UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot • your knowledge partner

Data availability and requirements for flood hazard mapping in South Africa

Author: Zelda Els

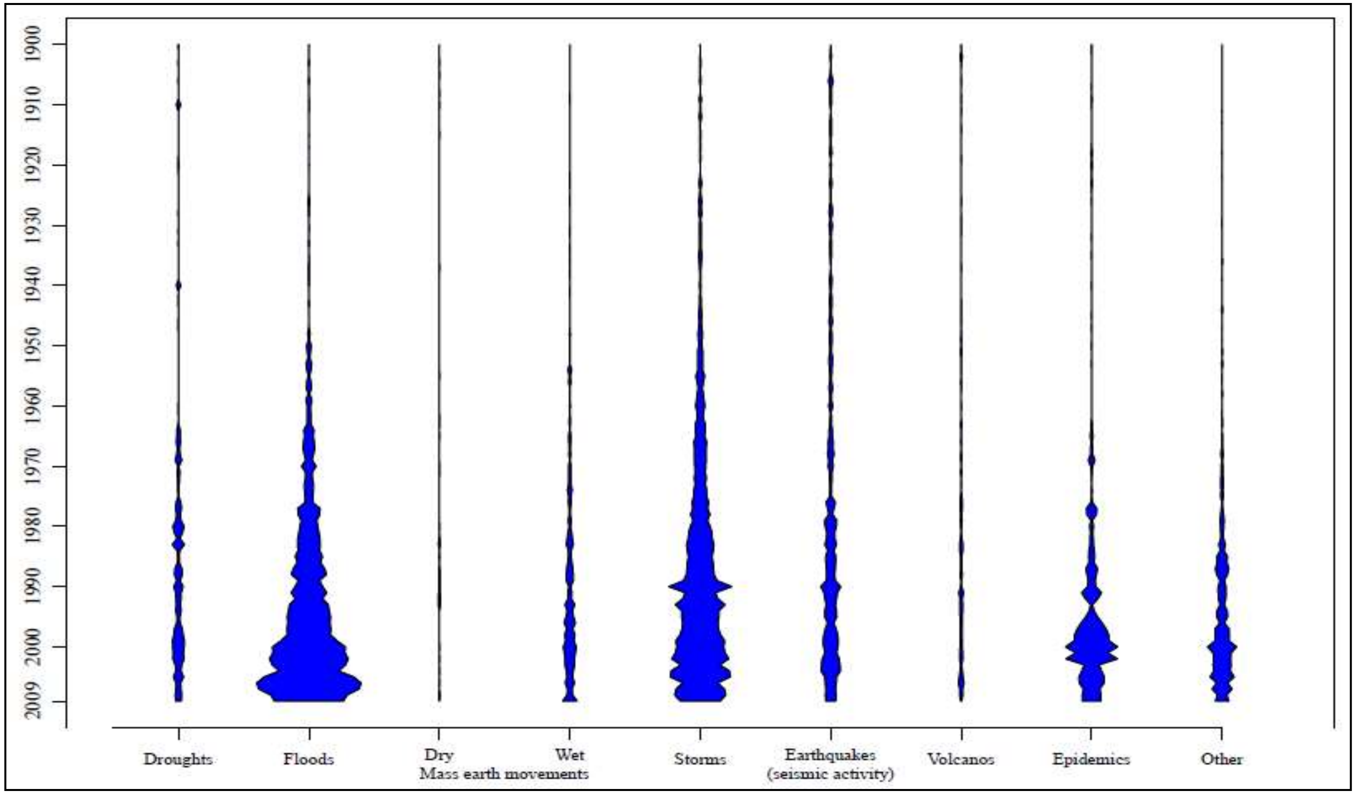
Co-authors: Dr A van Niekerk & Prof DM Sakulski

Research aim

The aim of this study is to evaluate if the existing data in South Africa is adequate for flood hazard mapping or if additional data are required.

Problem statement

Floods have been identified as one of the major natural hazards in both the world (Klijn 2009), and South Africa (Halloway et al. 2010).



Source: EM-DAT (2010)

Figure 1.1 Number of natural disasters reported 1900 – 2009

your knowledge partner

Problem statement

your knowledge partner

The Acts:

- The **Disaster Management Act of South Africa**, stipulates that measures to prevent and reduce disaster risks and to mitigate the severity of a disaster, must take place at all three levels of government, namely national, provincial and municipal (Act No. 57 of 2002).
- **National Water Act sections 121 and 144:** Flood hazard mapping is only required for dams or categories of dams with a safety risk and for new developments on town layout plans where the 100-year floodline needs to be indicated.

aurecon

Problem statement

Risk assessment

The first stage, the hazard assessment, is to define the hazard in terms of its frequency, magnitude, speed, onset, affected area and duration.

$$\text{Risk} = \frac{\text{Hazard} \times \text{Vulnerability}}{\text{Manageability}}$$

Problem statement

- Flood hazard mapping in the rural areas are limited to historical maps of floods where available. These historical maps frequently consist of maps from the 1:250 000 topographic map series on which the extent of a flood is indicated with pencil by the relevant DWA Officer for the region.
- Why?
  - Acts
  - Data availability

