State-of-the-art Methods of Hydrological and Meteorological Data Acquisition Systems for Flood Forecasting

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[Editor's Note: The following is taken from a presentation made to participants of the 2nd High Level Consultative Meeting on Establishment of a Regional Flood Information System, held in Kathmandu, Nepal, March 2003. The examples refer to the products of only a few companies; they are intended only to illustrate the type of instruments available and do not imply any endorsement or recommendation on the part of the publisher or any other organisation involved in the preparation of this book.]

Abstract
Effective flood forecasting uses hydrological and meteorological data both as input to computer models that produce extended forecasts and as input to systems that provide instantaneous readings for specific sites and for aerial distribution. Advances in technology have reformed a previously antiquated system by introducing newer and more efficient data acquisition, storage, retrieval, and quick transmission systems. The basic meteorological data for flood forecasting are precipitation, accumulated precipitation, rate of precipitation (and spatial distribution), wind speed and direction, surface and upper air observation of the type and amount of cloud present, weather systems, and cyclone or depression position identification. The hydrological data required to determine flow condition in the channels are based on stage flow data (collected at appropriate time intervals), reservoir level measurements, and channel flow characteristics. Data acquisition can be in situ or remotely sensed. In situ meteorological data is obtained from an observation network of fixed sites; remotely sensed data is required in areas where it is not possible to establish such a network. There is a wide range of equipment available for hydrological and precipitation measurement at different levels of sophistication and cost. Detailed analysis is required before selecting the appropriate equipment for a specific purpose and situation.

Introduction

Hydrological and meteorological instruments provide the input needed to run a flood-forecasting model. Hydrometeorological data is obtained either from compact observation stations or from detailed observations of individual parameters, both of which are recorded either manually or automatically. Specific instruments measure both the meteorological and hydrological parameters and should have the following characteristics: 1) provide precision measurements; 2) be compatible with peripherals; and 3) have capabilities for sensitivity checks and/or error elimination.

An integrated network of hydrometeorological stations not only gives real-time observations but also provides the inputs that are essential for forecasting. The success of any hydrological and meteorological data acquisition system depends upon the reliability, the compatibility and the calibration of the data system in use. The most up-to-date technologies incorporate non-contact observational techniques in order to reduce human error and circumvent frequent servicing of equipment.

Meteorological Data Acquisition Systems

Previously, meteorological data input was primarily restricted to rainfall measurement at fixed points, i.e. observational data only. These were mainly manual observations, although there was also some mechanical self-recording equipment. Over the past few decades, substantial technological development has taken place and now meteorological data can be obtained by satellite based sensors, radar-based sensors, and ground-based remote sensors.

Satellite Data Acquisition Systems

The next generation meteorological satellites have extensive capabilities for high-resolution data. For example, satellites coordinated by the National Polar-orbiting Operational Environmental Satellite System (NPOESS) will carry advanced meteorological sensors with a resolution of 250 metres, four times finer than the current best available weather imagery. The polar orbiters are able to monitor the entire planet and provide data for long-range weather and climate forecasts. The programme is being developed in close cooperation with the meteorological community.

Doppler Radar System (S-Band 3GHz)

The newest Doppler weather radar systems (NEXRAD or Next Generation Radar) can measure both precipitation and wind. They can detect a rainfall centeroid and can follow its movement allowing the operator the possibility of following systems which can lead to cloudbursts and thus flash flooding in a river basin. NEXRAD has a hydrological range of 160 km and a meteorological range of 450 km. It can detect heavy rainfall systems that generate floods, and can do so even in rainfall areas that cross national boundaries. Its 3-D capabilities (Figure 1) can give the exact location of cloud top and its rainfall intensity. This system can also monitor the probable direction and movement of cyclones or depressions.

