6 Pending Major Works

Due to various disruptions in the country, elections and the Covid-19 situation, the project has been extended beyond the original planned date of June 2019. Thus the completion of pumping stations, gates are delayed and procurement related to CUrW has been delayed over more than a year in many cases and the relevant work has not completed. Accordingly a modified work schedule to complete CUrW program by December, 2020 has been submitted to the progress review meeting held in 2019 October. Later this was modified to accommodate delays due to Covid-19 situation to complete by 2021 June taking into consideration the delays expected in the completion of the building and the pumping station. The period from June 2021 to December 2021 was set aside as operational fine tuning and complete handover to SLLDC and the team who would carry out future operations. This modified program was prepared for the meeting held in the ministry in June, 2020. The main pending works are described below.

6.1 Pumping Strategies

There are two major components of the project that need special attention. One of them is the development of rules for the operation of pumping stations. This because of the low conveyance of the system, the pumping operations based only on local water levels would not be adequate to ensure the best strategy to reduce flood risk. Furthermore gravity discharge can be nearly as high as the combined pumping strength of all the pumps, thus it is important to let gravity discharge continue till it become less than the pumping capacity at which points the gates to the Kelani river are to be closed and pumping can start. The most effective pumping strategies are determined as the scheme that result in the least number of persons affected and the highest economic damage reduction.

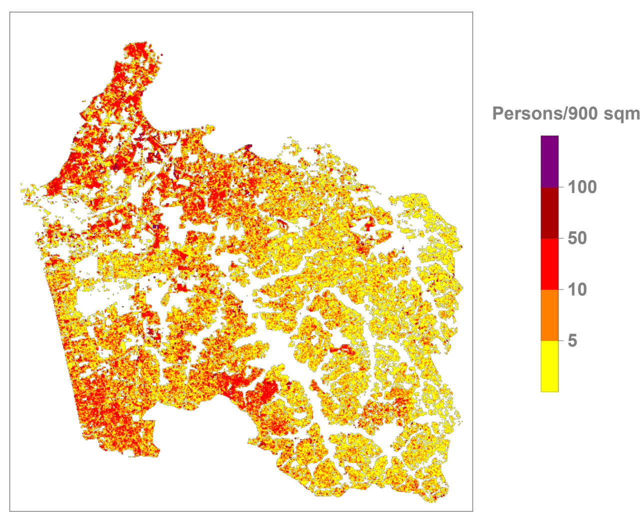


Fig. 26: Distribution of night time population estimated from census data and building footprint

The population distribution map for the project area is shown in figure(26). This distribution was made by developing an equation to distribute each GN division population among 9 different types of buildings using the the building footprint for the city. Population at risk is estimated as the inundation area above 50 cm water level multiplied by the population distribution at 30 m grids. The index of 50 cm was taken after comparing simulation results with past flood affected population figures from the Disaster Management Center. Figure (27) shows the comparison of model estimation of affected buildings compared to the affected population figures from DMC for the 2016 floods.

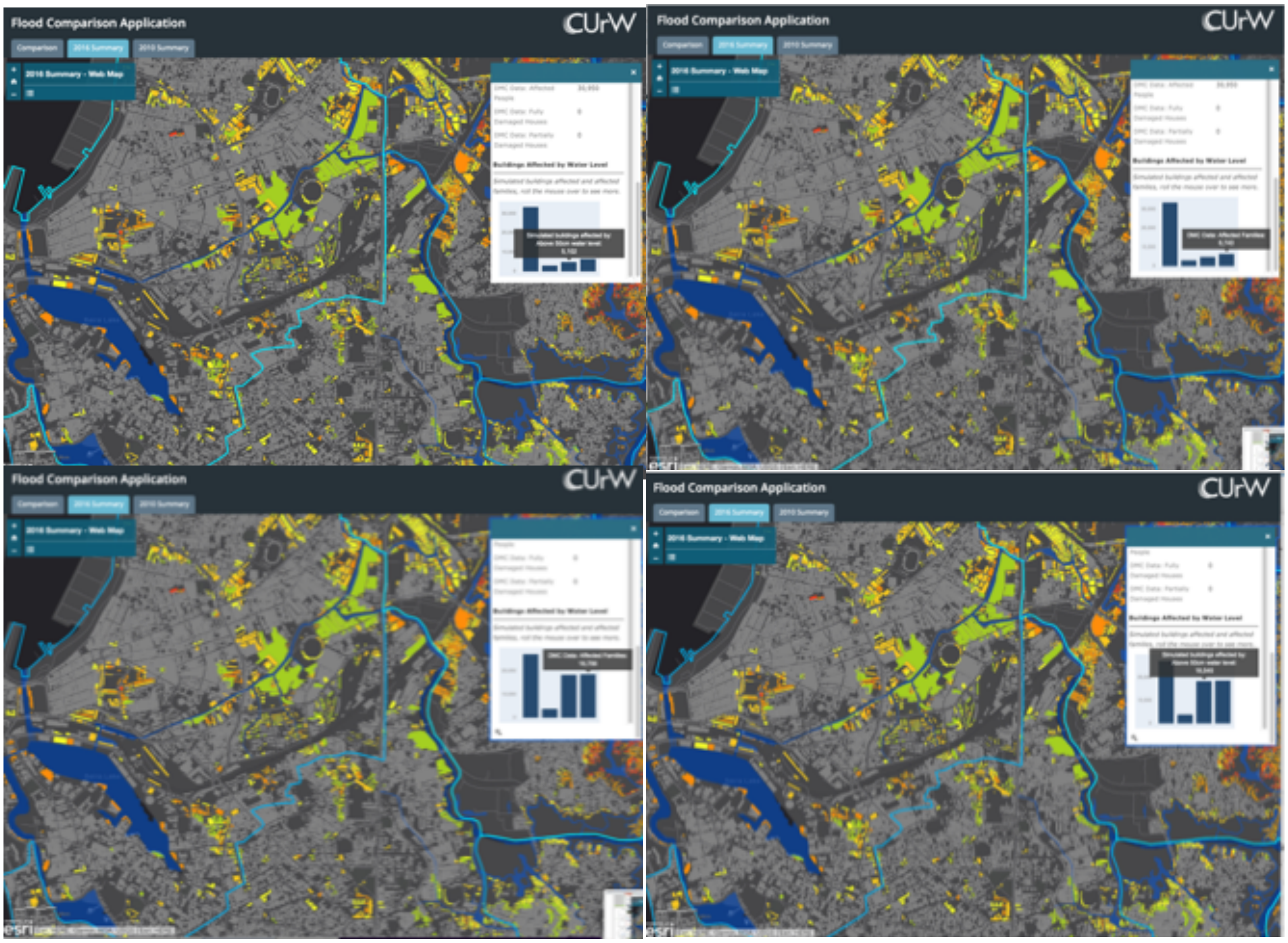


Fig. 27: Comparison of model estimation of affected population with DMC statistics for 2 districts

The methodology adopted for economic impact assessment is described in Annex System Development Process, section on Economic Exposure Assessment(Figures(4-6)).

The pumps in each station is grouped into low capacity, medium capacity and full capacity and simulations are carried out for different design rainfall frequencies to derive the basic guiding principles of pump operation. In real time operation, the most appropriate schemes from the pre-configurations will be tested with the rain fields generated for the current conditions. The impact assessment routines are already in operation to make this estimation within the hourly work-loop of the operational hydrodynamic forecast. The system and methodologies also can be used to estimate the economic benefits of any new intervention proposals including those for local (micro-drainage) flood prevention measures. The system provides many additional information as shown in Figure(28) that can be used in flood risk reduction.

Also the annual benefit curve shows that SLPS can be as efficient as the NLPS at high frequency, low magnitude events (Figure(28)). Therefore the pumping operations can be made very effective by combining with the forecasting system that model the whole system and select the best pumping strategy that minimize the impact on people and property. The framework for this is done and now simulations need to be carried out for various scenarios to develop pumping strategies that can be used for a given scenario. Currently three engineers are allocated for this work. The actual operational conditions, such as time required to close gates, starting up pumps, etc., needed to be included in the decision making process.

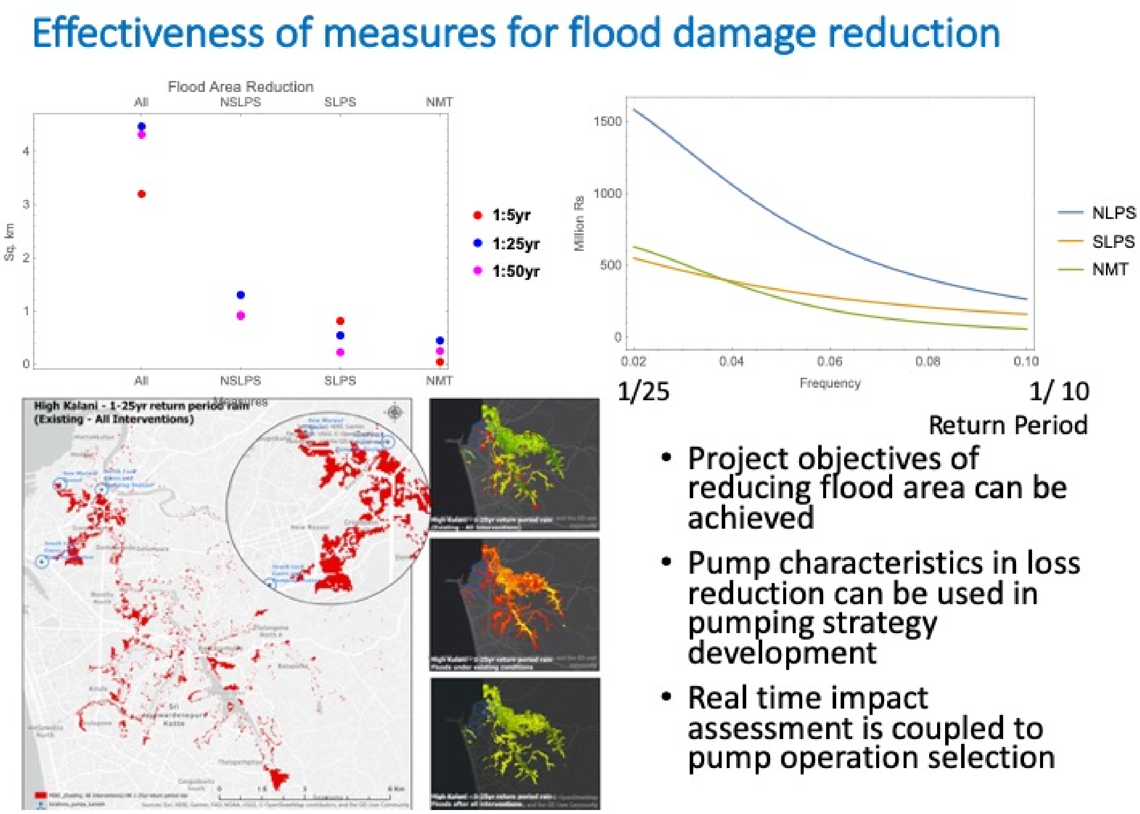


Fig. 28: Inundation area reduction and performance characteristics of individual measures

6.2 X-band Radar

X band radar is in tender stage at present. It has two main purposes.

1. Operation of small wetland storages to store storm water. If the storm water is stored from the beginning of an event, the storages will be filled up and not be effective in holding the peak discharge that cause inundation. Thus there has to be continuous pumping of small storages to keep them empty and use it only to capture the peak discharges. Simulating this has been done already using past data. To be effective the precipitable

water quantity need to be estimated accurately in advance. X band radar is to be procured for this purpose.

2. Recently there had been many occasions of torrential rainfalls occurring in a short period of time that overwhelm urban communities. These are some times alled *guerrilla rains* and cause injuries or even deaths in urban communities. It has been shown that x-band radar can detect the evolution of these rain cells that lead to sudden downpours and can be used for early warning purposes. This activity is also part of the original TOR of the RTC and a X-band radar can support flood early warning to a much precise level than that can be provided by corrected numerical models.

In addition, X-band radars are complimentary to C-band radar sets and will fit well with the C-band radar that will be installed in Sri Lanka through a JICA project in the near future.

7 Future Directions

The current flood control approach to Colombo depends heavily on pumping out water from the outlets or removing water through two tunnels to sea. However, given the extremely low surface gradients the conveyance cannot be improved beyond a certain level as the storm water runoff in the middle part of the basin cannot be sucked out from the outlets given the low hydraulic gradient that can be achieved in the canal system. Thus, in the implementation of IFMS, much emphasis was placed on orecasting rainfall in advance and emptying storages in central water bodies so that they can store runoff till the peak rain intensities pass. Simulations has shown that keeping water levels at 0.3 m can greatly reduce the flood peaks and inundation areas. However, keeping water levels at a low elevation continuously may affect ecology in and around wetlands and also would have implication on aesthetic appeal of river front environment. Thus pumping may be carried out in advance to achieve low water levels in water bodies prior to expected heavy rains forecasted from numerical simulations.

In the long term, in order to reduce flood risk from macro drainage system as well as reduce local flooding it is necessary to enhance the storage capacity within the basin so that a considerable portion of storm water runoff can be stored within the basin to support conveyance based water removal. Optimal conjunctive use of both surface water retention within the catchment and removal from conveyance improvement should be the guiding flood control management policy.

In addition to operations during the extreme events, CUrW has an important role to play in improving the quality of life in the city. Cleaning canals using flushing gates, water quality management supporting the wetland strategy is one of the main objectives the center is working on.

A third component of the center's contribution to improving city life would be in providing appropriate information to business sector so that quality of life can be improved is the third area CUrW can work on. Food choices, traveling, outdoor activities and sports are greatly affected by micro climate. Climatic information and forecasts are utilized by the business sector in many developed countries to customize their services. The third floor of the Center building was designed as an area for innovation and business application to promote use of environmental information to analyze environmental conditions and improve services and develop projects based on the environmental information generated by the center.

Therefore the important future directions for the center, in addition to operation and management of flood control facilities would be,

1. Increasing surface retention storage in the catchment and use that for flood control
2. Improving water quality in the canal system and support wetland management and improving water quality in the water bodies and canals
3. Provide information and support new environmental services and businesses

7.1 Increasing surface water retention capacity

Utilization of available surface storage capacities effectively as well as creating new storage facilities should be considered. In the center three designs were carried out to demonstrate the possibiltles. These storage facilities cover three different spacial scales as large, medium and local. One important characteristic of such storage utilization is that nearly flat terrain of low elevation, it is not possible to create large storage facilities for storm water runoff. Thus the common characteristic of all these facilities is the utilization of the available storage volumes to store only the storm discharges that exceed the capacity of existing conveyance drainage capacity. The following designs were carried out in each category and the detailed methodology and design reports are available in the center.

Macro Systems: Use of Wetlands It is proposed to use existing wetlands effectively to store stormwater runoff using gates and pumps where necessary through Central SCADA control. A design study is carried out for the use of Diyasaru Uyana (above the Parliament lake) as an emergency storage. In order to use the storage volume to capture only the storm water drainage that exceed the canal conveyance capacity below the parliament lake, the inflow into the Diyasaru Uyana is pumped out to the Palirament Lake. To prevent water inflow to the wetland a gate is used and the gate and two pumps to be provided will be operated through the Central SCADA system. The details are available also in the Center Website page pub.curwsl.org/diyasaru.

Large Scale Storage Systems Underground storages are commonly used in many urbanized and rapidly urbanizing major cities in Asia to temporarily store storm water drainage. The peak discharges usually last only a short time period and if that discharge is to be accommodated in micro drainage network, very large canal cross sections have to be used. However if this peak volume can be retained for a short time usually, usually a few hours, the existing drainage system can cope up with the drainage demand. An underground storage device of 6000 m^3 has been proposed under the Saunders soccer field to prevent flooding near the bus stand. The proposal and its impacts are also available in the website at pub.curwsl.org/saunders. A guiding design and ToR for the project were prepared and funding secured, but could not be implemented due to opposition from the soccer team for the request to temporarily close the soccer ground during the construction period.

Local Storage Systems The locations where Large Scale Storage systems can be established under ground will be limited to a number of special cases only where the other drainage solutions are not viable. This is mainly due to the high ground water levels in the city which would require water proofing of underground structures to prevent ground water seeping in and filling up the storage space. On the other hand it would be more practical to implement a policy of managing storm water drainage excess locally at the places of new urban development. Following discussions with the CMC engineers, a proposal to make local storm water management mandatory was developed. As per the guidelines developed all medium to large scale developers are required to retain excess storm water produced on site. They would be allowed to discharge storm water equivalent to the peak runoff at 0.3 runoff coefficient corresponding to 1:5 year return rainfall. The capacity to retain maximum discharge resulting from 1:5 year rainfall and this allowed discharge should be built into the development system in order to receive CFC from CMC. A design for such installation was developed for a 5 story residential complex in Edmonton place, Colombo 5 as an example. This is attached as Annex 05

7.2 Improving water quality in the canal system

One of the functions of the center is to implement a program of cleaning canal system with water pumped from Kelani River in to the canal system using the reverse pumping gates of North Lock. A comprehensive program with three components was launched to achieve this objective as follows;

Monitoring There had been a water quality monitoring program in Canal Network in Greater Colombo basin at 20 locations covering 10 Parameters observed Monthly from 1997 by SLLDC under 'Greater Colombo Flood Control & Environmental Improvement Project. The parameters used in the previous program are BOD, COD, DO, Nitrate, Phosphate, Ammonia, pH, Conductivity, Turbidity and Temperature. Under the CUrW program it is planned to monitor the following parameters;

Physical: pH, EC, turbidity, conductivity, salinity, temperature

Chemical: Nitrate, Nitrite, ammonia, total phosphate, COD, BOD, total organic carbon, TDS, calcium, magnesium, sodium, potassium, chlorides, sulphates, fluorides, heavy metals (Cd, Pb, Cu, As, Zn, Mn), pesticides, organic micro-pollutants, PAH

Microbiological: E.coli, plankton dynamics, coliforms, pathogens

Modeling A Volume and Concentration Based Analysis and Design program is set up at the Center that will carry out water quality modeling carrying out continuous simulation parallel to Hydrodynamic modeling. The model will update initial conditions from observations to optimize and calibrate using real time and historical data. These simulations will also help to detect polluters when observations deviate from expected concentrations. Thus real time data collection and archiving similar to water levels and rainfall monitoring is a fundamental component of the program.

Under the present plan CUrW will initially start monitoring at 10 locations out of which 6 match with the previous monitoring stations. The selection of the monitoring stations have been decided based on the importance of locations, their inflow coverage by existing monitoring and modeling tools and the ease of automated water quality monitoring using CUrW's third communication network. This communication network, The

Things Network use Long Range low power wireless communication platform that use radio frequencies for communication. This is described more fully in the next section.

Colombo Canal System Cleaning Program This program consist of the following sub components:

- Integrated Canal Monitoring, Modeling & Maintenance Program: Derive flushing gate operation and scheme and program the central SCADA system to operate and monitor flushing operations.
- Wetland Management: Lias with wetland management program providing it with wetland water quality updates as well as on canal conditions to support canal transport as well as city amenity.
- Pollution Control & Policy Making with related Authorities and detection of potential polluters based on deviation/changes to water quality
- Collaboration with Line Agencies / Organizations by exchanging information and developing support service programs

7.3 Provide information and support new environmental services and businesses

Supporting new services and businesses using environmental information is also one objective of the center. The third floor of the new building is expected to serve as a venue for this collaboration among academia, government and private sector evolving into a platform for innovation and incubation of new projects.

In order to support collection of new and additional information a scalable third network is being setup in addition to fiberoptic and cellular networks used for collection and transmission of weather and water level data. This network, The Things Network (TTN), is planned as a redundant network for The Center for Urban Water. It is an additional networking capability which can be used in the event of failure to use the global internet due to unavoidable circumstances which would disrupt the fiber optic based information collection and dissemination and also may affect the cellular network at such an occasion. The Things industries is a full-service Internet of Things (IoT) network specializing in LoRaWAN M2M communication. Where, LoRaWAN is the standard protocol for Wide Area Network (WAN) communications and LoRa is used as a wide area network technology. Further, LoRa is a long range, low power wireless platform where communication medium is based on radio frequency. There are 10 base stations in the Things Network and each base station can handle up to around 1000 nodes on radio wave communication.

7.3.1 Planned application overview

In the initial stage Center will be using TTN's cloud host platform to route real time data to Center's servers, later it will be self-hosted locally. This is an independent network that will relay a subset of following real time monitored data covered by the two regular networks,

- Rainfall

- Water levels

In addition it will be the sole carrier for the following real time monitoring data

- Water Quality
- Traffic Monitoring

As the last step, TTN architecture will be further designed for ad-hoc communication. Where, base station to base station communication will take place making the TTN a highly disaster resilient communication network.

Collaborations with local universities

CUrW recruits fresh graduates from local universities for capacity development of the local professionals. Staff can get enrolled for Masters degrees in either University of Moratuwa or University of Peradeniya while following research work at CUrW. Also the Internship programs and collaborative research work with undergraduates help to improve the skills of future professionals.

