Flood and landslide warning systems

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Abstract

Flood and landslide warning systems play a key role in emergency preparedness. According to the great variation in meteorological, hydrological, geological, topographical and morphological settings in flood and landslide endangered zones and to the different infrastructures existing within these zones, many different systems exist throughout the world.

Different types of monitoring and warning systems have been in operation in Switzerland for many years. In the framework of the International Decade for Natural Disaster Reduction (IDNDR) and in close co-operation with the World Meteorological Organization (WMO), which has the international leadership in this field, these activities have been reinforced.

Case studies of some selected flood and landslide warning systems which are in operational use in Switzerland, are briefly described in the paper. Included are:

- A discharge forecast system for a large basin based on quantitative rainfall forecasts and rainfall-runoff modeling;
- A flood warning system based on automatic water level and discharge measurements;
- A system of forecasting the inflow in a regulated lake with the aim of pre-emptying the lake to gain flood-retention volume;
- A warning system indicating the failure of the dam of an artificial reservoir;
- A monitoring and warning system in a narrow alpine valley endangered by massive rockfalls (network of geodetic, meteorological and seismic stations).

The effectiveness of these systems will then be used to discuss general problems associated with the implementation and operation of warning systems related to "data collection", "forecast", "warning dissemination", "co-ordination", "land-use planning" and "responsibilities" in a decentralised country where disaster prevention and management are mainly in the hands of regional authorities.

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1. FLOOD WARNING SYSTEMS

Flood warning systems play a key role in emergency preparedness. According both to the great variety in meteorological, hydrological, geological, topographical and morphological settings in flood endangered zones, and to the different infrastructures available in these zones, many different systems exist all around the world. Floods can be caused by heavy rains, storm surges, a combination of both, the damming up and release of water initiated by a landslide or a glacier burst, as well as by human impact due to a failing of hydraulic structures, e.g. river dikes and reservoirs.

A comprehensive flood warning system includes sub-systems such as data collection and transmission, the calculation of forecasts, the evaluation of this information for decision-making and action, the warning dissemination, and the carrying out of measures (cf Figure 1). Based on cost-benefit evaluations, these sub-systems are to be developed by considering local conditions and by establishing the warning system's objectives.

Since such warning systems represent but one component of flood protection, they have to be considered as an integral part of a comprehensive flood protection concept embracing flood mitigation, emergency preparedness, and disaster management. Structural engineering measures and non-structural interventions are central to flood mitigation whereas active flood protection measures mainly focus on water-control structures such as the widening, deepening, construction or diking of river beds, protecting river banks and bottom, retarding flood peaks (artificial flood retention reservoirs, flooding of special areas, storage in natural lakes), the construction of flood diversion structures, by-pass flood ways, drainage evacuation systems, and reforestation.

Non-structural measures cover passive flood protection, for example the selection of danger- and protection zones, the proclamation of building bans and cultivation bans on plantations sensitive to floods, flood proofing of specific buildings, and also flood forecasting, early warning, regulation of reservoirs and lakes, preparedness education and training, hazard mapping, public awareness programmes and legal frameworks for disaster management systems. The management of observation systems, the operation and maintenance of warning systems, preparedness training and emergency repair are significant within a reliable emergency preparedness. For disaster management emphasis is put on questions of communication, adequate transport, feeding, relief supply depots, sheltering, flood fighting equipment and techniques, and repairs - the whole range of measures, however, being relevant to social benefit and cost-benefit analysis.

