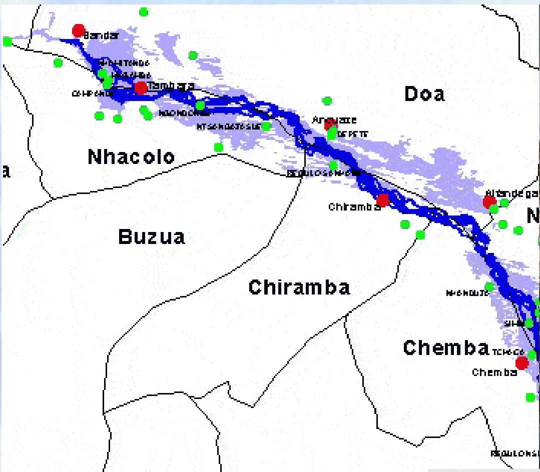
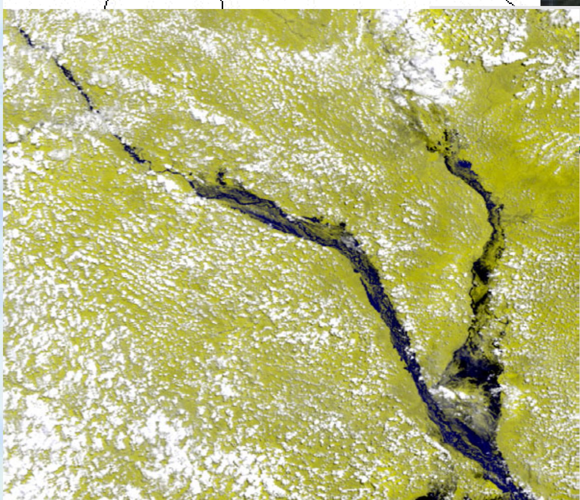
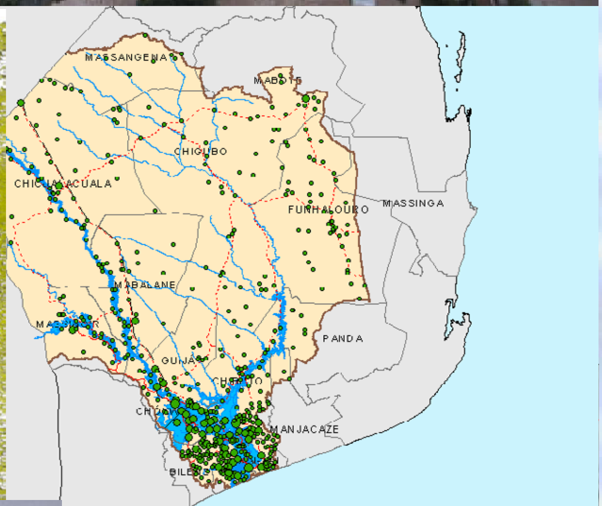
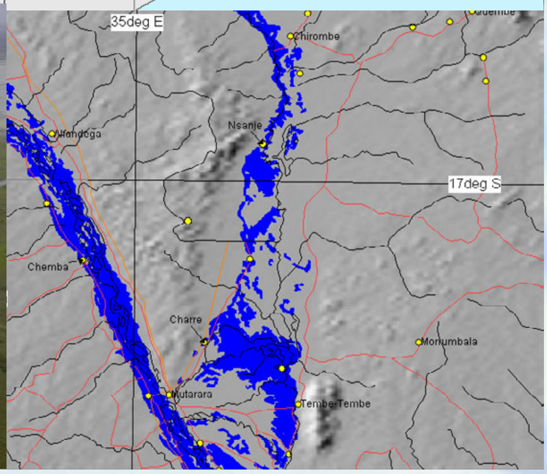
GUIDANCE ON NATIONAL FLOOD RISK ASSESSMENTS









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Contents

1. INTRODUCTION

The objective of this document is to provide guidance on how to carry out national flood risk assessments for water management organisations in southern Africa. The document has been structured as follows:

Flood map used in England showing the 1% (1 in 100 year) and 0.1% (1 in 1000 year) flood extent (Reference 1).

- Chapter 1 provides background on national flood risk assessments, the frequency of flooding, and definitions of flood hazard and flood risk;
- Chapter 2 outlines methods that can be used for identifying flood hazards and producing flood hazard maps;
- Chapter 3 summarises techniques for the establishment of national flood risk maps;
- Chapter 4 describes methods for disseminating flood maps;
- Chapter 5 provides a list of useful references.

This document is intended to give an overview of the methods available and has been kept deliberately brief. More details on the production of national flood risk maps are provided in the cited references.

