PAPER 10

Forecast early warning system:
Operational engineering to manage disasters

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ABSTRACT

Early warning systems are used to effectively plan and manage predictable events. Predicting impacts of weather events well in advance, allows disaster management practitioners ample time to manage their already limited emergency services to where they need to be and at what time. Weather related disasters such as Durban's October 2017 storm event claimed 13 lives and caused infrastructure damages to an estimated R213 million within the eThekwini region. The residual damage to communities' quality of life, livelihood, personal assets, health and business is, in some instances irreversible. The eThekwini Municipality and surrounding areas are prone to flood and coastal related disasters which have increased in intensity and frequency in recent years.

In an effort to proactively prepare and mitigate for the forecasted impacts of weather related disasters and fulfil the responsibility of developing disaster risk reduction and management activities, the eThekwini Municipality undertook the development of a Forecast Early Warning System (FEWS). FEWS currently includes an operational flood forecasting module with plans to roll out a coastal forecasting module by the end of 2019. The system is supported by an open source data management platform that can be tailored for each user organisation. The components of the system include a configuration, instrumentation and a modelling team. By integrating hydraulic models with forecasted rainfall, provided by the South African Weather Service, the FEWS team identified and classified possible river levels that trigger different warning categories along with their impacts. This information is disseminated to the relevant stakeholders in a format that can be interpreted by the reader.

Having no point of reference on how to develop a cost effective yet purpose driven forecasting system, many a lesson was learned along the way. This paper outlines the challenges and learnings of eThekwini Municipality's roll out of an operational early warning system in consideration to human resources, cost, collaboration with internal and external entities and warning dissemination for internal and public response. The challenge of skills deficit was met with a concerted effort by management to identify and up-skill willing and dedicated technical staff. Freeware software were used as the FEWS team was conscious of costs and the design and development of the system. The purpose of this project required a large effort into how impact based warnings were issued to public considering format and South African Weather Service (SAWS) approval. Collaborations with key role players such as SAWS and eThekwini Disaster Management Unit were invaluable in fulfilling eThekwini's purpose of getting Impact Based Warning out in the right format, to the right people, at the right time.

INTRODUCTION

Early warning systems are used to effectively plan and manage predictable events. Predicting impacts of weather events well in advance, allows disaster management practitioners ample time to manage their already limited emergency services to where they need to be and at what time. International organisations such a World Economic Forum and World Meteorological Organisation have realised the impact of climate change and the devastation it can create without disaster risk reduction methods such as early warning systems.

Established Early Warning Systems such as European Flood Awareness System; the European Hydrological Predictions for the Environment Model; the Australian Flood Forecasting and Warning Service; the U.S Hydrologic Ensemble Forecast Service; Global Flood Awareness System and Global Flood Forecasting Information System has seen the benefit of reduced loss of life since its existence. The eThekwini Municipality has experienced the effect of climate change in the intensity of rainfall events and coastal surges.

In an effort to proactively prepare and mitigate for the forecasted impacts of weather related disasters and fulfil the responsibility of developing disaster risk reduction and management activities, the eThekwini Municipality undertook the development of a Forecast Early Warning System (FEWS). FEWS currently includes an operational flood forecasting module with plans to roll out a coastal forecasting module by the end of 2019.

The development of the eThekwini Forecast Early Warning System was the first of its kind in South Africa and Africa. Being pioneers with no point of local reference, eThekwini faced a number of challenges including skills deficit, creating a cost effective yet value driven system, acquiring the information required to run the system efficiently and disseminating warnings effectively. Some challenges unique to a third world country like South Africa included something as simple as getting the warnings out to people in a way they best interpreted it. These challenges were addressed with investment in up-skilling internal staff, investigating freeware software, collaborating with internal and external entities to acquire the right information by promoting mutual benefit and understanding how to deliver the right message to the right people, in the right format and at the right time.

EARLY WARNING SYSTEMS

'The paradigm shift from post disaster response to a proactive risk reduction approach requires meteorological, hydrological and climate services to support science-based risk management decisions, as well as investments in early warning systems' (WMO 2018). The United Nations Sendai Framework for Disaster Risk Reduction (SFDRR) as well direct national, local, regional and global disaster risk reduction by underlining four priorities for action i.e. *'(1) Understanding disaster risk. (2) Strengthening disaster risk governance to manage disaster risk. (3) Investing in DRR for resilience. (4) Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction'* (UNISDR 2015). In response to these priorities, early warning systems are being invested in for a proactive approach to disaster risk reduction.