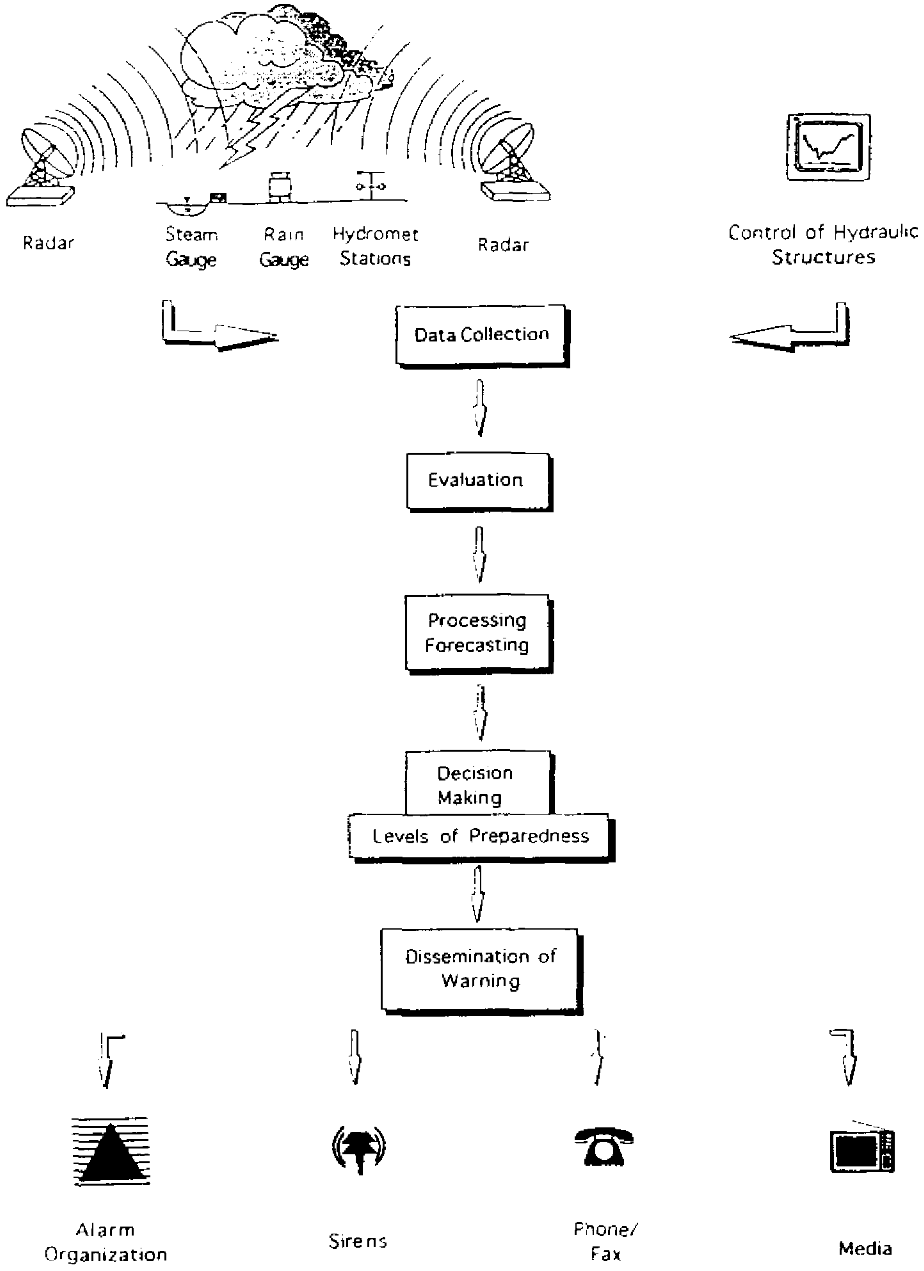

Figure 1 - Organization of a flood warning system

2. EXAMPLES OF FLOOD WARNING SYSTEMS IN SWITZERLAND

Switzerland, situated in Central Europe and covering a surface of about 41,300 km^2, is a mountainous country with most of its area located in the Alps. Geologically, topographically and hydrologically, Switzerland comprises manyfold characteristics. Due to great differences in soil types, land use, and climate within a small area, there are considerable variations in the quantity and distribution of precipitation as well as a great number of different runoff regime types. From 1901 to 1980, the mean annual values of the water balance components of Switzerland are the following: precipitation 1456 mm, runoff 978 mm, evaporation 484 mm, and the change in water reserves (lakes, reservoirs, glaciers, groundwater) -6mm. In the northern part of the country, the maximum values are significantly lower than in the southern part. Flood discharge varies very widely in neighbouring hydrological basins and causes great damage per year, e.g. in 1987 over 2 billion dollars.

