and their contents moved up to higher floors in time of flood and that the construction materials are able to withstand immersion without damage. Wet floodproofed buildings must be able to withstand the drag and scour effects of the flood waters, just the same as dry floodproofed buildings.

Floodproofing is sometimes regarded as a "poor man's solution" to flood problems in that it provides a low level of protection when more satisfactory solutions are not available. It can, nevertheless, be valuable in this role. It is also valuable when normal flood defences fail either because the flood exceeds the design level or because the defences have not been properly maintained. It is for this reason that some authorities require all properties in the flood plain, even those behind a dyke, to be floodproofed. The infrastructure systems such as the electricity and water supplies, the telephone system and the sewer system must always be floodproofed. Modern society is so dependent on these systems that they must be designed and built to resist floods.

Soil and water conservation

As noted previously, most human changes in a catchment tend to reduce infiltration and increase runoff and erosion. The aim of soil and water conservation is to reverse this tendency and to preserve soil and water resources by good land-use practices, which also help reduce floods. Overland flow, resulting from poor infiltration, gives rise to rapid increases in river flows (i.e. floods) and to soil erosion. Good land-use practices enhance infiltration, which reduces overland flow and erosion and by delaying the movement of water to the stream reduces flood peaks. The infiltrated water will appear in the stream much later, increasing dry weather flow so that more water is available when it is needed. The diagram, figure 5.1, summarizes the methods used.

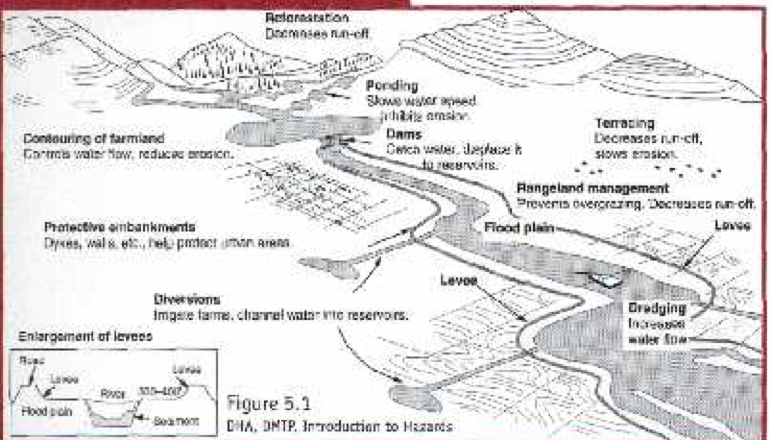

Figure 5.1
DHA, DMTP. Introduction to Hazards

Reforestation decreases runoff and stabilizes soils. In many cases, excessive deforestation has produced bare soils, extremely prone to erosion, with poor absorptive capacity and that are often of little value for agriculture. Replanting the forest is a long-term measure, requiring some decades to become fully effective. Existing forests need careful management if they are to continue to provide protection. Over-mature forests need to be rejuvenated by planting new trees. Herbivorous animals, such as deer, need to be controlled to protect the forest. Cattle grazing in forest pastures can be even more damaging than deer because they eat much more. Grazing therefore needs to be carefully controlled. For commercial reasons, large areas are often planted with a single, fast-growing species of tree. These monocultures are especially at risk from disease, so a healthy mix of species is needed in any forest.

Reforestation is not always possible and when the land is used for agriculture or grazing, sensitive land-use practices need to be applied. Steeper land has to be terraced. This not only provides flat areas for growing crops, but also makes more water infiltrate, reducing floods and adding to water resources. Where terracing is not possible, techniques such as contour ploughing must be used. If the plough furrows run downhill, they provide a ready path for water, leading to increased

Cleaning tropical rainforest
WWF. S. Zalveski

and more rapid runoff and more erosion. Ploughing along the contour obstructs the flow of water, which can then infiltrate more easily. Overgrazing removes vegetation, leaving the soil bare leading to increased erosion and runoff. Proper range-land management is needed to restrict stock numbers to the carrying capacity of the soil.

When runoff does form, it can be retarded by small ponds or farm dams. These are low earth banks bulldozed across gullies to catch the surface runoff. The water so trapped can be used on the farm for stock watering or for minor irrigation and the presence of the dam slows the runoff, reducing flood peaks, inhibiting erosion and enhancing infiltration.