Early warning systems for weather related disasters such as flooding, have been developed and tailored over the past decades across the world. First world countries have invested time and resources on tailoring their early warning systems for their respective application, climatic conditions and data availability. Extreme weather events, natural disasters and failure of climate change mitigation and adaptation have ranked in the top five global risks by likelihood and impact for this year by the World Economic Forum (2019). Climate change, although a highly debated topic, is most certainly taking centre stage in recent years. Floods have affected more lives in the world than any other disaster (CRED 2019). In 2018 alone 50% of lives affected by natural disasters were attributed to flooding (CRED 2019). That being said, in 2015, the World Meteorological Organisation reported that although economic losses caused by hydrometeorological events had increased by 50 times over 50 years, loss of life however, had reduced by a factor of 10 over the same period (WMO 2015). This is attributed to the presence of early warning systems.

Hydrometeorological early warning systems and the like are therefore becoming a higher priority to mitigate against loss of life and infrastructure. This section describes some of the existing early warning systems in the world and then looks at how the operational processes and purpose of the systems compare to the operational needs of South Africa and eThekwini in particular.

Global and Continental Scale Early Warning Systems

Dynamically improving numerical weather prediction models allows operational centres to input better meteorological data into their hydrological models to produce improved forecasted flood levels (Emerton et. al. 2016). Figure 1 describes basic hydro-meteorological integration required to produce flood forecasts.

Some global and continental scale examples of hydrometeorological operational forecasting centres, include the European Flood Awareness System; the European Hydrological Predictions for the Environment Model; the Australian Flood Forecasting and Warning Service; the U.S Hydrologic Ensemble Forecast Service; Global Flood Awareness System and Global Flood Forecasting Information System. Most of the modelling tools used to determine these systems flood inundation are geospatial in nature of a relatively courser scale. Models such as Lisflood, HYPE and HydroSHEDS are some examples of the rainfall-runoff and routing models being used to forecast between 10 -15 days (Emerton et.al. 2016).

The information generated from these models are then compared to preset thresholds that determine the warning level that is required to be reported. This is the information dissemination process of the system. Information (warnings) are disseminated primarily through websites where or automated platforms, however in some instances fax, email and telephone are also used as in the Australian system. Currently, the Australian Flood Forecasting and Warning Service is the only system that includes manual forecast verification conducted by designated forecasters (Emerton et.al. 2016).

Climate Change Impacts

While the National Climate Change Adaptation Strategy describes positive trends in the increase of rainfall in parts of South Africa and negative trends in others (Environmental Affairs 2017), the Durban Climate Change Strategy highlights a positive increase of 500mm in aggregated rainfall for Durban between 2065 and 2100 (eThekwini Municipality 2014). In addition to that, average temperatures are expected to rise by between 1.5 and 2.5 degrees Celsius by 2065 along with heat waves and higher intensity rainfall events among others. In response to these alarming climate changes, the South African Department of Environmental Affairs has raised national priorities for human settlements disaster risk reduction and management provisions and expanding of early warning networks for disaster management (Environmental Affairs 2017). The following section will detail how the eThekwini Municipality (eThekwini) has invested in a Forecast Early Warning System to address these priorities in an operational approach to engineering for disaster management.

ETHEKWINI FORECAST EARLY WARNING SYSTEM

Background

Initially intended for flood early warnings, as time progressed, eThekwini saw

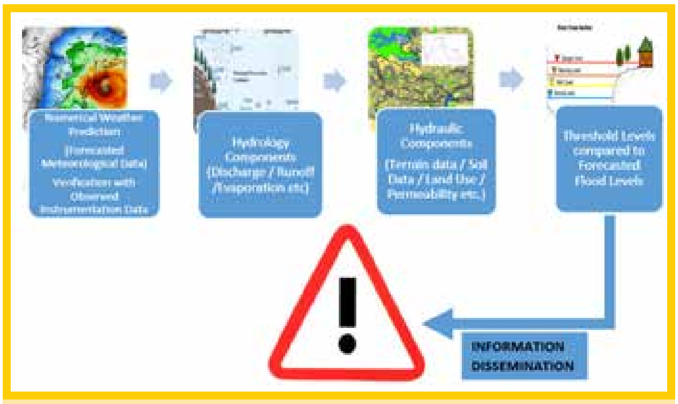

FIGURE 1: Basic Integration of Meteorological and Hydrological/ Hydraulic Components of Flood Early Warning Systems

greater potential to apply this system to other early warnings such as water quality, risk assessments, coastal and real time data management (Chrystal 2015). Hence, Flood Early Warning System evolved into Forecast Early Warning System (FEWS). Driven by an open source data management platform. The system is built on tailored processes that fit the needs of eThekwini. Similarly, no two platforms are built for the exact same purpose in the world.

