

# NATIONAL FLOOD NOWCASTING SYSTEM TOWARDS AN INTEGRATED MITIGATION STRATEGY IN SOUTH AFRICA

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## Abstract

This paper highlights the key aspects of a new (2003) Water Research Commission (WRC) project aimed at a national initiative to provide timeous information and where possible, nowcasts of river flows at the scales of large and small catchments, rural and urban. The initiative brings together the following organisations under one umbrella project: SA Weather Services' METSYS in Bethlehem (South Africa), The National Disaster Management Centre (NDMC) and Department of Water Affairs and Forestry Public Safety Unit (DWAF: PSU) in Pretoria under the leadership of Civil Engineering at the University of Natal in Durban.

The new project aims are to:

- put an effective, efficient and available national flood-forecasting system in place.
- use this system to forecast flood inundation levels routinely.
- use these forecast inundation levels to alert disaster managers in order to mitigate the effects of floods threatening vulnerable people and industry.
- have recent information (satellite, radar and gauge estimation of rainfall) distributed from the NDMC & DWAF:PSU to the regions as necessary.
- provide flood nowcasts/forecasts (with horizons of ½ to 12 hours) to sensitive regions in as much detail as required/feasible.
- interact and work with local disaster managers and local authorities to convert flows to inundation levels.
- provide training initiatives (annual courses, presentations and software) for local disaster managers using simulated weather systems to augment training on historical events.
- encourage disaster managers, water resources and hydraulic engineers, hydrologists and meteorologists to communicate freely and to work together for the common good

The paper focuses on the **overall organisation of the project** and highlights those aspects of the **technical input which have so far been successfully completed**. The latter include a method of providing optimal ensemble streamflow forecasts, the stochastic nowcasting of advecting rainfields measured by radar using the "String of Beads" model and the merging of satellite, radar and raingauge fields to provide a "best" estimate of areal rainfall country-wide, important as input to the catchment modelling process.

**Key Words:** weather radar, stochastic nowcasting, advecting rainfields, streamflow forecasts

## Introduction

The main requirement of an effective flood forecasting system is the provision of reliable, intelligible forecasts of flood flows with a long lead-time and explicit error bounds, made available at frequent intervals to hydrological operators, decision makers and disaster managers.

Important key phrases for on-line operation are: long lead time, frequent updates, accurate intelligible estimates, confirmatory information from the catchment, redundancy and feedback to update and improve estimates.

For off-line work the key phrases are: evaluation, instrumentation and validation of system, improvement of models, commitment to recalibration, ability to simulate alternative scenarios, operator training and a reliable alerting system.

Two recently completed WRC contracts, (K5/1005 by Pegram and Sinclair, 2002 and K5/1217 whose final report is shortly to be submitted), focused on developing a computationally efficient rainfall runoff model incorporating radar estimates of rainfall and implementing that model in a pilot study to provide efficient flood nowcasting in important Durban catchments. The focus was to provide timeous warning for those most vulnerable and least protected against flooding (informal settlements in flood-prone areas near rivers) as well as strategically important industries. An extension to the flood nowcasting contract provided the important link between flood flows and inundation levels in the Mlazi River and canal, south of Durban.

The lessons learned were that the flood nowcasting methodology in the South African context is feasible but needs more work to:

- Ensure that the Disaster Managers are well informed of the implications of the flood forecasting information available to them.
- Improve the method of dissemination of information by making the data streams dependable and sustainable once the WRC contracts have been completed.
- Extend the ideas to flood prone areas in Southern Africa besides Durban.

In the new project, the tasks are to be divided between those most skilled in researching the different facets of the work. Its thrust is to seek collaboration between several different organizations: South African Weather Services Meteorological Systems (SAWS: METSYS) in Bethlehem, the National Disaster Management Centre (NDMC) and Department of Water Affairs & Forestry: Public Safety Unit (DWAF:PSU) in Pretoria under the lead of Civil Engineering at the University of Natal in Durban (CEUND). SAWS: METSYS scientists will continue to collect and provide best estimates of rainfall from satellite, radar and gauges; improvements are happening continually. More specifically, in August 2002, the European Space Agency launched METEOSAT Second Generation (MSG) which will, after some hitches, routinely provide finer resolution images of cloud and water vapour at 15 instead of the current 30 minute intervals by early 2004.