List of Staff members who are enrolled in a Master's Programme in University of Moratuwa or University of Peradeniya

Present Members

Staff Member	Institution	Department	Master's thesis title
Hasitha Adhikari	**University of Moratuwa**	Department of Computer Science	An Automated Framework For Weather-Related Decision Making
Shadhini Jayathilaka		Department of Computer Science	Information Collaboration Platform for Weather related Data
Supun Kulathunga		Department of Civil Engineering	Water resources engineering and management (Course title)
Chinthana Rajapaksha		Department of Civil Engineering	Water resources engineering and management (Course title)
Muditha Dantanarayana	**University of Peradeniya**	Department of Civil Engineering	Improving storm forecasting in the Kelani river basin using WRF
Asanka Weerasinghe		Department of Civil Engineering	Flood early warning system for metro Colombo incorporating both macro drainage and micro drainage system

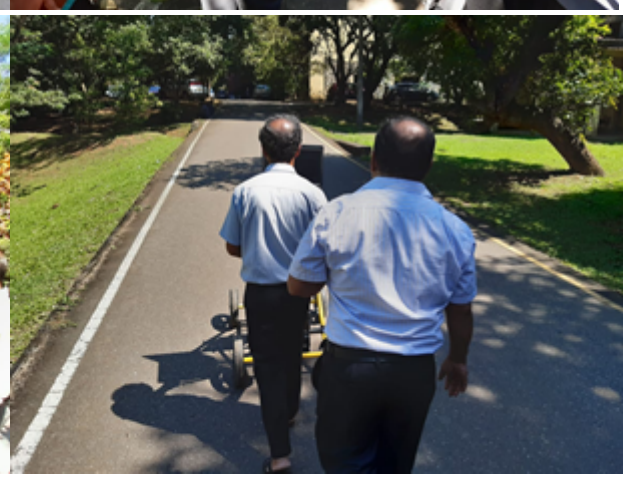
Past Members

Staff Member	Institution	Department
Gihan Karunathilaka	**University of Moratuwa**	Department of Computer Science
Niranda Perera		Department of Computer Science
Thilina Madumal		Department of Computer Science
Niluka Munasinghe		Department of Civil Engineering
Piyumi Weerasinghe	**University of Peradeniya**	Department of Civil Engineering
Lahiru Lindamulla		Department of Civil Engineering
Thrishan Hettiarachchi		Department of Civil Engineering

Collaboration with University of Moratuwa

Center for Urban Water has been collaborating with the University of Moratuwa for the following tasks, apart from the university's role in project administration. In the year of 2019, the Department of Earth Resource Engineering held a workshop for the CUrW staff, in the topic of 'Ground Penetrating Radar' (GPR) equipment. The workshop covered the fundamentals of the GPR working mechanism, working bandwidths and their respective responses, capabilities and limitations and the specifications of the existing GPR resources followed by the hand-in experiences in maneuvering a GPR equipment and its utilization to identify the objects underneath the ground.



In addition, 5 internships from CUrW were offered to 5 interns from the Department of Earth Resource Engineering of the University of Moratuwa were placed in CUrW, for their industrial training which commenced on 24th June 2019 and continued until 6th December 2019. In the training period, the interns were able to gain experiences in Geographic Information Systems (GIS), on many aspects such as data insertion and validation, georeferencing, 3d modelling the buildings. In addition, they were able to gain experiences on water flow measurements using the state of the art equipment, developing an app to insert the collected date in-situ to update in to a database, finding correlations for the real time responses of the routine metro Colombo for the utilization of water, roads, workplaces and schools etc. Furthermore, they played a major role in the formation of the display systems for the newly built Real-Time-Flood-Controlling center.

Their major outputs in their time of internship, can be described as the web portals for the canal and cross section databases, verified building layer for the Colombo area, developed application for entering the measurement data to the database, proposals for the display systems of the RTC center and the earth/response simulators, which are meant to showcase the routine responses of the people in Colombo. In the end of the internship program, a workshop (short-course) was organized for the benefit of the interns alongside the staff of the CUrW, on the theme of "UAV advanced mapping and applications" which was held in the University of Peradeniya, on the very last 2 days of their internship.

Collaboration with University of Peradeniya

<u>Master's program</u>

Civil Engineering Department of the Faculty of Engineering, University of Peradeniya hosts Masters programs, where eligible staff members at CUrW could enroll under the Environment and Water Engineering Master's program. This adds value to the research based studies carried out at CUrW which can be published as the required research work to fulfill the Master's degree.

Upto now 5 staff members have enrolled in this program and 3 members have already completed their Master's Degree.

a. Lahiru Lindamula
b. Thrishan Hettiarachchi
c. Muditha Dantanarayana
d. Asanka Weerasinghe
e. Piyumi Weerasinghe

2.2.2. Workshop on Hydrological modeling

Center for Urban Water, Sri Lanka (CUrW) in partnership of NORAD WASO Asia Project at Civil Engineering Department, Faculty of Engineering, University of Peradeniya conducted a two-day workshop from 28th of February, 2019 to 1st of March, 2019 to promote discussion among Computer Science, Communication and Civil Engineering specialists on collaboration for Urban Water Management problems, which includes a seminar conducted by field professionals and researchers followed by a field visit to Polgolla Dam Safety Monitoring station and Victoria Dam SCADA control center which is under the Mahaweli Authority of Sri Lanka (MASL).



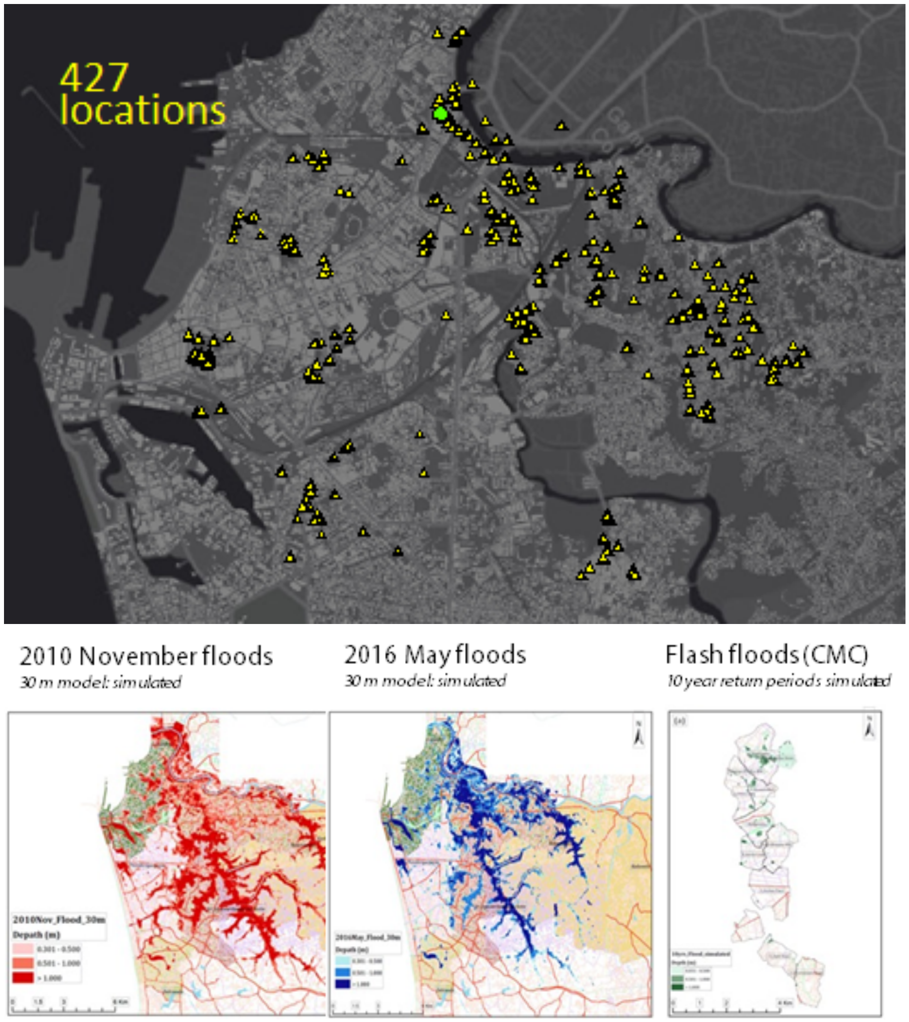
Short Course on UAV Advanced Mapping and Applications

Postgraduate Institute of Science (PGIS), University of Peradeniya conducted a 2-day short course on UAV Advanced Mapping and Applications, for the staff members of CUrW and representatives from related organizations. Program included an Introduction for UAV, Advanced Flight Planning and Management, Image Acquisition and Data Processing, Global Navigation Satellite System and Internet of Things applications in Aerial Remote Sensing. Participants were able learn about the principles of UAV, its system components and different applications, establishing precise GCP's by DGPS, performing UAV Image acquisition, UAV data processing and products generation for earth observation and 3D mapping, designing the flight plan of UAV for different types of applications and integration of Aerial Remote Sensing, IoT and other sensor data for modelling and analytics.


Collaboration with University of Ruhuna

Internships

14 interns from the Department of Civil Engineering, University of Ruhuna were placed in CUrW in the first quarter of 2019. In the first part of their internship period, they were trained to model local flooding situations in 10 m resolution models, which enabled them to identify the flooded building locations in Colombo. Next, with the aid of the modelled flood results of the 14 locations chosen, they were directed to do an economic exposure survey, by visiting the flood affected buildings and collecting the data on structural and content damages occurred for the past flood events. For the data collection purpose, inhouse customized Survery-123 app was used.



In this economic exposure survey, more than 400 places were visited to collect data, and data attributes such as GPS coordinates (using the mobile phones), name of the institution, address of the institution, type of the industry, name of the owner and contact details (telephone/email), number of employees, approximate floor area used by the institution etc. were attempted to collect.


i-Dine

Individual research projects and comprehensive design projects of the final year students of University of Ruhuna

Below tabulated are the research topics and the respective individuals of the collaboration. CUrW team leader was a co-supervisor of each of the project, and center staff assistance alongside with other resources was made available for researchers whenever required.

Name	**Title**
Harshana K.A.M.	Study the management of wetland water storage in purview of flood mitigation; A case study at Diyasaru Park, Colombo.
Kavindra Lewkebandara	Kelani river basin water resources analysis to optimize hydropower reservoir operations.
Kushan W.L.M.	Establishment of flood damage estimation model to evaluate economic and lifeline losses.
Samarakoon K.R.M.R.A.	Study on onsite water management in urban areas to mitigate flash floods
Tharika J.A.D.S.	Evaluation of storm water drainage options with respect to national policy making; case study for Galle municipal area

In addition, a Comprehensive Design Project (CDP) was assisted by the SLLDC and CUrW, of which the intention was to obtain the bathymetric profiles of the Diyasaru Wetland park, in order to propose a multi-purpose development for the park. Explicitly, the CDP title was 'Development of a master plan to convert Diyasaru park into sustainable wetland'. This CDP was conducted by 6 engineering undergraduates (final year) of the University of Ruhuna.

System Development Process

Monitoring
- Weather stations
- Water level stations
- Maintenance of Rain Gauges and Weather Stations
- Obtaining canal discharge measurements using the ADCP equipment

Modeling System
- Rainfall forecasting
- Flood Forecasting and Inundation Modelling

Computational Environment
- Integration of observed data and forecasted data into CUrW system

Economic Exposure Assessment

Monitoring

In first phase of real time monitoring, deployment three types of devices, (a) weather stations that measure rainfall and other weather parameters (b) Rain gauges that measure only rainfall and (c) water level sensors using both radar and ultra-sonic devices was carried out. The figure shows different installations by various vendors which started in July 2017. Performance of these instruments were evaluated to prepare specifications for an accurate and reliable monitoring system.

Figure 2: Snapshots of installations in the first phase

Weather stations

CUrW has been working its way to install the permanent weather stations to cover the whole island, including the Metro Colombo Urban Development Project (MCUDP) area. The installation work of the weather stations is reaching its completion, having more than 96% of the planned stations already being installed. Most of these weather stations are situated in schools and now the real time data is being reported to the center's servers. The center will need another one month of time to complete the rest of the installations, with the existing conditions.

The locations of the weather stations are shown in the Figure 3.

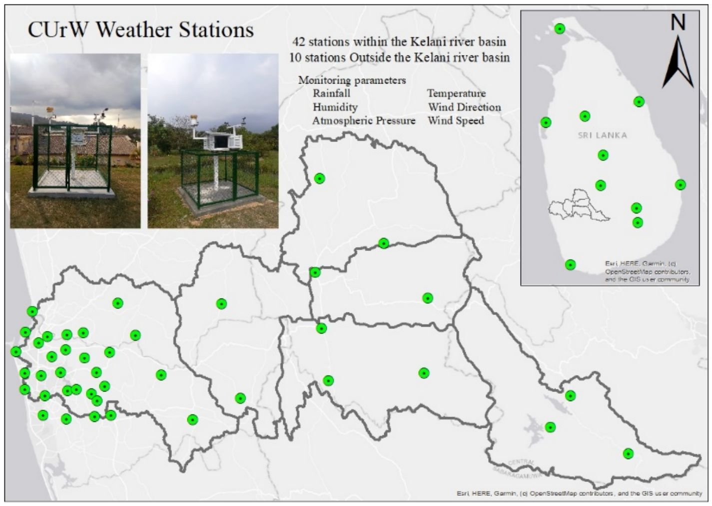


Figure 3: Locations of the weather stations

Some snaps from the weather stations at the schools are shown in Figure 4.

Figure 4: Installed weather stations at schools

In addition, the data summaries and historical data are being displayed in the CUrW website as shown in Figure 5 and 6, which is accessible to the public. The links to access the public website is pub.curwsl.org.

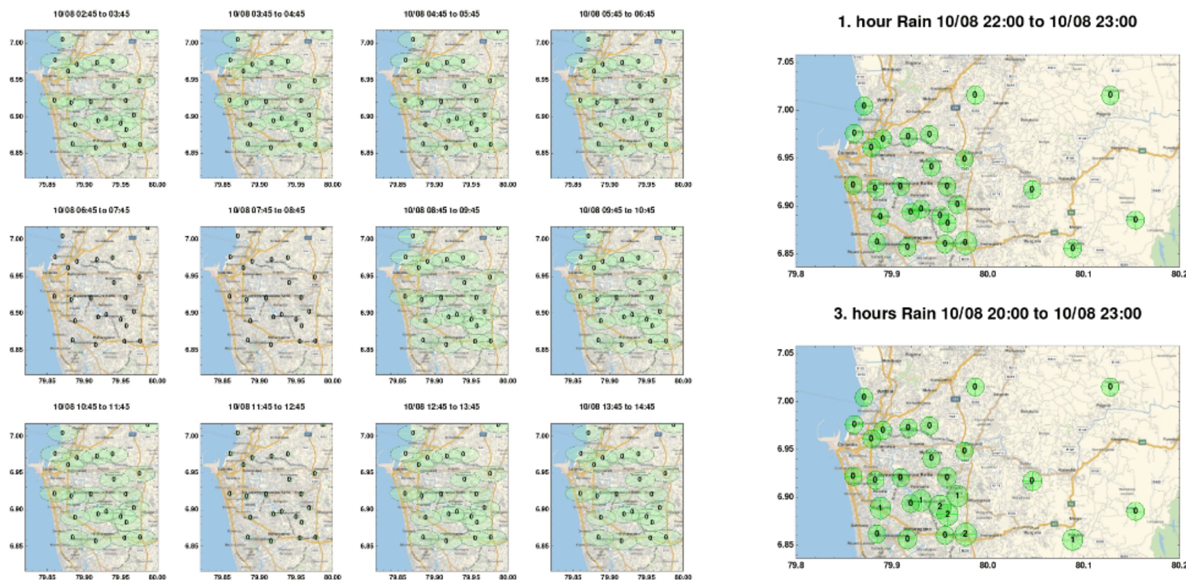


Figure 5: Rainfall data summaries from CUrW website

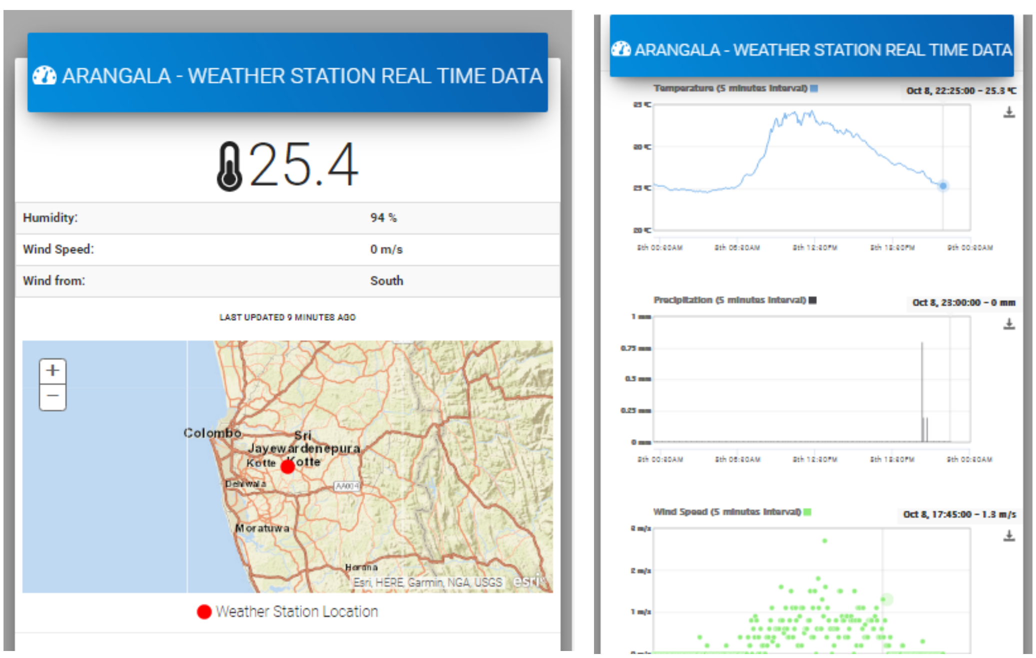


Figure 6: Historical data from CUrW website

Currently a total of 50 Weather stations have been deployed to capture the rainfall distribution. These gauges require regular maintenance to avoid any obstruction in data acquisition or data transmission to CUrW (Center of Urban Water) Database. Hence, frequent field visits are being carried out by RTC Research Engineers in order to investigate any obstructions caused to rain gauges and weather stations in field conditions. This will enable RTC to understand any probable issues that may be encountered at field in relation to sensors and communication modules.

Water Level Gauges

Internet of Things (IOT) enabled Water Level Gauges were tested and installed in Colombo canal system. These devices will allow RTC to obtain high precision real time water level data which will be utilized in flood monitoring and improving the reliability of flood forecasting system. Figure 7 below shows the water level gauges that have been installed in Colombo area and their locations.

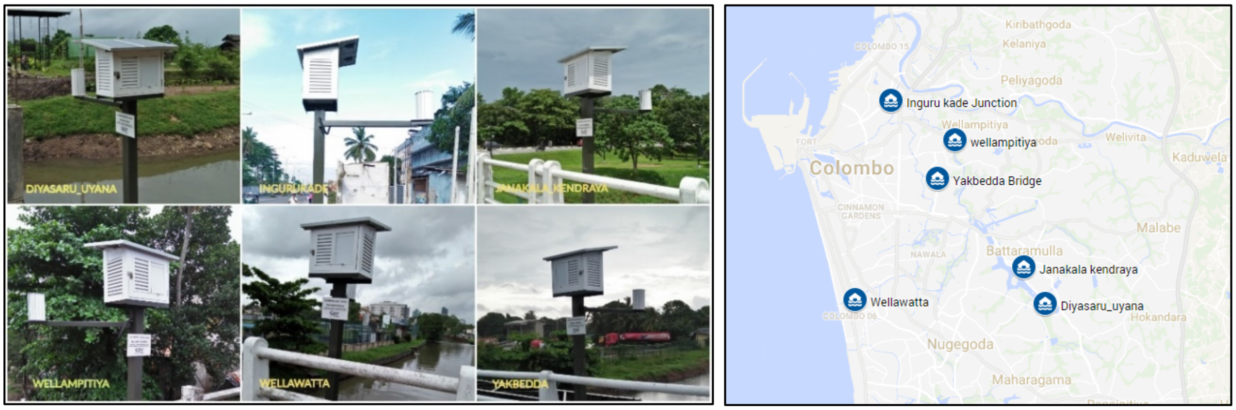


Figure 7: Snapshots and locations of water level satation around Colombo

The water level gauges required to define the boundary conditions of the cloud-run automated and manually run models have been restored with the new water level gauges at the Mattakkuliya brige (Figure 8) and at the Ranwala bridge.

Figure 8: Water level gauge at Mattakkuliya

Further the procurement process for permanent water level station network installation is near to its awarding stage. The locations of the permanent water level gauges are shown in Figure 9.

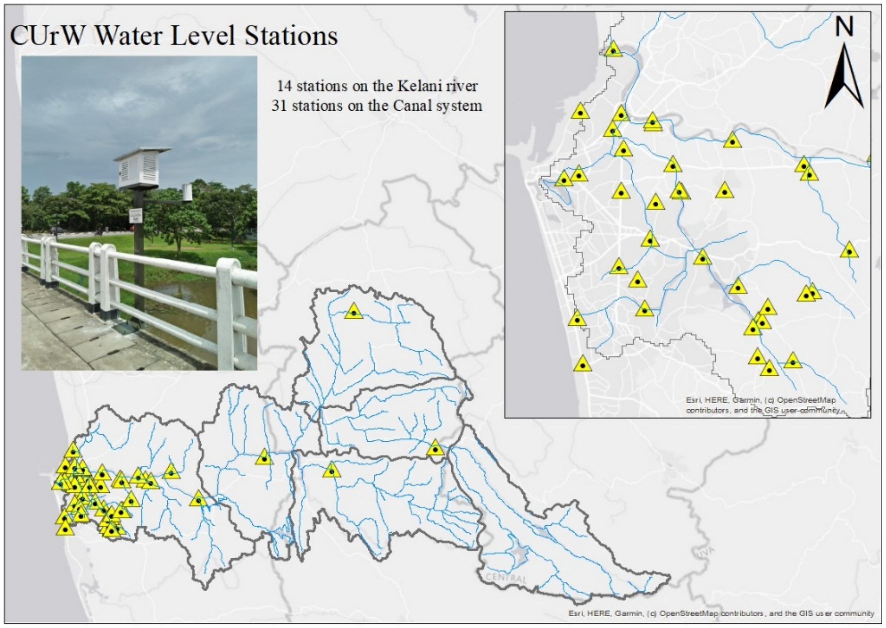


Figure 9: Locations of the Water Level stations

Obtaining canal discharge measurements using the ADCP equipment

During the heavy rains, CUrW was able to measure the canal discharges using the Acoustic Doppler Current Profiler (ADCP) equipment, for several canal outfalls in Colombo. Field visits were made to the outfall locations based on the rainfall and water levels of the canals, and the discharges were recorded. Some of the visited places with their canal discharges are listed in the table below.

Canal	**Canal Discharge (m^3/s)**	**Date**
Wellawatta (Kirulapone Canal)	35.2	2019-09-24
Dehiwala Canal	7.17	26-09-2019
Nagalagam Street Canal	12.6	2019-09-24
Sedawatta Canal (Kitthampahuwa)	0.574	11-10-2019
Ambatale Canal	11.5	25-10-2019

Some snaps from the field visits are attached below.