The eThekwini Forecast Early Warning System is developed and managed by the Coastal Stormwater and Catchment Management (CSCM) Department since its inception in 2011.

2011 -2013

CSCM was first introduced to this system and its capabilities in 2011, after which feasibility investigations had commenced to apply it in a South African context. After realising its benefits in over 35 countries worldwide (Chrystal 2015), there was no doubt that a proof of concept existed with an established user community to draw learnings from. This time was also used to interrogate the skills requirements and shortage the municipality had to supplement. Being the first in South Africa and in Africa to embark on this kind of system, there was no similar point of reference aside from those of 1st world applications.

2013 – 2014

As a starting point, CSCM embarked on a pilot study Forecast Early Warning System that involved an operational flood hydraulic model forced by a U.S numerical weather prediction model called Global Forecast System (GFS) and the City's existing telemetry system for verification (Chrystal 2015). The success of this pilot study would serve as the basis for approval to extend the system to the rest of the City. The challenge in any foreign system is how to substantiate its value for money. Because of this, the FEWS team was always conscious of costs during design and development of the system. The data management platform and the hydraulic design software are both freeware and GFS was chosen as it's also freely available to eliminate licensing costs. Internal staff were up-skilled instead of outsourcing development and management of the system entirely. Although the pilot study focused on the flood early warning module, a coastal and water quality early warning test study was also incorporated into FEWS which would later be expanded on.

2014 – 2015

A consulting and support contract was initiated and approved between eThekwini and the host developer for a period of three years. The scope of the contract included consultation on configuration and design software; IT support (registered repository and backup systems) and infrastructure and training. The collaboration would open resources to the City from the bank of

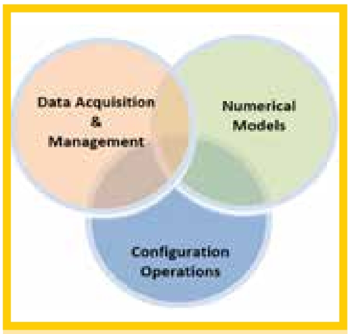

FIGURE 2: eThekwini FEWS Team Structure

experience the host developer had gained around the world.

To address the skills gap identified, three FEWS team members attended a week training and attendance at the international user days in the Netherlands. This equipped the team in building and managing the processes required within the data management platform. The team was able to attend training seminars and presentations by other established configuration managers as well as present on the South African application of the system. The second most important outcome of the trip was the relationships that were established with global users and the host developer team.

The three year contract included training for the configuration of the system and training of IT support being the City's Information Management Unit (IMU). The host developer travelled to South Africa and conducted initial five day training for both configuration managers and IMU staff. Collaboration with eThekwini's IMU team would be seen as one of the most important relationships for the success of the system.

From the valuable knowledge gained, the team realised that in order to bring in as much information into the catchments (watersheds) as possible, the City's Survey and Land Information Department had to be engaged. Geographical Information Systems (GIS) specialist within this sister department was able to generate maps of permeable vs impermeable areas and higher resolution terrain information. This also highlighted the benefit of a GIS specialist within the team.

To avoid dependence on the host developers, eThekwini began up skilling internal employees and duplicating roles to manage and build the system in-house thereby compounding resilience within the system. At the initial stages these employees volunteered to the training with the understanding that the responsibilities that came with being a FEWS team member far exceeded usual expectations. The pilot study was completed with a coarse operational forecast river model setup, triggering warning levels at strategic points along the river, based on pre-set thresholds.

The system was run twice a day using an automated scheduler. At this point the team structure was established as Figure 2.