The Alps as a tertiary chain of mountains mainly consist of crystalline and sedimentary rocks including a wide range of different lithologies, whereas the Swiss midlands mainly cover tertiary layers which are deposits of early alpine erosion, and of a sequence of deposits of ancient seas and lakes. The northernmost geological region is formed by limestone rocks. The main part of the flood problems originate in the Alps.

Switzerland has a very dense federal observation network of more than 2 stations per 100 km^2, providing measurements of both water level and runoff. A great number of the stations are equiped with automatic teletransmitters for water level control and flood warning. The meteorological service covers a total of 780 stations measuring climate parameters, a storm warning network of 29 stations and 3 rainfall radars. The snow and avalanche detection network is composed of 74 stations with daily measurements and 33 stations with a reduced programme. These data allow a precise forecasting of avalanche and snow conditions in the Alps. Since 1880, more than 120 glaciers have been observed with respect to their variation in length and volume, and particular attention is given to the variation in the permafrost belt due to possible climate change. The health of the forests is essential in our country; a monitoring programme by means of several campaigns of observation is therefore carried out every year. The Swiss seismological survey comprises 22 stations with automatic teletransmitters. A network of 33 strong-motions instruments, mainly around the major dams, has been set up across the country.

2.1 Flood warning based upon operational real-time forecasting of. discharge

For the Rhine area with its 34,500 km^2, the short-term flow forecasting is calculated by means of a detailed river-basin model. The forecasting period covers 64 hours at most; prediction includes hourly mean values of the water level recorder readings, and the discharge from 14 sub-basins as well as from Rheinfelden. Since a main part of the area is located in either the Alps and their foothills (cf Figure 2), the build-up and melting of the snow cover is the deciding factor in discharge. With all but one of the larger lakes of the alpine border being subject to lake control, the relevant regulations are therefore tied to the forecasting system. Operational forecasting relies on inputs of the following variables measured every morning at 7.30 am:

- 2-hourly instantaneous values of about 30 automatic water level recorders or discharge gauging stations;
- hourly precipitation totals of 42 automatic weather stations;
- 3 daily readings of air temperature and 2 daily readings of snow depths of 40 climatic stations.