Figure 10. Snapshots during the canal measurement field visits
(Left: @Wellawatta Canal, Middle: @Nagalagam Street, Right: @Sedawatta Canal)

The canal discharges and many other information is processed using the measurement data and extracted on the site using the dedicated software for the measuring device. A preview of such a result obtained for a particular canal is attached below. Also, CUrW has internally developed its capacity to derive the cross section profile data of the measured cross sections, as the dedicated software does not directly provide the cross section data. A result of one such derivation is attached as well.

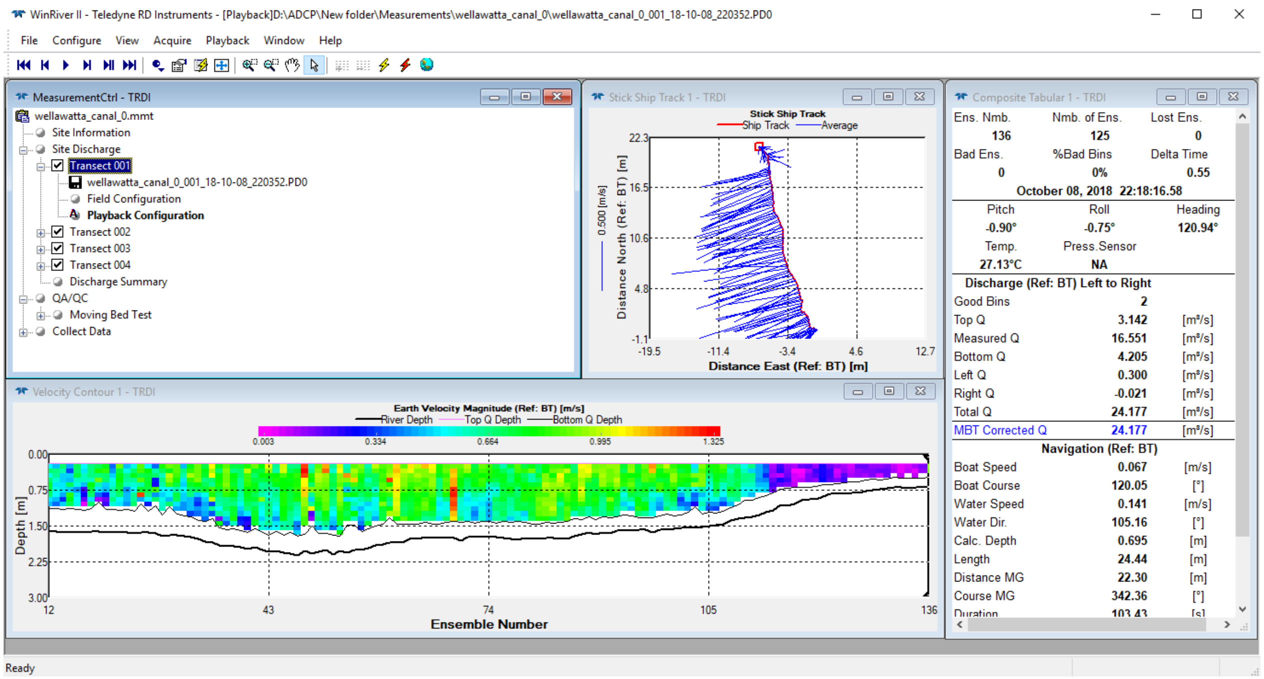


Figure 11. User interface of the dedicated WinRiverII software

Station Number:	Meas. No: 0
Station Name: nagalagama_240919	Date: 09/24/2019

Party:	Width: 17.0 m	Processed by:
Boat/Motor:	Area: 18.0 m²	Mean Velocity: 0.697 m/s
Gage Height: 0.000 m	G.H.Change: 0.000 m	Discharge: 12.5 m³/s

Area Method: Avg. Course	ADCP Depth: 0.000 m	Index Vel.: 0.00 m/s	Rating No.: 1
Nav. Method: Bottom Track	Shore Ens.:10	Adj.Mean Vel: 0.00 m/s	Qm Rating: U
MagVar Method: None (0.0°)	Bottom Est: Power (0.1667)	Rated Area: 0.000 m²	Diff.: 0.000%
Depth: Composite (BT)	Top Est: Power (0.1667)	Control1: Unspecified	
Discharge Method: None		Control2: Unspecified	
% Correction: 0.00		Control3: Unspecified	

Screening Thresholds:		ADCP:	
BT 3-Beam Solution: YES	Max. Vel.: 1.66 m/s	Type/Freq.: RiverRay / 0 kHz	
WT 3-Beam Solution: YES	Max. Depth: 1.42 m	Serial #: 10300	Firmware: 44.21
BT Error Vel.: 1.00 m/s	Mean Depth: 1.06 m	Bin Size: 50 cm	Blank: 50 cm
WT Error Vel.: 10.00 m/s	% Meas.: 59.24	BT Mode: 0	BT Pings: 1
BT Up Vel.: 10.00 m/s	Water Temp.: None	WT Mode: 1	WT Pings: 1
WT Up Vel.: 10.00 m/s	ADCP Temp.: 25.8 °C	WV : 170	
Use Weighted Mean Depth: YES			

Figure 12. Result sheet produced by the WinRiverII software

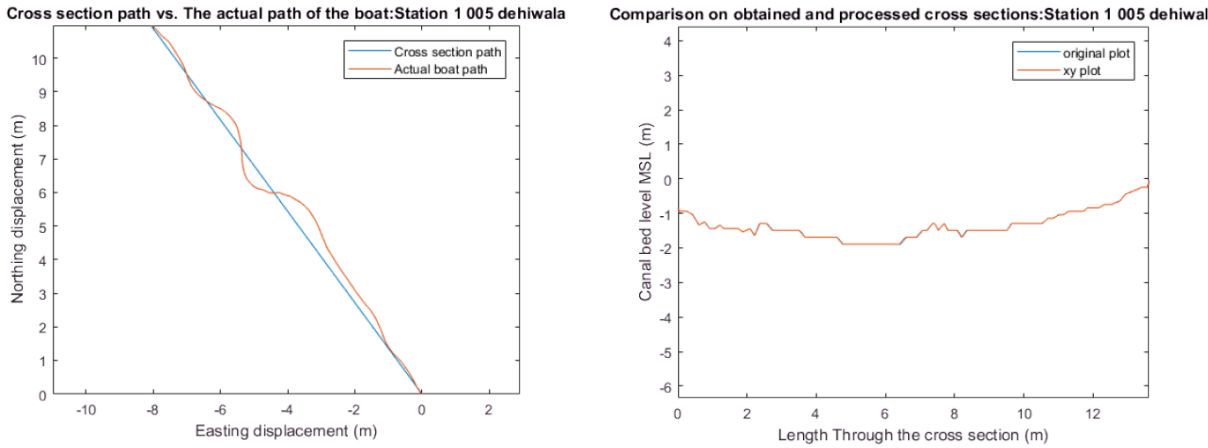


Figure 13. Separately processed cross sections

Modeling System

The following modeling systems have been developed and are at various stages of calibration and finalization

1. Satellite rainfall data feeds at hourly intervals are received and integrated. The process is automated.
2. Weather forecast system for three-day forecasts at 3km resolution for the country is established and automated.
3. Real time data assimilation platform with both temporal and spatial databases completed.
4. Hydrological model has been established and verified
5. Operational hydro-dynamic models (250m and 150m resolution) have been established and verified. Detailed inundation modeling system (at 30m resolution) is now complete and used once alerts are triggered.
6. On risk assessment, building foot print of the city now completed and damage estimation for potential structural flood damage (pre-disaster damage estimation) is completed. Exposure mapping will be carried out in the near future to assess economic vulnerability. Possible evacuation locations and people at risk for different flood frequencies have been established.

<u>Rainfall forecasting</u>

CUrW has been working on the accuracy of the rainfall to be used to run the flood and water level simulations. The previously used method is to run the identified set of numerical weather forecast WRF models for a chosen time period (usually 3 days) using the 18:00 hours global data. The validation of the data was done using the observed data for the first day of the forecast period. Now this method is modified in the following way.

First, the best fit model from the WRF run for 18:00 hours global data and the observed data for the for the first day is chosen. Next, with the best fit WRF model, another run is performed with the 00:00 hours global data for the following day. The results from these data is modified from a pre-identified basin factor, which is calculated based on the past data of the forecasted and the observed cumulative rainfalls. A comparison for the basin mean cumulative rainfall: observed and simulated, using the model 'C' is shown below.

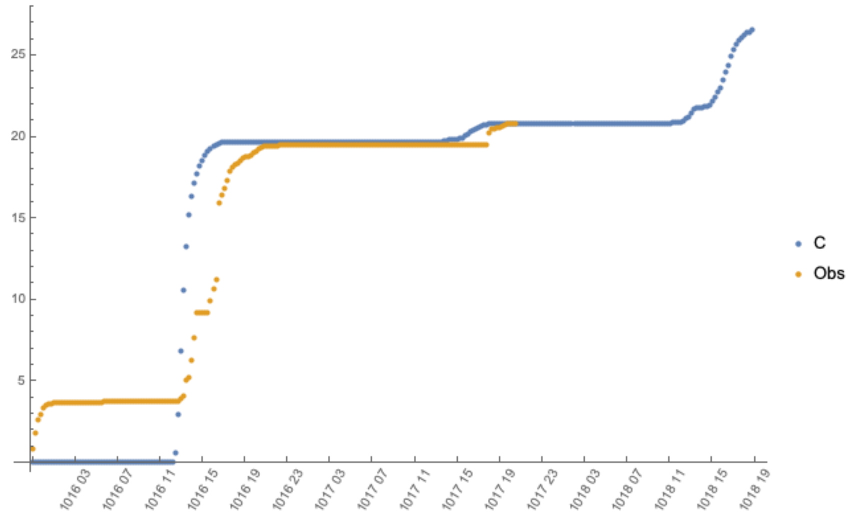


Figure 14. Comparison for the basin mean cumulative rainfall: observed and simulated

This method has resulted in producing hourly and cumulative numerical weather forecasts in higher resolutions, where the spatial references can be given, as shown in the figure below.

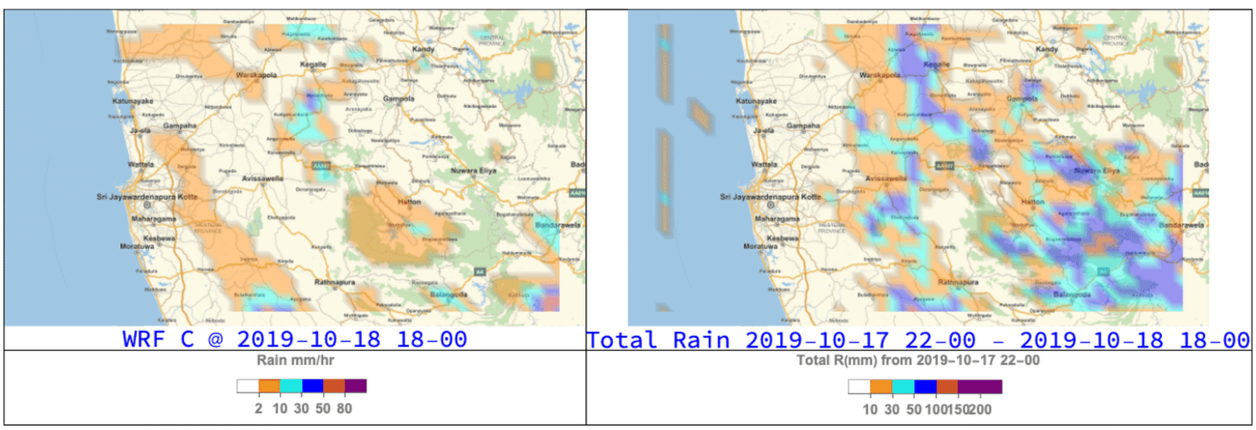
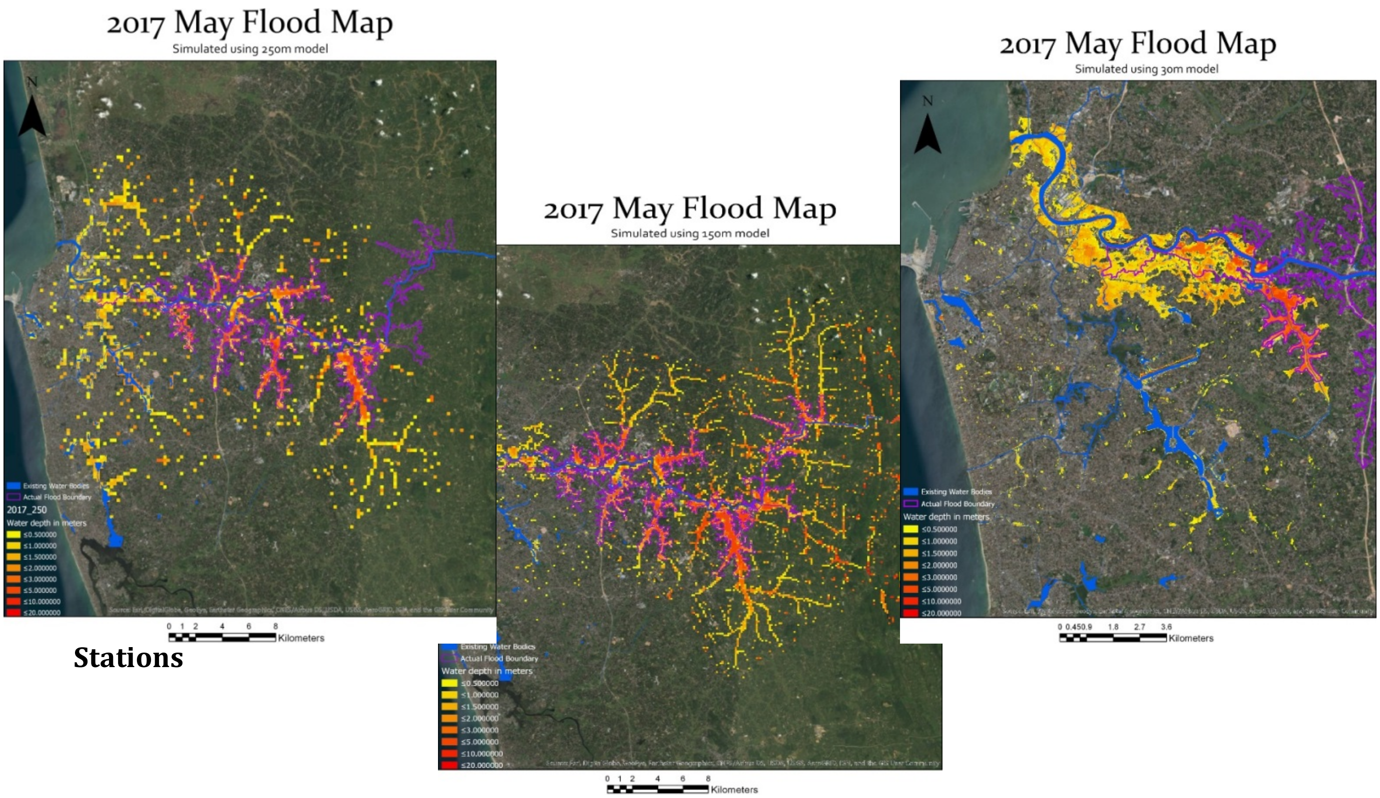


Figure 15. Hourly and cumulative numerical weather forecasts

<u>Flood Forecasting and Inundation Modelling</u>

Three inundation (flooding) simulation models are now available at RTC. They have spatial resolution of 25m x 250m, 150m x 150m and 30m x 30m. The coarse models (250, and 150m grid size) are extremely fast and are used to model whole lower Kelani basin from Glencourse station downwards. They are used for operational forecasts every day. The 30 m model covers only Colombo and use the boundary conditions from other models. It is used for forecasting when there is a threat of flooding in the city. Simulation results of 2017 May event from 250m, 150m and 30m grid resolutions are shown in the following figures and they are almost same as the observed flood map prepared by Survey Department.



Stations

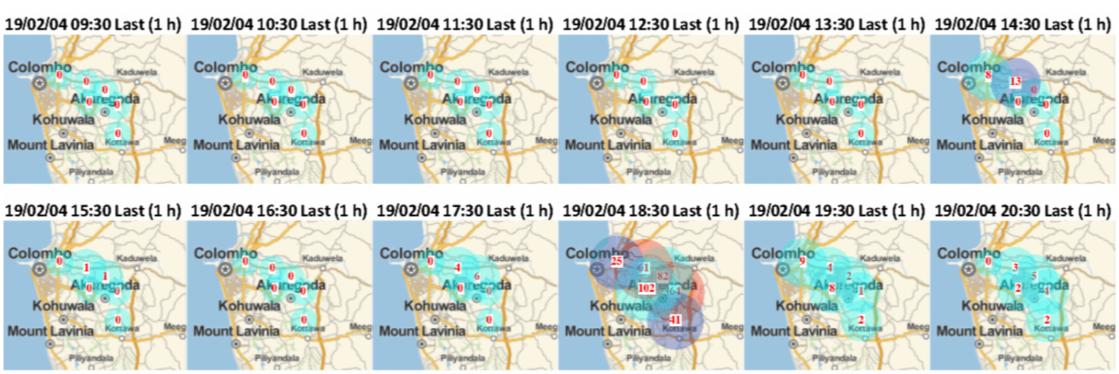
Figure 16. Flood model outputs

Computational Environment

The computational environment is already established in Google Cloud. Rainfall data integration to hydrological and hydrodynamic modeling and processes are linked and automated and the main workflow framework is now completed.

Integration of observed data and forecasted data into CUrW system

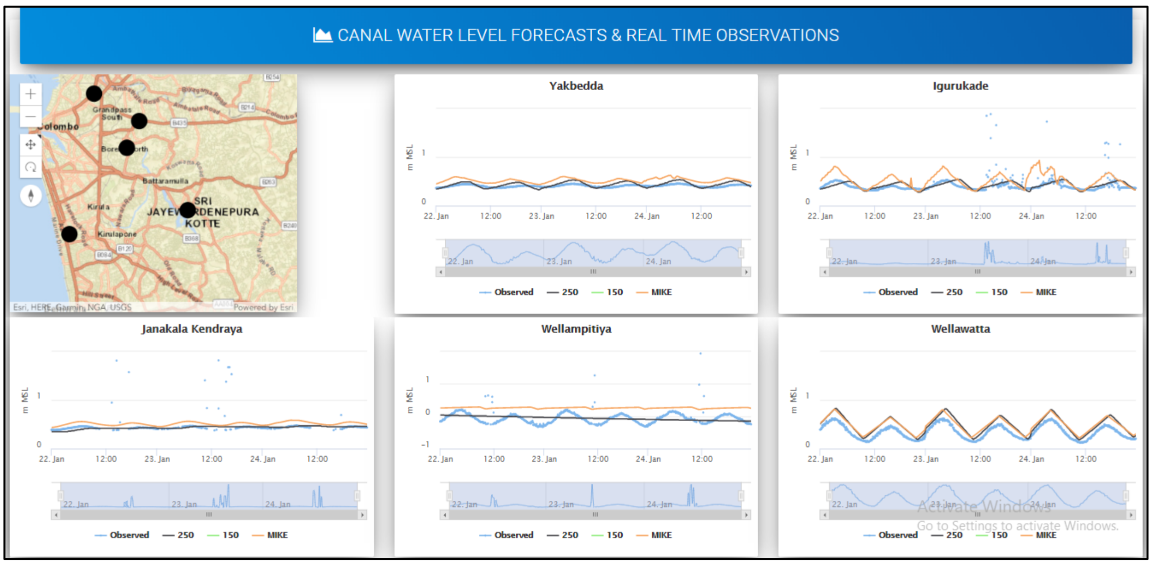
1. Rainfall Monitoring and dissemination



The real time rainfall data observed through CUrW gauges are disseminated depicting both the spatial distribution and the intensity. The above figure shows the hourly rainfall distribution on February 04th. Rainfall of more than 100 mm volume just concentrated in hour was observed from 17:30 to 18:30 on that day as seen from the above figure. We are experiencing such short torrential rain events frequently these days. If these rain spells last longer, heavy local flood damage would occur in the city. Rain data summaries such as above are presented in CUrW www system updated every 30 min.

2. Water level data

Observed rainfall data from monitoring devices and forecasted rainfall data from WRF models are used to forecast water levels Colombo canal systems. Flo 2D and Mike 11 models are used for this purpose. Currently 6 real time water level gauges are deployed in Colombo canal system that allow us to test the forecasting system. Figure below shows the comparison of observed and forecasted water level in lower Kelani basin Flo2D models of 250 and 150 m grid resolution together with the Mike 11 model output. The blue color line is from observed water levels from the real time gauges.



Based on the forecasted water levels, pump operating rules are being designed to minimize flood extent and flood damage.

Economic Exposure Assessment

Introduction

CUrW is now setting up systems to estimate potential economic loss from an impending or future flood. Field surveys to assess economic and financial damage to the structural and content damages to the buildings, which were exposed to the recent floods have been carried out. Data from two sets of such surveys, one for structural damage and the other for flood affected commercial and industrial entities, in the Metro-Colombo Urban region were used to develop loss functions to be used with inundation maps to estimate economic losses.

Selection of case study scenarios and case study areas

Hazard maps from three different types of flooding in Metro Colombo region, namely river floods, surface or urban floods and flash floods were developed from numerical simulation to identify target areas for survey. The flood events used are overflowing of Kelani River (2016), local floods from surface and canal overflow in Colombo (2010) and the flash flooding in most vulnerable locations in Colombo. Hazard maps generated from 30 m resolution models, for the 2010 and 2016 floods and the flash floods, simulated for a return period of 10-year rainfall used for the survery are shown in Figure 1.

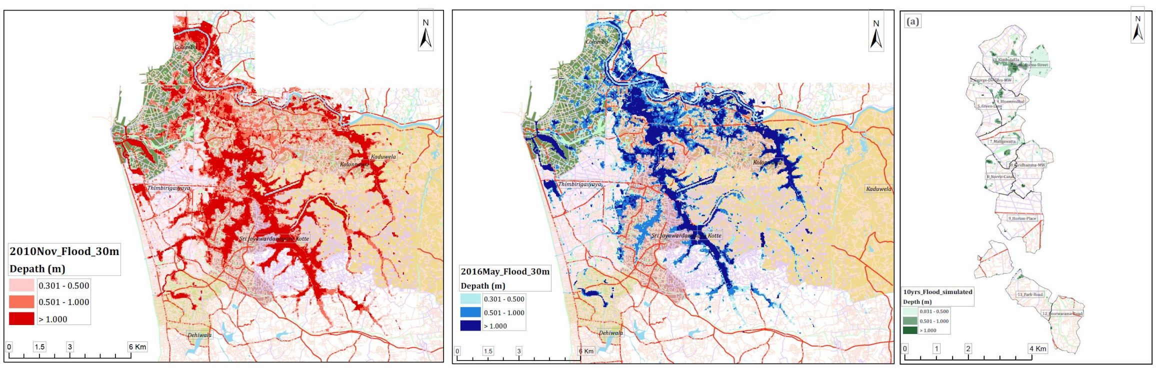


Figure 1. Simulated 30 m flood models for 2010 (image 1), 2016 (image 2) and flash flooding (image 03)

The locations for different types of buildings were then identified by overlaying the flood extent layers with the building footprint layer. The buildings that were prone to the most severe flooding event(s) were selected as the survey locations, as shown in the Figure 2.