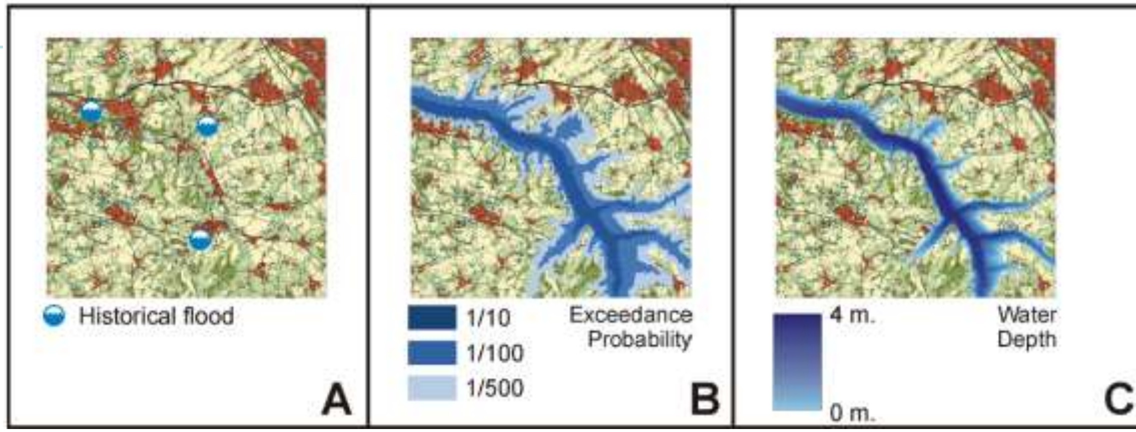
Research objectives

- Review the literature on disaster risk management, floods, flood hazard mapping, and different types of existing flood modelling methodologies.
- Determine the minimum data requirements for flood modelling and carry out an assessment of available data in South Africa.
- Perform and evaluate the suggested methodology for flood modelling with the available data.
- Evaluate the flood mapping results to identify any limitations and propose recommendations should alternative data sources be required for flood modelling in South Africa.

Flood hazard mapping

- The purpose of flood hazard mapping (Martini & Loat 2007):
  - Frequency-the probability of an occurrence in a specific time period;
  - extent-the geographical area of impact;
  - severity (intensity)-the water level or water depths; and
  - flow velocity and/or direction of flow.

Flood hazard mapping



Basic types:

- historical (event) map indicates the locations of historical events with point symbols on a map (see Figure A);
- extent map: is the most common and displays the inundated areas of a flood event that can either be historical or hypothetical (see Figure B);
- flood depth : displays the water depths (levels) derived from one- and two dimensional models for river flooding (see Figure C);
- flow velocity: indicates the velocity of the water flow and are determined with two dimensional models. One dimensional models can also be used but it is more complex;
- flood wave: displays the movement of the wave and are determined by two dimensional models; and
- duration of inundation: the period that an area is under water.

Flood hazard mapping

Requirements and scale

REQUIREMENT	SCALE/LEVEL		FLOOD PARAMETER (**BOLD** indicates minimal parameters to be mapped)
Disaster management planning	National/regional	1:100 000-1:1 000 000	**Extent**
	Local	1:5 000-1:50 000	**Extent, depth** and other parameters if appropriate
Town planning (Land use)	National/regional	1:100 000-1:500 000	**Extent**
	Local	1:5 000-1:25 000	**Extent for different probabilities**, depth, velocity and duration
Emergency planning and management	National/regional	1:100 000-1:500 000	**Extent**
	Local	1:5 000-1:25 000	**Extent and depth for different return periods, and other parameters if appropriate**
Public awareness	Local	1:10 000-1:25 000	**Extent for different probabilities and depth**
Insurance	Local	1:10 000-1:25 000	**Extent for different probabilities**, depth, and velocity (if significant)

Adapted from: Martini & Loat (2007: 13-16)

Flood hazard mapping

Requirements and scale

In South Africa, the National Water Act (sections 121 and 144), only requires the 100 year flood line for new developments on town layout plans (South Africa 1998). No further guidelines are available for the mapping of probability or scale of a flood hazard in either rural or urban areas.

Flood hazard mapping

Flood modelling software

Dimension	Distinguishing Features	Available Software	Potential Application
0D	No physical laws included in simulation	ArcGIS, Delta Mapper,etc.	Broad scale assessment of flood extents and flood depths
1D	Solution of one-dimensional St. Venant equations	Infoworks RS (ISIS), Mike 11, HEC-RAS	Design scale modelling which can be of the order of 10-100 s of km depending on catchment size
1D+	1D plus flood storage cell approach to the simulation of floodplain flow	Inforworks RS (ISIS), Mike 11, HEC-RAS	Design scale modelling which can be of the order of 10-100 s of km depending on catchment size, also has the potential for broad scale application if used with sparse cross-section data
2D-	2D minus the law of conservation of momentum for the floodplain flow	LISFLOOD-FP	Broad scale modelling or urban inundation depending on cell dimensions
2D	Solution of the two-dimensional shallow wave equation	TUFLOW, Mike 21, TELEMAC	Design scale modelling of the order of 10 s km. May have the potential for use broad scale modelling if applied with very course grids
2D+	2D plus a solution for vertical velocities using continuity only	TELEMAC 3D	Predominately coastal modelling applications where 3D velocity profiles are important. Has also been applied to reach scale river modelling problems in research projects.
3D	Solution of the three-dimensional Reynolds averaged Navior Stokes equations	CFX, FLUENT, PHEONIX	Local prediction of three-dimensional velocity fields in main channels and floodplains

Source: Pender & Néelz (2007: 108)