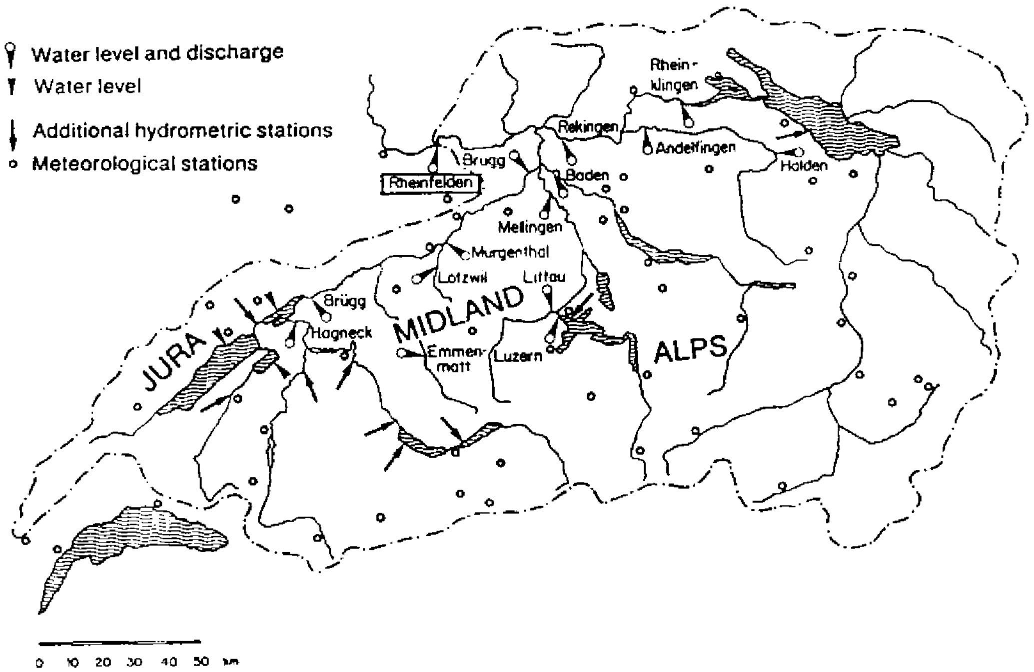

Figure 2 - Observation network of the forecast system

A 3-day-forecasting period is indispensibly based on quantitative precipitation- and temperature forecasting to bridge the short travel time of the flood waves (10 to 12 hours between the highest-lying lakes and Rheinfelden).

An individual discharge prediction is worked out for each of the 14 sub-basins starting with the headwaters. As input data the predicted discharge of each sub-basin is merged into the forecasting model of the subsequent downstream station, and compiled with the meteorological values of the intermediate basin (cf Figure 3). The models are based on 1-hour steps in view of the minor size of the sub-basin and the relevant reaction- and travel time.

The concept model is based on the following 5 sub-models:

- Sub-model 1: Interpolation of hourly rainfall in space and time
- Sub-model 2: Determination of snow melt in alpine regions
- Sub-model 3: Non-linear rainfall-runoff of the sub-basins
- Sub-model 4: Non-linear retention of the larger lakes
- Sub-model 5: Linear flood routing in rivers.

The parameters applied to the concept model were established from the measured data.

