

The Hydrology of Disastrous Floods in Asia – An Overview

NAGINDER S. SEHMI

*Hydrology and Water Resources Department,
World Meteorological Organization, Geneva, Switzerland*

Introduction

THE HYDROLOGY of disastrous floods in the tropical cyclone and monsoon countries of Asia is changing rapidly, mainly as a consequence of the high rate of economic development accompanied by growing urbanization. It is becoming increasingly 'intensified' and 'localized' both in terms of cause and effect. For thousands of years the problem of flood disasters has been associated with the plains in the middle and lower reaches of the major rivers which now accommodate approximately half the population of the world. These people have known their rivers for centuries and have, in most cases, tamed them to an extent that the major rivers no longer appear to cause direct major disasters. Feelings of security from floods have increased population pressure beyond any expectations. This has led to the development of land and water resources beyond what is desirable, at the expense of shrinking forests, eroded pastures and polluted rivers and lakes. Traditionally, operational hydrological activities are geared to floods in large rivers, whereas the major flood disasters now occur in densely populated areas in small river catchments. A Persian proverb aptly describes the problem: 'In the ants' house the dew is a flood'.

The Problem

The damage caused by floods in Asian countries was estimated at more than US \$5 billion in 1981, and is steadily rising. At the same time the areal extent of flood disasters is increasing rapidly. In India, for example, the total area subject to flooding doubled from 20 million ha in 1971 to over 40 million ha in

THE HYDROLOGY OF DISASTROUS FLOODS IN ASIA

1981 (Darryl, 1985). This has happened as the number of large dams (over 15 m) alone has risen from about 1700 to 1950 to over 23 200 in 1982, not to mention the more numerous, smaller than 15 m high dams. Then there are the flood control levees whose total length exceeds 200 000 km (ESCAP, 1986). Failures of these structures, which is not uncommon, has produced catastrophic floods.

The countries in Asia are experiencing a reduction in the safety of existing flood control structures, and at the same time an increase in the risk of disasters from flash floods in small catchments and densely populated areas, in particular in the cities. In some cases the flood control structures have contributed to the magnitude of flash floods, especially when they impede runoff drainage. Many population centres in Asia are finding it more risky to be totally dependent on levée and canal systems for flood protection. This is because most flood protection works were built to standards applicable to pre-development, when the basin possessed undisturbed hydrological conditions. But now these standards – the design criteria – are being exceeded frequently. Intense rainfall on a small steep catchment upstream of a poorly drained urban centre causing a devastating flash flood is becoming a common occurrence. Such flooding is the cause of about 90 per cent of lives lost through drowning in tropical cyclone countries.

Major changes in the use of water and land resources have adversely affected the environment, in particular the hydrological regimes of many basins. These adverse trends, in turn, have aggravated the flood problem, as shown by Uehara (1987) in Table I.

For example, in the Mekong Basin, a large portion of the forest cover has been removed over the last 30 years as timber to create agricultural land. The negative hydrological consequences of deforestation and incorrect land-use policies have resulted in an increase in the sediment load of rivers, siltation of irrigation works and reservoirs, and an increase in the flash flood hazard (Mekong, 1987). The metamorphosis of hydrology and the resulting problems are addressed according to the size of the river basins.

Major rivers

All countries in this region experience a monsoon climate with great seasonal rainfall variations. Between 70 and 90 per cent of the total annual rainfall occurs during the wet season (May to October). As would be expected, river flows show even more pronounced seasonal variations which amplify difficulties in the control of floods.

The large amount of effort and investment injected into flood control measures in the major river basins of the region are well known. For example, the vast low-lying alluvial plains of China drained by seven major river systems (the Yangtze, the Yellow, the Huai, the Hai, the Laio, the Pearl and the Songhua Rivers) cover an area of over one million square kilometres, and

TABLE 1 *Increasing rates of population and assets in flood risk areas in Japan*
(Percentage of whole country)

	1960	1970	1980	1985
Risky area	10	10	10	10
Population	44.7	46.3	48.2	48.7
Assets	51	63	72	75

contain half the population of China and most of its important cities. The ground levels of the plains are generally lower than the flood stages of the rivers. Consequently, these areas have been safeguarded by dykes with a total length of over 160,000 km, most of them built since 1949. In addition, numerous flood water storage and diversion facilities have been created to contain the overflows. In short, flood control structural measures have made the vast plains largely safe from floods of a 10- to 20-year return period (Qian Zhengying, 1983).