1.1 BACKGROUND TO NATIONAL FLOOD RISK ASSESSMENTS

A national flood risk assessment involves finding out:

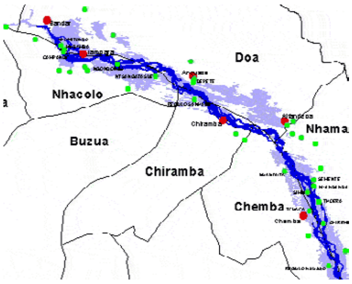
- The locations where flooding can occur (the floodplain);
- What is at risk of being flooded, normally expressed in terms of the number of people at risk and/or the assets at risk (for example, number of houses).

In some parts of southern Africa the river systems have very large floodplains where many properties are at risk, whereas elsewhere in the country, river valleys are narrow and properties are generally outside the floodplains. In this case, it is clearly advisable to concentrate on areas of greatest risk.

The location of houses and other assets, and therefore the location of people, are normally available on national maps. The key element of a national flood risk assessment is to find out where flooding can occur. Hence this document is primarily concerned with methods of mapping flood extents. When maps of the flood extents are available, the locations where assets and people are at risk can be determined by overlaying these two sets of information. This will provide a visual assessment of flood risk, and an indication of where the risk is greatest.

Flood maps can also be used for planning purposes, to inform decisions regarding where to locate new developments. Techniques are available to quantify the flood risk and develop strategies and plans for mitigating the risk. However, these are beyond the scope of this document.

The first step in undertaking a national flood risk assessment is to establish the significance of flooding on a national and regional basis, in order to decide where to concentrate the greatest effort. This might be done from knowledge and records of natural disasters that have affected the country in the past.



Flood map produced by the United States Geological Survey for the Upper Zambezi River in Mozambique based on a sustained release of 12,000 m^3/s of water from Cahorra Bassa Dam (Reference 2).

There is a range of sources of flooding including:

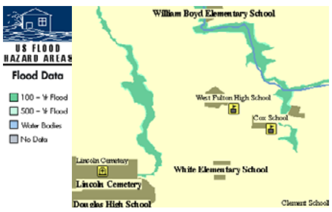
- Rivers;
- The sea (from high tides, cyclones and tsunamis);
- Groundwater;
- Local drainage channels and sewers, particularly in urban areas.

It is important to appreciate that a national flood risk assessment will only give an overview of the flood problem, concentrating on flooding from the larger rivers and the sea. It will not provide detailed information on local flooding, for example caused by drains in urban areas.

1.2 FREQUENCY OF FLOODING

Flooding is a natural and recurring event for a river or coast. On rivers, flooding is a result of heavy or continuous rainfall exceeding the absorptive capacity of soil and the flow capacity of the river channel. This causes a river to overflow its banks onto adjacent land. On coasts, high sea levels and waves can cause flooding. These may be caused by extreme weather, for example cyclones, or tsunamis created by earthquakes.

Floodplains are situated adjacent to rivers and coasts. Floodplains are therefore "flood-prone" and are hazardous to people, property, animals and other assets. Box 1.1 describes the terminology that is generally used to describe the frequency of flood events.



National flood hazard maps produced by the Federal Emergency Management Agency in the USA showing the 1 in 100 year and 1 in 500 year flood extents (Reference 3).

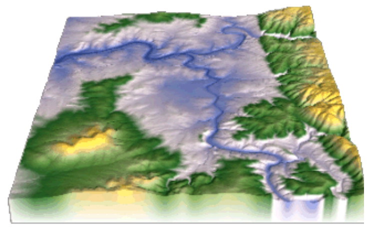
Box 1.1 Frequency of flood events

Floods are usually described in terms of their statistical frequency. A "1 in 100 year flood" describes a flood event that has a 1% probability of being equalled or exceeded in any given year. Similarly, a "1 in 100 year floodplain" describes the area that would flood in such a flood event.

This does not mean such a flood will occur only once in one hundred years. Whether or not it occurs in a given year has no bearing on the fact that there is still a 1% chance of a similar occurrence in the following year. Since floodplains can be mapped, the boundary of the 1 in 100 year flood is commonly used to identify areas where the risk of flooding is significant.

1.3 FLOOD HAZARD AND FLOOD RISK

Flood hazard maps show the extent of the floodplains, and flood risk maps show the extent of the floodplains and the assets at risk of flooding within the floodplains. Not only are these maps needed for a national flood risk assessment, but they can also provide valuable information for planning a range of activities including the emergency response to a flood disaster. Hazard and risk are defined in Box 1.2.



Three-dimensional digital terrain model (DTM) used for delineating flood extents.

Box 1.2 Definition of hazard and risk

Hazard

A hazard may be defined as a situation with the potential to result in harm. A hazard does not necessarily lead to harm, but identification of a hazard does mean that there is a possibility of harm occurring. In the context of flooding, a flood hazard exists in areas where flooding can occur.