Precipitation Monitoring

In-situ precipitation monitoring is conducted with different types of precipitation gauges. These gauges measure rainfall and snow according to syphon, weighing or tipping bucket principles. For real-time forecasting it is important that the instrument has electrical signalling capacity, this both for real-time data transmission as well as for the measurement of precipitation rates and duration. Heating devices and heated equipment are available for measurement at sub zero temperatures. There is a large range of available equipment, some examples of more sophisticated instruments are given below. For ease of reference, the examples are drawn from the products of one company, but many others offer similar types of apparatus.

Rain Gauge Using the Weighing Principle with Integral Data Logger or Pulse Output Function

Rain gauges are available in which the weight of precipitation gathered in the collecting container is measured by an electronic weighing cell (resolution 0.01 mm / 0.01 inch). Different versions are available depending on the climatic requirements and areas of application (Figure 2). Beneath the defining ring of the measuring surface, the precipitation directly enters the collecting container. Thus liquid or solid precipitation can be measured immediately, and the time delays customarily associated with tipping buckets, filter screens, or inlet tubing are avoided. A high accuracy is obtained by an automatic self-calibration system, which uses an internal calibration weight. The use of frictionless link-joint elements guarantees a high long-term stability and maintenance-

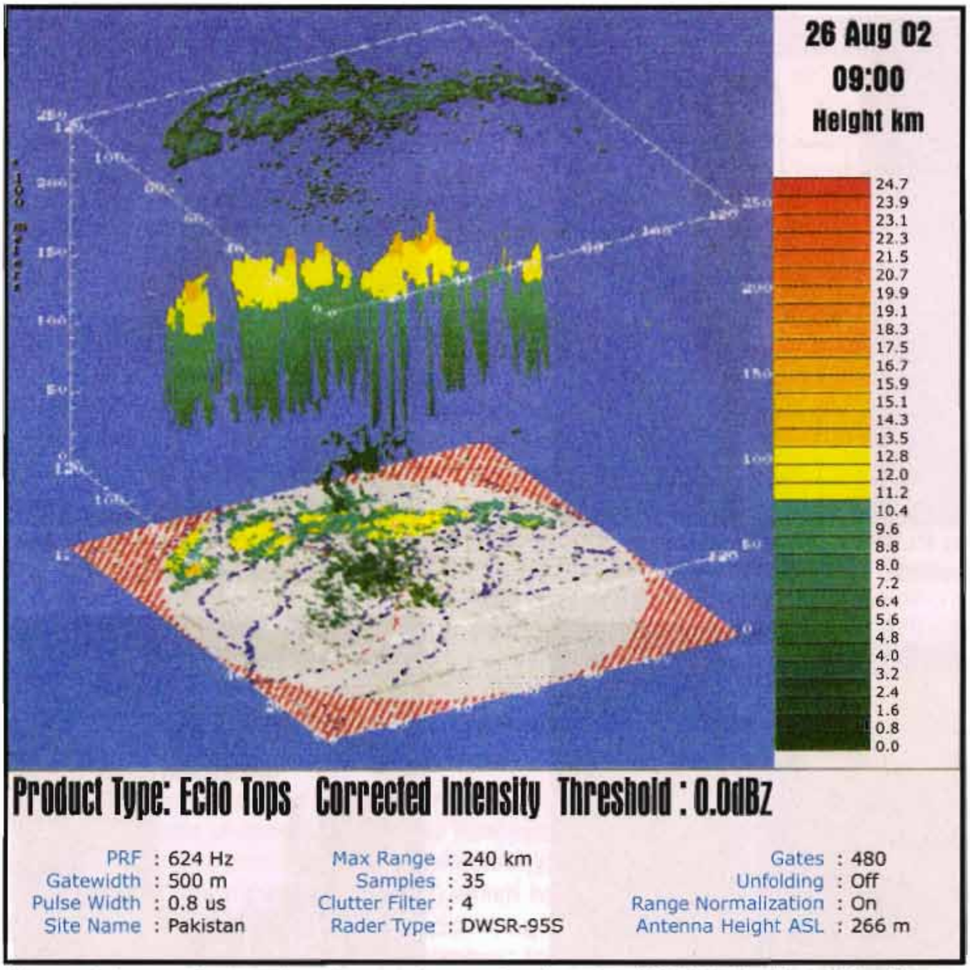


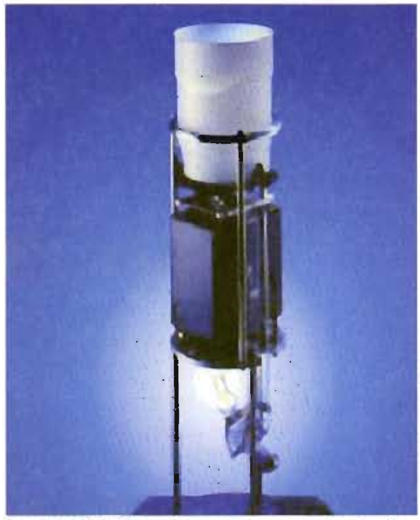
Figure 1: Image from a doppler weather radar detector (NEXRAD). The Echo Tops image shows the maximum height of precipitation echoes. NEXRAD can be used to identify the probable direction of movement of a cyclone or depression.

free operation. Due to the measuring principle and design, the unit is ideally suitable for both, low and high precipitation rates and intensities. In addition, evaporation can be determined on the basis of the recorded precipitation event.