The dyking has triggered aggradation of river beds, thus reducing the safety of the existing structures. It is estimated that, if the rainstorm of 1981 (China, 1987) had extended to cover the middle and lower reaches of the Yangtze, as occurred in 1954 (a 40-year flood), the probable losses would have been in the tens of billions of dollars; more than half a million people would have had to have been evacuated, and only the safety of the Jingjiang Dyke and Wuhan city could have been ensured. In addition, river channel obstructions caused by vegetation growth and deposition of debris (naturally or by man) have become paramount in amplifying disasters even from a flood of low return period.

Cognizant of such possibilities, in particular of the decreasing safety of existing flood control structures, China has developed an elaborate and modern, but very complex, flood forecasting service for monitoring the entire country on a real-time basis. In fact, the hydrological forecasting and warning systems are seen as the 'eyes and ears' of the country, without which it would be difficult, if not impossible, to mitigate a flood disaster (China, 1987).

Small rivers

Monsoon rains, tropical storms and typhoons usually result in very intense rainfall in a short time over a small area, leaving little time for the collection of data and issuing of forecasts. Hence the forecast or warning lead time is frequently non-existent or very short indeed. Such meteorological situations lead to treacherous 'flash' floods, defined as floods of short duration with a

relatively high peak discharge where the time interval between the observable causative event and the flood is less than four to six hours (WMO, 1987). In some countries the flood forecasting service, with the collaboration of the meteorological services, monitor the behaviour of tropical cyclones and storms and provide generalized heavy rainfall, flash flood or storm surge warnings without delaying to prepare refined, site-specific forecasts. Much remains to be done, however, in order to increase the lead-time.

Vulnerability to flood damage in small catchments has increased because development and land-use practices have depleted their rainfall retention and runoff retardation characteristics, causing not only higher flood peaks but also shorter times of concentration. The drainage and river channel improvement works have had a similar effect on the flow. Inefficient or poorly maintained drainage systems exacerbate the situation.

Kuala Lumpur case study

The city of Kuala Lumpur (Malaysia) is prone to severe flash floods. It is situated at the confluence of three short (30 to 50 km long) and relatively steep streams which drain the small (427 km²) catchment of the Kelang river (Figure 1). The fan-shaped catchment has the almost perfect hydrological characteristics for producing severe floods. The average annual population growth rate in recent years has been 4.3%, of which natural increase is 2.2%. The population is expected to increase from 1 million in 1980 to 1.5 million in 1990. From the earliest days Kuala Lumpur has been subject to flooding, but the extent of damage caused in recent years is beyond any expectations. The tropical storm of 1-5 January 1971 produced a record flood of 569 m³/s over a period of 16 hours. The flood damage was estimated at over US \$14 million.

Of the three reservoirs planned on the tributaries, the one on the Kelang has been completed. In addition, considerable channel improvement works have been undertaken. On completion of the project, the city is expected to be protected from a 100-year flood. But the project, involving an investment of over US \$92 million, will require 13 years to complete. In the meantime, the flood damage potential is on the rise. Large-scale development for housing and industrial estates is rapidly replacing the thick vegetation of the hillsides. Figure 1 also shows the urban expansion since 1962.

These developments, both urbanization and structural measures for flood control, have evidently changed the hydrology of the catchment. Based on the flow records at Market Street and Sulaiman Bridge in Kuala Lumpur, the historical variation of the runoff pattern is represented by a sharpness index which is the ratio of instantaneous peak discharge to the daily mean discharge. Figure 2 shows that the sharpness index has been increasing since 1960 (TCS, 1987).