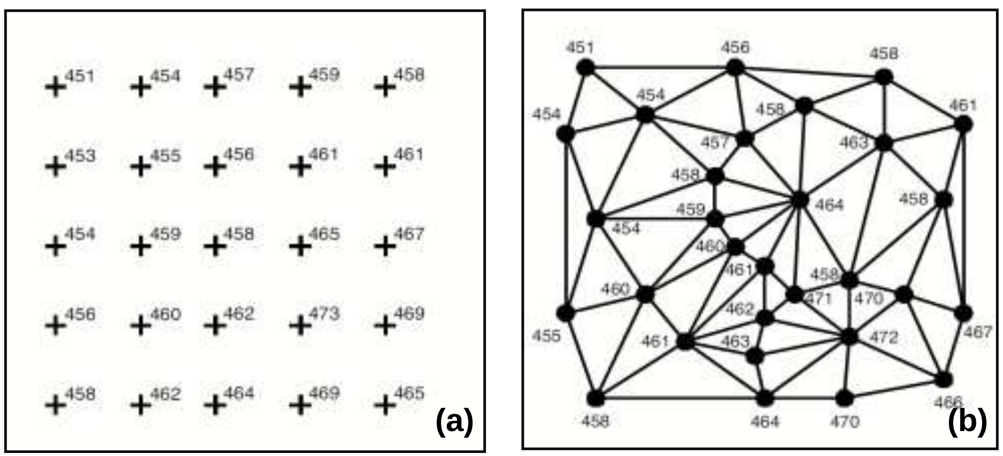
Minimum data requirements

To model basic flood parameters (extent and depth):

- Topographical data that describes the topography of the study area;
- Land cover (land use) data to calculate Manning’s roughness coefficient;
- Historical data hydrological data input and for the calibration and validation of the flood modelling.

Topographic data

- Topographic data is required to describe the river and its surrounding area.
- DTMs are the most frequently used data source for topographic data.



Source: Zeiler (1999: 163)

Data structures: (a) DEM and (b) TIN

your knowledge partner

Topographic data

Type	Data Set	Resolution/ Scale	Coverage	Source
Contour	CD: NGI 1: 10 000 contours	5 m	South Africa (SA) (partial coverage)	CD: NGI (2010a)
	CD: NGI 1: 50 000 contours	20 m	SA	CD: NGI (2010a)
DEM	CD: NGI 25m DEM	25 m	SA (partial coverage)	CD: NGI (2011a)
	ASTER GDEM	30 m	Near-global	ERSDAC (2009)
	CD: NGI 50m DEM	50 m	SA (partial coverage)	CD: NGI (2011a)
	SRTM 90m DEM	90 m	Near -global	ERSDAC (2009)
	GTOPO30	1 km	Global	ERSDAC (2009)

Topographic data

Martini & Loat (2007) recommends a 0.5 metre vertical resolution and a 10x10 metres (possibly even 5x5 metres) horizontal resolution as minimum requirements for a DEM. Where contours are used to generate a DEM, the contour should at least be at 1 metre vertical intervals.

Topographic data

- Low resolution (>10 m) DEMs are insufficient for hydraulic modelling of river channels as it cannot represent sharp topography changes in the terrain.
- DEMs are sufficient for extracting watershed characteristics in hydrologic analysis and TINs for stream channel description in hydraulic analysis.
- Although a TIN can be created from a DEM, the stream channel detail is still not sufficient for hydraulic analysis.
- Generally TINs are recommended as they can potentially provide a better representation of the river channel and surrounding area

Topographic data

Type	Data Set	Resolution/ Scale	Coverage	Source
Contour	CD: NGI 1: 10 000 contours	5 m	South Africa (SA) (partial coverage)	CD: NGI (2010a)
	CD: NGI 1: 50 000 contours	20 m	SA	CD: NGI (2010a)
DEM	CD: NGI 25m DEM	25 m	SA (partial coverage)	CD: NGI (2011a)
	ASTER GDEM	30 m	Global	ERSDAC (2009)
	CD: NGI 50m DEM	50 m	SA (partial coverage)	CD: NGI (2011a)
	SRTM 90m DEM	90 m	Global	ERSDAC (2009)
	GTOPO30	1 km	Global	ERSDAC (2009)

Land cover (land use) data

Land Cover and land use (Thompson 1996)

- Land use refers to the human activity (e.g. grazing, conservation) associated with a specific land unit.
- Land cover refers to all natural features (e.g. vegetation (natural or planted), water, ice, bare rock) and man-made features (e.g. buildings, roads) on the surface of the earth.

Land cover (land use) data

- Land cover data is required to assign the Manning's roughness coefficient in the hydraulic modelling

Type	Name	Resolution/Scale	Coverage	Source
Vector	NLC 1994	1:250 000	SA, Lesotho & Swaziland	Fairbanks et al. (2000)
Vector	NLC 2000	1:50 000	SA	Schoeman et al. (2010)
Vector	ENPAT	1:250 000	SA	ENPAT (2001b)
Raster	NLC 2009	30m	SA	SANBI (2010)
Raster	Globcover	300m	Global	Bicheron et al. (2008)
Raster	GLC 2000	1km	Global	Mayaux et al. (2006)

Historical data

- Hydrological data input.
- Calibration and validation of the flood modelling.
- Sources including:
  - dated flood maps;
  - water level records of rivers;
  - gauge station records (for velocity);
  - flood marks;
  - pictures, paintings and drawings;
  - newspaper articles about past flood events, with dated photographs;
  - historical reports or books about flood events; and
  - aerial and satellite photos.

Historical data

The capturing of hazard events, both spatially and non-spatially, are very limited in South Africa (Halloway et al. 2010). Details of historical events are mainly obtained from newspaper articles and South African Weather Services (SAWS) reports (Sakulski 2007).

Historical data

Water level and velocity

- DWA is the government organisation responsible for the monitoring, recording, assessing and making available information about water resources in South Africa:
  - hydrological (flow and rainfall in rivers);
  - water quality;
  - groundwater; and
  - water use licenses and other water use.

your knowledge partner

Water level and velocity

800 gauging stations for river flow exist and each station has one or more monitoring points (DWA 2009)

Historical data

Photo and Satellite imagery

- Two types of satellite imagery:
  - optical images: visible (0.04 µm to 0.7 µm) and infrared (0.7 µm to 100 µm) range on the electromagnetic spectrum;
  - Radio Detection and Ranging (RADAR): microwaves on the electromagnetic spectrum that have longer wavelengths (1 cm to 1 m).