Data Acquisition and Management – *'Delivery of good data to the system'*

This Team is is responsible for ensuring good data is supplied to the system by:

1. Identifying gaps in data collection
2. Acquisition of data / instruments (via Tender procurement)
3. Overseeing installations or consultancies awarded projects to install instruments
4. Ensuring procedures are followed to ensure data is uploaded to the correct Web Servers, in the requried formats and quality checked.
5. Setting the required Config for Importing Data via webservers and FTPs to the FEWS Data Server.
6. Monitoring of data feeds and quality checks
7. Setting up export systems for data displays of instrument management

Numerical Modelling – *'Confidence in all forecast operations'*

This Team is is responsible for ensuring the forecasted warnings from the hydraulic models are within accepted confidence levels. For example, a flood warning can only be issued if there is confidence in the model outputs. This role encompasses the following functions:

1. Setting up hydraulic models
2. Collection and management of model input data (Surveys, River level data etc.)
3. Calibration and validation of hydraulic models
4. Ensuring configuration is setup to execute models, importing required data sets, manipulating if necessary and exporting in the correct format.
5. Identifying gaps in models and rectifying
6. Updating existing models and necessary works to improve models where required
7. Integrating models from consultants including vetting models received
8. Ensuring outputs are configured correctly for decision makers and displayed correctly on the web pages

Configuration Operations – *'Ensuring data exchanges function for the execution of FEWS tasks'*

1. Routinely check the health of the Server system via the web portal and:
   a. Maintain and repair server system if required.
   b. Liaise with IT and host developer if and when required
2. Ensure Web Display outputs are concurrent with latest info and timestamps
   a. If not, rectify as required. Check data flow path for any errors
   b. Update any info as required from the Models or new Data coming in.
   c. Liaise and run contracts with web developers to continue growth of system
3. Configure updates and manage relationship with IT as required.
4. Support other divisions with config when necessary.
5. Oversee config management and Operator Client for system.
6. Liaise with host developer on config issues for FEWS Team.
7. Assist and implement Python scripts when needed for FEWS Team

2015 – 2016

The FEWS setup was extended for all rivers within eThekwini including far west of the boundary tracing the rivers to their farthest upstream points. The inflows for all rivers at their point of entry into the municipal boundary had to be accounted for. Risk zones were collated from the City's flood complaint database, disaster management database and essential services departments such as Electricity and Water Departments were engaged for their priority infrastructure. Risk zones included informal settlements, flood prone areas along rivers, electricity substations, sewer substations, water treatment works and economic priority nodes. These were mapped with threshold levels (Safe, Alert, Watch, Warning). The eThekwini Municipal area was then divided into 3 hydro meteorological models (North, Central and South) that were run on the latest GFS data twice a day on an automated scheduler. Any thresholds crossed by forecasted hydrographs were configured to be emailed to the configuration managers who then vetted the results.

The team had an approved budget for procuring IT infrastructure to support the early warning system. This budget was discussed in collaboration with IMU to a) procure the correct infrastructure and b) provide support and maintenance of the same.

2016 –2017

Upon realising the value of the system the team had then began building a relationship with the eThekwini Disaster Management Unit for information and the benefit of sharing the results. The system, still in its infancy and new to disaster management practitioners, the concept and team faced challenges gaining credibility. In parallel to this the FEWS team and the Survey and

Land Information Department investigated options to improve the terrain and land use data that represent the hydraulic catchments. LiDAR (Light Detection and Ranging) was introduced and found to improve catchment terrain by replacing the 2m contours with a high resolution (0.3m x 0.3m pixel) digital elevation model. The challenge the system then faced was the computational time required to run large higher resolution models. The solution to this was further subdividing the hydraulic models into 7 major river systems and its relative catchments. Hydraulic design consultants were appointed for each model to extend available design capacity in vetting these new models to verifying river crossings, threshold elevations, catchment parameters and merging existing work done on the catchments. The consultants were supplied with the models and rainfall data for testing. This allowed the consultants to also develop their skills in modelling operational hydraulic models. The models continued to be updated and refined as more accurate information became available over the years.

In April 2017, three FEWS members attended meetings with the Australian Bureau of Meteorology to gain insight and knowledge on how to manage and operate a national scale early warning system using the same data management platform. While attending meetings with each division of the Australian Flood Forecasting and Warning Service, the team also attended a 2 day User Days workshop where a number of Australian organisations presented on how they had tailored the system for their specific purpose.

The outputs generated from the early warning system interface was relatively technical to interpret for decision makers. In the effort of getting the right information in the right format to the right people, the FEWS team initiated a website development (referred to as FEWS technical website) that would be accessible only by eThekwini internal decision makers such as disaster management practitioners and heads of effected infrastructure departments. The alerts generated from the early warning interface is pushed to the 'FEWS technical website' and registered users would be alerted by means of push notifications on their device. An intermediate vetting stage of the warning notifications was later built in for the FEWS team to insure the integrity of each alert notification.