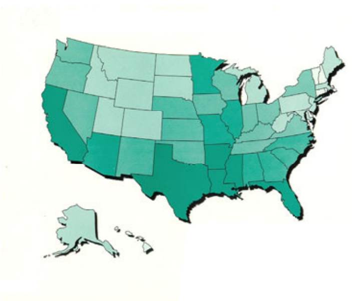
Risk

Risk is a combination of the chance of a particular event, with the impact that the event would cause if it occurred. Risk therefore has two components: the chance (or probability) of an event occurring and the impact (or consequence) associated with that event.

Risk = Probability x Consequences

In the context of flooding, the probability is the chance of the flood occurring and the consequences are the impacts of the flood (for example, damage to buildings).

2. FLOOD HAZARD MAPS



Flood hazard map of the USA showing the area of land liable to flood in each state. The darker the shade of green the greater the area liable to flood in each state. (Reference 4).

The main method for identifying flood hazards at a national level is via flood hazard maps. To evaluate flood hazard fully, the following is needed:

- Where the floodplain areas are;
- How often the floodplain will be covered by water;
- The depth of the floodwater;
- How long the floodplain will be covered by water;
- At what time of year flooding can be expected.

In a national flood risk assessment it is important to assess the degree of hazard in the floodplain and to prioritise the effort in producing flood maps where the flood hazard is high. One method by which flood hazard can be categorised is as shown in Table 2.1 based on the impact of flooding on people.

Table 2.1 Flood hazard categories

In the late 1960s flood protection measures for Winnipeg in Canada, were completed at a cost of $US 92 million. A rough estimate of damages prevented in five large floods since then is approximately $US 2.0 billion (Reference 5).

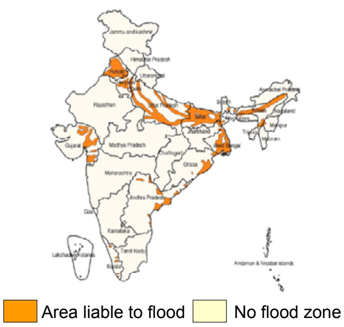
Hazard category	Description
Low	There are no significant evacuation problems. If necessary, children and elderly people could wade to safety with little difficulty; maximum flood depths and velocities along evacuation routes are low; and evacuation distances are short.
Medium	Areas where fit adults can wade to safety, but children and the elderly may have difficulty; evacuation routes are longer; and maximum flood depths and velocities are greater.
High	Fit adults have difficulty wading to safety; evacuation routes are longer again; and maximum flood depths and velocities are greater (up to 1.0 metre and 1.5 metres per second respectively).
Extreme	Boats or helicopters are required for evacuation; wading is not an option because of the rate of rise and depth and velocity of floodwaters. Maximum flood depths and velocities are over 1.0 metre and 1.5 metres per second respectively.

In general most national flood hazard maps only show the flood extent for a particular annual probability of flooding or return period. The 1 in 100 year return period (or 1% annual probability) flood extent is often used for national flood mapping projects.

2.1 OPTIONS FOR MAPPING FLOOD HAZARD AT A NATIONAL LEVEL

There are a number of options that can be used to map flood hazard at a national level. These include the following:

- Information on historical floods;
- Soil maps;
- Aerial photography;
- Satellite imagery;
- Hydraulic modelling;
- Use of national digital terrain model and water levels.



Example of a national flood zone map produced for India (Reference 6).

2.1.1 Use of information on historical floods

Historical flood information from major flood events that have occurred in the past can be used to produce flood hazard maps. The information may take the form of approximate flood extents for small areas (for example, parts of settlements known to have been flooded) or flood extent maps produced after the occurrence of a flood for most if not all of the affected area. Where historical flood information is used, it is normal practice to plot all available information on maps to try to obtain a first estimate of the overall national position.

A major deficiency of such mapping is that the information is often difficult to find and only covers parts of the country. The resulting flood maps are therefore incomplete. However they may show areas that have flooded in the main settlements and therefore provide information on the main flood risk areas. A further problem is that the data rarely identifies the flood frequency associated with a flood event. Nevertheless such event mapping can assist in identifying flood prone areas.

2.1.2 Soil maps

Soil maps can provide information on soil series associated with river, lake, wetland and tidal deposition. They can be useful in determining historic floodplain at geological time-scales but do not provide any indication of event probability. Raised beaches provide an example of how soil data can mislead, as these were created by isostatic uplift and may be several metres above any current flood risk. Other than being indicative of fluvial or tidal influence at some time in the past soil maps cannot provide all the information required for the assessment of flood risk.

2.1.3 Aerial photography

Aerial photograph of flooding on the Ohio River in the USA in 1937.

If a historical flood was particularly large and of sufficient duration to permit mobilisation of aircraft then aerial photography may have been carried out by an organisation (for example a river management organisation or news media) with an interest in flooding. This will provide reliable information on areas that flooded during the particular flood being photographed although the magnitude of the flood (expressed in terms of probability of occurrence) may not be known. It is also difficult to capture the flood at its peak throughout a catchment using aerial photography. In heavily forested areas it is often difficult to establish the edge of the flood extent.