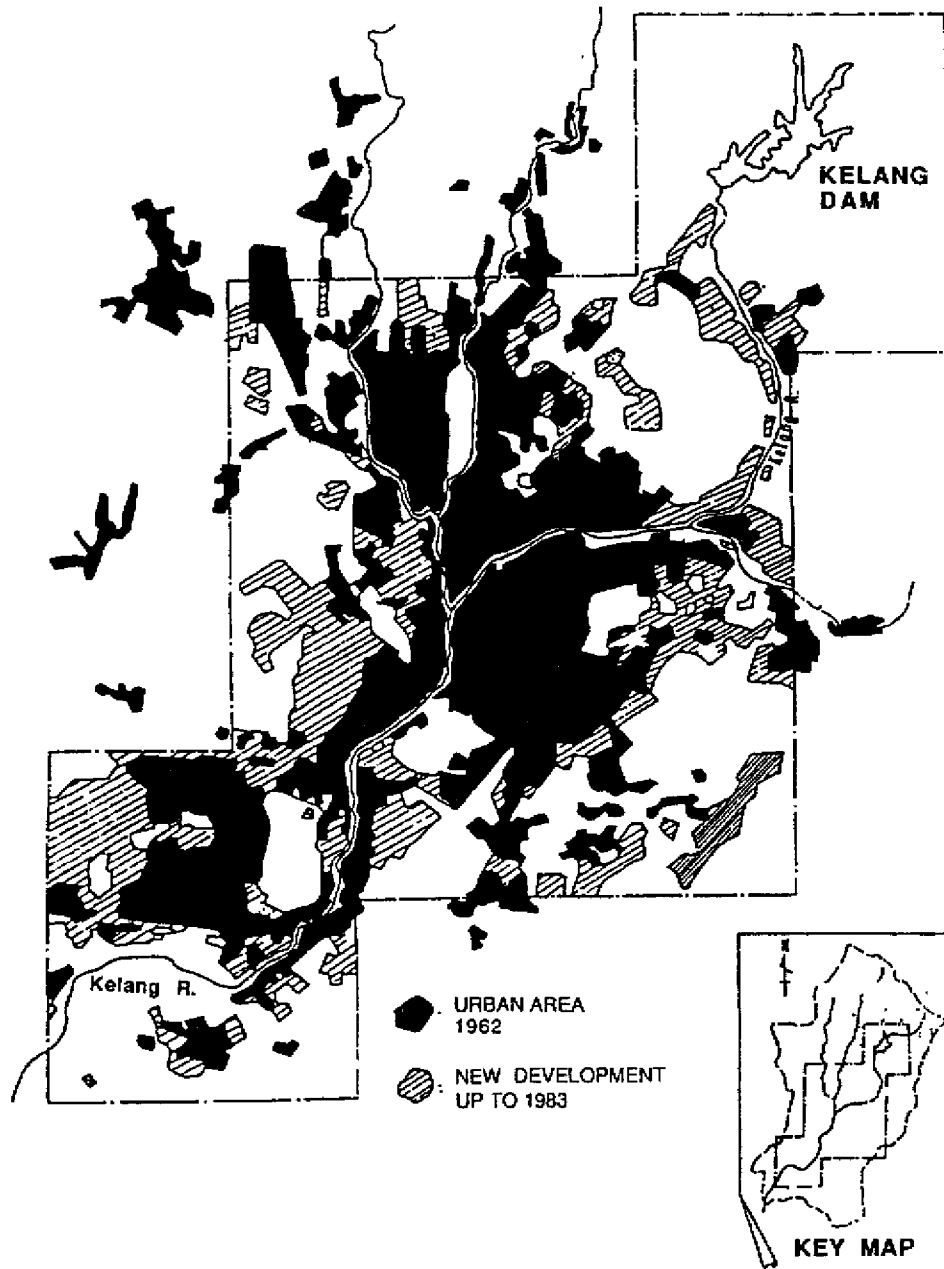


FIGURE 1 *Urbanization of the Kelang river basin, Kuala Lumpur (Malaysia)*

Flash Flood Incidents in Selected Countries

The actual extent and gravity of disasters caused by flash floods in densely populated areas other than cities is difficult to determine until countries carry out systematic surveys. A breakdown of deaths caused by major forms of natural disasters in Japan is shown in Figure 3 (NRCDP, 1983). Floods are responsible, on average, for over 60% of them. Reports on some recent flash floods attest to their seriousness.