Historical data

Photo and Satellite imagery

- Satellite imagery is classified into three different categories according to their geometric resolution (Altan et al. 2010):
  - high: 0.01 m – 10 m; **local scale (1: 5 000 to 1: 25 000)**
  - medium: 10 m – 30 m; **local scale (1: 25 000 to 1: 50 000)**
  - low/medium: 30 m – 1000 m.

national/regional (1: 100 000 to 1: 1 000 000)

Historical data

Aerial imagery

Type	Name	Resolution/ Scale	Coverage	Source
Aerial photo	CD: NGI Panchromatic (Pan)	1: 20 000	SA	CD: SM (2006)
		1: 30 000	SA	CD: NGI (2011b)
		1: 40 000	SA	CD: SM (2006)
		1: 50 000 – 1: 60 000	SA	CD: SM (2006)
		1: 80 000	SA	CD: SM (2006)
		1: 150 000	SA	CD: NGI (2011b)
	CD: NGI Colour	1: 10 000	SA	CD: NGI (2011b)
		1: 20 000	SA	CD: SM (2006)
		1: 30 000	SA	CD: SM (2006)
Orthophotos	CD: NGI Colour	1: 10 000	SA	CD: NGI (2011b)

your knowledge partner

Historical data

Satellite imagery (optical)

Type	Name	Resolution/ Scale	Coverage
GeoEye-1 Pan	0.41 m	global	GeoEye (2011)
Worldview-1 Pan	0.5 m	global	DigitalGlobe (2011b)
Worldview-1 MS	0.55 m	global	DigitalGlobe (2011b)
WorldView-2 Pan	0.46 m	global	DigitalGlobe (2011c)
WorldView-2 MS	0.52 m	global	DigitalGlobe (2011c)
Quickbird Pan	0.65 m	global	DigitalGlobe (2011a)
IKONOS Pan	0.82 m	global	GeoEye (2010)
GeoEye-1 MS	1.65 m	global	GeoEye (2011)
Spot 5 Pan	2.5 m	global	Spot Image (2008)
Quickbird MS	2.62 m	global	DigitalGlobe (2011a)
IKONOS MS	3.2 m	global	GeoEye (2010)
RapidEye (Level 1B)	5 m	global	RapidEye (2011)
RESOURCESAT-1 (IRS-P6) Liss 4 MS	5.8 m	global	ISRO (2011)
Sumbandilasat MSS	6.25 m	SA (partial coverage)	Kokemoer et al. (2011)

Type	Name	Resolution/ Scale	Coverage
Spot 1, 2, 3 Pan	10 m	global	Spot Image (2010)
Spot 4 Pan	10 m	global	Spot Image (2010)
Spot 5 MSS	10 m	global	Spot Image (2008)
Landsat 7 Pan	15 m	global	GLCF (2009)
Spot 1, 2, 3 MS	20 m	global	Spot Image (2010)
Spot 4 MS	20 m	global	Spot Image (2010)
CBERS CCD	20 m	global	CBERS (2011a)
RESOURCESAT-1 (IRS-P6) Liss 3 MS	23.5 m	global	ISRO (2011)
Landsat 4, 5 MSS	30 m	SA	GLCF (2009)
Landsat 7 MSS	30 m	SA	GLCF (2009)
Landsat 1-4 MSS	60 m	SA	GLCF (2009)
Modis MS(band 1-2)	250 m	global	NASA (2011)
Modis MS(band 3-7)	500 m	global	NASA (2011)
Modis MS(band 8-36)	1 km	global	NASA (2011)
NOAA AVHRR	1 km	global	NOAA (2011)

aurecon

Historical data

Satellite imagery (RADAR)

Type	Name	Resolution/Scale	Coverage
TerraSAR-X High Resolution Spotlight	1 m	global	Infoterra (2011)
TerraSAR-X Spotlight	2 m	global	Infoterra (2011)
Radarsat-2	3 m	global	CSA (2011)
TerraSAR-X StripMap	3 m	global	Infoterra (2011)
Radarsat-1	8 m	global	CSA (2011)
ERS AMI SAR 2	30 m	global	Eurimage (2011)
TerraSAR-X ScanSAR	100 km	global	Infoterra (2011)