Note that in all of these the soil and the water are considered together and both benefit from these measures. The promotion of a good deep soil profile, with a healthy cover of vegetation, whether trees, crops or grass, can only reduce flooding and increase flows in dry periods, thus making the water more readily available for human use.

Flood forecasting

Hydrological models, described in chapter 2, can be used to forecast future river flows, giving the population time to take precautions against floods. During a flood the information provided by the forecasts is used for planning the flood-fighting. The forecasts will indicate when and where dyke systems are likely to be overwhelmed, enabling resources to be concentrated in critical areas. The use of forecasts to plan the operation of flood control reservoirs was discussed in chapter 4.

The hydrological models used for forecasting use measurements of the rainfall over the catchment and produce estimates of future river flows. The rainfall data have to be particularly detailed because the rate of rainfall varies greatly from time to time and from place to place. Usually, a network of telemetering rain-gauges is used to collect the data automatically and to transmit it to a central site, either by land-line or by radio. Radar is also used to estimate the rainfall over an area. The radar beam is reflected off raindrops and the intensity of the reflection gives a measure of the rate of rainfall. Unfortunately, the reflection also depends on other factors, including the size of the raindrops, and radar rainfall measurements have to be continuously calibrated by comparison with the telemetering rain-gauge network. Radar is capable of giving a detailed picture of the variation of rainfall over an area and successive radar images can be combined to show the movement of the rainstorm. Computer analyses of the movement can be used to provide a short-term forecast (a few hours ahead) of the rainfall.

Once all the data have been received at the forecasting centre they are checked and can be displayed and used to run the forecasting model. The results of the model calculations will give forecast flows and levels at the selected sites for a short period ahead. This can only be a short period because the direct runoff, by far the largest component of the flood, will have left the catchment in a few hours and the time this takes, called the «time of concentration» of the