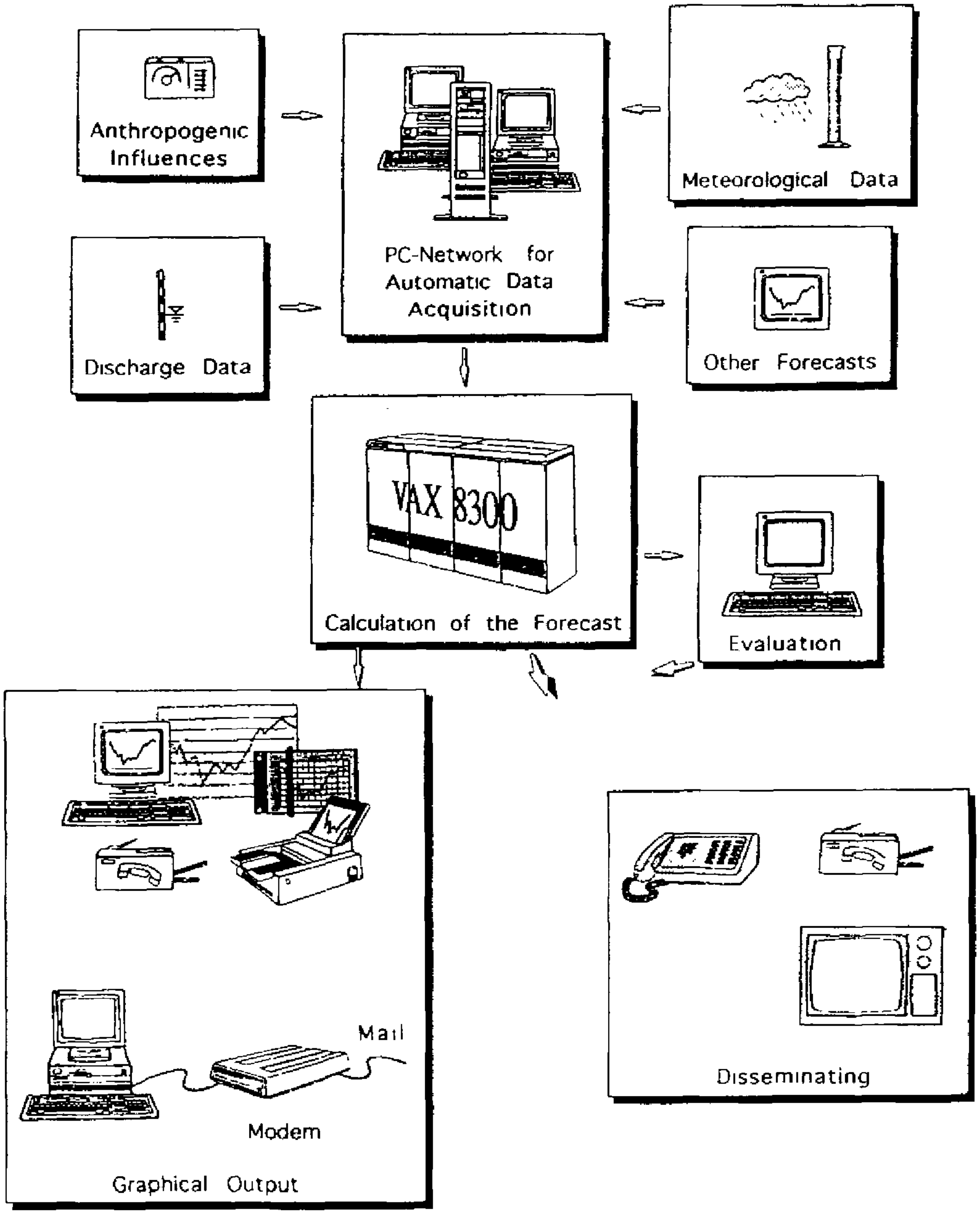

Figure 3: Organization of the forecast

Revealed by long-term experience in operational management, problems of either data flow, software or hardware have hardly ever occurred, due to the fact that the system remains constantly ready and the operators are close to the hydrological events. Not only does the model represent one component of flood warning and equally serves the organisations in charge of flood protection as an essential means of decision-taking, but helps broaden the temporal-spatial information gained from the gauging network of the flood warning stations (cf subsequent chapter). Apart from flood warning, the model also helps the water power agencies, the control of lakes, the water supply agencies, navigation and public information.

2.2 Flood warning based on automatic water level and on discharge measurements

In spite of long-term experience and integration of the latest technologies, difficulties in precipitation forecasting in the Alps, and the complex heterogeneity of hydrological processes impair Switzerland's establishing totaly reliable predictions. For this reason, the Swiss National Hydrological and Geological Survey maintains in addition short-term warning systems. These warning systems are based on gaugings of both water level and discharge at selected points (cf Figure 4). In case the measured water level exceeds a certain predetermined fixed limit, a flood warning will be given by means of automatic teletransmitters. The teletransmitter automatically calls the responsible authority. All the telephone numbers of the persons to be warned must therefore be known, in order to be incorporated into the teletransmitter. The persons involved are called in a given order by the teletransmitter. Once the connection has been established, the teletransmitter sounds the alarm, and receipt for the warning has to be given by the receiver. If a connection fails at first call, the transmitter calls the subscriber again later, four times at most.

In case of continuously rising water level, flood- or catastrophe warning is given only once. A second warning, however, is given when the water level meets the flood level again after having subsided to a previously determined lower level.