Study area

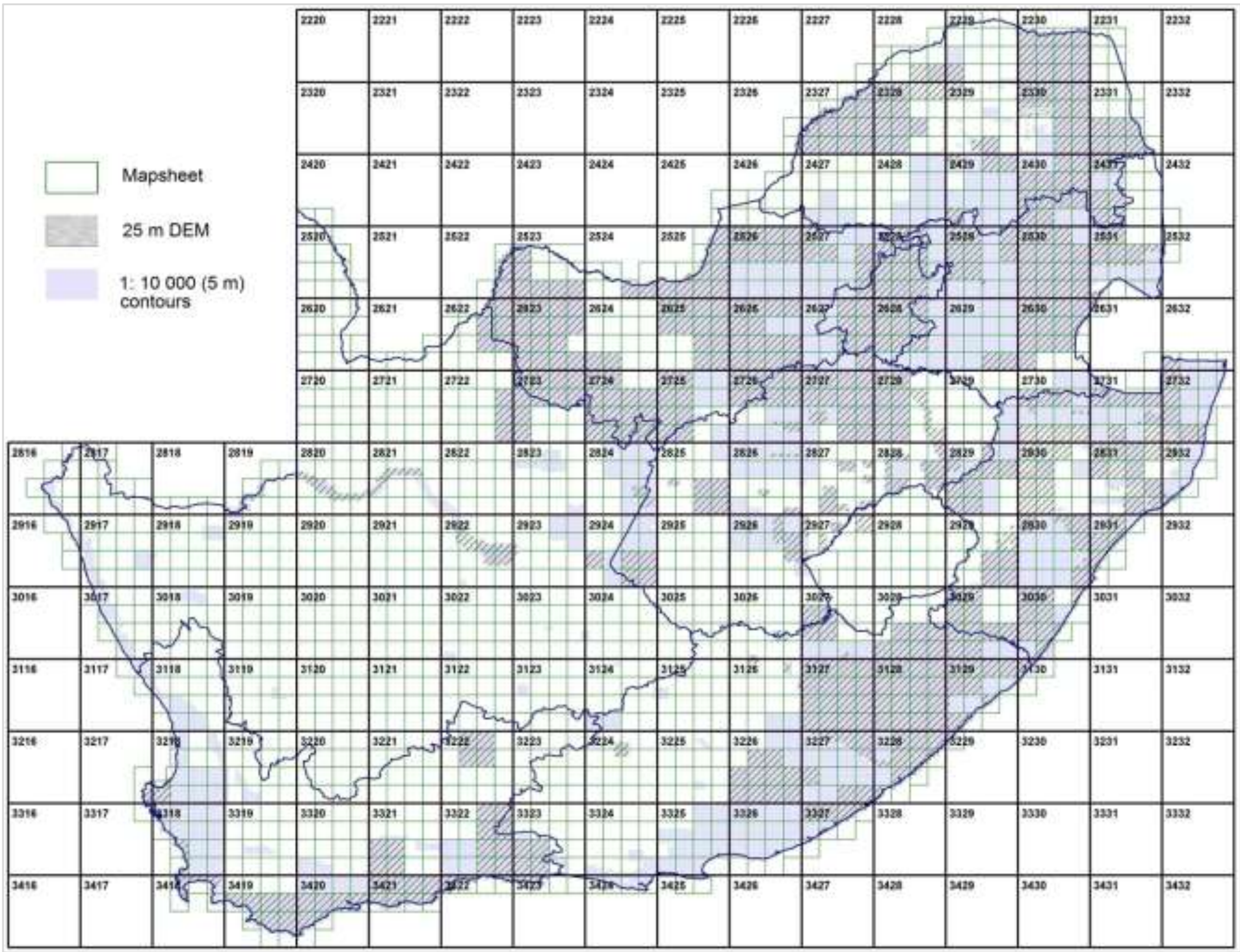
- Suitable data sources:

Data Input	Name
Topographic	CD: NGI 1: 10 000 (5 m) contours
Land cover	NLC 2000
Water level	DWA's Hydrological Information System

- Study area determined by coverage of 5 metre contour and locations of the river gauge stations.