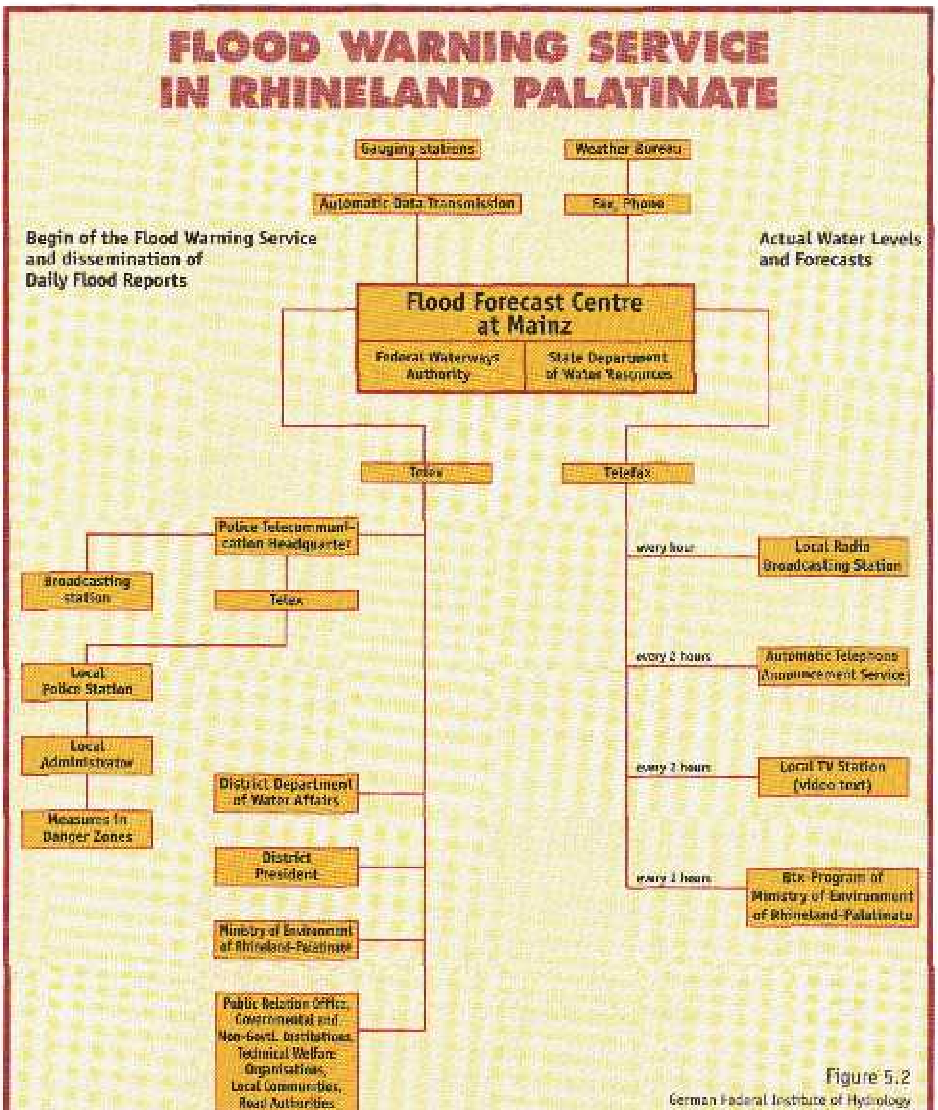

Figure 5.2
German Federal Institute of Hydrology

catchment is the upper limit for forecasts based on current rainfall data. The time of concentration is longer for larger, flatter catchments and also depends on soil types and land use. Typical values would range from several hours to a few days.

The forecast period can only be extended beyond the time of concentration if some estimate of future rainfall, a so-called quantitative precipitation forecast (QPF), is available. QPF methods are being developed using data from radar and satellite observations which can be analysed using a limited area meteorological model, which gives more detailed coverage of the limited area than the general weather forecasting models. These QPF methods are starting to enter operational service, but as they are very advanced techniques it will be some time before they are in general use throughout the world. In the absence of QPF the hydrological forecaster can only imagine some future rainfall scenarios and calculate model results based on these. Typically the forecaster might calculate the future flows if the rain were to stop, which gives a lower limit to future flows, or if it were to continue at the same rate for the next few hours. The skill and experience of the forecaster become important in these circumstances.

Any forecast should be compared with later readings of river levels to check its accuracy. The internal model parameters can then be adjusted to correct the forecast. This procedure, termed model updating, is increasingly being used to keep the model on track in its simulation of the behaviour of the catchment. Early forecasting systems, including manual systems that predated the use of computers, were run on an event basis, that is to say only during floods, and gave forecasts for one or two critical points in the river system. Modern systems are capable of providing forecasts at a large number of points and are run continuously and are thus useful for other water resource management functions. The forecast system might be run once a day to keep the model updated during normal flow periods and more frequently once an emergency occurs.

Once the forecast is made it must be put into terms that the layman can appreciate and then disseminated to those that need it and can act upon it, including the civil authorities, the police, the media and the general public. The diagram show the forecast dissemination network of flood forecasts on the Rhine at Mainz, figure 5.2 and the Australian meteorological hydrological forecasting system, figure 5.3. Note in both cases, the great emphasis placed on

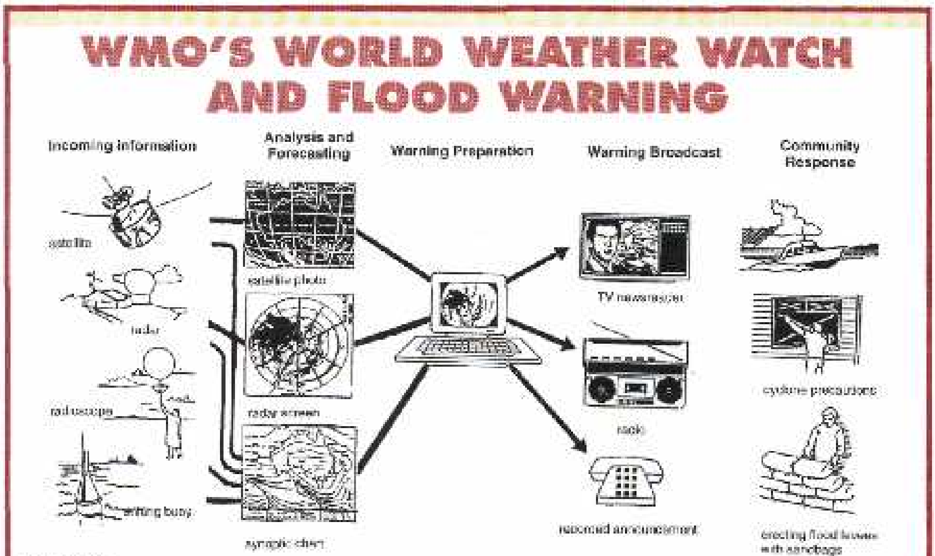

Figure 5.3

DHA, DMTP, Introduction to Hazards

the dissemination of forecasts. The forecast system can be considered in terms of information flow from the collection of data to the dissemination to the end-users. The design of the complete forecasting system needs to be considered starting from the point of view of the end-users. The design should identify these end-users and their requirements for forecasts in terms of the information to be provided at specific sites. It is only once these forecast requirements have been formulated and agreed by the users, that the technical people can start work to build the forecasting system.