Based on the development of the Mgeni flood nowcasting system (WRC project K5/1217) and the Spatial Integration and Mapping of Rainfall (the suite of three WRC projects under SIMAR: K5/1151, 2 & 3), CEUND will improve and adapt models for rainfall estimation from gauge, satellite and radar which have already been successfully implemented in prototype and are available on a daily basis on the SAWS: METSYS website covering the Southern African continent at a spatial grid resolution of one minute of arc. In addition, the linear transfer function model designed (under WRC project K5/1005) for high speed adaptive nowcasting in combination with a Kalman Filter can be calibrated on real data or on an existing rainfall runoff model of the conceptual type. The conceptual models which are physically based are usually designed for off-line or desk-top studies and are often too clumsy to adapt to nowcasting, especially if the parameters need on-line up-dating, hence the adoption of a transfer function type of model.

In order to efficiently disburse, archive and quality control the data stream and modelling, the strong IT division of NDMC/DWAF:PSU is to be used. This will remove much of the busy work from researchers who can spend more time doing the science and engineering to sustain the system. Crucial to this project is the development of training initiatives to ensure efficient technological knowledge transfer to those doing the job on the ground - the Disaster Managers - and to build their capability and capacity to cope with flooding disasters, besides providing them with interpretative confidence and leadership skills.

The maps of daily rainfall over South Africa produced in an associated new WRC project ("Daily Real Time Mapping of Rainfall over South Africa (2) Modelling" - a follow-on from SIMAR) will have been constructed from the basic data streams. These meteorological data streams (satellite estimates of rainfall in 30 minute intervals or better and radar estimates of rainfall at 5 minute intervals, together with telemetered raingauge data available at 10 minute intervals) it is proposed, will be "piped" to NDMC/DWAF:PSU and will be useful for a variety of purposes. What is germane to this project is that the wetness of catchments can be gauged from the rainfall maps and satellite estimates of soil moisture level and vegetation wetness, indicating those areas which are saturated and therefore prone to flooding if more rain falls. To convert rainfall information to inundation levels and their associated risks which can be useful to Disaster Managers, several steps have to be put in place, which include:

- Good rainfall estimates in fine temporal and spatial resolution – this is to be accomplished by a combination of Kalman Filtering and Kriging (Sinclair et al., 2003).
- Good rainfield forecasts – up to an hour and possibly two hours ahead. These will be computed using field advection algorithms based on the “String of Beads” model of WRC project K5/1010 (Clothier and Pegram, 2002).
- Fast efficient rainfall runoff models for computing flows. These will be based on the work done in previous WRC projects K5/1005 (Pegram and Sinclair, 2002) and K5/1217 (Sinclair and Pegram, 2003, final report shortly to be submitted) or by adaption of existing rainfall-runoff models to a real-time environment.
- Streamflow gauges on larger catchments capable of telemetering real time flow information to NDMC/DWAF:PSU to update and monitor flow forecasts. These will come from DWAF, Metros etc. (Mkwanzani et al., 2003). DWAF has begun to implement this on several important catchments.
- Digital terrain/elevation models (DEMs) combined with soil, geological, vegetation and ground cover maps and, where available, satellite imagery, to enable efficient modelling of rainfall/runoff conversion and detailed enough to compute inundation levels from flows. These are increasingly becoming available routinely in the Metros and will extend to the rural areas.
- After computing these levels they are disseminated with the rainfall images (satellite, radar, etc) to the local Disaster Manager Ops Rooms. These local managers are then able to use the information to anticipate trouble spots and deploy emergency services to warn, move and help people who are threatened, depending on the associated risk levels. They will need the information feed, the software and the hardware to get this information, as well as the skills to interpret it.
- To enable to Disaster Managers to be effective and proactive rather than reactive, training courses and software will be devised to help them interpret the information meaningfully. Feedback from them will help the technical people to improve their information product.

It is envisaged that the larger Metros will have in place many of the components of the system germane to their particular situation (DEMs, hazard assessments, calibrated rainfall-runoff models, rare flood inundation levels, telemetering raingauges, flood warning systems) and therefore they (and of course DWAF:PSU) will not need to rely on centralized computing power at NDMC to achieve their flood mitigation objectives. It is to be noted, however, that there will be areas not so fortunately endowed with technology (one can think of rural communities and eco-tourism endeavours in wilderness areas) which will benefit from a National flash-flood nowcasting scheme served by a centrally processed information stream situated at the National Disaster Management Centre. These needs will be progressively met, based on the lessons learned, as the project develops.