The processor-controlled evaluation unit supplies a temperature-compensated and linearised output signal, which is available either directly as a pulse output or in the integrated data logger. The measuring system consists of a maintenance free electronic loadcell, amplifier, and AD-converter. The loadcell is hermetically sealed against dust, atmospheric pressure, and similar. To achieve high accuracy, a specific mechanical balance construction is used. Accuracy in the measurement of precipitation is guaranteed by eliminating wind effects using an integrated software filter algorithm. The software also automatically compensates for any temperature effects.

Precipitation measurement at subzero temperatures has special requirements. Solid precipitation must be melted before measuring and in a normal rain gauge collected water could freeze and possibly destroy the instrument. If a normal instrument is

a) PLUVIO 250 mm standard version



b) PLUVIO 250 mm incl. automatic drain-off system (siphon)

c) PLUVIO 250 mm extended version with automatic drain-off system

d) PLUVIO 1000 mm with collecting-ring heating device

Figure 2: Different models of a rain gauge with integrated data logger (Source: OTT MESSTECHNIK, Germany)

equipped with an electrical heating device and a snow cross (extra cost), recording is still possible at light frost temperatures. Models with a double-walled case or with a heating device can be used at temperatures as low as -25°C. The heating not only melts solid precipitation, but also protects the siphon and the collecting can from freezing. For hydrometric measurements, the unavoidable minimal evaporation losses and slight retardation between the falling and the recording times is of minor importance.
The advantages of the system described are: 1) since it uses a weighing principle it is capable of high resolution (0.01 mm / 0.01 inch) measurements; in addition, the software allows for temperature compensated measurement of quantity and intensity, including fine precipitation (drizzle, fog catchment; 2) it eliminates sources of error

commonly associated with conventional systems such as tipping buckets, filter screens, collecting inlet pipes, maintenance problems caused by snow, hail, leaves, bird excrement, insects, and so on; 3) easy and cost-effective installation and operation, low maintenance required; 4) 12V DC low power supply enables operation with rechargeable batteries or solar; 5) suitable for solid precipitation like snow, hail, and freezing rain; 6) RS 232 interface (data logger version); 7) siphon device automatic drain-off system (optional); 8) documentation of evaporation in the integral data logger; 9) 40 inch (1,000 mm) collecting bucket for applications in areas with huge quantities of precipitation like mountains and rain forests.