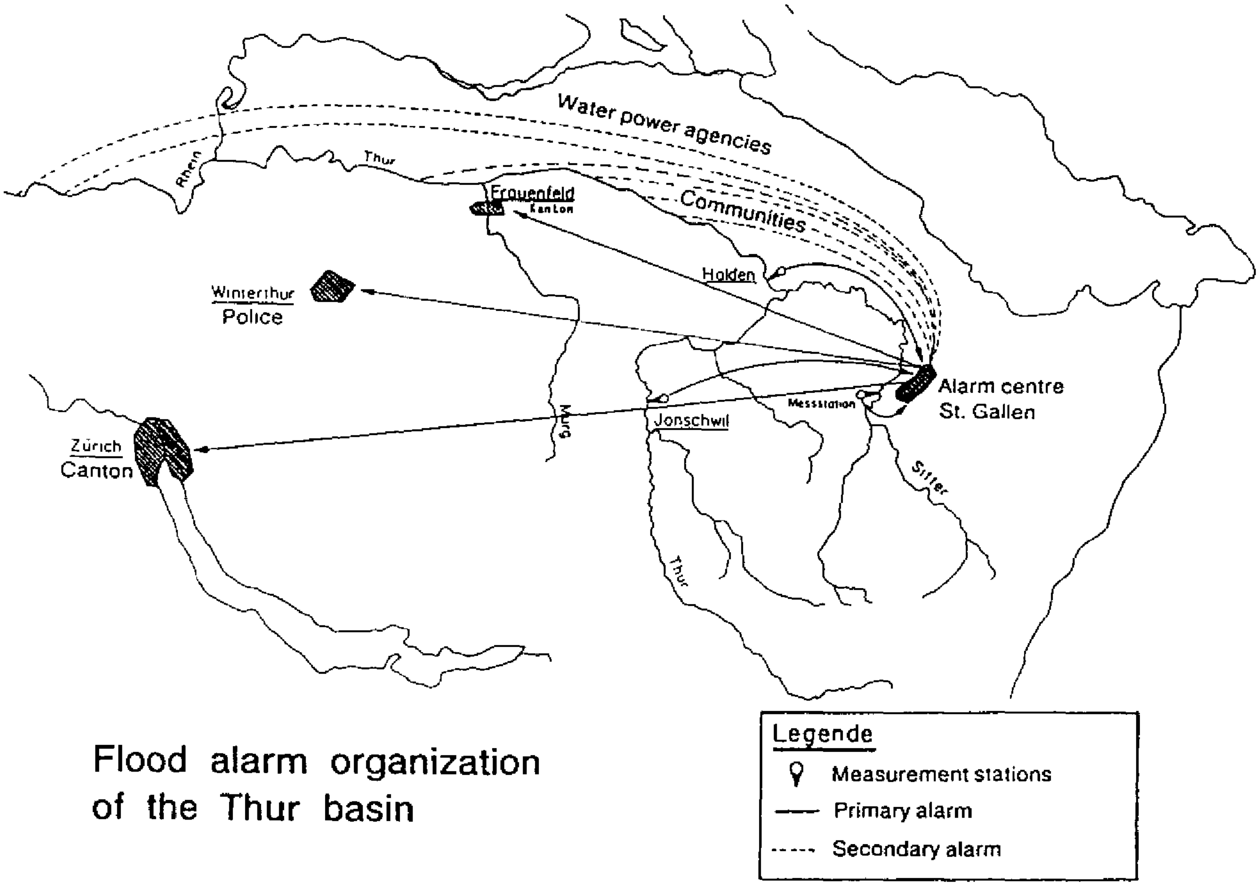

Figure 4 - Example of an alarm dissemination system

Great attention is shifted to the reliability in operating the flood warning system, a reliability that is guaranteed by periodical service and control achieved by either the observers or the specialised staff of the Hydrological Survey. Test warnings are also performed by collaborators of the Survey. Additionally, the reliability of the system is guaranteed by the automatic control of the installations. In case of mechanical failure, a disturbance warning is given, addressing the place of the observer. He immediately takes charge of the faulty transmitter and calls the subscribers if necessary, trying at the same time to repair the fault according to special instructions. In case he does not succeed, repair is carried out by a specialist of the Survey.