THE HYDROLOGY OF DISASTROUS FLOODS IN ASIA

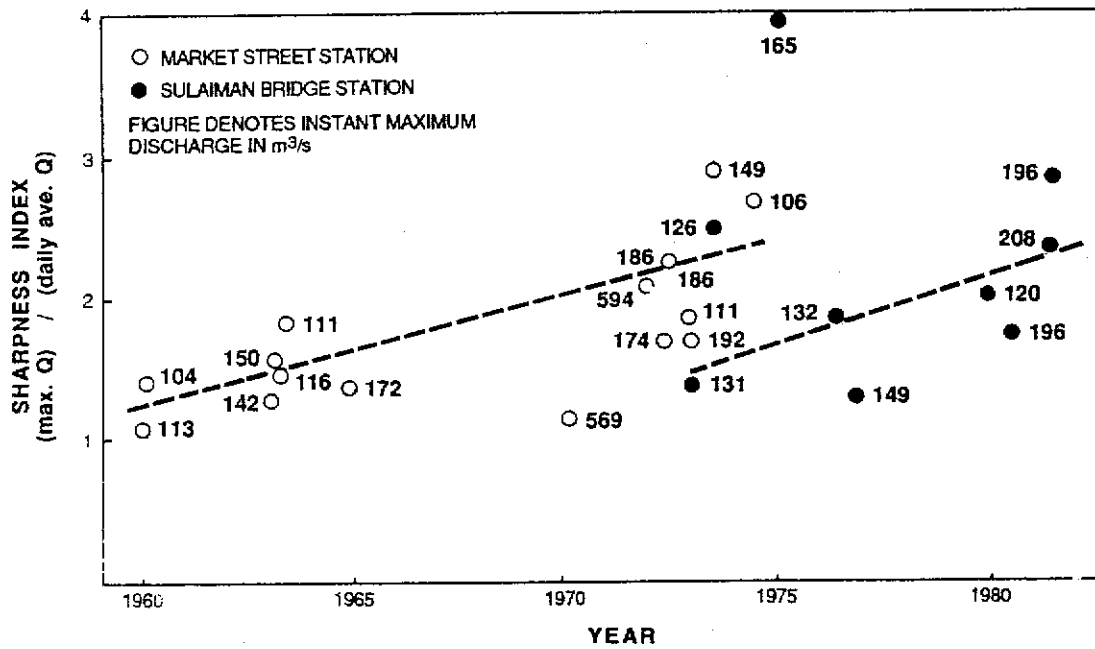


FIGURE 2 Historical variation of flood flow pattern

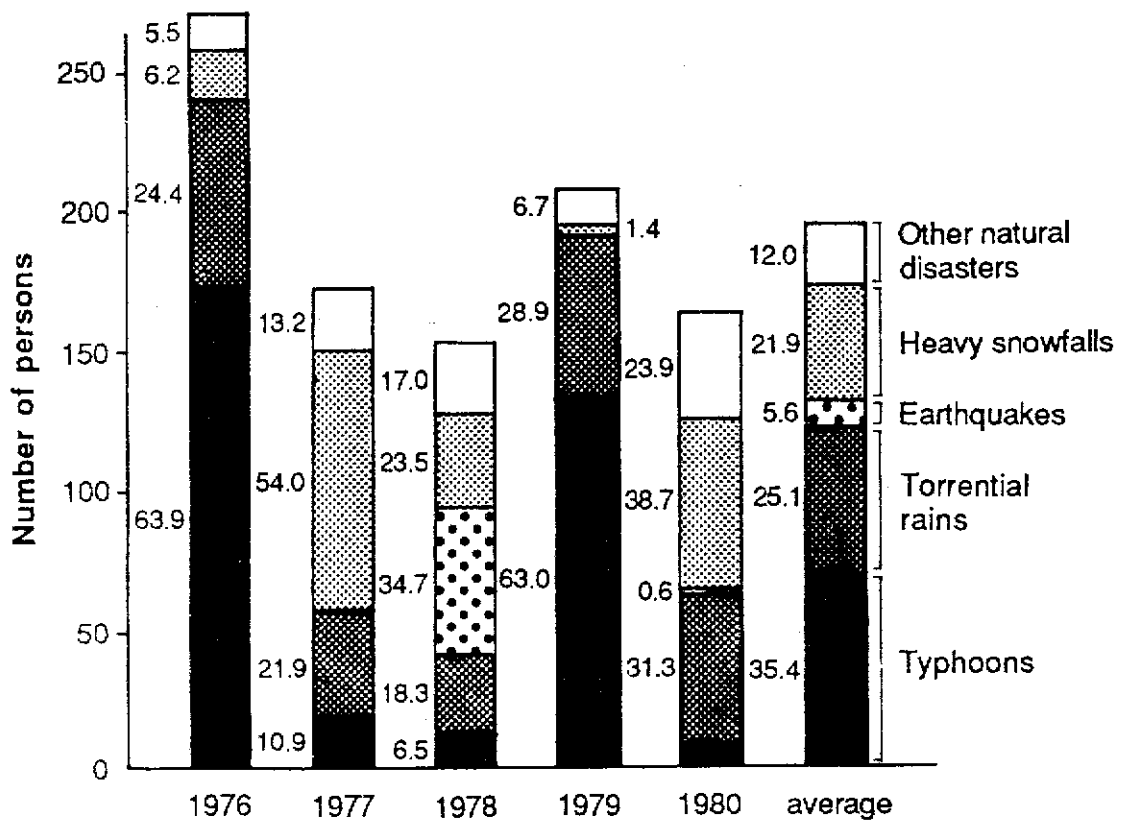


FIGURE 3 Deaths caused by major forms of natural disasters in Japan (NRCDP, 1983)

Intense precipitation usually results from tropical storms which frequently penetrate into the temperate regions of China. Typhoons from the China Sea give rise to extraordinary rainfalls (for example, 1605 mm in 72 hours at Linzhuang in Hanan Province in August 1975) resulting in severe flash flooding. On 11 July 1986 typhoon PEGGY shed between 500 and 1000 mm of rain in the Fujian provinces; Mei Xian was under 2 to 4 m of water for 40 hours. In 1987, floods and typhoons caused 2300 deaths, and destroyed 650000 homes. The losses were estimated at US \$2400 million.

In Malaysia, other urbanized areas such as Penang, Kota Baharu, Ipoh and Johor Baharu experience increasingly severe flash floods. In November 1986, the heaviest rainfall for 15 years caused severe flash floods in the lower Trengganu and Kelantan rivers. Fourteen people drowned and 20000 had to be evacuated; the cost of the damage was estimated to be more than US \$11.4 million.

All parts of the Republic of Korea experience floods which pose a severe hazard to the population and exert a major negative effect on the economic growth of the threatened areas. Floods have occurred in the Han river on an average of about twice a year, and severe flooding is experienced on an average of once every four years. The disastrous effects of floods have been mitigated by constructing major flood control works, including a system of seven dams and river training works supported by a flood forecasting service (Figure 4). However, the problem of localized flash floods in small river basins, particularly in coastal areas, is still to receive attention. In 1987, in the Chungchung and Seoul Kyunggi areas three heavy rainfalls and associated flash floods caused 243 deaths through drowning.

Flash floods, usually associated with typhoons, often take a heavy toll of life and cause much property damage in the Philippines. On 3 October 1981 for example, a flash flood in a volcanic catchment carried soil with it into the Amacon Creek causing overtopping of an earth dam. In 30 minutes, the deluge composed of mud, debris, logs and boulders destroyed houses and a market centre leaving behind 124 dead, 12 missing and the 204 injured employees of a mining corporation. A total of 622 families (3732 persons) were affected by the disaster. In September-October 1985, intense flooding in 18 townships caused an even bigger disaster. In major urban centres, particularly Manila, flash floods have become more frequent, causing serious damage. It is estimated that in Manila about 70% of the urban drains get clogged. It is feared that, should a major flood occur, it could cause a disaster far greater than anything experienced in recent times.