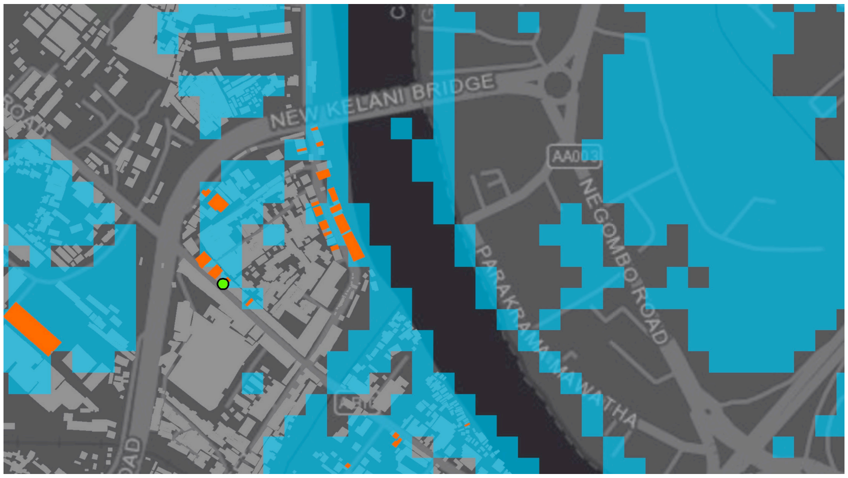


Figure 2. Selection of survey locations: Blue-flood extent, Orange-Selected buildings

Data collection

In the first survey 297 survey field data points were collected and used to formulate the structural damage curves for 4 types of building. Current building footprint available with CUrW is divided to 10 categories. The 4 loss functions were mapped for this 10 types of buildings to estimate the total damge. In the second survey, data was collected on 427 locations, covering all 3 types of flooding in the Metro Colombo region, to assess the structural damage to the buildings

Figure 3. CUrW survey team at the field survey

The survey was conducted as a comprehensive questionnaire survey, by visiting each building and discussing with the occupants.

Validation of collected data

The collected data is required to be validated. Especially the building footprint and the inundation depth, check the reliability of the values obtained during the questionnaire survey. Therefore, the collected data weer linked to the building footprint using the google maps and street view, and the information on the building footprint layer.

Structural damage curves

The data collected for the structural damage curve establishment showed that there are 4 main categories of building types by structure: A) Unreinforced masonry (URF), B) Concrete frame with masonry walls, C) Wooden and D) Commercial. For each of these categories, a damage curve was developed, which is in the format of $D_f = C_1 ln\ x + C_2$, where D_f = damage function, C_1 and C_2 = damage coefficients for any given landuse type, and x = inundation depth. The damage is normalised with respect to the floor area of the building. The derived curves are shown in Figure 4.

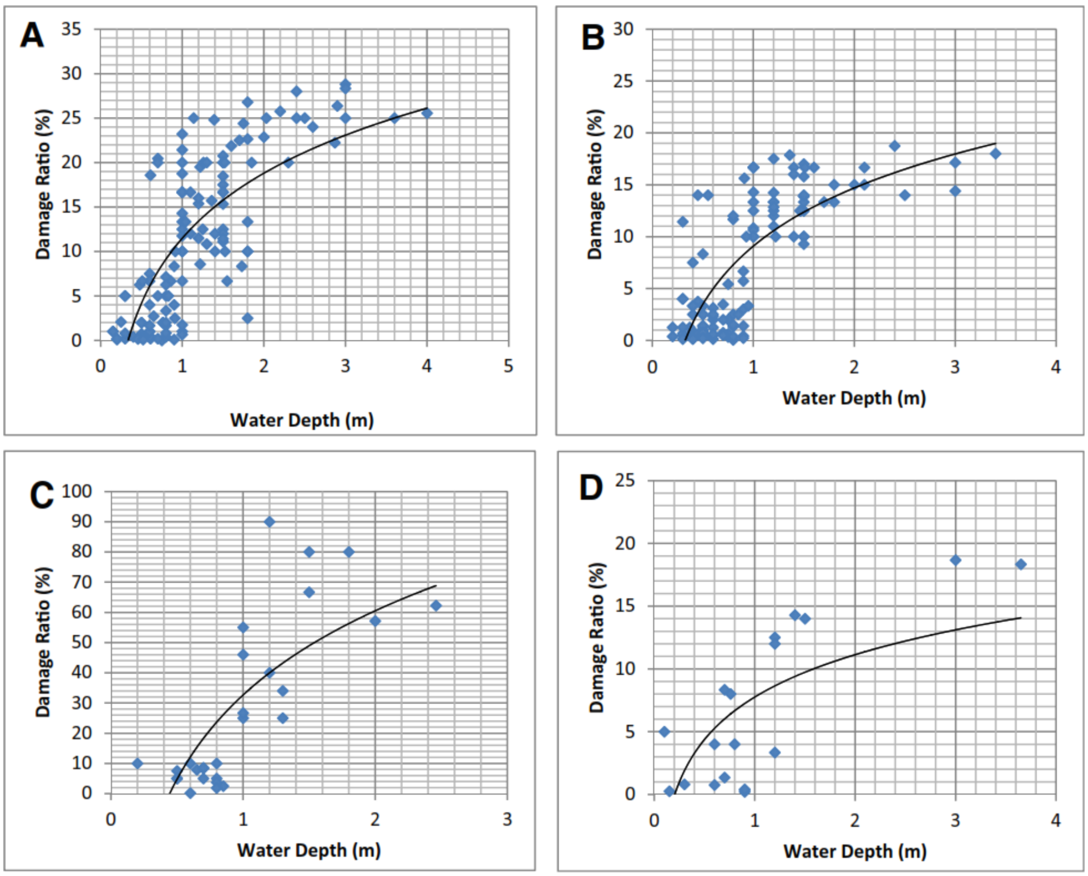


Figure 4.Damage curves for structural damage for A) URF, B) Concrete frames with masonry walls, C) Wooden, D) Commercial buildings

These curves have been validated by estimating the structural damage values for the floods in 2010, and comparing them with the damage values provided by the Disaster Management Center (DMC) for the Colombo District. The simulated damage was able to estimate 70% of the total damage, quite satisfactory considering the uncertainties in both estimates and the area covered. Figure 5 shows an example of building by building structural flood damage estimation available on line at CUrW home page.

Figure 5. Flood Damage example from CUrW website.

Economic Exposure Field Surveys

Economic Exposure field data for past flood events using Survey123 GIS app (as per the developed questionnaire) by 4 groups in predefined areas based on the simulated (FLO-2D) flood maps.

The survey data was mainly categorized into 5 main categories: A) Automobile, B) Food, C) Grocery, D) Hardware, and E) Industrial categories, depending on the building use and the data availability. For each of these categories, a damage curve was developed.

Use of damage estimation

One of the use of damage estimation is the cost-benefit analysis to arrive at appropriate investment figures for flood control measures. The Figure 6 shows 3 types of building distributions, the flood extent from 1:50 year return period rain event, the reduction of flood height when flood control measures are implemented and finally the benefit as estimated from (flood loss with no measures – flood loss with flood control measures). From simulation results for different rain frequencies (1/return period) we can estimate the expected annual benefit and thus the recovery period for investment.

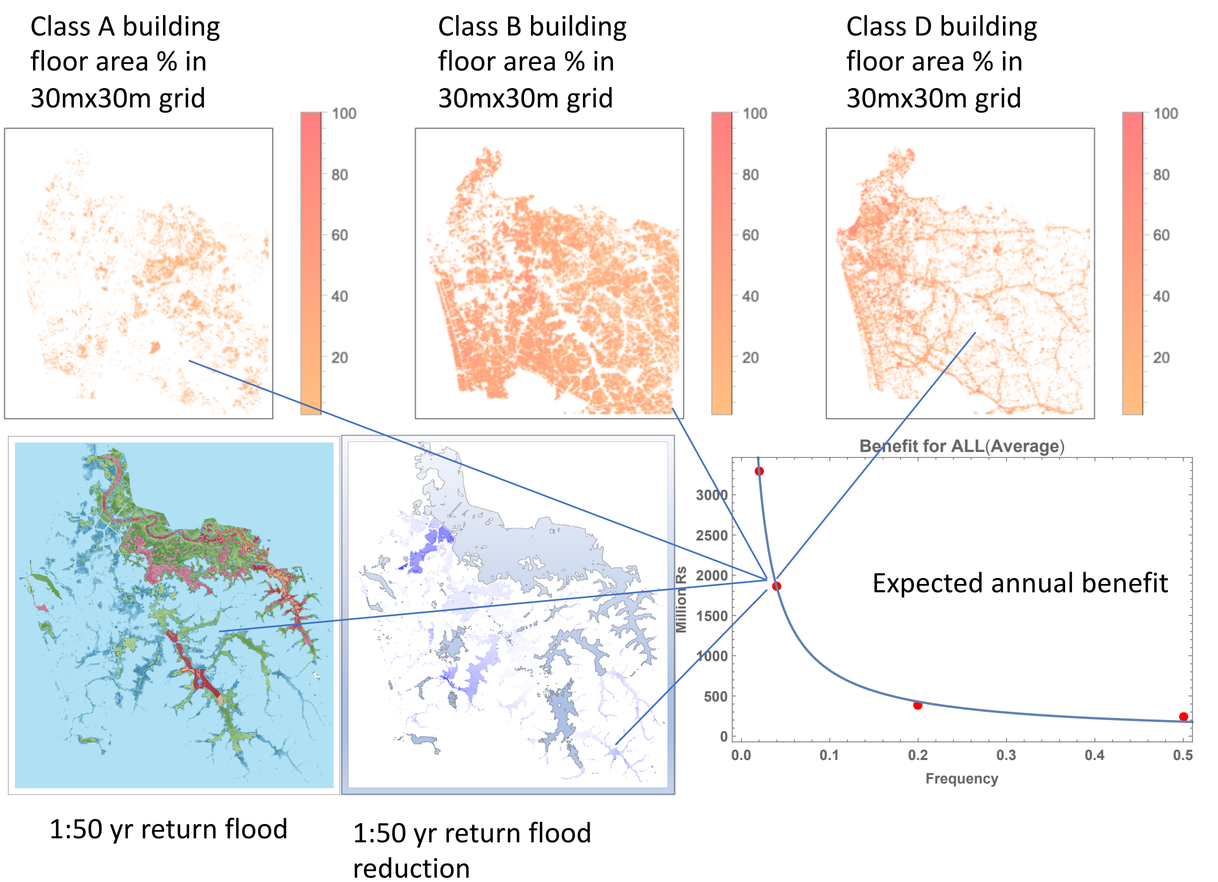


Figure 6. Expected annual benefit estimation with MCDUP flood control measures.

Rainfall Intensity Duration Frequency Curves for Colombo

Urban Storm Water Management under Metro Colombo Urban Development Porject

Centre for Urban Water
http://www.curwsl.org

Srikantha Herath

CUrW Report 003

August 10, 2018

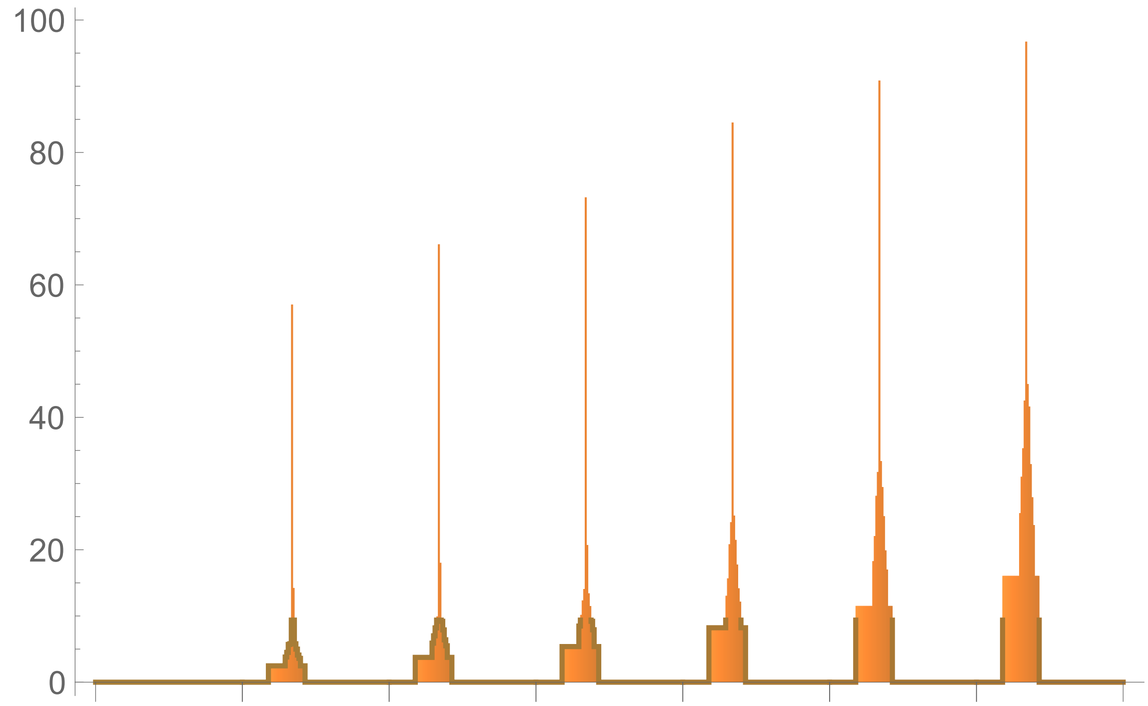


Fig. 1: SLLRDC Design rains for 2, 5, 10, 25, 50 and 100 years

1 Review Background

The design rainfall used by SLLRDC for macro design and the rainfall used by the CMC in micro drainage projects shows a slight difference. As we now reconcile the surface runoff generation based on physical characteristics, both analysis need to utilise the same methodology in deriving the time series and ensure they are compatible. For physically based runoff modelling we also need high time resolution data preferably 10-15 time intervals where as the current design rainfall series for macro drainage uses hourly time series, and this needs to be extended for sub-hourly time series.

The current design rainfall series have been derived for 2 yr, 5 yr, 10 yr, 25 yr, 50 yr and 100 yr return periods. This hourly rainfall data for 24 hour period is shown in the Figure(1).

The micro drainage uses the IDF curves presented in the COWI report II on micro drainage. The analysis is baed on 30 years of data from 1981 to 2010 and annual maximum and exceedence series at 15, 30, 60 , 90, 120, 180 and 240 min durations. The COWI analysis used GEV and EV type I, (Gumbel) II (Frechet) and III (Weibul) to fit observed data and design storms have been estimated from the excedance series for 2,5 and 10 year return period and from the maximum value series for return periods beyond that.

SLLRDC time series has been derived laterhtp by adopting exponential function for lower return period.

The one hour rainfall from the two analysis have slight differences for each return period as shown in the Table (1).

Tab. 1: 1 Hour Design Rainfall Estimates

Return Periods	2	5	10	25	50	100
SLLRDC	57	66.1	73.19	84.49	90.83	96.7
COWI	79.2	91.83	101.65	117.35	126.15	134.31

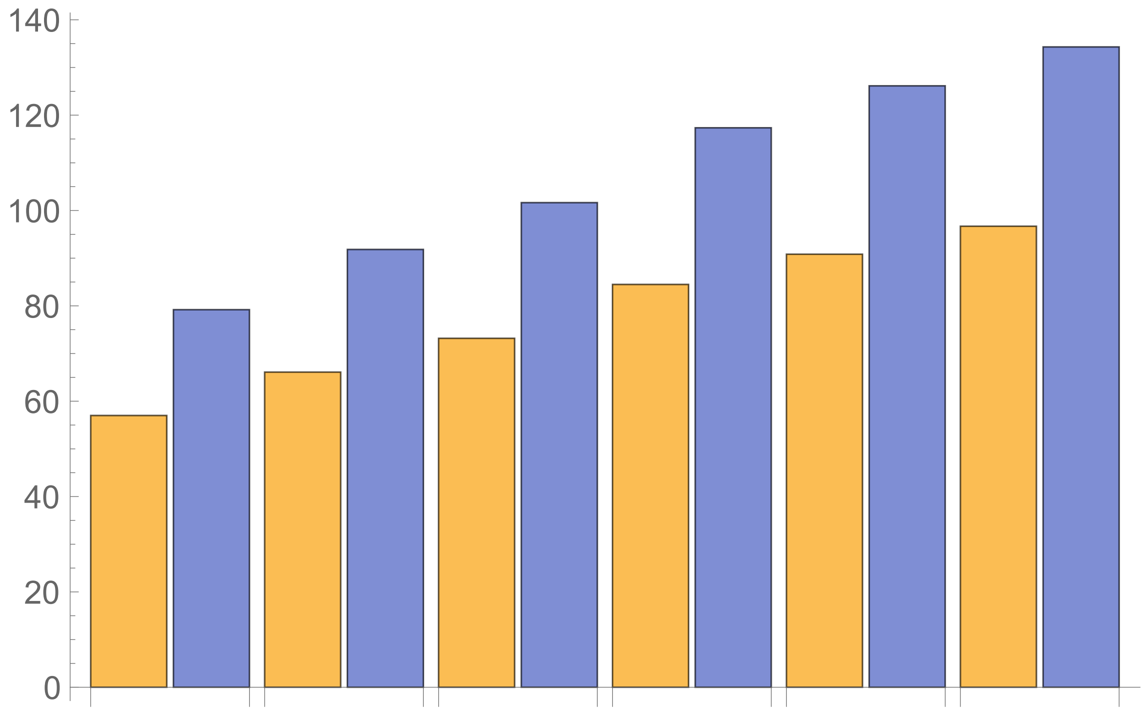


Fig. 2: SLLRDC and COWI report Design rains difference

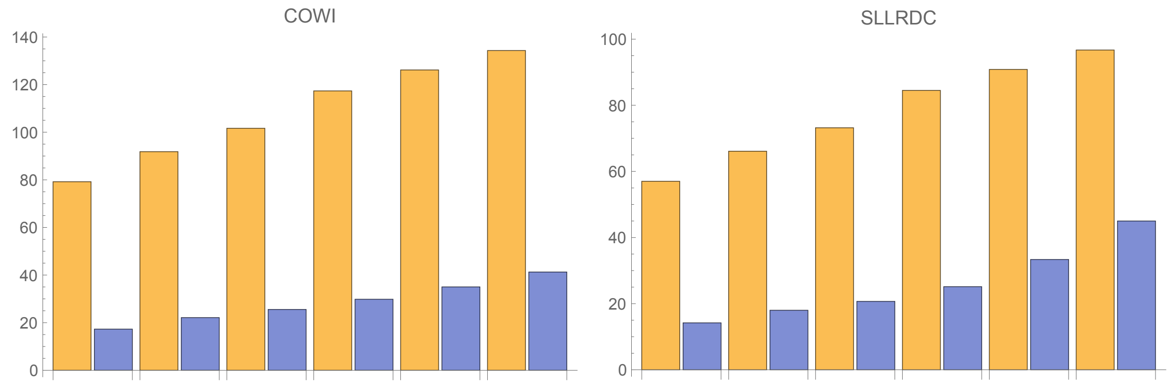
This discrepancy is shown in the Figure below.

The difference between the maximum hourly rainfall and the next hour rainfall as shown in Figures (3a and 3b).

A review analysis is carried out in this report to reconcile these differences and to derive a procedure to derive IDF curves for a required return period at any duration and resolution required.

2 Analysis Methodology

In this review, MaxStableDistribution (GEV max: generalized maximum extreme value distribution), Gamma, Gumbel (type I min extreme value distribution), ExtremeValueDistribution (type I max extreme value distribution), Frechet (type II max extreme value distribution) and



(a) Max and next hourly rainfall difference - COWI (b) Max and next hourly rainfall difference - SLLRDC

Fig. 3: Colombo Hour1 and 2 hour rainfall distribution

Weibul (type III min extreme value distribution) are fitted to to each time series for a particular duration. Then the best fit function is selected based on the score of the DistributionFitTest of *Mathematia* computing library. This function is then used to generate the rainfall for different return periods for that particular duration.

Both the exceedence and annual maximum time series are analysed in this manner. Next a function is derived that express rainfall at any duration for a given return period for all the return periods. These functions then can be used to generate any IDF curve for a required duration and time step resolution.

3 Analysis of Annual Excedance Series

The results of functions fitted are summarised in Figure(4) and Figure(5). The plots of histograms and probability functions are shown in Figure (6).

4 Analysis of Annual Maximum Series

The results of functions fitted are summarised in Figure(7) and Figure(8). The plots of histograms and probability functions are shown in Figure (9). .

5 Combining exceedence and Annual Maximum Series

The 2 and 5 year return period rainfalls by excedance series and 10,25,50 and 100 year return period rainfalls by Annual maximum series provides a smooth fit from the results of the analysis of the two time series. This combined curve is shown in Figure (10).