In accordance with the regulations, the warning is transmitted to the persons involved. The authority in charge has the possibility of watching the development of discharge in the upper course of the river. By means of additional teletransmitters for water level control, and assisted by flood routing models, it is possible to calculate the progression of the flood in the lower course of the river and to observe the discharge of other rivers within the basin area. Additionally, the option of a temporal and spatial extrapolation is given, fostered by the rainfall-runoff forecasting model.

2.3 Flood warning system in case of failure of a reservoir dam

Switzerland is equipped with about 50 reservoirs for hydro-electric power production, each containing 10 to 400 million m^3 of water. In mountainous regions the density ranges from 2 to 3 reservoirs per 1000 km^2. Obviously enough, Switzerland with a proportionately dense population pays great attention to the safety of its reservoirs, including the appropriate dams.

In cases of damage and floods beneath the dams and in spite of precautionary measures, warning systems have been established to be on the safe side. The so-called water alarm is given if the dam connected to a full or partly filled reservoir suddenly breaks, threatens to break, or if there is an imminent danger of a flooded dam. For this reason, the reservoirs are permanently observed at varied intensity, depending on the stand-by degree (normal to crisis situation). The specifications of the responsible authorities are therefore very precisely defined, and stand-by duty is checked within regular training exercise.

Flood warning is organised as follows:

With the aid of a local warning system, the alarm is sounded in the areas threatened to be reached by the flood wave within less than two hours. The alarm is given by low-pitched sirens spread throughout the area. They can easily be disconnected by means of a very reliable transmission system. Once the alarm has been given, the affected population has to take immediate action in carrying out evacuation of the zones previously mapped. It is taken for granted that the population was made aware in a timely fashion of the flood wave likely to occur, and of the escape routes. For this purpose, leaflets are published including detailed information on the scale of flooding, means of giving the alarm and advisable behaviour in case of emergency.

The area likely to be reached by the flood wave beyond a period of two hours at the earliest will be informed by the so-called long distance alarm, based on a special alarm organisation (cf Figure 5).

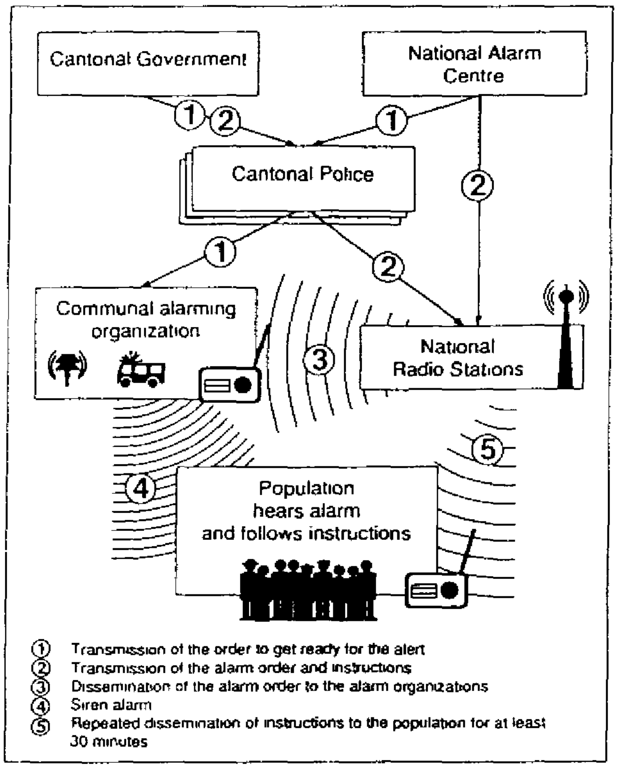

Figure 5: Alarm of the population in case of a flood caused by a failure of a dam (outside of the 2-hours zone)
Source: Info Federal Office of Civil Defence