The end user (flood prone people, industry etc) will eventually become educated to make demands of the Disaster Managers, who will in turn demand good (and better) service from NDMC/DWAF:PSU who in turn will expect unbroken information feed from SAWS: METSYS and improved forecasts and models from hydrologists. This accountability and responsibility is a crucial aspect of the system. Television documentaries on the system will go far to educate the public on what they can come to expect from their service providers.

## **Overall Organisation of the Project**

This section outlines the loose structure of association between the participants in the project and indicates the paths followed by the flow of information as visualized in the initial planning stages. It is remarkable that these organisations, which are imbedded in Government Departments traditionally not seen to be comfortable working with others, have enthusiastically grasped the vision of the National Flood Nowcasting System. Specific individuals have made considerable contributions to previous WRC contracts mentioned in this paper and are to be commended for the generous way in which they have shared their knowledge, time and expertise, often putting themselves out in the manner of true public servants.

### Outline of the information flow between participants

There are four sets of stake-holders in this phase of the project:

- The Metro Disaster Managers
- The National Disaster Management Centre
- The Department of Water Affairs and Forestry
- The South African Weather Service

The information transfer flow diagram between them is indicated in Figure 1.

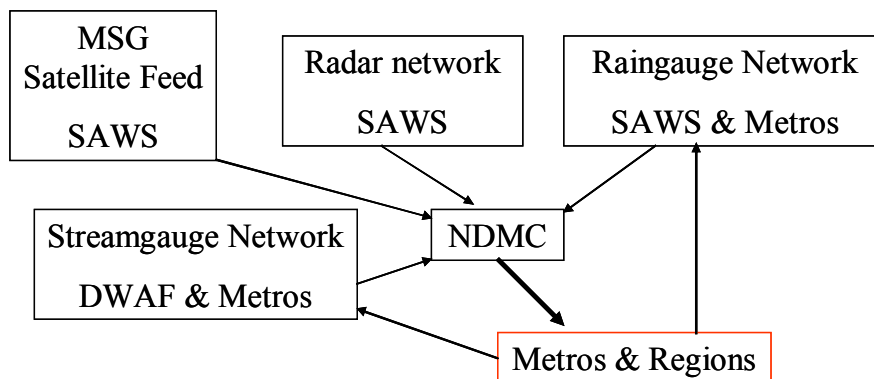


Figure 1. National Flood Nowcasting System data flow

### The SAWS component of the information transfer

The South African Weather Services METSYS division in Bethlehem has responsibility for concatenating into a mosaic on a 5-minute to daily basis all the working radar rainfall estimates for the country. They are negotiating with Botswana and Mozambique for information feed from their radars, the latter when they come on stream in a year or so.

In addition, they are responsible for the collation of the data from the daily recording raingauges around the country - currently about 130 automatic gauges which are reliable. It is hoped that there will be other gauge networks in South Africa (owned/operated by, among others, the Agricultural Research Service) which will yield data to augment the SAWS network.

Currently, SAWS receives information, via Eumetsat, from METEOSAT, a satellite which is in geostationary orbit at 0° latitude and 0° longitude about 34 000 km above the earth's surface. The transmission includes visual, infrared and water vapour channels of scans of the hemisphere every 30 minutes with a 30 minute delay. These data are used to compile an estimate of rainrate at ground level at 30 minute intervals, online. In 2004, METEOSAT 2<sup>nd</sup> Generation (MSG) should be transmitting its data capture routinely to SAWS at 15 minute intervals at a resolution twice as fine as its precursor.

A milestone product for Southern Africa is the map of the previous daily rainfall over the subcontinent available automatically every day at 11:30am at: <http://metsys.weathersa.co.za/simar-info.html>

This website displays other products, such as the radar mosaic of the previous hour's rainfall, updated every 30 minutes. An example of the merged (from gauge, radar and satellite) 24 hour rainfield for 12 May 2003 is shown in Figure 2. This is the fruit of the SIMAR project.