Duration min: 15

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	31.7941	34.8799	35.5545	34.0135	33.5835	36.0788
5	39.1511	40.3411	41.5059	39.1635	38.8343	42.1568
10	50.5981	43.4077	44.3288	42.5733	42.7549	44.7408
25	82.9761	46.8421	47.1428	46.8815	48.2796	47.1578
50	134.195	49.1521	48.8626	50.0775	52.8345	48.5649
100	232.044	51.2918	50.3492	53.25	57.7806	49.7419

F 1 MaxStableDistribution[30.6617, 2.59056, 0.934617]	0.521529
F 2 GammaDistribution[32.1544, 1.09611]	0.247183
F 3 WeibullDistribution[5.44297, 38.0311]	0.191558
F 4 ExtremeValueDistribution[32.3482, 4.54372]	0.283391
F 5 FrechetDistribution[7.80223, 32.0423]	0.32696
F 6 GumbelDistribution[38.7232, 7.21504]	0.125949

Best Fit 1

==

Duration min: 30

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	54.3267	55.8377	56.5145	54.7491	54.2407	57.0045
5	62.2995	63.6521	65.67	62.3314	62.3181	67.0569
10	68.099	68.0099	69.9987	67.3516	68.3172	71.3306
25	76.0791	72.8678	74.3056	73.6946	76.7299	75.3282
50	82.509	76.1234	76.9338	78.4002	83.6333	77.6554
100	89.3558	79.1312	79.2035	83.0711	91.0999	79.602

F 1 MaxStableDistribution[51.9365, 6.40256, 0.100239]	0.970471
F 2 GammaDistribution[39.7831, 1.4154]	0.796786
F 3 WeibullDistribution[5.61057, 60.3296]	0.30587
F 4 ExtremeValueDistribution[52.2972, 6.68975]	0.979925
F 5 FrechetDistribution[8.16477, 51.8597]	0.963039
F 6 GumbelDistribution[61.3781, 11.933]	0.118896

Best Fit 4

==

Duration min: 60

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	77.0623	80.0713	81.0565	78.3699	77.5598	81.927
5	89.2318	92.5377	95.7737	89.4453	89.1461	98.3236
10	99.0627	99.5356	102.814	96.7781	97.7544	105.295
25	113.952	107.371	109.867	106.043	109.829	111.815
50	127.109	112.64	114.194	112.917	119.741	115.611
100	142.267	117.52	117.943	119.739	130.464	118.786

F 1 MaxStableDistribution[73.7145, 8.78284, 0.212667]	0.974425
F 2 GammaDistribution[32.4983, 2.48935]	0.463659
F 3 WeibullDistribution[5.04907, 87.1592]	0.165041
F 4 ExtremeValueDistribution[74.7885, 9.77157]	0.87398
F 5 FrechetDistribution[8.14081, 74.1454]	0.965719
F 6 GumbelDistribution[89.0608, 19.4642]	0.0607962

Best Fit 1

==

Duration min: 90

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	88.4545	92.0852	93.2715	90.1075	89.0174	94.3313
5	103.625	107.174	110.925	103.931	103.581	114.141
10	115.882	115.673	119.408	113.083	114.511	122.563
25	134.449	125.209	127.929	124.647	129.986	130.441
50	150.856	131.633	133.167	133.225	142.803	135.027
100	169.761	137.591	137.713	141.741	156.774	138.863

F 1 MaxStableDistribution[84.2815, 10.9474, 0.212808]	0.780766
F 2 GammaDistribution[29.5071, 3.15637]	0.7047
F 3 WeibullDistribution[4.85991, 100.578]	0.258786
F 4 ExtremeValueDistribution[85.6375, 12.1959]	0.839804
F 5 FrechetDistribution[7.48029, 84.7609]	0.817127
F 6 GumbelDistribution[102.95, 23.516]	0.0808605

Best Fit 4

Fig. 4: Probability Function Fitting for exceedence Series

==

Duration min: 120

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	95.2387	99.871	101.569	97.5576	96.2757	103.096
5	112.681	116.963	120.655	113.11	112.572	123.541
10	127.558	126.619	129.819	123.407	124.852	132.233
25	151.248	137.475	139.02	136.418	142.302	140.364
50	173.208	144.799	144.674	146.07	156.804	145.097
100	199.568	151.599	149.58	155.651	172.661	149.056

F 1
MaxStableDistribution[90.6528, 11.9008, 0.271226] 0.957368
F 2
GammaDistribution[27.186, 3.71911] 0.591627
F 3
WeibullDistribution[4.89204, 109.47] 0.262677
F 4
ExtremeValueDistribution[92.5283, 13.7218] 0.840734
F 5
FrechetDistribution[7.24796, 91.5283] 0.934869
F 6
GumbelDistribution[111.991, 24.2699] 0.107674

Best Fit 1

==

Duration min: 180

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	101.281	109.757	111.193	106.928	104.98	113.383
5	122.84	134.102	140.188	125.471	123.287	148.033
10	147.161	148.133	154.702	137.748	137.132	162.764
25	197.525	164.113	169.634	153.261	156.869	176.544
50	257.325	175.005	178.983	164.769	173.325	184.565
100	346.211	185.189	187.197	176.192	191.367	191.275

F 1
MaxStableDistribution[96.827, 10.9139, 0.576286] 0.774234
F 2
GammaDistribution[16.7699, 6.6771] 0.182831
F 3
WeibullDistribution[3.6355, 122.988] 0.0744741
F 4
ExtremeValueDistribution[100.931, 16.3604] 0.259776
F 5
FrechetDistribution[7.05105, 99.6622] 0.349539
F 6
GumbelDistribution[128.459, 41.1323] 0.0176606

Best Fit 1

==

Duration min: 240

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	105.396	117.862	119.718	114.751	111.905	123.116
5	135.176	149.379	156.42	138.116	134.85	167.932
10	177.427	167.856	175.254	153.585	152.575	186.986
25	286.584	189.126	194.918	173.131	178.339	204.808
50	445.57	203.746	207.366	187.631	200.225	215.183
100	728.024	217.495	218.387	202.025	224.604	223.861

F 1
MaxStableDistribution[100.399, 11.6635, 0.830926] 0.740481
F 2
GammaDistribution[11.9167, 10.1735] 0.190568
F 3
WeibullDistribution[3.15022, 134.489] 0.074407
F 4
ExtremeValueDistribution[107.196, 20.6143] 0.323552
F 5
FrechetDistribution[6.07677, 105.355] 0.437217
F 6
GumbelDistribution[142.615, 53.2005] 0.0134778

Best Fit 1

==

Duration min: 1440

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	140.257	162.047	166.507	159.134	151.572	179.862
5	183.321	237.202	248.066	201.669	186.494	288.261
10	254.114	284.209	293.885	229.831	213.935	334.347
25	465.544	340.482	344.373	265.414	254.453	377.454
50	816.91	380.308	377.669	291.811	289.394	402.549
100	1517.99	418.511	407.979	318.014	328.82	423.54

F 1
MaxStableDistribution[133.966, 14.2201, 0.996721] 0.923172
F 2
GammaDistribution[4.55836, 38.3117] 0.0108745
F 3
WeibullDistribution[2.11307, 198.043] 0.00582741
F 4
ExtremeValueDistribution[145.379, 37.528] 0.0323315
F 5
FrechetDistribution[5.46665, 141.743] 0.176426
F 6
GumbelDistribution[227.025, 128.678] 0.000993489

Best Fit 1

Fig. 5: Probability Function Fitting for exceedence Series

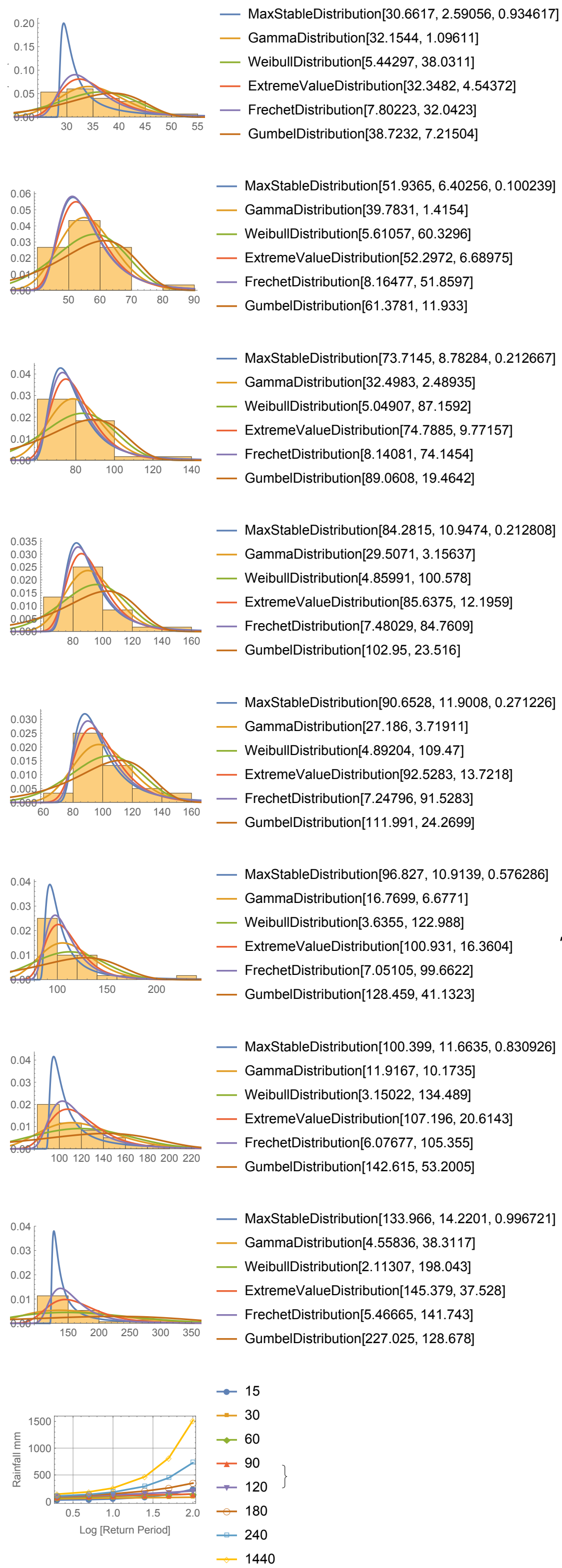


Fig. 6: Probability Function Fitting for exceedence Series

Duration min: 15

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	31.8855	32.3282	33.2978	31.5672	30.7107	34.2451
5	39.447	39.7567	40.6447	39.4371	39.9704	41.4726
10	44.115	44.051	44.2402	44.6477	47.5898	44.5454
25	49.6534	48.9511	47.8907	51.2313	59.3274	47.4196
50	53.5178	52.2961	50.153	56.1154	69.8686	49.0928
100	57.1595	55.4272	52.1272	60.9634	82.1835	50.4923

F 1 MaxStableDistribution[29.3012, 7.1472, -0.0741374]	0.895592
F 2 GammaDistribution[15.7149, 2.10157]	0.861993
F 3 WeibullDistribution[4.22515, 36.3152]	0.70627
F 4 ExtremeValueDistribution[29.0223, 6.94349]	0.927606
F 5 FrechetDistribution[4.30098, 28.2021]	0.90992
F 6 GumbelDistribution[37.3897, 8.57964]	0.425951

Best Fit 4

==

Duration min: 30

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	50.9981	51.699	52.9572	50.5508	49.3927	54.0097
5	62.1102	62.4618	64.059	62.1234	62.8636	65.6853
10	68.9891	68.632	69.4579	69.7855	73.747	70.6492
25	77.1712	75.6356	74.919	79.4666	90.2322	75.2922
50	82.894	80.3967	78.2938	86.6485	104.8	77.9952
100	88.2981	84.8403	81.2331	93.7775	121.585	80.2561

F 1 MaxStableDistribution[47.2086, 10.4747, -0.0712013]	0.906686
F 2 GammaDistribution[18.8565, 2.79089]	0.935771
F 3 WeibullDistribution[4.42617, 57.529]	0.908483
F 4 ExtremeValueDistribution[46.8086, 10.2103]	0.883294
F 5 FrechetDistribution[4.6998, 45.6872]	0.743932
F 6 GumbelDistribution[59.0895, 13.8599]	0.508178

Best Fit 2

==

Duration min: 60

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	73.1483	74.208	76.0113	72.5725	70.6832	77.7378
5	90.3249	90.8393	93.4415	90.376	91.8532	96.3705
10	101.068	100.433	102.014	102.164	109.251	104.292
25	113.964	111.365	110.743	117.057	136.021	111.702
50	123.065	118.819	116.165	128.106	160.035	116.016
100	131.725	125.792	120.903	139.073	188.064	119.624

F 1 MaxStableDistribution[67.3378, 16.0294, -0.0603495]	0.927634
F 2 GammaDistribution[16.4538, 4.60299]	0.970868
F 3 WeibullDistribution[4.08032, 83.155]	0.850162
F 4 ExtremeValueDistribution[66.8154, 15.7077]	0.877714
F 5 FrechetDistribution[4.32634, 64.9418]	0.596898
F 6 GumbelDistribution[85.8446, 22.1187]	0.352519

Best Fit 2

==

Duration min: 90

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	81.8338	83.3871	85.4251	81.4832	79.1284	87.5889
5	102.449	103.31	106.566	102.465	104.173	110.529
10	115.707	114.867	117.07	116.357	124.976	120.282
25	132.027	128.083	127.831	133.909	157.3	129.405
50	143.829	137.121	134.546	146.93	186.571	134.716
100	155.293	145.59	140.432	159.855	221.01	139.158

F 1 MaxStableDistribution[75.0119, 18.7183, -0.0308198]	0.881078
F 2 GammaDistribution[14.6301, 5.83203]	0.942856
F 3 WeibullDistribution[3.80962, 94.052]	0.841101
F 4 ExtremeValueDistribution[74.6984, 18.5117]	0.861627
F 5 FrechetDistribution[4.12179, 72.396]	0.655834
F 6 GumbelDistribution[97.5697, 27.2319]	0.310741

Best Fit 2

==

Fig. 7: Probability Function Fitting for Annual Maximum Series

Duration min: 120

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	88.4602	90.7083	93.1842	88.4997	85.7656	95.9912
5	111.534	112.94	116.299	111.536	112.551	120.01
10	126.855	125.866	127.788	126.788	134.74	130.221
25	146.264	140.669	139.56	146.059	169.137	139.773
50	160.7	150.803	146.906	160.355	200.213	145.334
100	175.06	160.308	153.347	174.546	236.703	149.985

F 1 MaxStableDistribution[81.0164, 20.2984, 0.00309546]	0.924068
F 2 GammaDistribution[13.964, 6.65403]	0.966506
F 3 WeibullDistribution[3.80162, 102.615]	0.866284
F 4 ExtremeValueDistribution[81.0505, 20.3244]	0.925141
F 5 FrechetDistribution[4.1703, 78.5497]	0.77323
F 6 GumbelDistribution[106.441, 28.5122]	0.37588

Best Fit 2

===

Duration min: 180

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	93.6247	98.6852	101.082	96.2303	92.2841	105.065
5	124.151	128.963	134.311	124.517	124.812	143.555
10	147.744	146.964	151.562	143.245	152.432	159.919
25	182.056	167.869	169.698	166.907	196.234	175.225
50	211.216	182.333	181.24	184.462	236.676	184.136
100	243.712	195.999	191.494	201.887	285.057	191.589

F 1 MaxStableDistribution[84.9148, 23.0524, 0.165141]	0.850853
F 2 GammaDistribution[9.30972, 10.9912]	0.835879
F 3 WeibullDistribution[2.96388, 114.388]	0.527019
F 4 ExtremeValueDistribution[87.0835, 24.9564]	0.857665
F 5 FrechetDistribution[3.75383, 83.6996]	0.810497
F 6 GumbelDistribution[121.811, 45.6908]	0.105507

Best Fit 4

===

Duration min: 240

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	96.8229	103.835	106.41	101.37	96.4163	111.999
5	132.559	141.161	147.505	133.527	132.814	161.515
10	162.554	163.754	169.475	154.817	164.186	182.567
25	209.613	190.278	192.977	181.718	214.632	202.259
50	252.62	208.783	208.132	201.674	261.829	213.722
100	303.622	226.365	221.719	221.483	318.934	223.311

F 1 MaxStableDistribution[87.2997, 24.793, 0.253871]	0.844431
F 2 GammaDistribution[7.0415, 15.4721]	0.661396
F 3 WeibullDistribution[2.57957, 122.656]	0.337648
F 4 ExtremeValueDistribution[90.9721, 28.371]	0.800417
F 5 FrechetDistribution[3.53891, 86.9304]	0.837683
F 6 GumbelDistribution[133.542, 58.7806]	0.0456489

Best Fit 1

===

Duration min: 14 440

Return Prd	F 1	F 2	F 3	F 4	F 5	F 6
2	134.357	148.312	152.612	146.34	136.1	169.119
5	192.823	226.821	237.717	200.142	191.124	282.239
10	248.419	276.872	287.005	235.763	239.3	330.332
25	346.385	337.45	342.319	280.771	317.904	375.317
50	446.351	380.662	379.306	314.161	392.47	401.505
100	576.684	422.329	413.295	347.304	483.773	423.41

F 1 MaxStableDistribution[120.338, 35.5859, 0.389152]	0.921105
F 2 GammaDistribution[3.66705, 44.4096]	0.0994175
F 3 WeibullDistribution[1.90079, 185.067]	0.0488737
F 4 ExtremeValueDistribution[128.942, 47.4683]	0.248959
F 5 FrechetDistribution[3.33824, 121.949]	0.885644
F 6 GumbelDistribution[218.336, 134.283]	0.00368853

Best Fit 1

===

Fig. 8: Probability Function Fitting for Annual Maximum Series

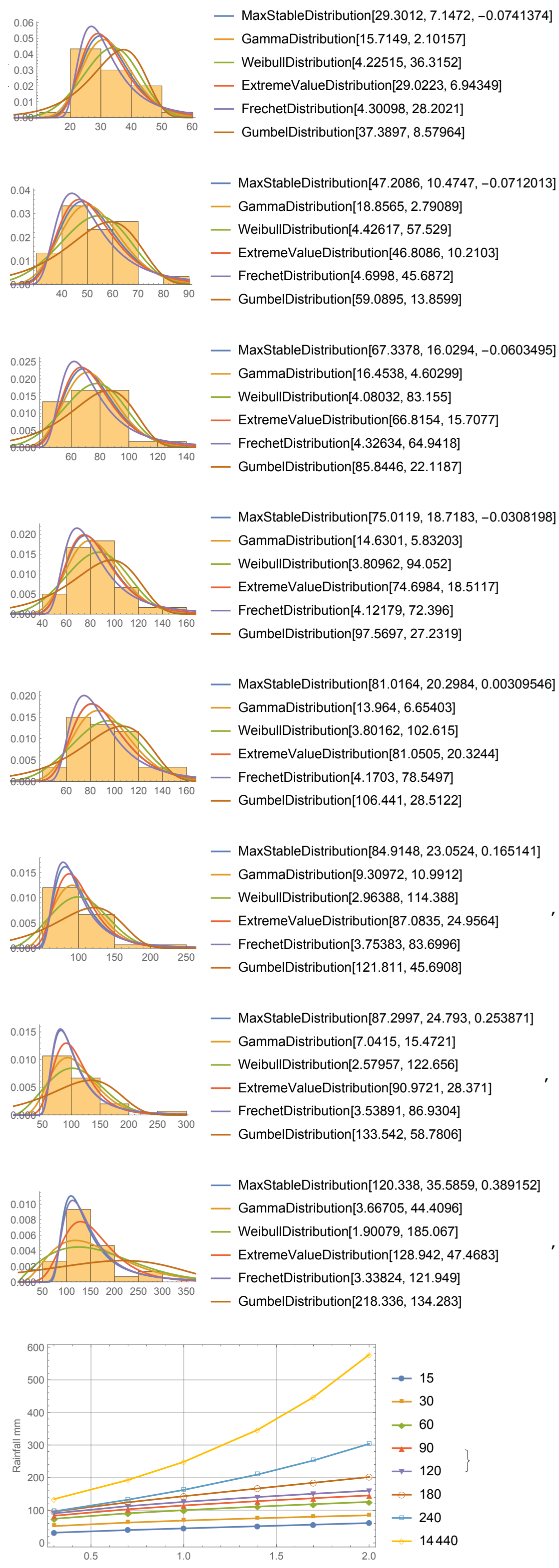


Fig. 9: Probability Function Fitting for Annual Maximum Series

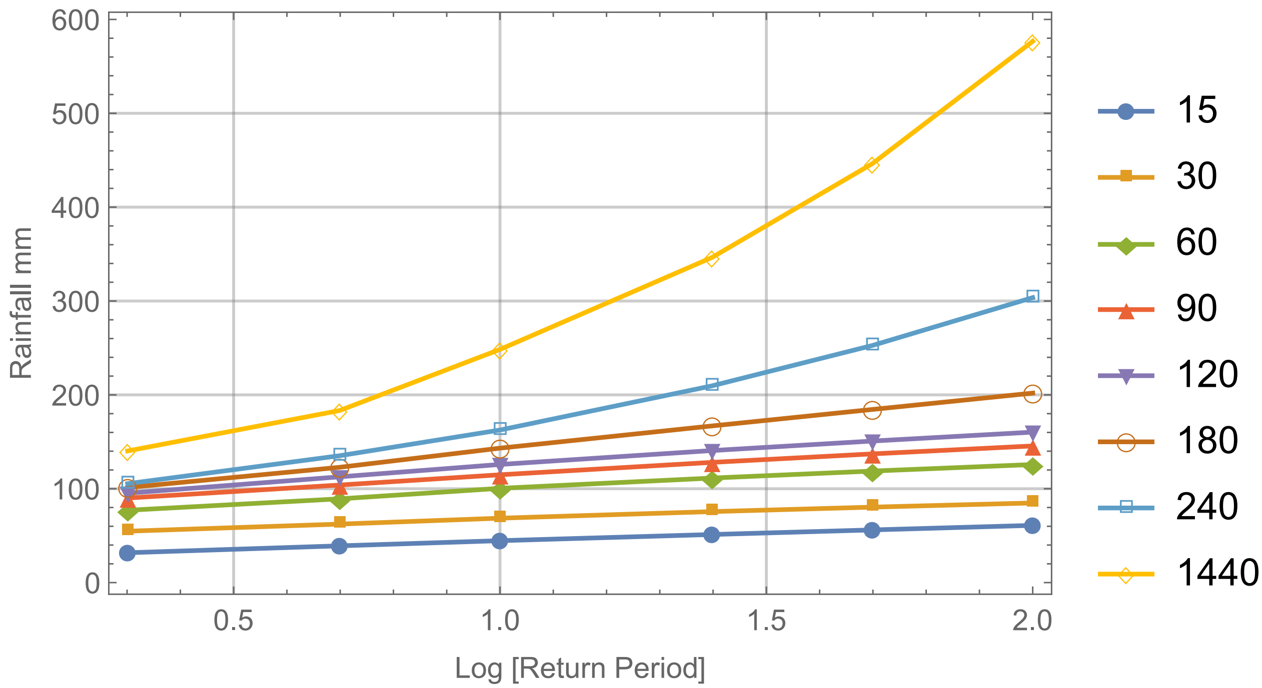


Fig. 10: Combined Rainfall Estimates for Different Durations& Return Periods

6 Rainfall Duration Functions for Different Return Periods

From the estimated maximum rainfalls from the previous analysis, the rainfall is modelled as a function of duration for different return periods. The following form is used to model the rainfall.

$$Rain = \frac{a}{b + t^c}$$

The estimated parameters are,

$$Rain = \frac{152.585}{0.0288095t^{0.86633} + 0.554569} \quad \text{(10 yr:)}$$

$$Rain = \frac{138.71}{0.0618373t^{0.679779} + 0.287313} \quad \text{(25 yr:)}$$

$$Rain = \frac{121.111}{0.113604t^{0.531229} + 0.0601981} \quad \text{(50 yr:)}$$

$$Rain = \frac{96.0643}{0.215595t^{0.37475} - 0.201781} \quad \text{(100 yr:)}$$

The functions were fitted using the data for durations 15, 30,60,90, 120, 180 and 240 minutes. Then their validity is tested by plotting the functions with the data including 1440 min (1 day) duration. The applicability of these functions are shown in Figures 11, 12, 13 and 14. The fitting of the data point at 1 day duration which was not used in the model calibration serves as an acceptable validation of the models.