2017 – 2018

A rain gauge network is not enough to account for rainfall within gaps between gauges by simple interpolation as rainfall is not always unified over a geographic area. As a supplement to the rain gauge network eThekwini procured and commissioned an X-band rain radar with a 50km radius of coverage. The radar is located along the coast in a centralized position enough to cover all of eThekwini and off the coast.

The team had engaged with the South African Weather Service (SAWS) to acquire a more refined rainfall forecast specific to South African conditions. After understanding the benefit the system has on a local and national scale, SAWS had agreed to provide a trail period of data to eThekwini during the rainy season (August – March). This was an informal arrangement preceding a formal Memorandum of Understanding between the two organisations. EThekwini had to be sensitive in the use of the data as SAWS is the mandated body to issue weather warnings in South Africa. The model configuration for meteorology inputs were then adjusted to accept both the SAWS and GFS gridded rainfall data. This allowed some ensemble forecasting. Meteorology is not an exact science therefore building in for parallel checks improves the credibility of the outputs.

The team subsequently contacted the local SAWS office to collaborate in this effort. Each province is set up with a local SAWS office of forecasters that develop the local warnings to feed back to the national office. This forms another fundamental relationship for the success of the early warning system. The SAWS forecasters are expert meteorologists that advise on the integrity of the input data into the system whereas the FEWS team comprises of hydraulic engineers that are experts in designing the hydraulic models that respond to the met data.

The FEWS team realised the potential to duplicate this system for the rest of South Africa. The team engaged with the eThekwini Municipal Institute of Learning (MILE) to assist in setting up a national workshop that introduced the system and its capabilities to other South African public organisations that would benefit in early warnings. A three day hands on workshop was set up, 1st-3rd August 2017, (CPD accredited) for all local, district and metro municipalities; universities; National/Provincial/Local Disaster Management Units; SAWS; Council for Scientific and Industrial Research and internal eThekwini Departments. The benefit of creating a South African community of early warning system developers encourages a bank of skills that can be expanded to other realms of early warnings such as traffic; fisheries; agriculture etc.

In October 2017 Durban was hit with a severe storm which provided a testing ground for FEWS. The team had picked up on the storm and alerted eThekwini Disaster Management Unit. At this point in the FEWS development, there was no official standard operating procedure developed in communicating the impending disaster. Nonetheless, an accidental text message alerting an eThekwini Municipality employee of storm had leaked through social media and within a matter of a few hours had spread to most communities in the City. This is when the power of social media was realised. In the midst of the disaster, FEWS had gained credibility with disaster management practitioners. During disaster operations the FEWS team were requested to advise the Disaster Operations Centre (DOC) of the progress of the storm. This was yet another fundamental relationship for the success of the system. Disaster management practitioners are responsible for the action of disaster forecast information the system generates. It is for this reason that the team worked closely with the eThekwini Municipality Disaster Management Unit in developing the 'Technical FEWS Website' interface. Each risk zone was prepopulated with general disaster responses that would later be refined with finer detail.

The first experience during disaster operations on the 10th of October 2017 identified the expectations of the early warning team attending the DOC. The information disaster management practitioners required for the management of the City's emergency resources was a) where is the storm headed? b) what is the impact of the storm? and c) when will it end? The effective communication of this information requires at least two members of the team including one to monitor and interpret model forecasts and one to track live data from the instrument network. A third person, if available, would be a management official to report to the DOC. The FEWS Technical Website assisted in providing a visual representation of the FEWS geographical network to the rest of the DOC.

Some learnings from the DOC experience:

- The need to expand the City's instrument network for real time data. This was addressed by appointing an instrumentation contractor to develop and install new and replace old gauging locations that would eventually provide the City with a more realistic network coverage.
- An approved operating procedure before, during and after a disaster event for FEWS. Figure 3 describes the role of each key stakeholder in a standard operating procedure.