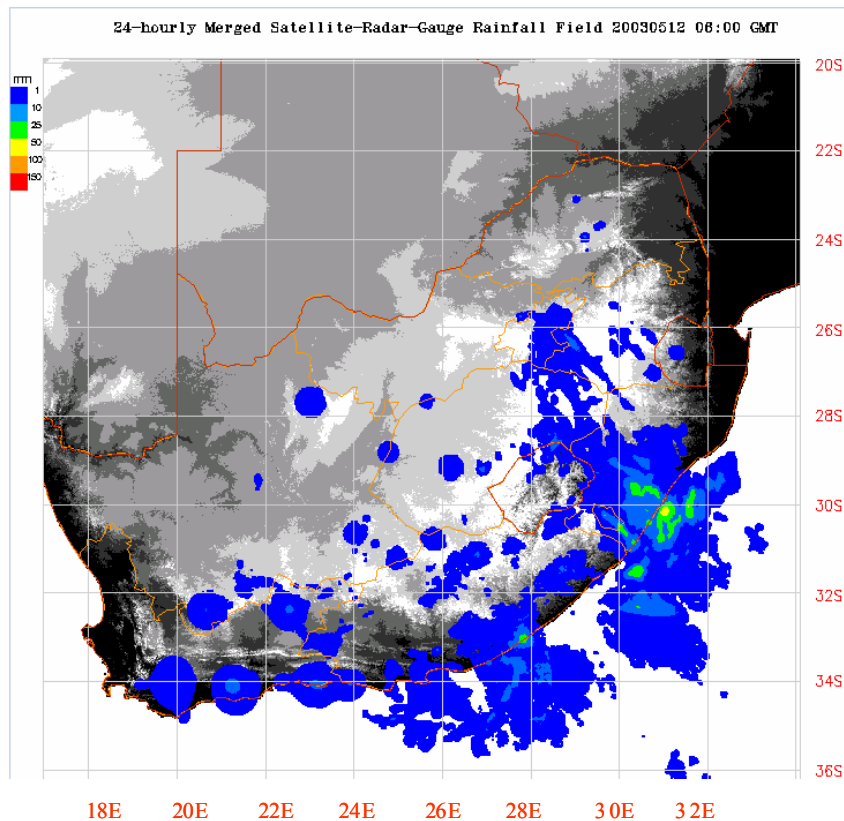


Figure 2. SIMAR merged, 24 hour rainfield at 0800 SA Standard Time, 12<sup>th</sup> May 2003, at 1' of arc resolution, from gauge, radar and satellite estimates.

### ***The DWAF component of the information transfer***

Traditionally, DWAF have busied themselves (in the flood forecasting context) almost exclusively with the “big stuff”, like the Vaal and Bloemhof dams. This is changing. One of the outcomes of the Mgeni and Mlazi study was the commitment of DWAF to instrument Inanda and Shongweni dams for high flow telemetering. This was accomplished in July 2003. This means that two crucial sites on the main rivers through Durban are now relatively inexpensively and reliably monitored, not for water resources purposes, but specifically for flood studies. The importance of these installations is that any flood nowcasts can be corrected online and model outputs adjusted as the information comes in to the real-time rainfall-runoff modelling system. It should not be too difficult to site such measures at other strategically sensitive sites in Metros around the country.

The expertise that DWAF have in collecting and collating streamflow data country-wide is likely to be exploited in the new project. This means that Metros who are routinely collecting streamflow data are to be encouraged to share that information with DWAF to expand the latter's data-base. This archiving might be more conveniently achieved by the NDMC who have strong information and organizational links with DWAF. However this is achieved, there is a benefit for the Metros to share their data in view of the returns they will receive from the National Flood Nowcasting System.

### ***The NDMC component of the information transfer***

In January 2003, the new National Disaster Management Act came into force. The NDMC is obliged to provide flood warning information (among other things) to the regions. The Centre thus has a pivotal rôle in the dissemination of weather, soil moisture and flood data to the Metros and regions. In addition, it is incumbent upon the NDMC to make this information transfer as efficient as possible. One of the Centre's other rôles is to archive data useful for the Management of Disasters.

Currently the NDMC receives satellite feeds via the Satellite Applications Centre of the CSIR which are not freely available to others, because of licensing agreements and the cost of the data streams. It is hoped that this rich source of information will become more widely available in the future in a routine way to serious researchers and those adding value for the “public good” and efforts are under way to make this happen. Of

particular interest to these flood study efforts is the set of satellite data including particularly NOAA's 3-hour updates of world rainfall estimates, the soil moisture estimates from satellites, imperfect though they are at the moment, the vegetation wetness index and of course digital elevation information on a relatively fine grid.

It should be possible, by the end of this project, for Metros to routinely and frequently receive, in real time, satellite and radar images of rainfall estimates over the subcontinent and more particularly in local detail in their areas of interest, satellite images of soil moisture, and derived products, such as maps of flood prone areas compiled as derivatives of the foregoing. These will not just be images, but will have numerical information attached to enable computation of interest and value to be done. This will be possible if the bureaucratic blocks on the information feed can be freed up for the "public good", so we can blend the information from SAWS:METSYS and SAC:CSIR.