Study area

1: 10 000 (5 m) contour coverage



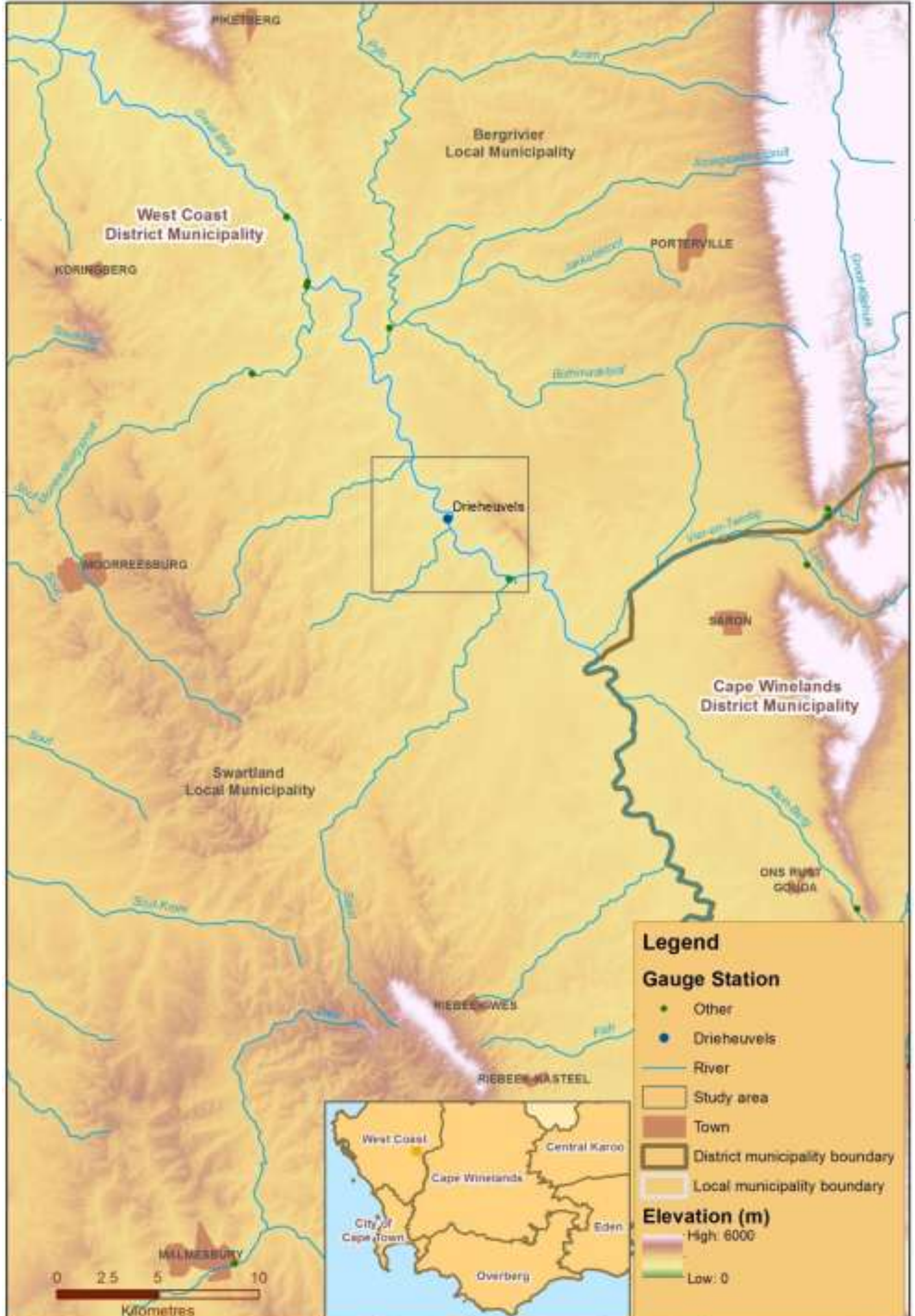
your knowledge partner

aurecon

River gauge station coverage

your knowledge partner

Study area: Drieheuvels



aurecon

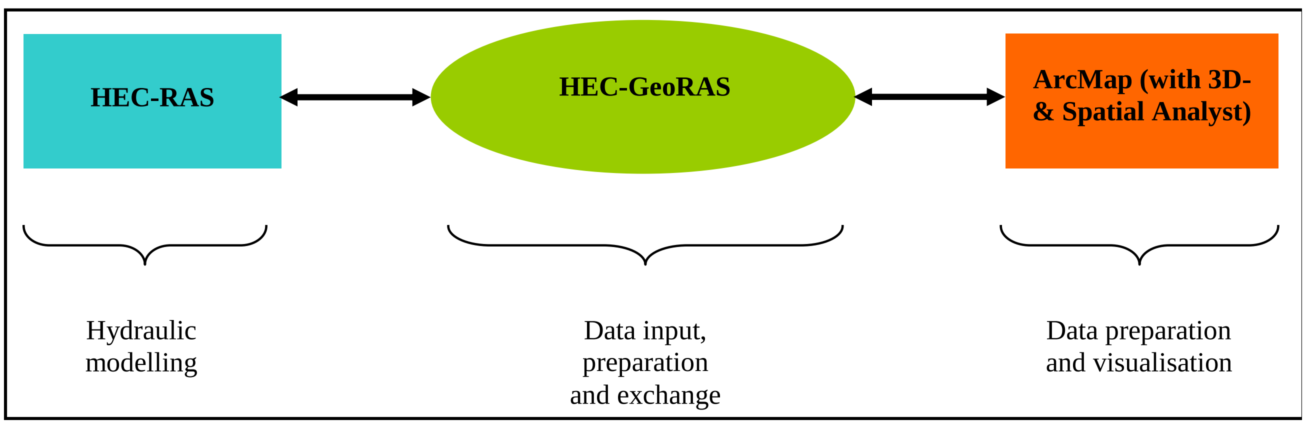
Study area

Calibration and validation

- Major flood events identified:
  - 06 to 11 June 2007; and
  - 25 to 28 June 2007.
- Dates confirmed by a report on the consequences of flood disasters that occurred in the West Coast district during this period (DIMP 2007).
- Searched archives of medium resolution satellite imagery listed in the Table 4.5.
- One Landsat 7 MSS (30 metre resolution) satellite images for 17 June 2007 could be found.
- The six day delay was too long to identify the flood extent with any certainty for calibration and validation of the model, which limits the level of uncertainty calculation.