2018 – 2019

EThekwini initiated a second contract with the host developer however this contract largely focuses on the development of an operational coastal and water quality early warning that will be added to FEWS. The team then

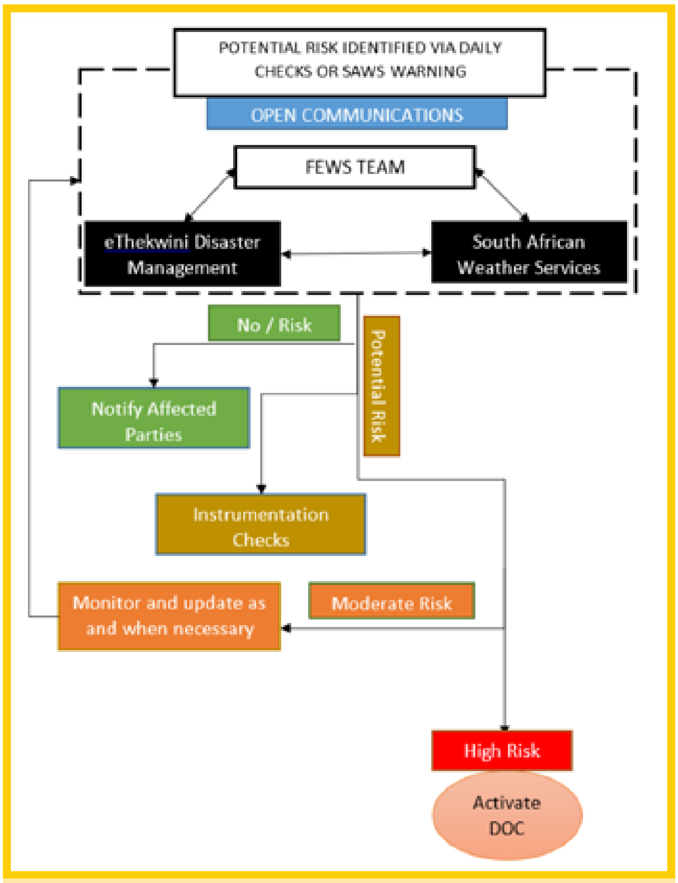

FIGURE 3: Flowchart of Operating Procedures for Forecast Early Warning

began discussions with coastal divisions from CSIR and SAWS for a collaborative effort in approaching the system. CSIR had shown keen interest in using a similar early warning system for a national coastal monitoring system and requested a workshop on how to set up a coastal early warning system. FEWS configuration managers developed training material in conjunction with the host developer and conducted a successful two day hands on workshop for a group of scientists from CSIR and the South African Department of Environmental Affairs (DEA).

CSIR and eThekwini then initiated a Memorandum of Understanding (MOU) between both parties for the exchange of skills. CSIR being established in coastal modelling would assist in up-skilling FEWS and FEWS would assist in configuration support to CSIR. Additional research opportunities that would develop through the collaboration would be managed under the MOU.

SAWS intends to move their method of forecasting to impact based. This means the warnings produced by SAWS will no longer just detail the kind of weather to expect but also the impact of the weather to the region. SAWS reports on weather conditions for each province and municipal region however SAWS produces these warnings based on general impacts across the region. FEWS produces impacts for specific locations within the region and therefore is able to supplement the warnings issued by SAWS without contravening the South African Weather Service Act of 2001. With reference to the Figure 3, both parties are aware of the forecasted met data and a channel of communication is opened to agree on the integrity of the forecast before processing and publishing warnings.

EThekwini was then able to initiate the development of a public website (still in development) that would educate and inform the general public of weather related news. The website can be integrated into home screens of the users, which allows eThekwini to push notifications to the users. The website is to be launched into the public realm, with the design lending it to be used on a daily basis with access to news, activities in the city, social media surrounding eThekwini activities, weekly weather forecasts etc. The website will feature SAWS warnings as well as eThekwini impact based warnings that would supplement the former. This initiative will create a platform for eThekwini to get the right information to the right people, in the right format, in the right time.

CONCLUSION

Recent effects of climate change have impacted world at large. While first world organisations in Europe, Australia, the United States and the like have invested resources in getting early warning right, third world countries like South Africa are lagging behind with challenges unique to its environment and people. Disaster response in South Africa is still predominantly reactive rather than proactive in the absence of early warning systems. The journey of eThekwini's Forecast Early Warning System development set the precedent for other similar entities. It has created a platform for proactive disaster risk reduction initiatives that can be duplicated across the country. EThekwini has evolved in its culture of knowledge sharing and in turn receiving the required knowledge at the minimum cost. Challenges in its development were resolved by consistent collaboration and up-skilling.

Collaboration is key! There should never be a silo mentality in addressing disaster management because DISASTER MANAGEMENT IS EVERYONE'S PROBLEM!!

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