The Yorkshire region of the United Kingdom Environment Agency operates a comprehensive flood forecasting system for protection of life and properties in its region. The rivers of Yorkshire, dominated by the River Ouse and its tributaries rising in the Pennines to the west and the North Yorkshire moors to the north, drain an area of 13,500 km^2. Snowmelt from the Pennines has been an important cause of flooding in the past and there is a risk of storm surges in the tidal reaches of the Ouse. In the region there are about 5,000 houses on unprotected flood plains and it has been estimated that the potential annual benefit of timely warnings exceeds £ 1 million (US$ 1.7 million). A flood in January 1982 caused extensive damage in two towns, York and Selby, with 800 properties flooded. In addition, 18,700 ha of farmland were flooded. The forecasting system was set up to meet a general forecast requirement for a four-hour warning of flooding on the middle and lower reaches of the main rivers. The forecasting system makes forecasts at some 115 points in the region and a total of 208 detailed forecast requirements, for flood and low-flow forecasts, was identified. Rainfall forecasts are necessary to provide flood forecasts in time in the upper reaches, but their importance diminishes in the lower reaches where the natural lag in the river system response makes forecasts more accurate and reliable. The hydrological portions of the system use the United Kingdom Institute of Hydrology River Flow Forecasting System (RFFS); a modular, generic modelling system that can combine different hydrological and hydraulic models with multiple data sources.

The Yorkshire forecasting centre receives information from an extensive telemetry network as well as radar and satellite data and results from numerical weather prediction models from the United Kingdom Meteorological Office. Input data and model results can be displayed graphically for the use of the forecasters and telexes and faxes for sending forecast results to the end-users can be generated on-line.

Monitoring the performance of flood forecasting systems

There are many individual elements in a flood forecasting system linked to one another like the links of a chain (see box). All links in the chain are necessary for issuing forecasts.

Countries participating in WMO's Tropical Cyclone Programme have been using a simple three-part points scoring system, based on this chain, to monitor the performance of their flood forecasting systems. The Management Overview of Flood Forecasting Systems (MOFFS) is designed to allow a flood forecasting system to be quickly described and monitored on a single sheet of paper. The aim is to highlight the weakest links in the chain for appropriate management action.

A standard form is used to assess for each link in the chain:

- **Minimum Requirement Points**
  The locally assessed minimum standard required to provide effective flood warnings.
- **Achievement Points**
  The level of performance actually achieved by the link in a particular flood event.
- **Deficit Points**
  Achievement Points minus Minimum Requirement Points.

Negative Deficit Points mean that the component in question has fallen below the standard judged necessary and management action is required to remedy this. An overall measure of the performance of the flood forecasting system in the flood event is obtained by summing all the negative Deficit Points and expressing them as a percentage of the total Minimum Requirement Points. The system operates in conjunction with a set of trigger levels which, when exceeded (or forecasted to be exceeded), would result in pre-specified actions such as calling out the emergency services. A lead time is associated with each trigger level and is the time required for effective dissemination of warnings and subsequent action (e.g. evacuation). The MOFFS manual, now in its third version, gives rules for deciding the Minimum Requirement Points and the Achievement Points.

LINKS IN THE CHAIN OF A FLOOD FORECASTING SYSTEM

Hydrometric Facilities:
- Meteorological Forecasts
- Satellite and Radar Data
- River Gauge Network
- Standard of River Gauges
- Standard of Main Forecast Site

Data Transmission and Processing
- Receipt of Meteorological Forecasts
- Receipt of Satellite and Radar Data
- Rainfall Data Transmission
- River Gauge Data Transmission
- Main Forecasting Site Transmission
- Data Forecasting Time Limit
- Model Type and Operation
- Flood Forecasting Centre Facilities

Issuing Forecasts and Warnings
- Reliability of Forecasts
- Dissemination to Next Users
- Dissemination to End-Users

The system is applied regularly by 13 countries in 25 river basins, ranging in size from 90 to over 100,000 km^2.