Aerial photographs can be used to determine the floodplain extent. A particular problem with aerial photography is that there is often no central repository of aerial photographs, and sources are likely to be many and widespread. It can therefore be a time consuming process to produce flood hazard maps from aerial photographs. An aerial photograph of the floods that occurred in Mozambique in 2000 is shown in Figure 2.1.

2.1.4 Satellite imagery

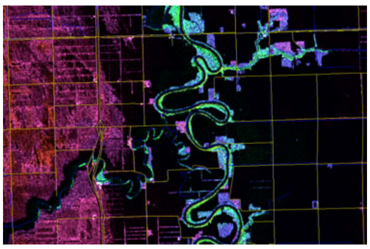


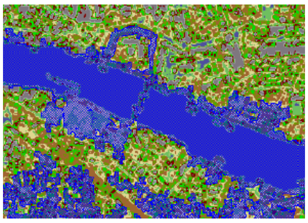
Image produced from a Synthetic Aperture Radar (SAR) of flooding on the Red River in the USA.

Microwave and optical satellite imaging of selected river reaches can be used to detect flood conditions. Satellite imagery will usually allow national flood maps to be produced at a scale of 1:250,000.

Remote sensing methods based on optical, medium resolution imagery such as Landsat and the French Satellite Pour l'Observation du Terre (SPOT), are limited in their applicability. This is because they depend on cloud free conditions and are relatively expensive. These remote sensing methods will also not penetrate flooded areas under canopies formed by trees.

In many parts of the world Synthetic Aperture Radar (SAR) has proved to be the ideal source for regional flood mapping. The resolution of the SAR image, provides a data set which can be handled with reasonable ease, and can provide sufficient vertical and horizontal detail for most national flood mapping project requirements.

Aerial photograph of central London in the UK.

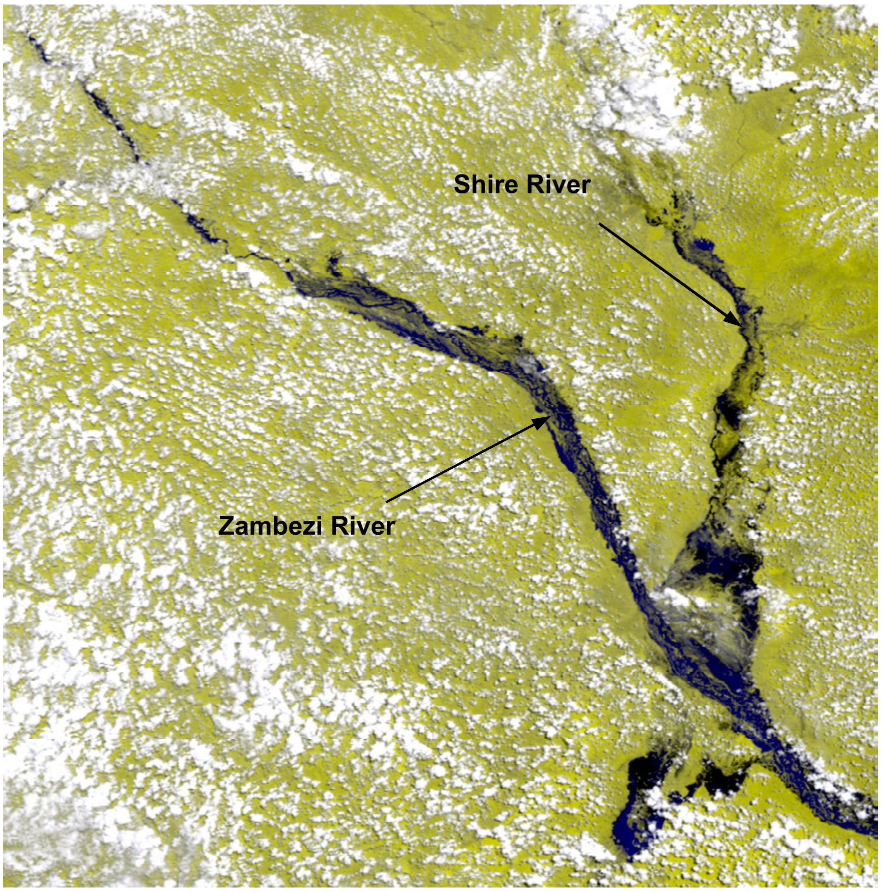


Flood map of the same area of central London produced using airborne SAR data.

There is also a temporal limitation. For example the Landsat satellite only returns over any given location once every 16 days. In a flood, when clouds frequently obscure the ground surface for several days at a time, this temporal limitation often impedes acquisition of adequate imagery for flood extent analysis. Figure 2.2 shows a satellite image of the Zambezi valley for a flood in 2001. Figure 2.3 shows the flood map produced from the satellite image.