Hydrological Data Acquisition Systems

Discharge is the most important parameter in terms of hydrological data. In general, discharge is measured indirectly by recording the flow velocity and the water level at a given cross-section in a river. For both parameters, different automatic sensors are available. For continuous flow velocity monitoring, currently ultrasonic systems are most frequently used in operational services. Radar technology is being tested for the continuous measurement of flow velocity. Water levels can be monitored applying floating devices, pressure transducers, bubble gauges and radar technology. There is a large range of available equipment, some examples are given below. For ease of reference, the examples are drawn from the products of one company, but many others offer similar types of apparatus.

Ultrasonic System for Discharge Measurement of Open Channel Flow Locations Using Differential Ultrasound Transit Time

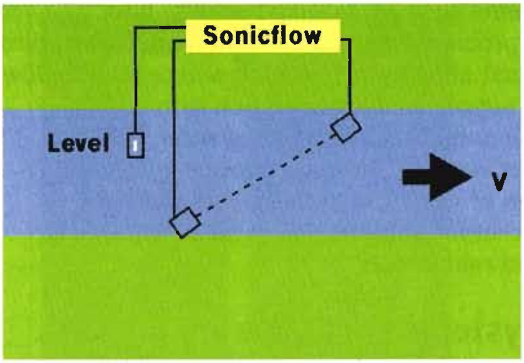
Sonic flow is a new ultrasonic measurement system designed to continuously log the flow velocity in open channels. The sonic flow system exploits innovative technology for signal processing and calculation of flow velocity. This technology is based on an intelligent digital signal processor (DSP) which has a very high measuring accuracy. In addition, it allows differential ultrasound propagation time measurements to be carried out even if the water level above the ultrasonic transducer is low.

An acoustic signal is transmitted at a defined angle so that it is simultaneously directed both towards and against the main direction of flow. The transit time for the signal transmitted against the main direction of flow is longer than the transit time for the signal transmitted in the main direction of the flow. The resulting time differential is directly proportional to flow velocity v in the measuring path. Different configurations can be chosen appropriate to the specific conditions of the river (Figure 3a-e).

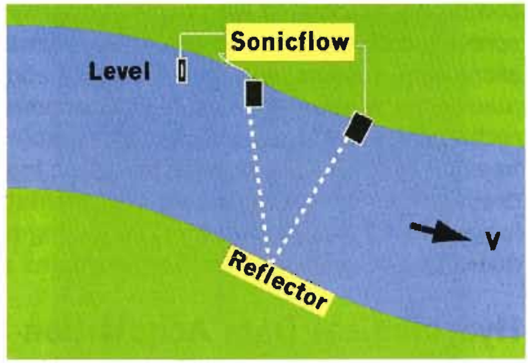
The advantages of this system include the fact that it is also suitable for use in situations where the water level is low since only minimal coverage of the sensors is necessary. Functional design ensures that the system is user-friendly, it is easy to install, operate, and maintain. No complicated equipment is needed to align the transducers. It uses a convenient evaluation software for professional processing and remote transfer of data using a variety of communication methods (serial modem, GSM modem, satellite, and others).

Radar Sensor for the Non-Contact Measurement of Surface Water Level

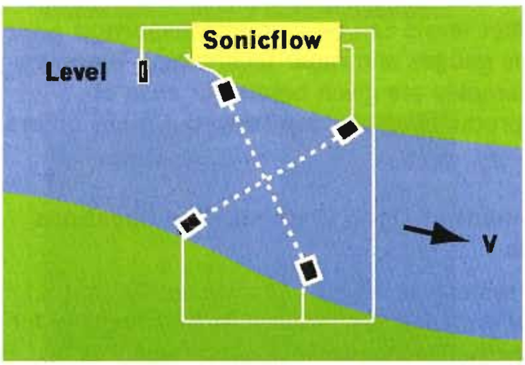
The radar sensor (Figure 4) represents a new type of measurement for surface water level, which offers many advantages in hydrological field applications since the sensor