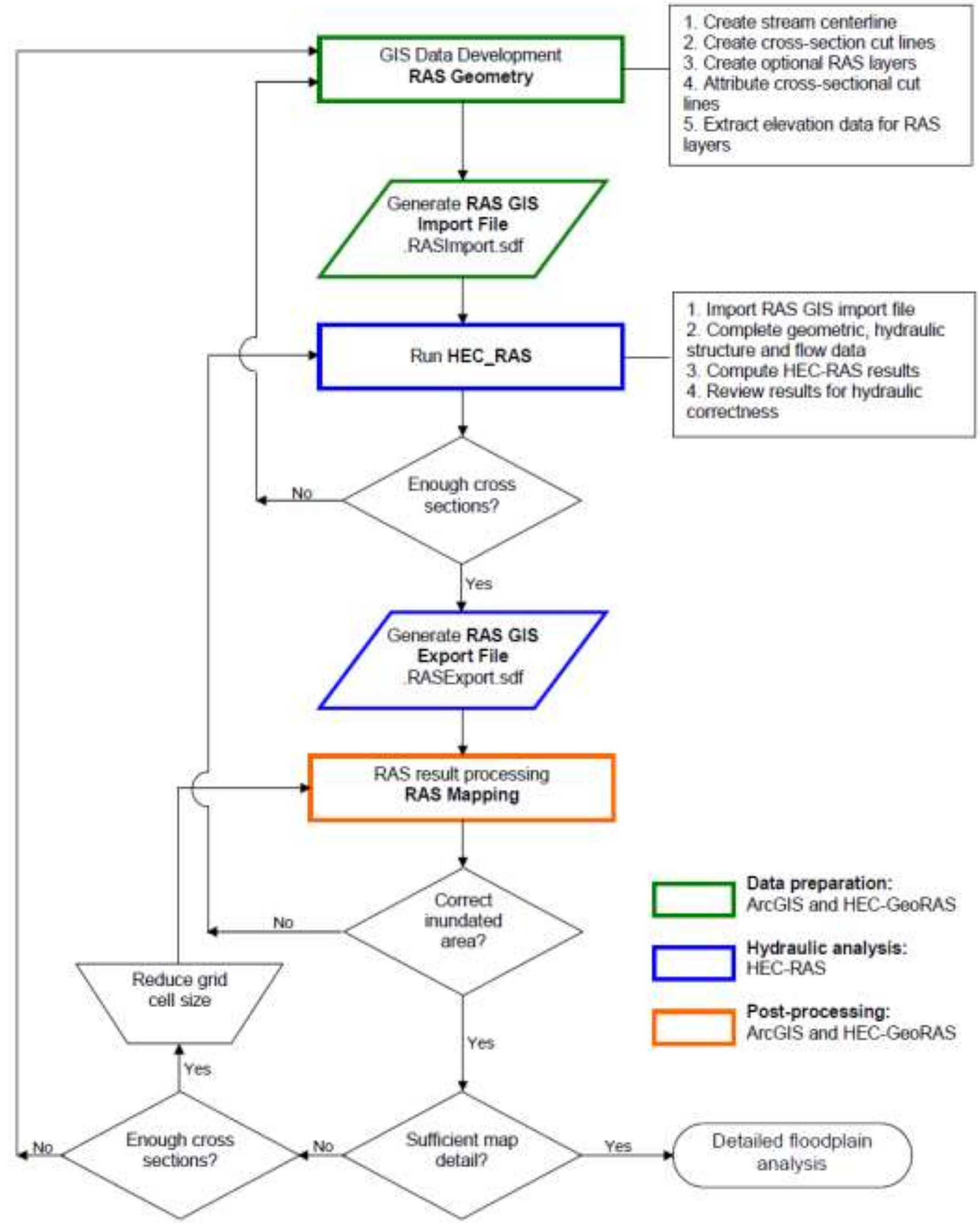
Flood modelling demonstration

- HEC-RAS: 1-dimensional hydraulic modelling software program;
- Most widely used program for flood plain analysis;
- Approved by FEMA.



Flood modelling overview

your knowledge partner



Adapted from: Ackerman (2005: 18)

your knowledge partner

Results: 1: 20 year flood depth map

your knowledge partner

Results: 1: 50 year flood depth map

aurecon

your knowledge partner

Results: 1: 100 year flood depth map

Conclusion

- There is a need for more accurate and recent data sets in South Africa as floods are becoming a more frequent phenomena.
- Without appropriate data, flood assessments will be limited, increasing the disadvantages of poor rural communities that are often without the means to cope with an extreme flood event.
- The availability of adequate data sets for the hydraulic modelling has restricted the scale of flood hazard mapping and the selection of a study area.

Conclusion

Topographic data

- The availability of topographic data to represent the river channel and surrounding terrain accurately was one of the main difficulties in this study.
- Topographic data are extremely important as they determine the elevation of intersecting GIS layers.
- In this study, 5 m (1: 10 000 scale) contours were used to create a TIN.
- Detailed analyses requires a DEM of 5 m to 10 m resolution or 1 m interval contours are required (Matini & Loat 2007).

Conclusion

Topographic data: Possible Solutions

- SANSA is investigating the inclusion of the Indian P5 (Cartosat-1) satellite data to its current portfolio by 2012. This will enable the development of 5 m DEM that can be applied in hydraulic modelling (Nieckau 2011).
- Possible other options to consider is lidar-based aerial surveys (LBAS) However, this approach is very expensive to follow (Joyce 2011).
- There a need to invest in high resolution DEMs in South Africa.

Conclusion

Land cover data

- Land cover data is needed to determine Manning's coefficient values along each cross-sectional cut lines in the hydraulic model.
- Most of the current land cover data sets in South Africa are very dated and at a large scale.
- The CD: NGI appointed SANSA, to facilitate workshops with all users of land cover data during January and February 2008, to determine a methodology for creating a new land cover data set (eight super classes and 32 sub-classes).
- These classes will be derived from a combination of satellite imagery that includes Landsat 7 ETM+, Spot 5, and SAR and Light Detection and Ranging (LIDAR) technologies (Lück et al. 2010).

Conclusion

Historical data: Velocity data

- Peak discharge values are required to calculate the flow for different occurrence intervals.
- Many river gauge stations do not capture discharge values. In such cases, a hydrologic analysis needs to be carried out for the specific river catchment before the hydraulic modelling can commence. In addition, very few of these gauge stations contains verified data sets.
- Day-to-day river basin management is vital for the effective management and forecast of floods. Real-time and historical databases are integral to such an information system (Terakawa 2003).

Conclusion

Historical data: Velocity data

- There is a need that the data recorded at gauge stations are more complete by also capturing water depth and discharge values.
- Firstly, attention should be given to updating existing gauge stations to record comprehensive hydrological databases. Thereafter, flood prone areas along the river should be identified where additional gauge stations could be positioned (Clarke & Ractliffe 2007).
- In addition, these gauge stations can be equipped to act as early warning systems for flood events, thus serving a dual purpose.

your knowledge partner

aurecon

Conclusion

Historical data: Velocity data

- Alternatively, various government organisations, from national to municipality level, have their own water monitoring programmes that capture detailed data with regards to water level, velocity and pollution.
- Possible planning and coordination between these organisations can allow stakeholders access to these water monitoring databases to resolve the gauge station data shortage.

Conclusion

Historical data: Imagery

- Historic aerial photography or satellite images are required for calibration and validation purposes where the extent and depth of a particular flood event are determined from an image and compared with the result of the hydraulic model.
- Although a wide selection of satellite images was available for the study site, none of these correlated with the date on which a historic flood event occurred.
- Thus, neither calibration nor validation of the hydraulic model could be completed.
- There exists no official archive of historical images capturing flood events, or any other hazards, in South Africa.