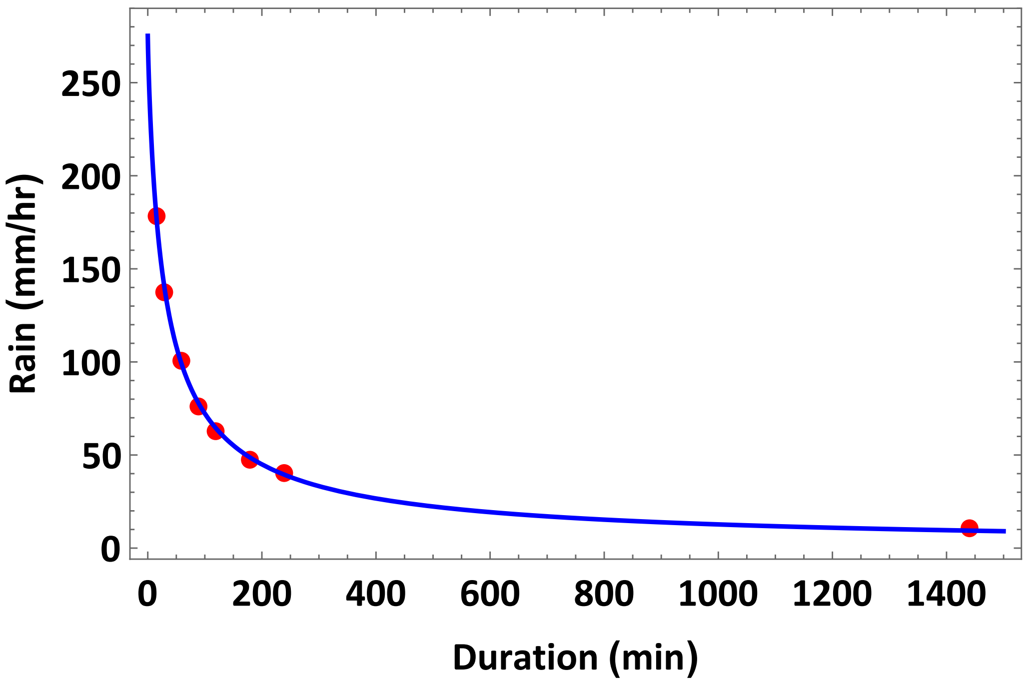


Fig. 11: Function for 10 year return period rain

7 IDF Curves for 1:50 year return period

By applying the function derived for 1:50 years, we can estimate the rainfall at 60,120,180, ... etc till 24 hours. Then taking the difference between the rainfall for 2 hours and 1 hour and subtracting we estimate the rainfall in the second hour. By repeating this procedure we can derive hourly design rainfall for 24 hours. The data are shown in Table(2). The plot of hourly blocks are shown in Figure(15).

We can now place the values in any order to create the design rainfall. A peak centered one would be as shown in Figure (16).

It is possible to make 30 min or 15 min time step design rainfall series by following the same procedure as outlined above.

Hour	Rain (mm)	Hr R. (mm)	Rain *.9 (mm)	HR*.9 (mm)
1	114.2	114.2	102.8	102.8
2	160.9	46.7	144.8	42.0
3	196.1	35.2	176.5	31.7
4	225.5	29.4	202.9	26.4
5	251.1	25.6	226.0	23.1
6	274.1	23.0	246.7	20.7
7	295.2	21.1	265.7	19.0
8	314.7	19.5	283.3	17.6
9	333.0	18.3	299.7	16.4
10	350.2	17.2	315.2	15.5
11	366.5	16.3	329.9	14.7
12	382.1	15.5	343.9	14.0
13	396.9	14.9	357.2	13.4
14	411.2	14.3	370.1	12.8
15	425.0	13.7	382.5	12.4
16	438.2	13.3	394.4	11.9
17	451.0	12.8	405.9	11.5

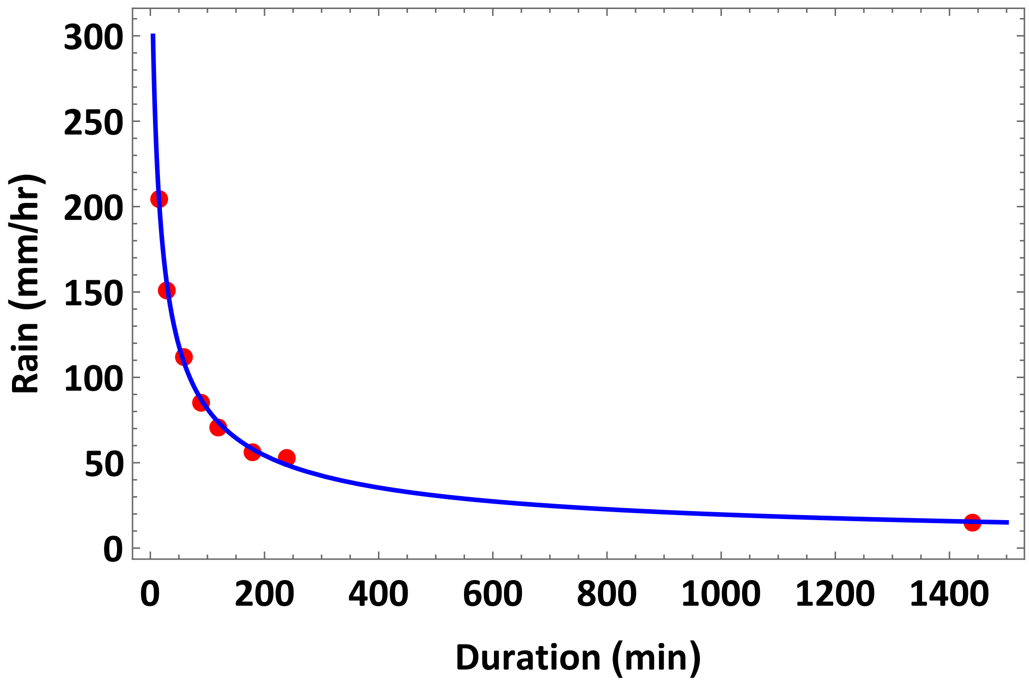


Fig. 12: Function for 25 year return period rain

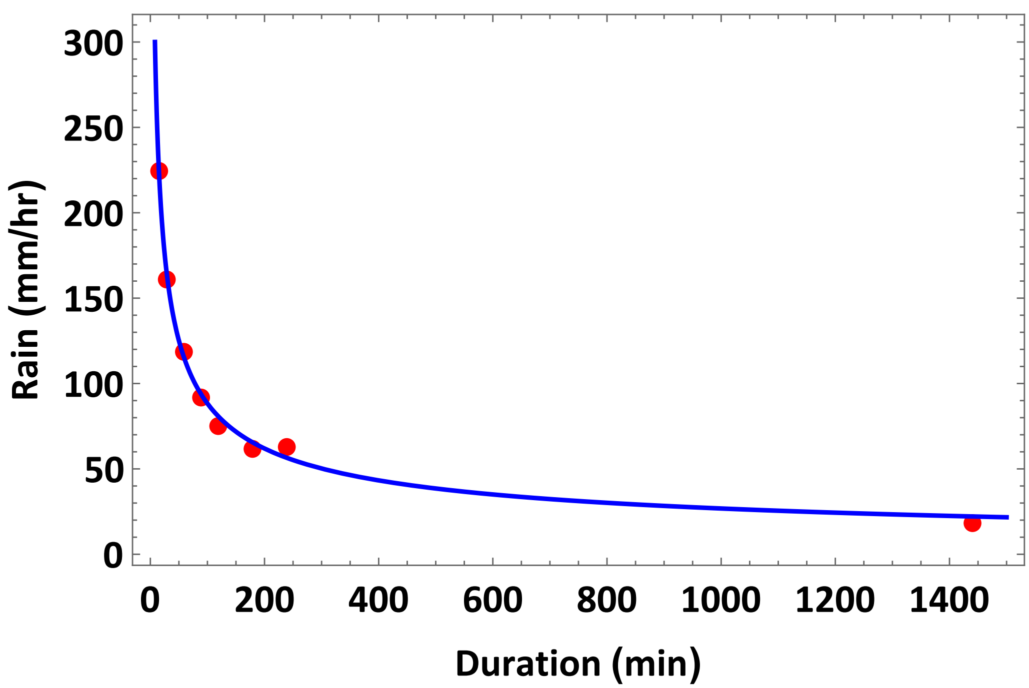


Fig. 13: Function for 50 year return period rain

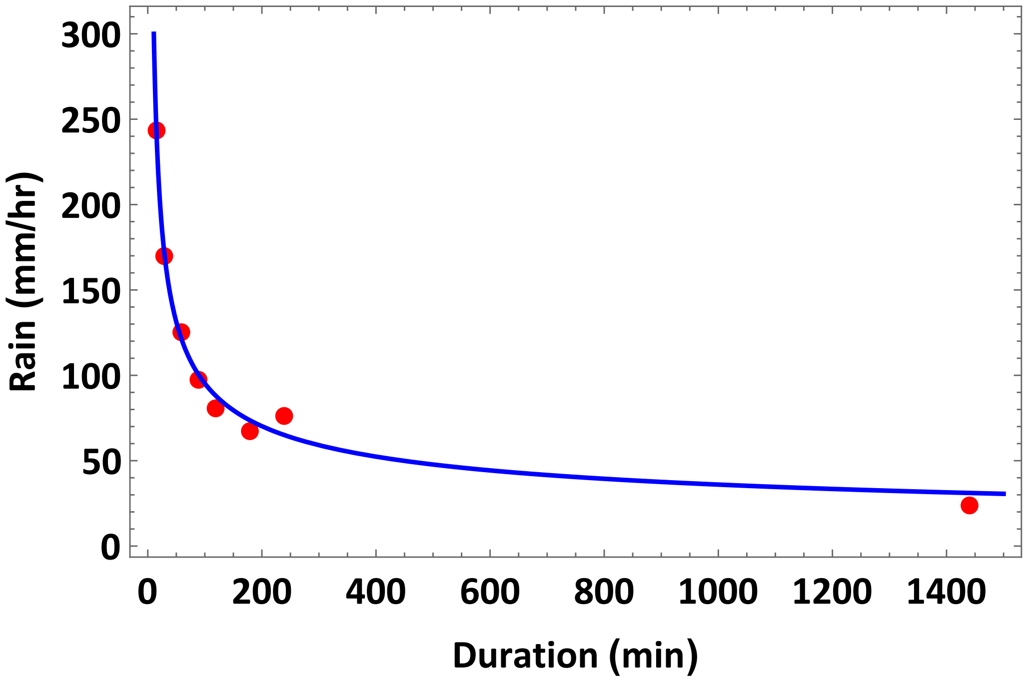


Fig. 14: Function for 100 year return period rain

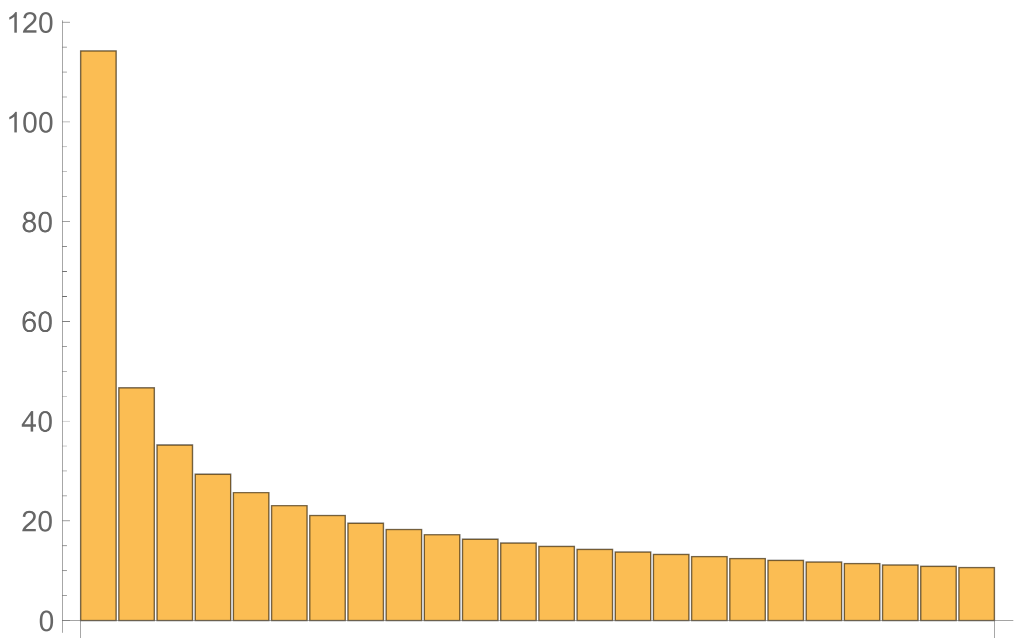


Fig. 15: Hourly rainfall blocks in 24 hour rainfall

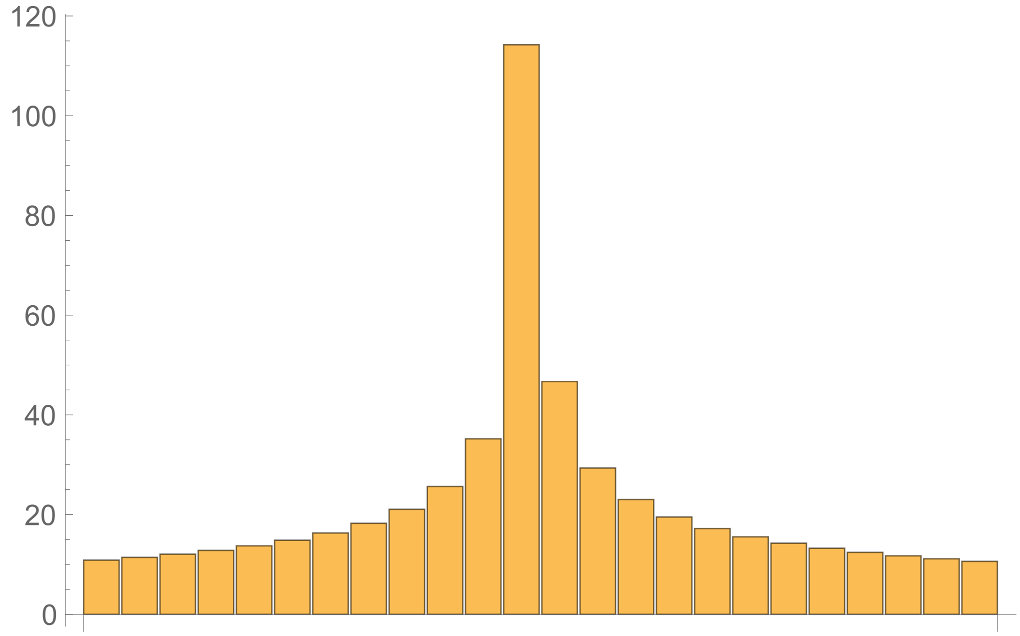


Fig. 16: Peak centred 24 hour rainfall

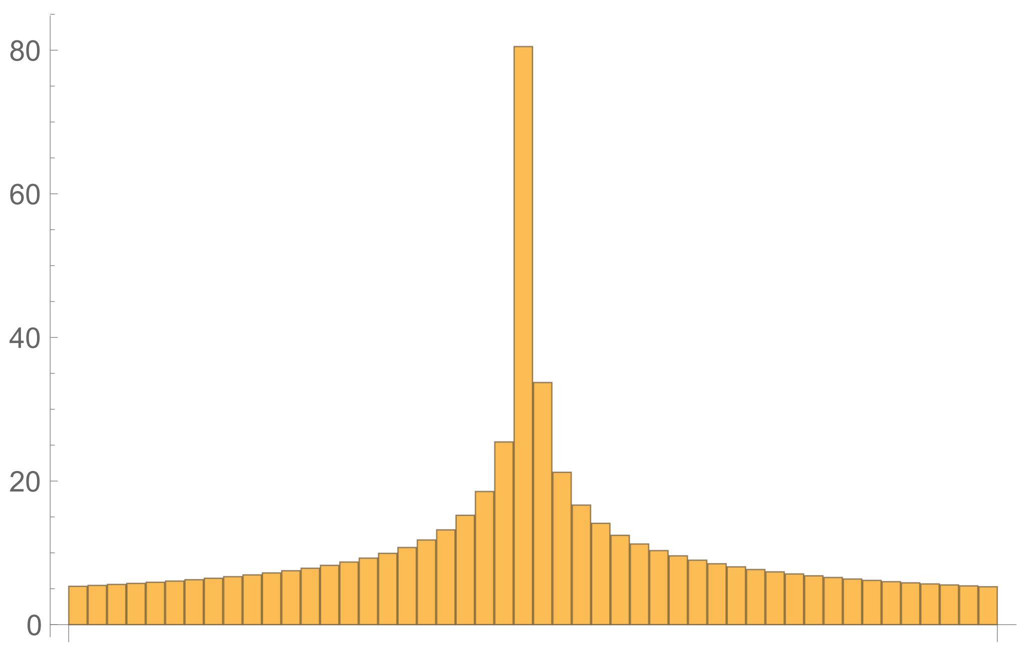


Fig. 17: Peak centred 24 hour rainfall for 30 min time steps

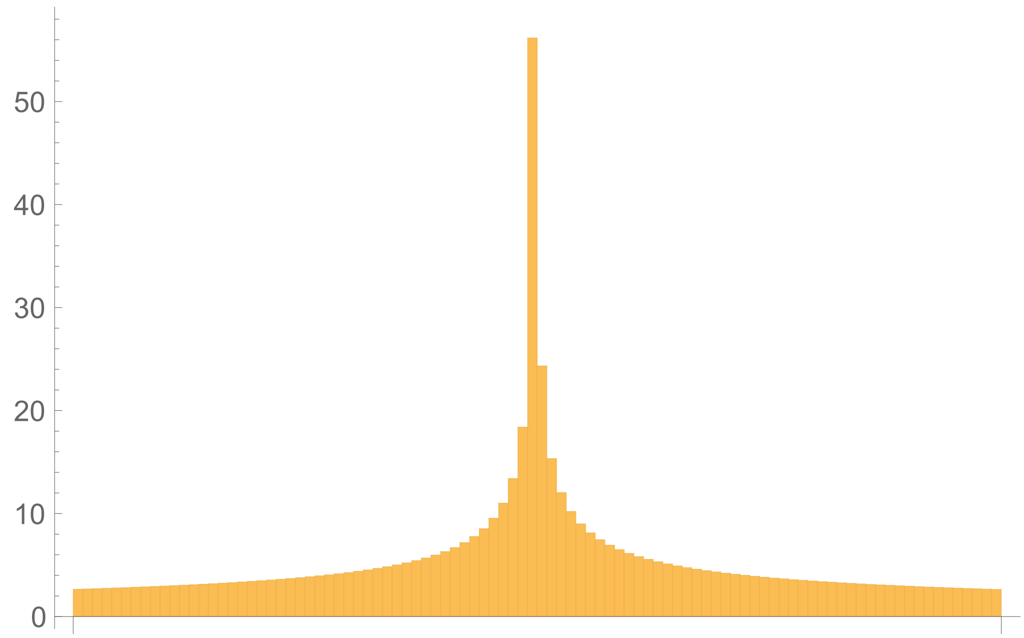


Fig. 18: Peak centred 24 hour rainfall for 15 min time steps

7.1 Areal Adjustment Factors

As these analyses are carried out for a point rainfall a depth-area correction needs to be applied that depend on the area of catchment as well as the duration of the storm. A typical reduction factor is shown in Figure (19) from *Applied Hydrology* by *V. T. Chow, et. al.*. In the SLLRDC analysis this areal factor is taken as 0.9. The reduced rainfall with this factor is also shown in the Table (2).

8 Summary and Next Steps

In this review, the both exceedence and annual maximum time series for different storm durations have been fitted to a range of extreme probability distributions and using the best fit distributions rainfall values for different return periods for durations 15, 30, 60, 90, 120, 180, 240 and 1440 min were estimated. Using the data for the first 7 durations IDF relations for different return periods were derived and they tested well with the 24hour maximum rainfall estimates. These set of equations now provide a consistent approach to derive design rainfall for both micro and macro drainage design.