## The Building Blocks For The National System

This section highlights the outcomes of the successfully completed WRC contracts which are germane to the National initiative. Without these completed tasks, the endeavour would be a plan in the guise of a wish list.

### The Durban Metro experience

In the recently completed Mgeni and Mlazi projects (under WRC contracts K5/1217 and K8/456) the structure of the information flow was as indicated in Figure 3. The rainfall information feed is a combination of Durban radar estimates of rainfall measured at Durban airport, disseminated by SAWS via a dedicated FTP link, with the raingauge estimates of rainfall from a telemetering network of gauges sited within the Durban Metro belonging to them and to SAWS. The information from these is shared, to the two organisations' mutual advantage.

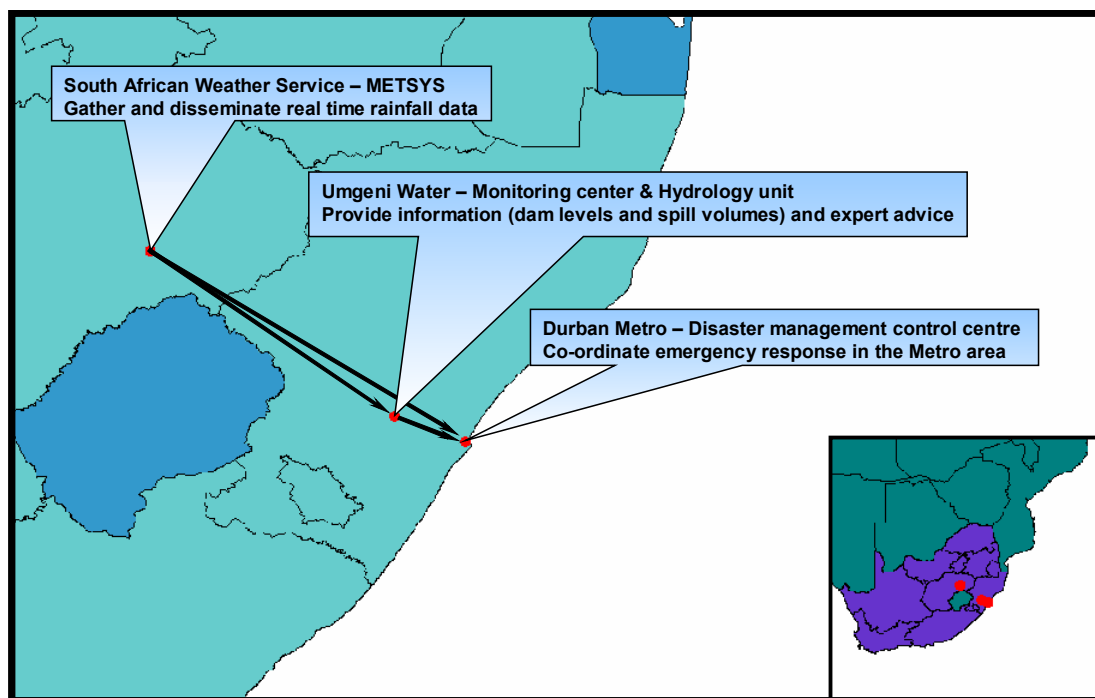


Figure 3. Roles and responsibilities of stakeholders in the Umgeni Flood Nowcasting project

The Mlazi River was modelled under a companion project and the rainfall-runoff conversion and levels of inundation were initially modelled using HEC-HMS and HEC-RAS, two freely available suites of software. The transfer function model was calibrated to the input and output associated with this set.

The Durban Metro Disaster Management group and City Engineer were extremely supportive of this initiative. This, the successful deployment of the information link between METSYS and Durban and the installation of the high flow gauges by DWAF, set the stage which led to the National System being suggested.

### **Technical Inputs**

There were several studies which added technical muscle to this project, many conducted under the leadership of CEUND. They are itemized here and reference is made to the relevant papers and reports where the ideas were published.

#### **Image cleansing**

Radar images suffer from contamination by several natural phenomena which make the rainfall estimates inaccurate. Research into some of these has been and is in the process of being completed. The phenomena dealt with are: bright band (Pegram and Mittermaier, 1998), ground clutter (Seed and Pegram, 2001) and anomalous propagation (Pegram and Wesson, 2003). In the last study, work is under way to devise algorithms which are fast enough to "clean" the data on-line, which is a demanding task, given that approximately 20 Mb of raw data are collected by each of the 10 radars in the country every 5 minutes.