Conclusion

Historical data: Imagery

- Pre-disaster images are available in South Africa but access to real-time satellite imagery during disasters is needed.
- Real-time satellite imagery is expensive and will restrict the development of a database for historic images.
- Alternative approaches to collecting real-time images are to utilise the opportunity to use the South African Sumbandilasat images or the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER).

Conclusion

Historical data: Imagery

- Sumbandilasat can capture frequent high resolution images of specific areas, at no cost, for natural disasters such as floods (Koekemoer et al. 2011).
- Although this satellite's attitude stabilisation system failed to function properly during the beginning of the mission, alternative settings were made that allows the satellite to tumble "head-over-heals" and capture images from south to north when orbiting in a north to south direction (Koekemoer et al. 2011).
- Simultaneously, high scale (1: 5 000 to 1: 25 000) hydraulic modelling can be attempted as the Sumbandilasat images have a pixel resolution of 6.25 m.

Conclusion

Historical data: Imagery

- The Spider programme was established on 14 December 2006 by the United Nations Office for Outer Space Affairs (UNOOSA) with the objective to provide access and develop the capacity of all countries and organisations (international and regional) in the use of all space-based information during the whole disaster management cycle.
- One of the frameworks used by the UN-Spider, is the use of SpaceAid that facilitate fast and efficient access to satellite imagery during a disaster on a 24 hours per day/7 days a week basis.

Conclusion

Final remarks

- This study has shown that flood modelling is possible with the existing data available in South Africa.
- However, the model could not be calibrated or validated due to the absence of historic satellite images of the flood event.
- This limits the use of these flood hazard maps in disaster management.

Conclusion

Final remarks

- The selection of methodology for the flood modelling was limited by available data sources.
- HEC-RAS is a software package that requires the minimum data input to perform hydraulic analysis.
- Although HEC-RAS is approved by FEMA as an acceptable software program to create flood hazard maps there are other more recent software packages with better analysis processes than HEC-RAS available. These software packages do however require large scale data input.

Conslusion

Final remarks

- If South Africa can enhance the existing data source required for hydraulic modelling, then the methodology can be improved and better flood hazard maps can be created.
- Vulnerable communities are indirectly influenced the most by the limited availability of flood hazard maps.
- Some African countries already have better quality historic satellite imagery and topographic data and this should encourage South Africa to improve their in-house data if they would like to become the leaders in spatial information in Africa.

References

Ackerman CT 2005. HEC-GeoRAS, GIS tools for support of HEC-RAS using ArcGIS. Davis: United States Army Corps of Engineers.

Altan O, Backhaus R, Boccardo P & Zlatanova S (eds) 2010. *Geoinformation for disaster and risk management: Examples and best practices*. Copenhagen: Joint Board of Geospatial Information Societies.

Clarke B & Ractliffe G (eds) 2007.*Berg River Baseline Monitoring Programme: Final Report–Volume 5: Synthesis*. Publication No P WMA 19/G10/00/2107. Pretoria: Department of Water Affairs.

DIMP (Disaster Mitigation for Sustainable Livelihoods Programme) 2007. Severe weather compound disaster: June 2007 cut-off lows and their consequences in the West Coast, South Africa. Cape Town: University of Cape Town.

DWA (Department of Water Affairs) 2009. Hydrological Services [online]. Pretoria: DWA. Available from http://www.dwaf.gov.za/Hydrology/about.htm [Accessed 18 October 2009].

Joyce K 2011. Remote sensing and geological hazard assessment. Paper delivered at the Earth Observation and Geological Hazard Assessment Workshop, Pretoria.

Halloway A, Fortune G & Chasi V 2010. *Risk and development annual review: Western Cape 2010*. Cape Town: Peri-Peri Publications, Disaster Mitigation for Sustainable Livelihoods Programme.

Klijn F (ed) 2009. *Flood risk assessment and flood risk management: An introduction and guidance based on experience and findings of FLOODsite (an EU-funded Integrated Project).* Delft: Deltares, Delft Hydaulics.

Koekemoer J, Govender N, Smit I 2011.SumbandilaSat provides valuable imagery. *PositionIT*. April/May 2011.

References

Lück W, Mhangara P, Kleyn L, & Remas H 2010. Land cover field guide. Pretoria: CSIR Satellite Application Centre (SAC). Available from: http://www.ngi.gov.za/images/stories/technical_info/publication/CDNGI_Land_Cover_Methodology_and_Field_Guide_v2.pdf [Accessed 3 February 2011].

Martini F & Loat R (eds) 2007. *Handbook on good practices for flood mapping in Europe*. Emmeloord: Drukkerij Feiko Stevens.

Nieckau N 2011. Providing access to cutting edge satellite imagery [online]. Johannesburg: EE Publishers (Pty) Ltd. Available from: http://www.eepublishers.co.za/article/providing-access-to-cutting-edge-satellite-imagery.html [Accessed 1 June 2011].

Pender G & Néelz S 2007. Use of computer models of flood inundation to facilitate communication in flood risk management. *Environmental Hazards* 7: 106-114.

Sakulski D 2007. Spatial and temporal frequency and distribution of hazardous events over South African territory for the period between years 1800 and 1995 based on 'CAELUM' document. Pretoria: Cooperation Unit for Southern Africa, United Nations University.

Terakawa A 2003. *Hydrological data management: Present state and trends*. Publication No 964. Geneva: World Meteorological Organisation.

Thompson M 1996. A standard land-cover classification scheme for remote-sensing applications in South Africa. *South African Journal of Science* 92: 34-42.

Zeiler M 1999. *Modelling our world: The ESRI guide to geodatabase design*. Redlands: Environmetal Systems Research Institute (ESRI), Inc.

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

Thank you

Contact details: zelda.els@aurecongroup.com

aurecon