The analysis has been carried out with rainfall durations up to 4 hrs. It would be good to prepare data for 6, 12, 18 hrs as well to increase the set of data points that can be used in

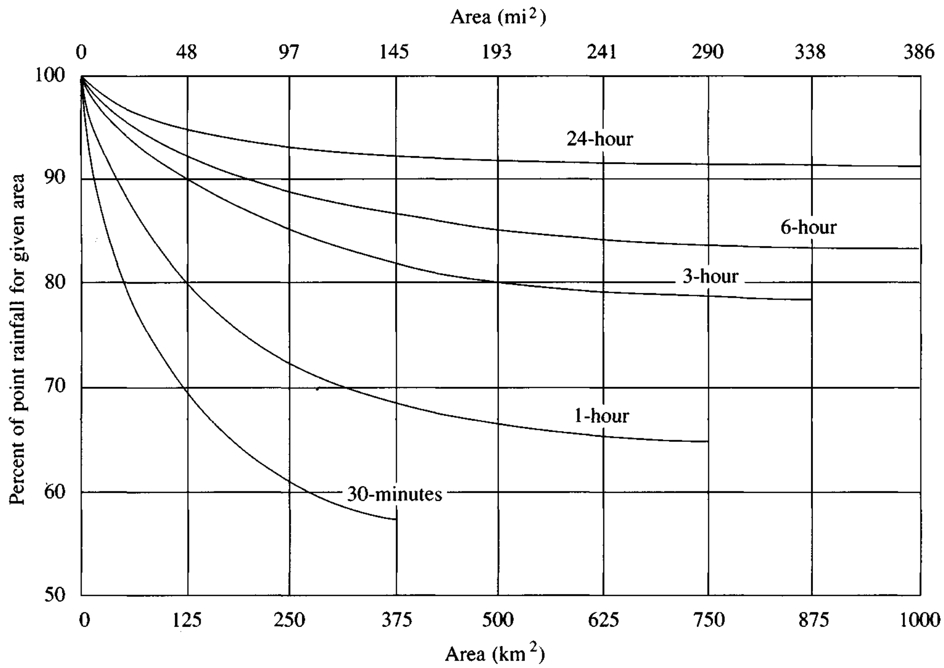


Fig. 19: Depth-area curve for reducing point rainfall to obtain areal average values - from Applied Hydrology, V. T. Chow, fig. 14.1.3

deriving these relations. Secondly the time series used currently is from 1981 to 2010. Now as we have 7 more years of data we need to update the time series and redo the estimates to understand changes as well as improve the IDF curves.

CUrW will carry out this upgrade after collecting the necessary information.

Design of storm water retention system for Edmonton Property

Proposal and Analysis

Srikantha Herath

May 18, 2018

Summary

The system is designed to capture peak discharge while allowing a base discharge corresponding to pre-development conditions. The allowed discharge is taken as that corresponding peak runoff for 1:5 year return period rainfall with a 0.3 runoff coefficient.

The retention facility need to store discharges above this rate for a 1:10 year return period design rainfall for a 0.9 runoff coefficient.

The total amount to be stored is 58 cubic meters of which 10 cubic meters are to be stored above ground and the rest to be stored in an infiltration gallery running on the side and back of the building. The trench system will have an effective storage corresponding to 2 m width and 60 cm height. The length of the trenches would be around 61 m and the void ration has to be maintained at 0.7 using appropriate materials. If this void ration cannot be maintained, the overland storage needs to be increased to accommodate the loss of storage volume.

This report summarises the hydrological and infiltration analysis. The detailed design to achieve these requirements need to be done separately including the mechanism for water allocation among the overland storage, continuous discharge and inflow to infiltration galleries. The infiltration galleries need not be lined and should be allowed to percolate to the natural ground water system. Appropriate measures to prevent clogging and at the surface need to be taken care of using geo-textile or similar materials.

1 Introduction

The millennium housing developers have constructed a six story apartment comples at Edmonton Road, Colomo 05. The site is approximately trapezoidal in plan and has an area of around 60 perches (1518 square meters). The ground water level is reported to be 0.8 m - 0.9 m. Completely weathered rock found at a depth of 9.4 m. During construction, as pile foundations have been used no soil remediation has been carried out thus leaving soil as in its original conditions. From the descriptions of soil profiles, a representative conductivity of 0.0001 cm/s is used in the analysis.

2 Design Criteria

The property need to take care of discharge resulting from 1:10 year rainfall to comply with local storm runoff design standards adopted for Colombo. The developer is expected to manage the increased runoff due to the construction of the building. The discharge corresponding to pre-construction state is expected to be taken care of by the existing drainage network. The allowable discharge is calculated as that correspond to a 1:5 year return period design rainfall that is more representative of the existing conditions.

The following conditions are assumed.

- The runoff coefficient before construction of the building = 0.3
- The runoff coefficient after construction of the building = 0.9

The water retention-infiltration facility at the site will be constructed to capture only the peak discharge allowing the maximum pre-development runoff volume to drain to the storm drainage network. The design is made to retain and infiltrate the excess volume resulting from the *peak-cut* after allowing pre-construction discharge to drain out. The peak-cut concept is shown in the Figure(1). This will be implemented by the arrangement shown in Figure(2).

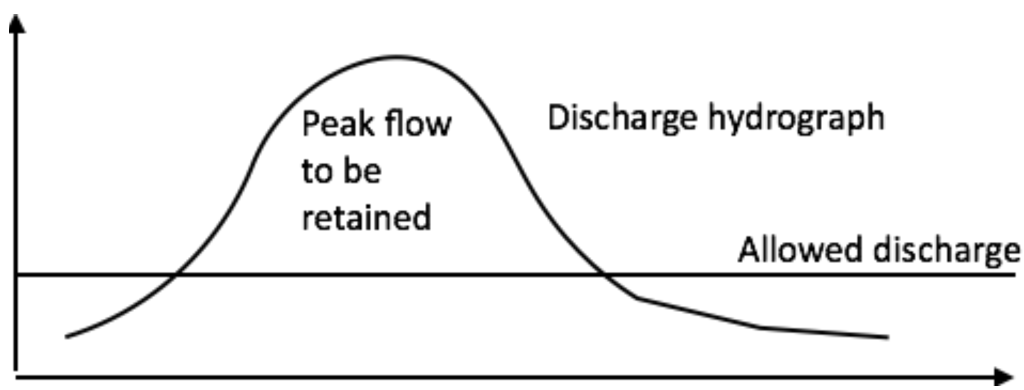


Fig. 1: Capturing the peak discharge

The system shown in Figure(2) comprise of a surface storage component, and an infiltration gallery running through the right side and back of the building.

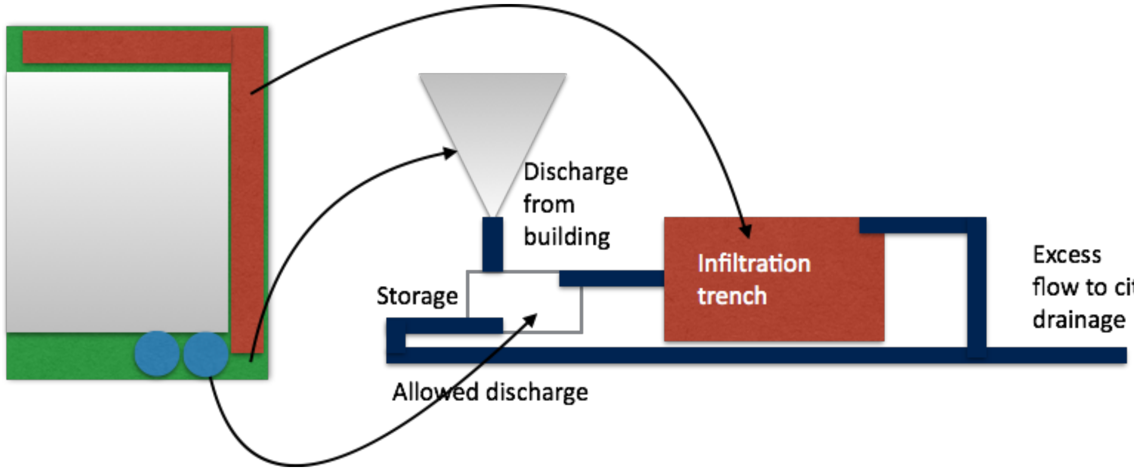


Fig. 2: Retention-Infiltration-Discharge arrangement for Edmonton

3 Hydrological Analysis

3.1 Design Rainfall

We have selected 1:10 year return period storm event as the design event for this intervention in accordance with the design standards for Metro Colombo loacal drainage. The design hyetograph was derived from the rainfall study carried out as part of the MCUDP project component *Development and Application of Urban Drainage Model* ([**udm˙2013**]).

The study has analysed 15 min rainfall data for the Colombo catchment and proposed the following formula to derive Intensity-duration relation for 1:10 year return period.

$$I_d = \frac{3473.1}{(T_d + 19.0520)^{0.8059}} \tag{1}$$

where I_d is the intensity for duration d rainfall event and T_d is the rainfall duration. Table 9 in the Appendix H of the *Development and Application of Urban Drainage Model* ([**udm˙2013**]) , page 104 lists the lists the Annual maximum rainfall series for durations 15 min, 30 min, 60 min, 90 min, 120 min, 180 min and 240 min in mm for the period 1981- 2010. The performance of the equation (1) was tested by comparing with these observed values.

A peak-centred 10min duration rainfall for 1 hour was estimated from the above equation and used for the design analysis. The design rainfall is shown in Figure (3). The rainfall volumes in each 10 min intervals are given below.

Time	Rain (mm)
5	3.46
10	4.18
15	5.22
20	6.88
25	9.81
30	16.01
35	22.31
40	12.25
45	8.11
50	5.95
55	4.64
60	3.79

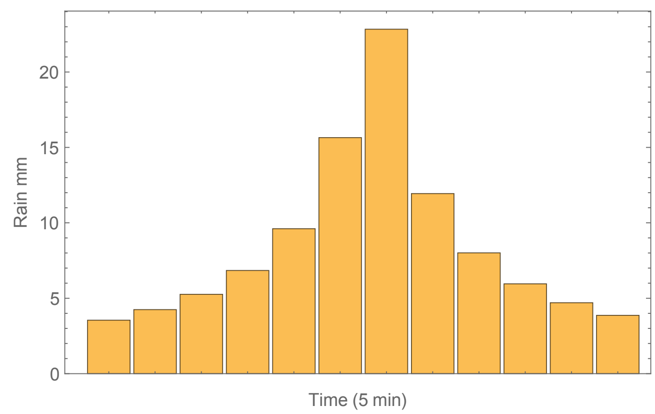


Fig. 3: 1:10 year design rainfall

3.2 Discharge

For the design rainfall, the discharge can be estimated from

$$Q = CIA \tag{2}$$

3.2.1 Allowable Maximum Discharge

The maximum allowed discharge is computed according to the 1:5 year return rainfall and estimated for 10 min time step. This design rainfall constructed for 60 min in 10 min time steps is shown in the Figure(4).

The maximum discharge corresponding to a runoff coefficient of 0.3 for this rainfall is taken as 0.25 m^3/s

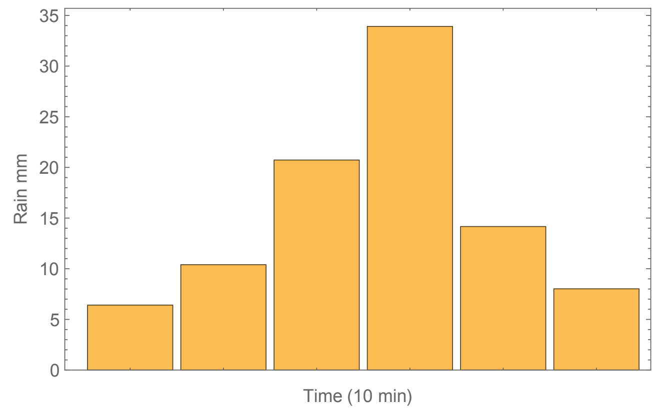


Fig. 4: 1:5 year design rainfall

3.2.2 Storage Required

The one hour duration 1:10 yr design rainfall produce a 102.5 mm total rainfall resulting in 140 cubic meter discharge in the developed conditions. When the allowed maximum discharge at pre-developed conditions corresponding is taken as 0.025 m^3/s. The total amount to be retained is 58 cubic meters as shown in the Figure(5).

4 Modeling Infiltration Systems

The water flow from infiltration facilities such as trenches and wells can be estimated using Richard's equation,

$$\nabla \cdot [k(\psi)\nabla(\psi - z)] = c(\psi)\frac{\partial \psi}{\partial t} \tag{3}$$

where ψ is the suction pressure, z vertical distance $k(\psi)$ is the conductivity at suction ψ, and $c(\psi) = \frac{\partial \theta}{\partial \theta}$ where θ is the moisture content. During infiltration from a trench or a well, the infiltration rate decreases gradually and attains a constant rate. Infiltration rate become constant when the saturated front attains a stationary shape, while unsteady unsaturated flow continues outside the stationary front. For soils with fairly high conductivity this quasi-steady state is reached in a short period of time. To estimate the final constant rate, steady state of Richards' equation is used with conductivity function $k(\psi)$ expressed as,

$$k(\psi) = K_0 kr(\psi) \tag{4}$$

where K_0 is the saturated conductivity of the soil and$kr(\psi)$ is the relative conductivity. The reason for this separation is to make the analysis independent of the saturated conductivity, which is the most sensitive parameter, as well as having a large field scatter. Using (2) in Richards' equation (1), and scaling with respect to the K_0 , the governing equation is obtained

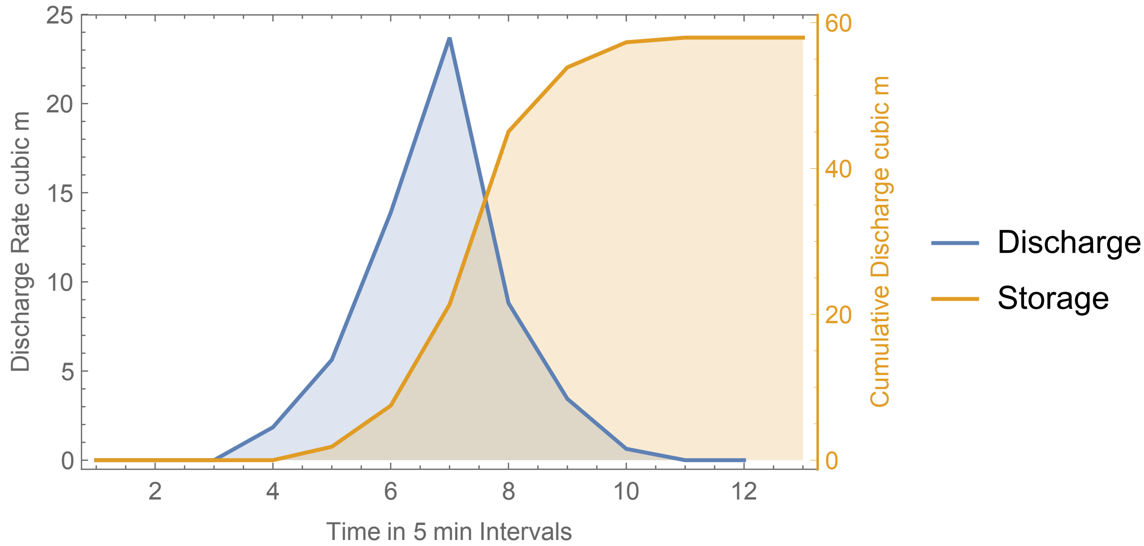


Fig. 5: Runoff to be retained locally

as,

$$\nabla \cdot [kr(\psi)\nabla(\psi - z)] = 0 \tag{5}$$

Due to eq. (2) only the relative conductivity is used in the simulation and the flow rates are expressed scaled with respect to soil saturated conductivity. After solving the equation for the required type of infiltration facility for given boundary and initial conditions, infiltration capacity is estimated from the final ψ distribution using the Darcy's law as,

$$\frac{Q}{K_o} = \int_{\Gamma} kr(\psi)\frac{\partial}{\partial n}(\psi - z) \tag{6}$$

where Γ denotes the infiltrating surface, and n is perpendicular to the infiltrating surface. For Cartesian co-ordinates, eq.(4) takes the form of,

$$\frac{Q}{K_o} = \int_{x=0}^{x=a} kr(\psi)\frac{\partial}{\partial z}(\psi - z)|_{z=z_b}dx + \int_{z=z_t}^{z=z_b} kr(\psi)\frac{\partial \psi}{\partial x}|_{x=a}dz \tag{7}$$

where a is the infiltration facility half width, z_b is the facility bottom and z_t is the facility top.

4.1 Estimating Infiltration Capacity

In order to follow the above procedure, soil properties in the form of conductivity-suction$kr(\psi)$ relation should be known. If this relation is not available from laboratory data, it can be generated from more common moisture-suction $(\psi - \theta)$ data, which can be reliably measured from small soil samples, or a representative relation can be used in its place (Herath et al., 1990).

A number of empirical regression equations also are available to generate $(\psi - \theta)$ relation from soil textural and other data. When $kr(\psi)$ relation is known, eq (3) and (4) can be used to estimate the Q/K_0 value for a given infiltration facility.

The soil moisture properties for the site are not available at the moment. Therefore a generalised loam type of soil is assumed. The soil conductivity - suction relation used in the simulation is described by the following equation,

$$kr(\psi) = \alpha\psi^{\beta} \tag{8}$$

Four representative soil types are used in numerical simulations when soil hydraulic properties are not available. The representative soil types are described by the parameters $\alpha = 131$ and $\beta = 2.31$

Numerical simulations for both deep and shallow ground water conditions have been carried out and the final infiltration rates for two different boundary conditions were estimated. The Figure (6) shows the distribution of final water pressure around the trench with a water head of 25 cm at constant head constraints.

The final infiltration rates for a trench 2m width and the bottom located at 60 cm for different water heads is shown in Figure (7) .

5 Numerical Simulation

The system is modelled as shown schematically in Figure(8). From left to right the icons represent the water head and infiltration rate relation for the trenches, the design rainfall, property, overland storage and trench storage. The Figure(9) shows the discharge rates in cms from the property, discharge to drainage system during the rain from the overland storage and the inflow to the trench system. The Figure(10) the same graph, but presented as the cumulative volume in cubic meters. The Figure(11) shows the variation of storage in the overland storage and the trench system. the storage within the trench system will be percolated if the soil conductivity is of the order of 1.0 $10^{-4} cm/s$.