#### **Merging data**

Radar images are tantalizingly full of spatial information about spatial rainfall, but are prone to bias in estimation. Studies have been completed (Sinclair et al., 2003) and are ongoing (WRC project K5/1425/1) to obtain optimal estimates of rainfall by combining radar images with gauge and subsequently satellite information.

#### **Nowcasting Spatial Rainfall**

A combination of the image analysis techniques developed for the "String of Beads Model" (SBM) (Clothier and Pegram, 2002) and an optical field flow forecasting algorithm applied to these images (Pegram et al., 2002) has promise in giving valuable nowcasts of rainfall (with advection of the fields) up to 2 hours ahead. This holds considerable promise for flash-flood nowcasting on relatively small catchments.

#### **On-line Rainfall-Runoff Modelling**

Conceptual rainfall-runoff models like HEC-HMS are very useful for desk-top studies, but are not readily amenable to online forecasting of streamflow if parameters have to be adjusted. As a substitute, a linear rainfall-runoff model of the transfer-function (ARMA) type was devised (Pegram and Sinclair, 2002) and calibrated on the Mlazi River (Mkwananzi, Pegram and Sinclair, 2003). It is particularly fast and amenable to forecast and parameter adjustment using recent streamflow and rainfall information in combination with a Kalman Filter. This linear model is not a prerequisite for the National Flood Nowcasting System's armoury, but is useful where there are historical data available and there has been no modelling done at a sensitive flood site.

What is remarkable about performing technological transfer into the "real world" is that new unforeseen problems crop up which are the raw material for new research projects. The above topics would not have been able to be "dreamt up" in a purely academic environment.

### **Conclusion and Prognosis**

This fresh new project which offers such promise is not an immaculate conception. It has progenitors in this country and certainly in the Northern Hemisphere. In South Africa, one can recall an initiative led by Des Midgley doing the hydrology and the CSIR providing the radar images of rainfall for flood forecasting on the Witwatersrand and another initiative by Will Alexander and Johan van Heerden (both of Pretoria University) collaborating with the SA weather Bureau to provide flood forecasts for Alexandra township. Experience with Flood Forecasting was initiated when the senior author was asked to edit the AFORISM study for the European Union by Ezio Todini while on sabbatical in Bologna in 1996.

There are several initiatives and activities which have by conjunction put Flood Forecasting on the table for discussion by Disaster Managers and others. Since 1994 there has been a steady influx of people from rural areas to the cities and a resultant occupation of flood prone areas - they were relatively vacant and there is water in our rivers for most of the time. The initiative of the METSYS group to educate and make their radar products available to hydrologists and water resources engineers was the start of many of the projects listed above. The eco-tourism disaster in the Storms river in 2001, which claimed the lives of 13 people, made many realize that these were needless deaths and could easily have been prevented if flash-flood information had been readily available. In January 2003, the National Disaster Act was promulgated; already, many Metros had started over the last few years determining high hazard areas and rare flood inundation levels from hydrologic and hydraulic studies. The ready availability of remote sensing of rainfall and other natural phenomena (fire, smoke, soil moisture, vegetation cover/wetness) using radars and satellites make it easier and more fruitful for us to need to understand and grasp the technical opportunities that they offer.

The WRC project will last for 3 years - the momentum built up in the interim should take it well beyond that.

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Geoff Pegram is Professor of Hydraulic Engineering at University of Natal, Durban, South Africa. He obtained his PhD from Lancaster UK on Stochastic Reservoir Theory. A South African Professional Engineer, he is the author of over 100 papers and reports. A collaborating researcher in the CRC for Catchment Hydrology, he was at the University of Melbourne in 2001 as the recipient of the prestigious Miegunyah Fellowship Award and returned to the University of Melbourne to work with the CRCCH for 2 months in 2002, 2003 and 2004. His current research interests include space-time modelling of rainfall, real-time flood forecasting and large water resources system analysis and reliability, extensions of his love of stochastic hydrology.

### ***Scott Sinclair***

Scott Sinclair Obtained a BSc(Eng) in Civil Engineering in 1998 and an MSc(Eng) in 2001 from the University of Natal. The topic of his MSc thesis was "Real-time Flood forecasting". He spent 2001-2002 working in the Water Resources planning department of Umgeni Water, South Africa. In 2003 he returned to the University of Natal where he is currently working towards a PhD, the topic of his research is "Improved rainfall estimation using remote-sensing techniques".