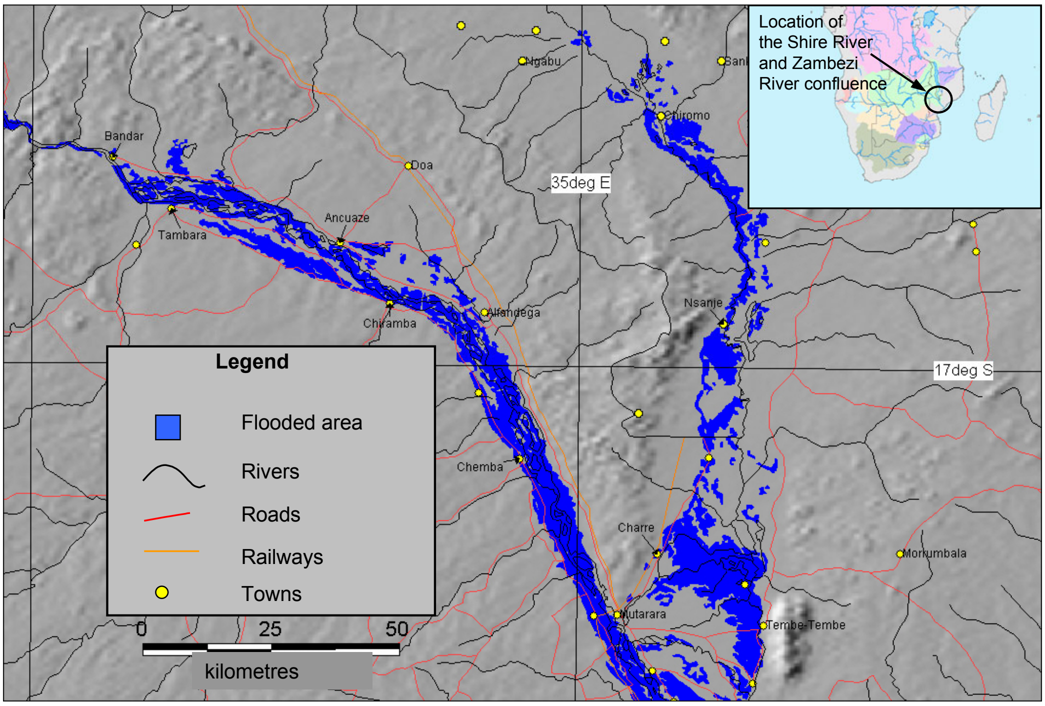
Flood maps can also be developed using satellite radar data. Synthetic Aperture Radars (SAR) can be used to acquire high-resolution large-scale images of the earth's surface. The advantages of a SAR device are that they can operate in all weather condition during the day and night circles of an orbit. As well as estimating the extent of actual floods, SAR can also be used to produce Digital Terrain Models (DTM) of large areas. These DTMs can be combined with information on flood levels to produce flood extents. It should be noted that DTMs produced by satellite mounted SARs generally have a low vertical resolution of the order of ±10 m. A SAR can be mounted on an aircraft and a DTM of a large area can be produced fairly rapidly with a good vertical resolution (for example ±0.5 m). In the UK airborne SAR has shown to be practicable in terms of processing over 200,000 km² of terrain data, including 80,000 km of river and to produce realistic national floodplain maps.

Figure 2.1 Aerial photograph of flooding in Mozambique



(Source: Reference 7)

Figure 2.2 Satellite image of the Zambezi and Shire Rivers in flood on 25 February 2001



(Source: Reference 7)

Figure 2.3 Flood map produced from the 2001 satellite image of the Zambezi and Shire Rivers

2.1.5 Hydraulic modelling of the river

Carrying out hydraulic modelling of all the major rivers within a country is not a cost effective or efficient method to produce national flood hazard maps. However, hydraulic modelling may be available where flood prevention schemes have been investigated and, occasionally, when flood hazard assessments have been carried out. The use of results from modelling is normally preferable to using historic flood event data since models are usually constructed to define a specific flood extent of stated probability over the whole modelled area.

2.1.6 Use of a national digital terrain model and design flood water levels

In January 1981 floods occurred in large areas of the semi-arid Karoo area of South Africa. In terms of loss of human life the town most affected was Laingsburg, where over 100 persons were drowned. The town's people had built their homes on the floodplains on both sides of the river. The water rose so fast that people were trapped in their homes. Today the high water mark of the flood is marked on various lampposts and in the church that survived the flood.

An effective method of producing national flood maps that has been applied in some European countries is to use a digital terrain model (DTM) of the country combined with estimates of design flood water levels at various locations. The steps in producing a national flood risk map via this method are as follows:

1. Establish the magnitude of the floods to be mapped (for example the 1 in 100 year flood);
2 Estimation of flood peak discharges for the defined floods at any point along the rivers in the country. This could be done by catchment modelling or statistical analysis of flow data;
3 Production of a DTM of the country;
4 Estimation of the water level for the defined flood at any point along the rivers;
5 Use of the DTM in combination with the water levels for the defined flood to delineate the flood extent.