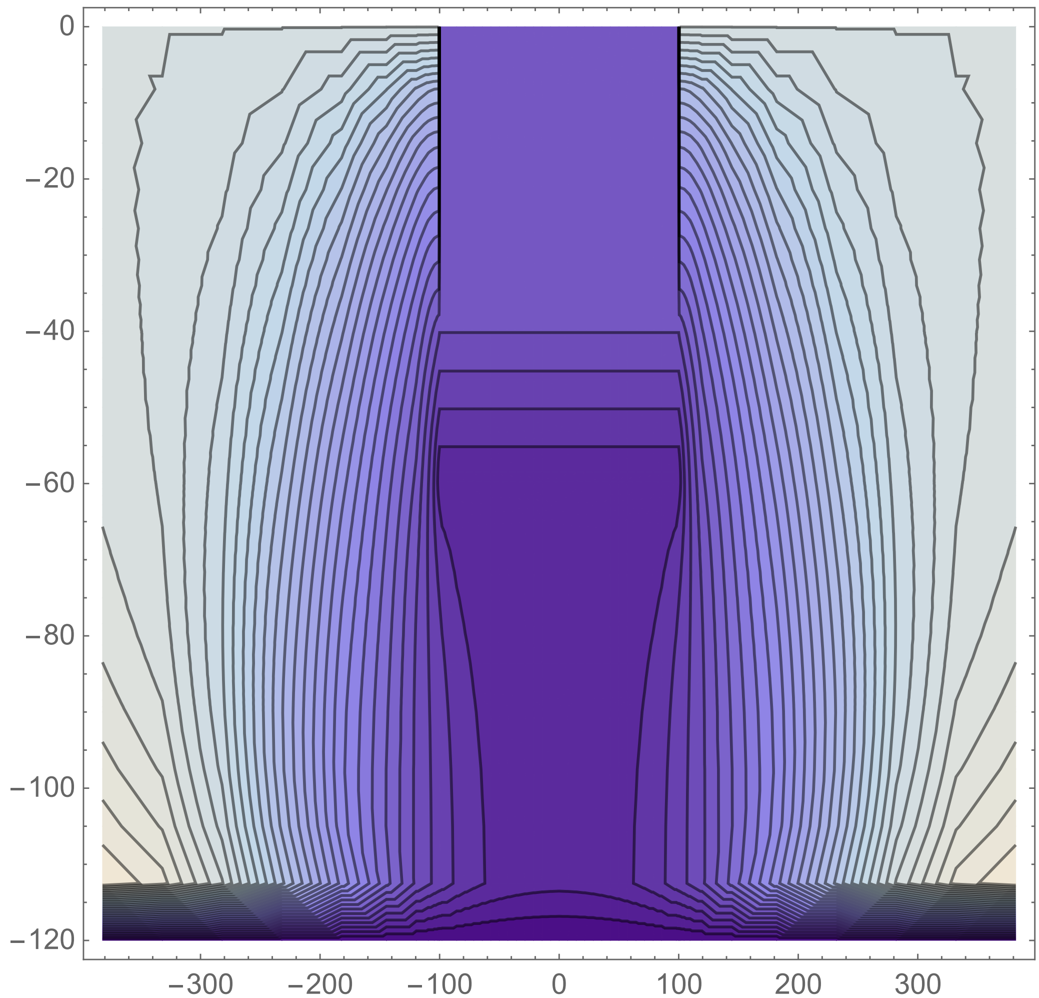


Fig. 6: Pressure distribution h=25cm

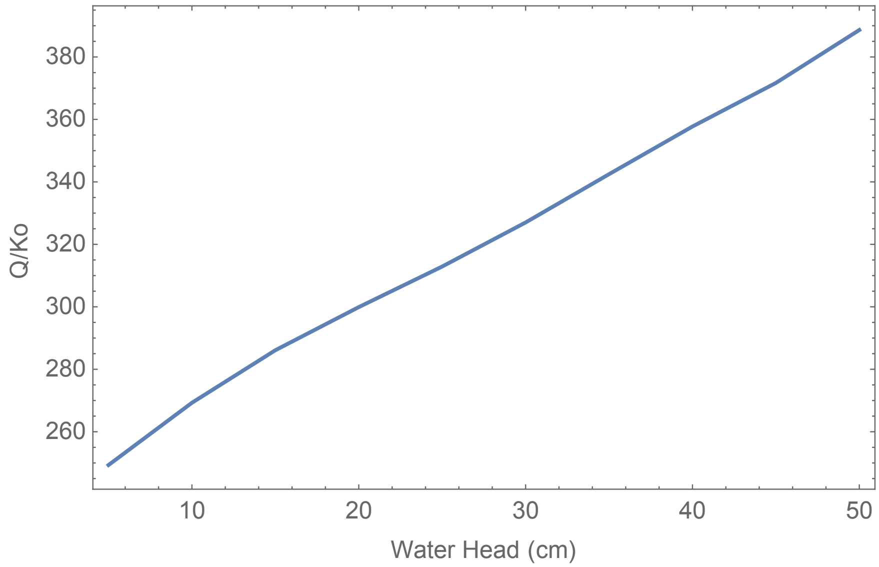


Fig. 7: Infiltration Rates normalised wrt to Conductivity

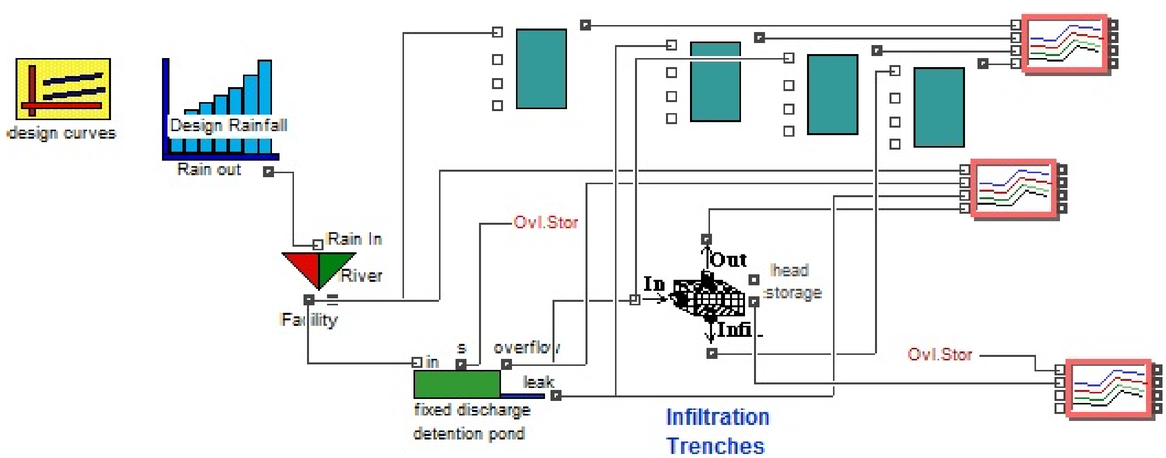


Fig. 8: System representation in the model

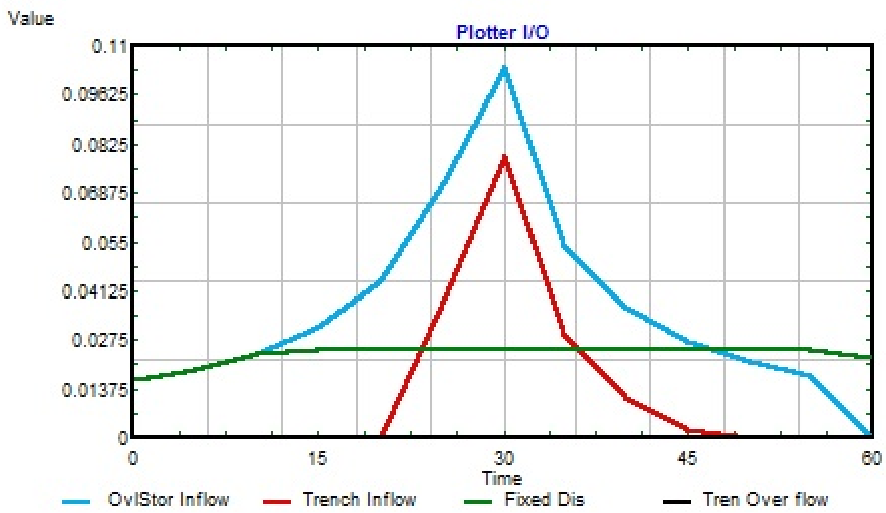


Fig. 9: Runoff rates from the property, overland storage and trench inflow

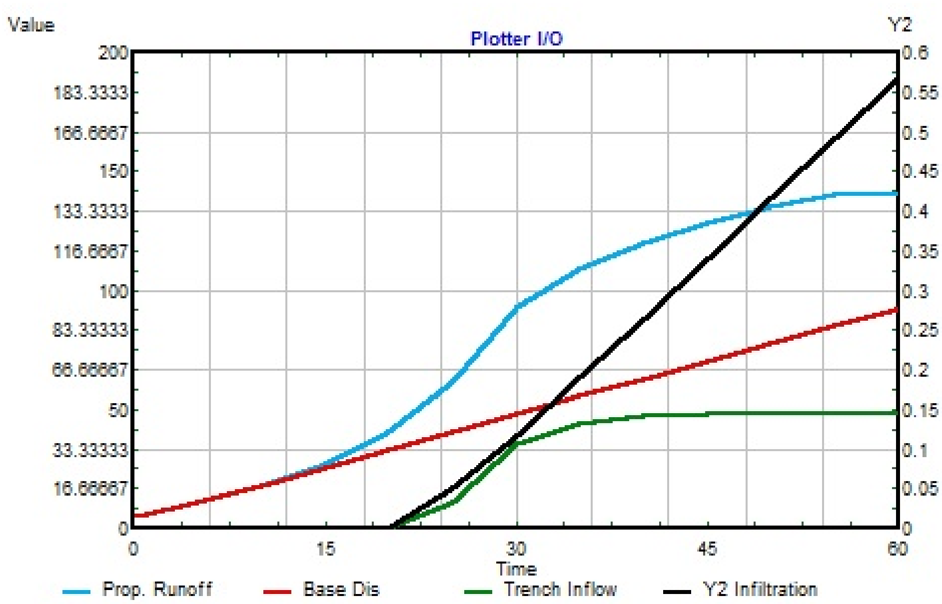


Fig. 10: Volumes of runoff from the property, overland storage and trench inflow

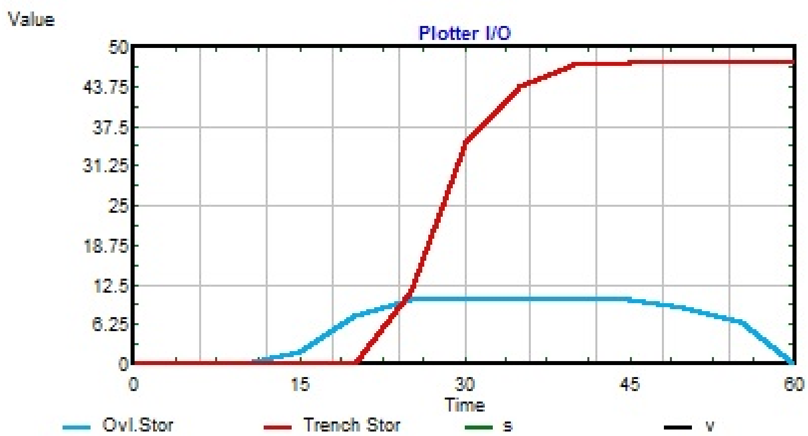


Fig. 11: Variation in the overland storage and trench storage

Evacuation Planning for Metro Colombo

Concept Note

1 Introduction

At present there are no controlling facilities such as pumps or gates to regulate the flow in the city to reduce flood waters in the event of an extreme rainfall that exceed to the drainage capacity of the network. At the completion of the metro colombo urban drainage project, it is expected the city can withstand a 500mm/day rainfall which is estimated as a 1:50 year return period event. However, the completion of these flood control measures would take about 2.5 years more and it is necessary to assess flood risks and develop warning and evacuation plans to address extreme events that may take place in the intervening years. This report presents a brief concept note on assessing and implementing such a plan.

2 Strategy

2.1 Rainfall categories

It is planned to design and implement a warning and evacuation strategy based on impacts. Thus, warning as well as response guidance should ideally be planned according to expected impacts. For this purpose the expected flooding conditions are to be categorised in to three groups as,

1. Frequent flooding conditions with a 2 year recurrence interval
2. Intermediate flooding conditions for over 5 year recurrence interval
3. Extreme conditions such as 2010 floods, or 1992 floods caused by a 500 mm/day (a 1:50 year) rainfall.

Flood risk maps estimated for a 2 year return periods is shown in Figure (1). The corresponding figure for a 5 year return period flood is shown in Figure (2). A 50 year return period flood map is shown in Figure (3). These maps have been derived through the numerical model simulation of floods corresponding to design storm for each of the

Fig. 1: Flood map for 1:2 year return period rainfall

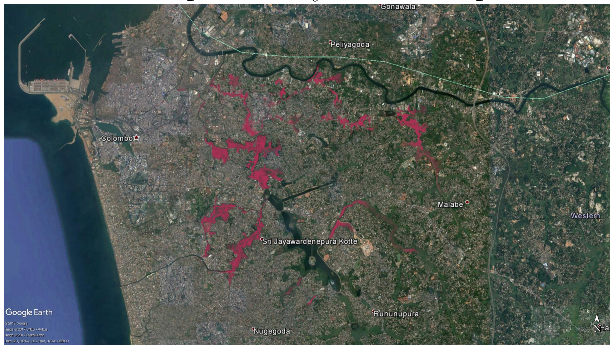
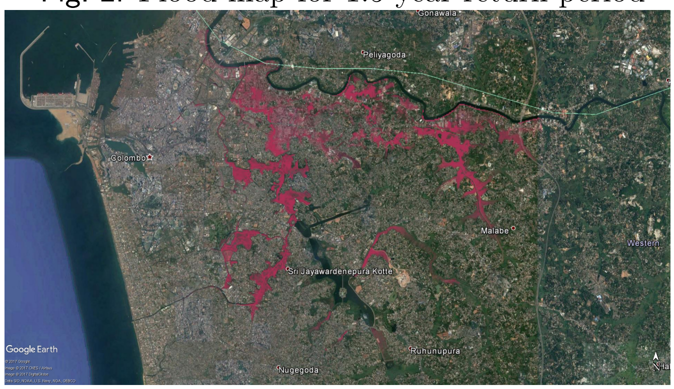


Fig. 2: Flood map for 1:5 year return period



return periods, as part of the risk assessment study carried out under Metro Colombo Urban Drainage Project (MCUDP).

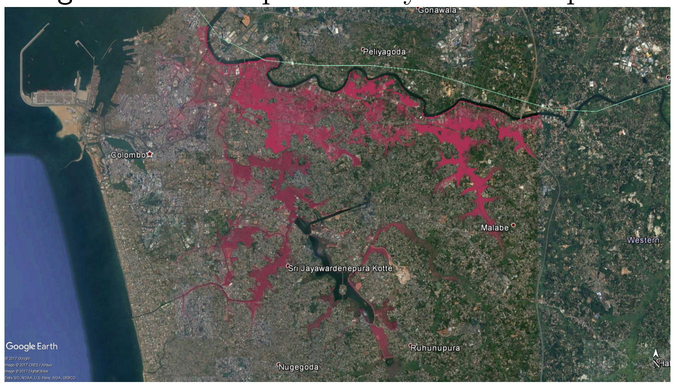
2.2 Evacuation center categories

Three types of evacuation centers may be considered based on the above mentioned three types of floods.

1. For very frequent flooding we may consider multi-purpose evacuation centers that can function as community development focal points that can be used for improving livelihoods of the people in affected areas through vocational training and similar community activities. Such community activities will help people to be familiar with the place they need to evacuate and make it easy to move quickly once a flood warning is issued.

2. For the second category, public facilities such as schools, temples, etc., can be utilised.

Fig. 3: Flood map for 1:50 year return period



3. For the third extreme events, some temporary facilities would be needed to accommodate the population that cannot be taken care of by the above two sets of facilities. These may be parks and playgrounds, where temporary shelters, normally tents are set up to accommodate displaced population.

3 Methodology

Ideally we should use the hazard maps produced at different rainfall frequencies to assess the risks and locate evacuation places. However, the maps shown in Figures (1 - 3) are produced by model runs used for planning purposes and are currently being verified for the use of detailed design purposes.

Alternately, the 2010 flood event is used to assess the flood risk as this is the event closest to flood risk reduction being considered in under the Metro Colombo Urban Drainage Project (MCUDP).

For a given flood category, people at risk are estimated $\leq 30cm$, water level $50-100cm$ and water level $\geq 1m$. The evacuation should start form those at highest risk and then proceed to lower risk areas. Here we can assume the population subjected to frequent flooding will be in the water level $\geq 1m$ in extreme conditions. Thus the concept of different frequencies in flooding is applied here through zonation of different flood depths.

The night time population is to be housed in the evacuation centers while the daytime population should be provided with transport facilities to move out of the city in an orderly manner.

3.1 Steps in assessment

1. Estimate the population at risk at each of the inundation range and summarize by GN division

2. Identify evacuation center locations for each of the above categories that are within walking distance to population being served.

3. For the frequent flooding areas (or high water level at extreme events) community dedicated community centers are recommended

4. For the next category of floods public buildings, here schools and religious grounds with a floor area $\geq 10000ft^2$ are identified as evacuation centers

5. We need to identify open spaces in high ground to accommodate evacuees where temporary shelters may have to be put up.

6. Assess the feasibility and modify initial locations to accommodate ground realities through a consultative process with relevant stakeholders.

4 Preliminary application of the methodology

We initially select 2010 flood event to estimate the evacuation needs and candidates for evacuation facilities. The Figure(4) shows the flood extent map prepared from remote sensing data by the WB project Wessa. Figure (5) shows the numerical simulation of this flooding event that provides flood heights in addition to extent. The combined map in Figure (6) shows that the simulated flood extent matches with the one prepared through satellite observations and thus this combined map is used for the estimation of the evacuation centers.

The Figure (7) shows the inundation areas categorised as .5m to 1m and above 1m. Then the population at risk in each zone is calculated using the building footprint and population distribution model. The building distribution is shown in Figure (8). The population in each GN division is distributed among the buildings using a model for the population density for different building categories.

The population at risk above 1 m range is shown in Figure (9). They may also be subjected to frequent flooding from less intense rainfalls. As much as possible they may be provided with evacuation centers that can also function as community development facilities. Such a model has been successfully adopted in Bangladesh for coastal storm surge evacuation.

The population at risk in 0.5 - 1 m range is shown in Figure (10). The GN divisions are categorised according to number of people at risk. These may be located in public facilities marked as circles in the map. These points represent schools and temples with a floor area above 10000 sq.ft.

Fig. 4: 2010 Flood extent from satellite images

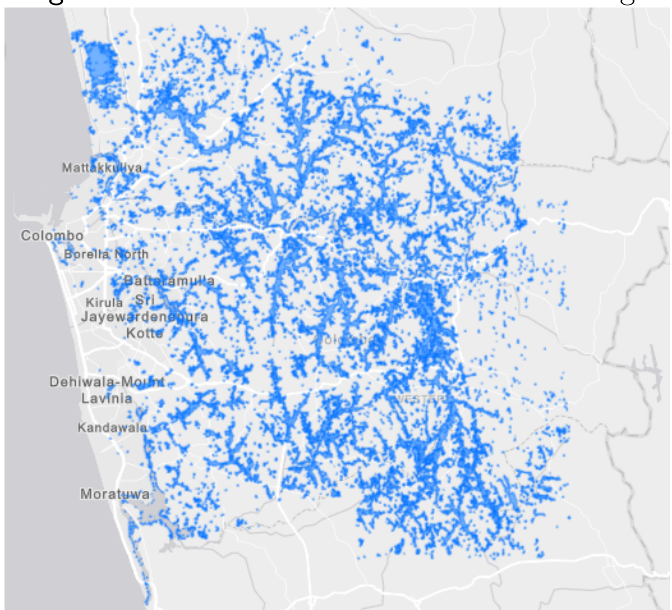


Fig. 5: 2010 Flood extent from numerical simulation

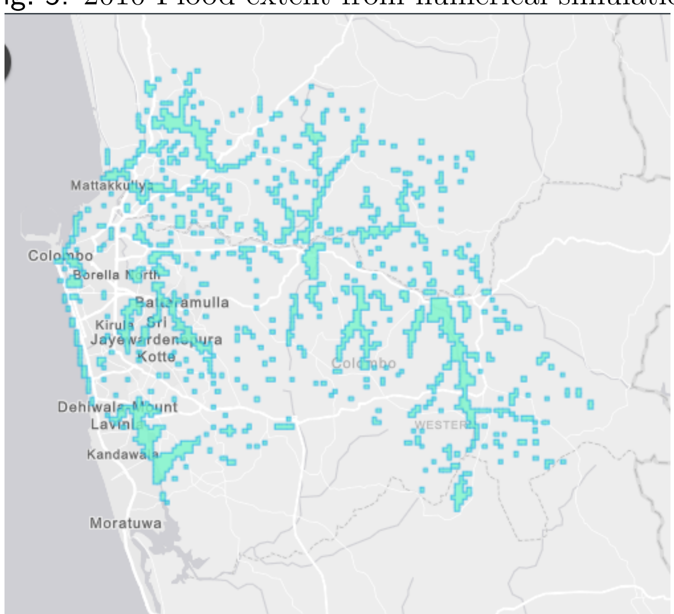


Fig. 6: 2010 Flood extent combined from satellite observations and numerical simulation

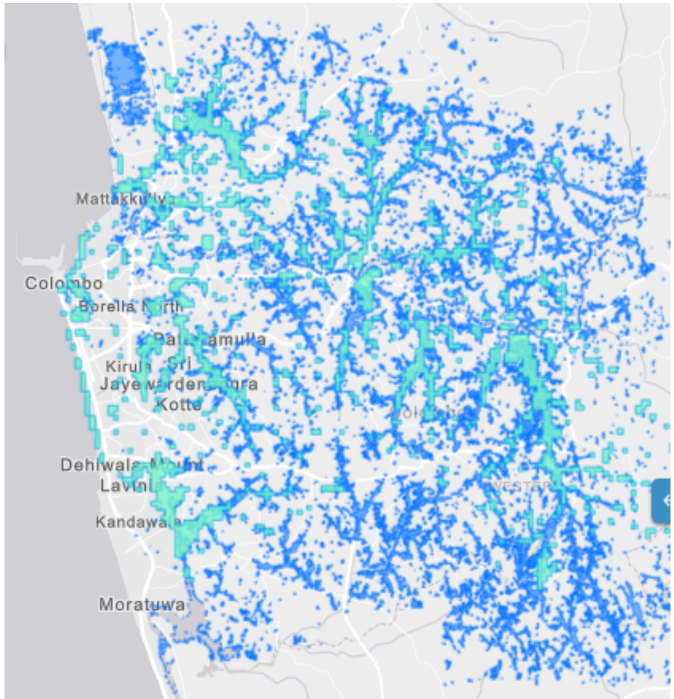


Fig. 7: 2010 0.5m and 1.0 m contours from numerical simulation

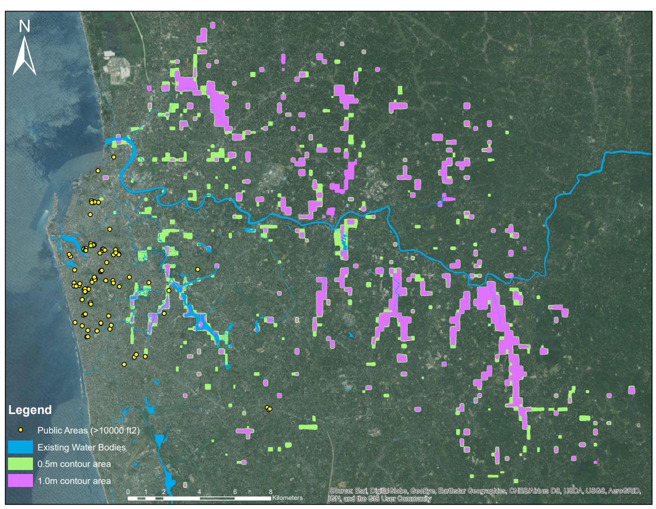


Fig. 8: Building footprint for Metro Colombo

Fig. 9: Population to be evacuated to evacuation centers

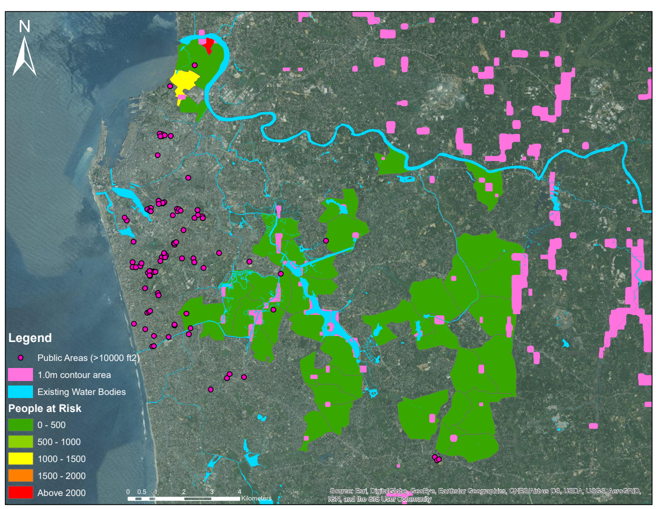
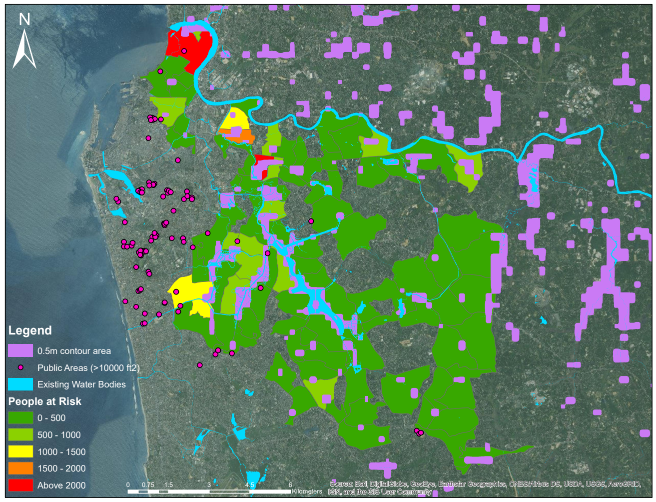


Fig. 10: Population to be evacuated to Public Buidlings



5 Areas to be clarified

Area Covered Whether the study area covers only the MCUDP area. If it extends beyond, not only city floods, but also the Kelani floods need to be considered.

Stake holder Collaboration Discussion with social development agencies on the possible collaboration in setting up evacuation facilities with community development programmes.

Logistics Whether DMC has plans on evacuation guidance and if so how they can be incorporated in the present study.