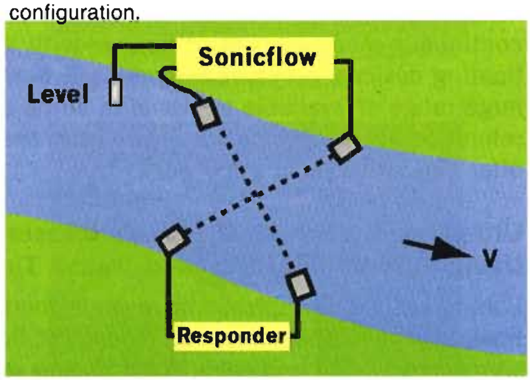
a) The 'single-path arrangement' is the simplest type of set-up. It is particularly suitable for use in waters where the flow angle is constant or bi-directional, e.g., in tidal areas. The water width is the largest measurable value (5... 150m) in this configuration.



b) The 'single-path reflector arrangement' is the preferred choice for waters with difficult inflow conditions where the flow angle is constant or bi-directional, e.g., in tidal areas. The water width is the largest measurable value (5... 150m) in this configuration.



c) The 'two-path cross arrangement' is least sensitive to changes in the flow direction. It is particularly suitable for use for large channel widths (5... 150m) with difficult inflow conditons; river bends; and where high accuracy is required.



d) Where the 'two-path-cross arrangement with responder' is used, laying of a connecting cable in or above the body of water is not necessary.

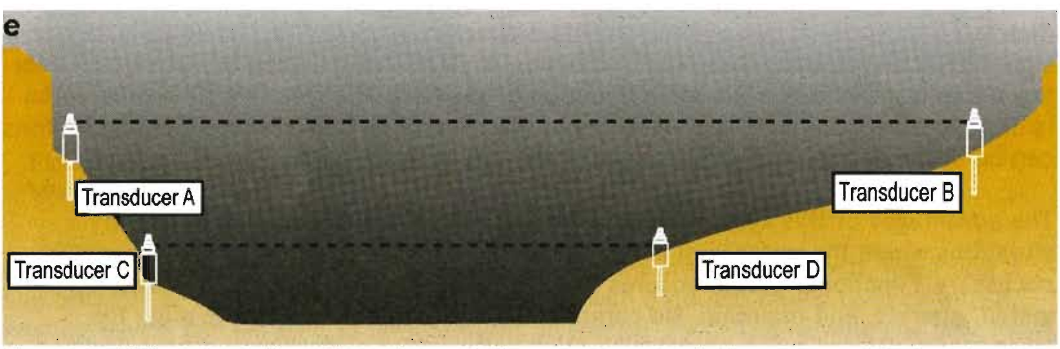


Figure 3: Different configurations for sonicflow measurement (Source: www.ott-hydrometry.de)

itself does not come into direct contact with the water. Its compact design and non-contact measuring principle ensure that the sensor can be installed easily and inconspicuously. Problems like disruption of measurement operation caused by high-water, silt accumulation, debris, and plant growth, as well as time-consuming maintenance, are eliminated.

In the example shown, an integrated software filter for averaging wave motion replaces cumbersome stilling wells. The water level is measured by sending radar waves (microwaves) perpendicular to the water surface and mixing these with the signals reflected on the surface. An intelligent DSP calculates the exact distance x (Figure 5) between the sensor and the surface of the water. Digitally measured values, status values, and any error messages present are transferred to a data logger via an interface and can be relayed over distances of up to 1,000m. The data logger calculates the water level y from the system length b and the distance x and makes the stored values available for further processing. A power supply with a 12V rechargeable battery, solar energy, and low power consumption enable the device to operate independently in the most remote areas. It is particularly suitable for areas where conventional measuring systems cannot be used or where a station needs to be set up quickly and inexpensively.