There are a number of DTMs readily available (for example via the United States Geological Survey). However, the vertical resolution of these DTMs can vary considerably. Geographic Information Systems (GIS) usually play a central role in the process for the production of flood maps.

3. FLOOD RISK MAPS

3.1 FACTORS AFFECTING FLOOD RISK

Flood risk is a result of the combination of the flood hazard and the consequences of the flooding. There are a number of factors that can affect flood risk. These factors can be grouped into the four broad categories of:

- Flood behaviour;
- Topography;
- Population at risk;
- Emergency management.

Table 3.1 identifies various factors in these categories.

Table 3.1 Major factors affecting flood risk

Flood behaviour	Topography	Population at risk	Emergency management
Severity Depth Velocity Rate of rise Duration	Evacuation routes Islands Presence of flood defences	Number of people Number of houses and other assets Type of land use Flood awareness	Flood forecasting Flood warning Flood response plans Evacuation plans Recovery plans

People being evacuated to safety in Mozambique in 2000.

The severity or size of a flood is generally the principal determinant of hazard. Not only does it affect aspects of flooding behaviour that individually influence hazard, for example depths, velocities, rates of rise, it also determines the number of people at risk.

3.2 DEGREE OF FLOOD RISK

The degree of risk and social disruption varies with the size of the population living in the floodplain or relying on it for their livelihood. The larger the population within the floodplain the greater the flood risk.

An analysis of the consequences of flooding considers the population and structures at risk within the flood prone area. The analysis may evaluate consequences of flooding in terms of the following:

- **Displacement and rescue.** Areas where the population will be displaced owing to the extent of the flooding and also possibly require rescuing;
- **Livelihoods.** Areas where there is an impact on people's livelihoods for example as a result of crops being destroyed;
- **Damage to houses and social infrastructure** (for example clinics and schools). The types of building in the floodplain should be established. For example many houses in southern Africa that are constructed from traditional materials will be more vulnerable to damage by floodwaters than buildings constructed from concrete.
- **Access to food and health care.** Damage to important infrastructure such as roads and railways (which will affect people's access to markets and the relief effort), and water supply, electricity supply and sewerage infrastructure that could lead to the spread of disease.

People crossing a river where a bridge was washed out in the Chapananga area of Malawi.

A vulnerability analysis, that identifies the population at greatest risk from flooding, can also be used to identify the emergency responses that may be required, including the need for temporary shelters and evacuation requirements. The analysis is also valuable for making a decision on the level of flood protection. The decision is based on knowledge of the cost effectiveness of various options.

3.3 THE PRODUCTION OF FLOOD RISK MAPS

Once information about the flood hazard and the communities at risk has been gathered the challenges are to present that information in useful and coherent ways and to overlay the physical flood extents with the vulnerable areas.

The following are required to produce national flood risk maps:

Flooding near Xai Xai in Mozambique in 2000.

- **Flood hazard maps.** These maps are developed using the methods described in Section 2.1;
- **Vulnerability maps.** These maps show the location, type and number of buildings, people, areas of crops and important infrastructure that are at risk from flooding.

The **flood risk maps** are produced by overlaying the flood hazard and vulnerability maps. Figure 3.1 shows the method by which flood risk maps at a national level should be produced and used. At a national level the maps should be produced at an appropriate scale for presentation to the public. For wide floodplains often 1:100,000 or 1:250,000 is the most appropriate scale. However, for smaller watercourses a smaller scale may be more appropriate. For example in the UK national flood maps are available at a scale of 1:25,000. An example of a flood risk map for the Limpopo River catchment in Mozambique is shown in Figure 3.2.

Flood risk may be quantified in order to describe the flood risk in a country. Possible simple methods include:

Flooding in the city of Xai Xai in Mozambique in 2000.

- Number of cities/towns/villages in the flood hazard area (with population estimates);
- Number of properties in flood hazard area;
- As above, but divided into different parts of the country to identify in which areas the greatest flood risk exists.

More sophisticated methods are available involving the use of a range of flood magnitudes, population census data and economic damage data. The format in which the flood risk maps also needs to be considered. There are two primary formats, these are:

- Hard copies, for example paper drawings or posters;
- Digital formats.