3. SELECTED PROBLEMS IN RELATION TO FLOOD WARNING

A fundamental difficulty in flood warning is the timely availability of reliable meteorological and hydrological information. Although nowadays advanced technologies in automatic data capture are at hand, a possible failure of either the measuring instruments or the transmission infrastructure during extreme disaster events on the one hand, the data transmission impaired or stopped by disturbing effects of the atmosphere on the other, have to be faced. Frequently, disasters are attended by power supply interruption. Transmission lines are destroyed or gauging stations washed away. In future, emphasis has therefore increasingly to be put on the building up of network-independent transmission infrastructures.

According to our experience, discharge prediction for mountainous regions above all has to face the following central problems:

- **Input data**: given a sufficiently dense information network, input data do not normally result in significant errors; paucity of data, however, can favour false prediction The spatial recording of precipitation is an additional problem area causing difficulties.

- **Meteorological forecasting**: discharge prediction valid for a period beyond 6 to 12 hours is heavily dependent on the quality of meteorological forecasting. In case limited reaction time of the catchment area requires quantitative precipitation forecasting, the quality of discharge prediction will largely be determined by this forecasting.

- **Modelling**: a wide range of models serves today's hydrological modelling. Apart from very extreme events, reality and background to send warnings in mid-size basins can mostly be reproduced with sufficient accuracy. Snow melt events combined with rain and strong winds, however, present great difficulties in discharge modelling.

Alarm reliability is an additional problem to be faced. Prediction should be accurate enough to rule out false alarms in order not to impair either acceptance or efficiency of the warning. Additionally, it is to be observed that not only is the intensity of precipitation and discharge often significant but the state of rivers and sediment transport also contributed to the damage.

The operating reliability of the warning systems is crucial. Apart from the sound functioning of the technical equipment, both the responsible authorities and the population have to undergo continual and realistic training exercises. Only in this way will the systems work in cases of disaster.

The impacts of storm events can very often be mitigated by an appreciable difference in applying appropriate preparatory measures, such as:

- **Computing and updating of available data**: the specific characteristics of each catchment are the clue to the shape of floods. According to the nature of flood, a variation of danger criteria will result for the channels, a fact that has to be analysed. Aspects such as snow situation, thunderstorm development, topography and soil cover significantly influence a flood event. Saturated with precipitation, a water-logged soil is by far more susceptible to erosion and slides - an aspect of vital importance to be equally considered with present and historical observations which should be analysed and evaluated by the authorities. The state of both the catchment and the channels plays a significant part in so far as non-balanced bed-load centres can lead to debris flows, whereas loose wood nearby channels is likely to block the channel flow. The precautionary construction of retaining measures can remove these difficulties. Observed faults producing a negative influence on the behaviour of bed-loads during a flood situation are to be rectified. The precautionary planning of security measures requires sound knowledge of the potential flood area, as well as of the endangered persons and infrastructures. The security of any means of communication is to be emphasized.

- **Aid in disaster management**: the choice of remedial actions is to be limited to measures apt to work in cases of disaster. Even cleverly thought out systems are of little help unless they give proof of their viability under the worst conditions.

Questions on an optimal and well-timed protection of endangered objects are to be cleared up. Since flood waves often proceed quickly, only very simple mobile and stand-by countermeasures stand a chance of protecting endangered objects. If need be, temporary blocking measures are to be taken within the catchment of concern. The availability of both building machinery and construction equipment being central to disaster management, the latter is to be kept at hand during critical times. Settlement areas affected by floods can easily be cut off from the outside world, and the decentralized storage of emergency material is therefore advisable.

Rescue, transport and welfare of injured persons are of vital importance and have to be included in the concept. The areas of competence and duty have to be specified and practiced. Rescue work is a matter of priority immediately after the event; it can, however, be impaired by bad weather conditions that are likely to hinder the persons involved in the operation. Thus weather observation and alarm within critical weather phases have to be ensured.