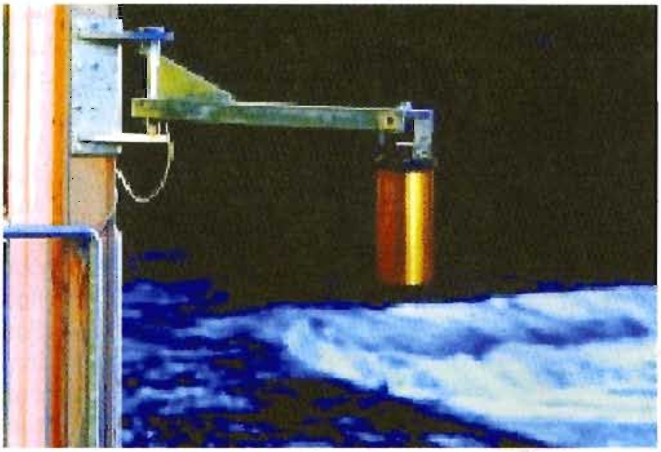


Figure 4: Radar sensor for unattended monitoring of surface water level

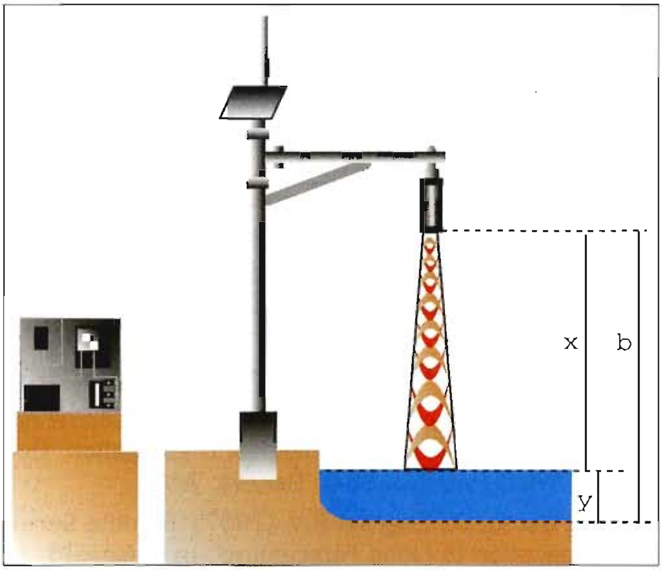


Figure 5: Measurement of water level by radar waves: the water level y is calculated from the system length b and the distance x

The features that make this system interesting are: 1) non-contact measuring principle, no damage caused by silt accumulation or debris; 2) simple, inexpensive installation - no difficult fitting procedure necessary; 3) 12V DC power supply; low power consumption enables operation with rechargeable batteries or solar; 4) cost reduction due to low maintenance requirements.

Autonomous Measurement Station for Collection of Hydrological Data

Some companies offer an integrated set of equipment or compact station which is supplied with all the components required to operate a measurement station: sensor, data-logger, communications equipment, as well as a power supply (Figure 6). In the

Figure 6: A fully equipped stand-alone hydrological measurement station (Source: OTT MESSTECHNIK, Germany)

example shown, these components are mounted on a sub-frame at the factory to the customer's specification. The sub-frame can then be inserted into the station during installation. The housing is constructed using the diving bell principle, this means that an air pocket prevents the unit from flooding even if it is inundated by floodwater and prevents the instruments from being harmed. The design and construction materials of the unit also deter unauthorised access to the instruments and protection against the elements. The compact station can be secured to a concrete foundation or mounted to a bridge or wall. The extension pole can have one or two solar panels as well as the communication antennae. The pole can also be used to mount meteorological sensors. GSM, radio, or satellite can be used for data communication. This is a fully autonomous monitoring station that can be erected quickly and cost-effectively. It can operate as a stand-alone unit with a solar power supply and GSM communication.