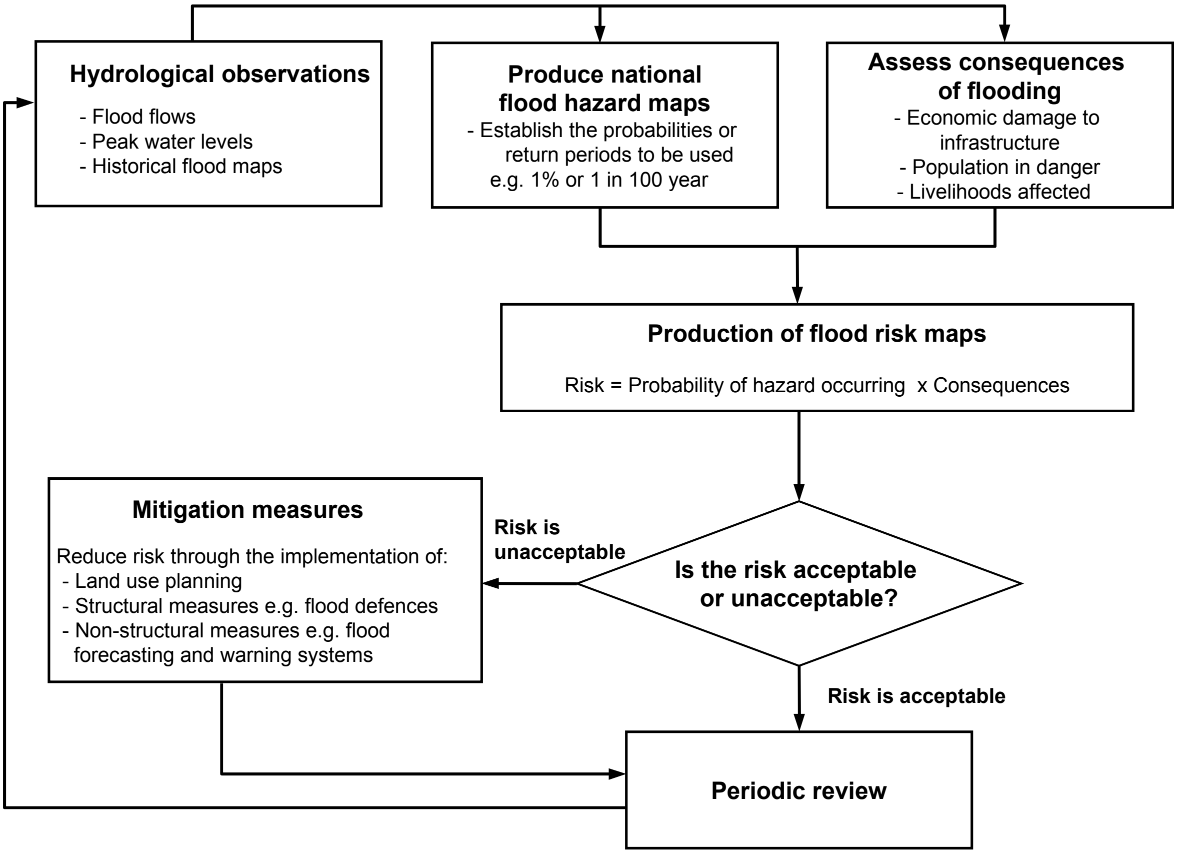
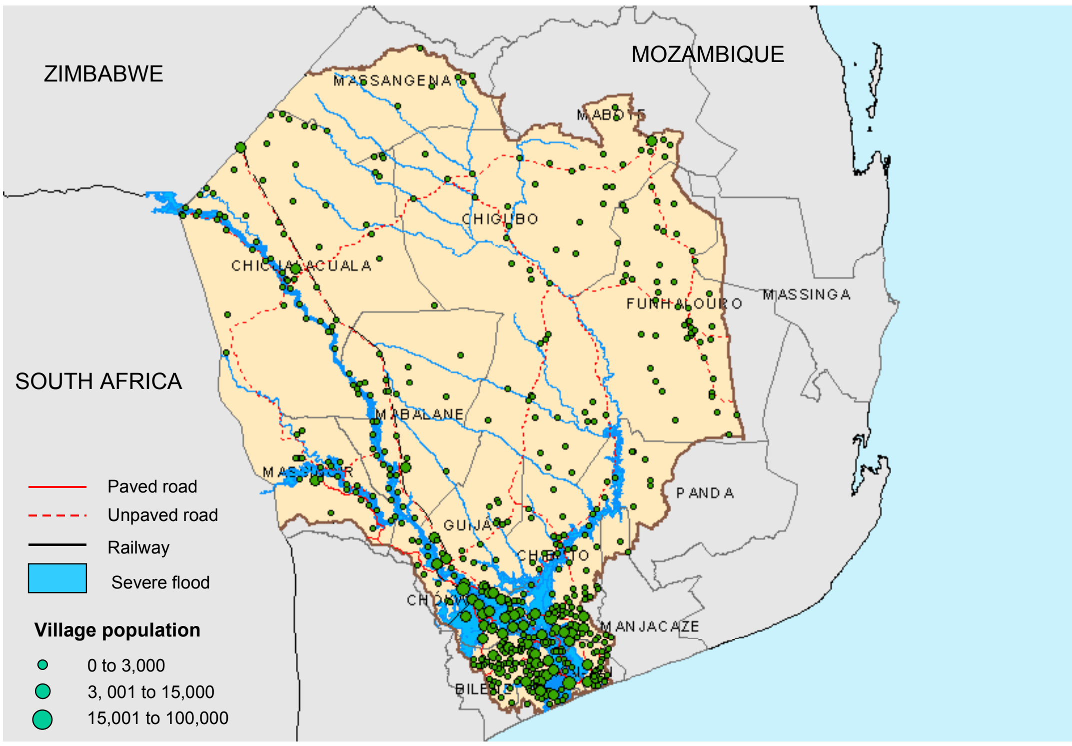


Figure 3.1 Flow chart for undertaking a national flood risk assessment



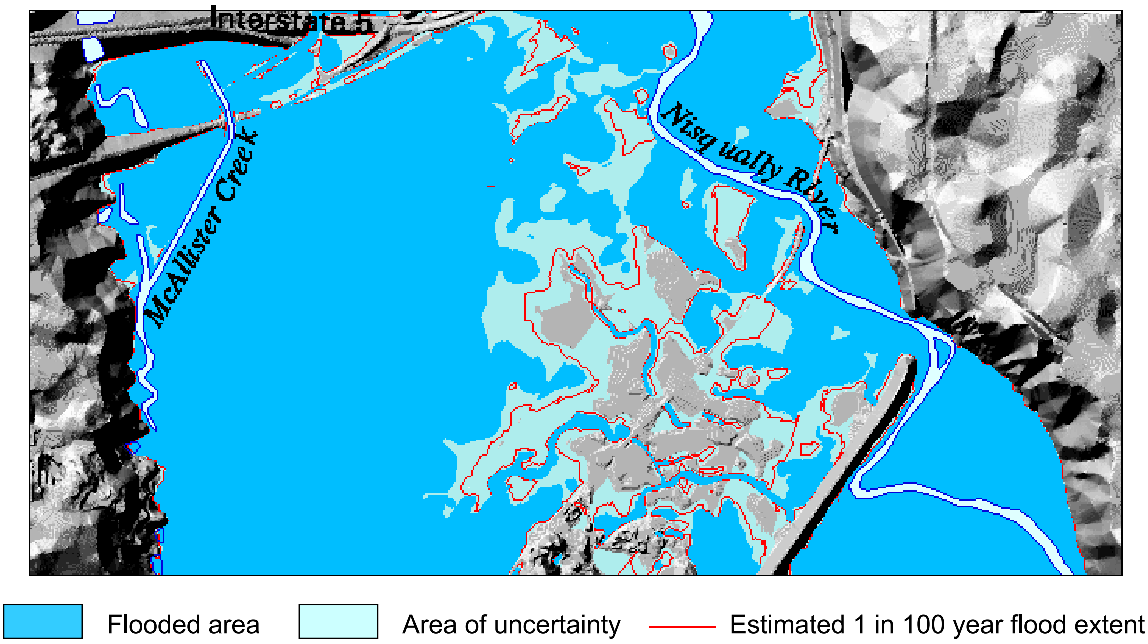
(Source: Reference 8)

Figure 3.2 Example of a flood risk map for the Limpopo River catchment in Mozambique

In the USA the Federal Emergency Management Agency (FEMA) has a responsibility under the National Flood Insurance Act 1968, to identify flood hazards nationwide, to publish and to update flood hazard information. Over the last 20 years FEMA has produced over 90,000 flood hazard maps covering some 19,000 communities representing approximately 150,000 square miles of floodplain. About 75% of the flood hazard maps are over 10 years old. In 2003 US$150 million was appropriated for flood hazard map modernisation including the conversion of paper maps to digital format (Reference 9).

National flood risk maps are commonly made available in digital and hard copy formats. It should be noted that large-scale paper maps used to display inundation areas could be difficult to update, store and distribute. Digital flood maps produced with a GIS allow users to overlay additional digital information such as population at risk, roads, buildings, and other important facilities. This allows a quick assessment of the potential impacts of a given flood level. Map storage and distribution is also greatly simplified and paper maps can be printed at any scale.

Another advantage of using GIS is the ability to map areas along the periphery of the inundated area where uncertainty in the water levels or land elevations translates into uncertainty about the extent of the flood. In a GIS it is a simple matter to adjust the flood elevation data by estimates of uncertainty, thereby delineating the areas where there may be less confidence that flooding will occur as shown in Figure 3.3.



(Source: Reference 9)

Figure 3.3 Flood map for the Nisqually River in the USA showing areas of uncertainty in the flood extent

4. DISSEMINATION OF FLOOD MAPS

The dissemination of national flood risk maps is crucial to the understanding of flood risk at a national level. Flood risk maps should be disseminated to the following:

- Water management organisations at a national and regional level;
- Disaster management organisations;
- Local and central government.

If possible the relevant flood maps should be distributed to schools and clinics in areas that have the potential to flood. Flood maps should also be made available via the internet. It is also important to address questions such as:

- What is a flood hazard and flood risk map?
- What do the flood risk and flood hazard maps show?
- How has the likelihood of flooding been calculated?
- What are the uncertainties in the flood map?

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