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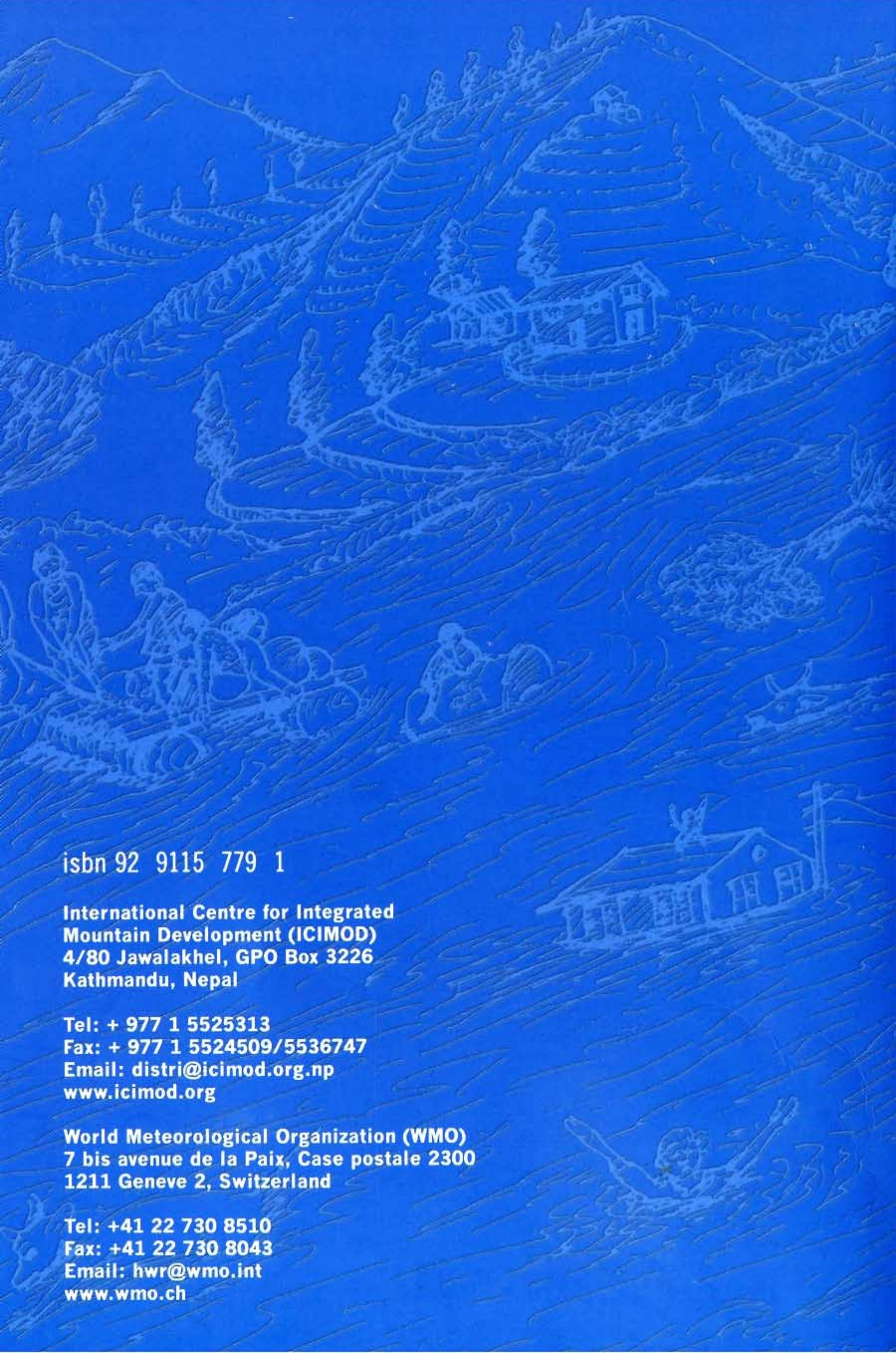

isbn 92 9115 779 1

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