Tropical storms and cyclones frequently cause destructive flash floods in Thailand, which are becoming increasingly disastrous with the rapid rate of development, deforestation and urbanization. Metropolitan Bangkok suffers from flood damage about once every two years. Flooding is caused by local flow being backed up by prolonged high water levels in the Chao Phraya River. On 8-9 May 1986, the 1000-year rainstorms over Bangkok resulted in

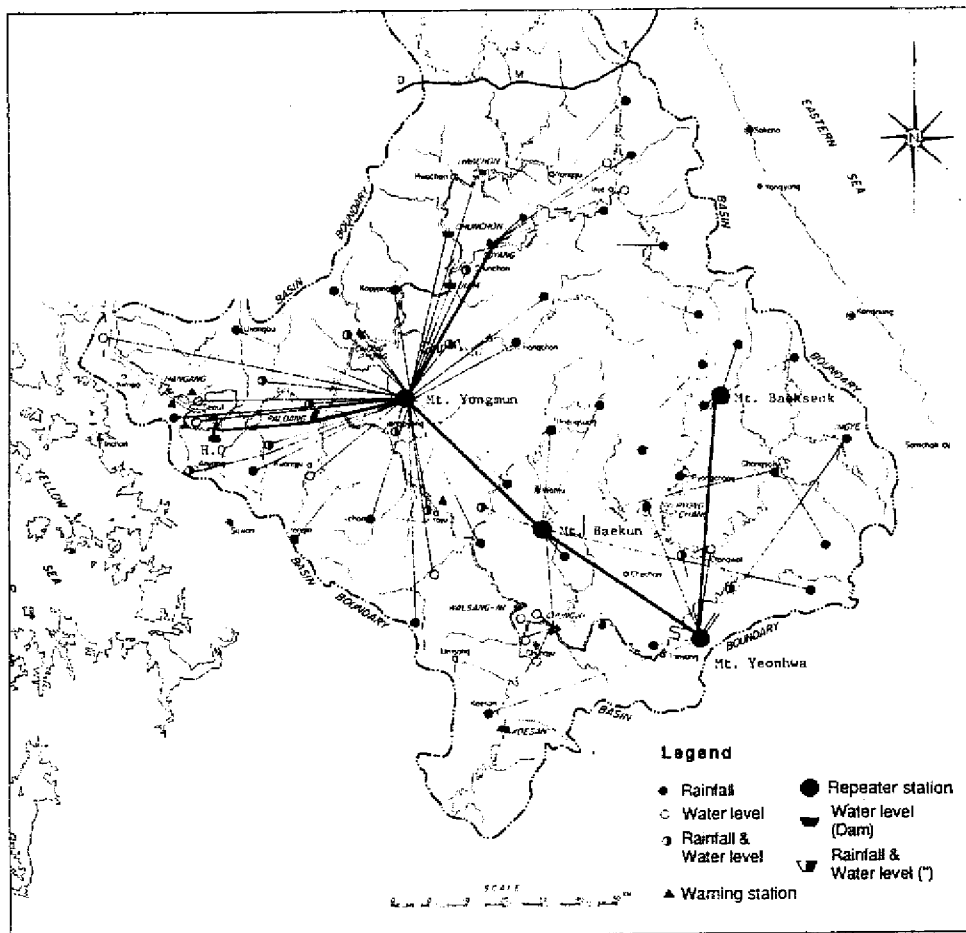


FIGURE 4 Telemetry network in the Han river basin (Korea, 1986)

historic floods. Two tropical depressions (BETTY and CARY) between 15 and 27 August 1987 produced severe flash floods in 39 provinces in northern Thailand and five provinces in the south resulting in widespread destruction. Table 2 shows the gravity of the situation.

Flash floods hit Afghanistan in June 1988, killing many people and 117,000 cattle, damaging 1,300 km of irrigation works in addition to roads, bridges and culverts, causing damage estimated at US\$ 260 million.

Land-use Studies and Applied Research

A number of countries have undertaken *ad hoc* studies on the effect of land use on the hydrological regimes of different basins, but systematic and intensive studies to investigate the effects of changing land use on flood characteristics have been undertaken only in Japan. One such study of the flood hydrology of the Shakujii river basin (48 km²) during its 20 years of urbanization (1958–1977) has shown that the 1977 peak discharge had

TABLE 2 Summary report on flash floods in northern Thailand

No.	Duration August 1987	Disaster areas		Damages						Financial mitigation by DPW* (bahts)	Notes		
		Province	Amohoe	Kring Amohoe	Families	Persons	Deaths	Houses	Other structures			Agricultural area (ha)	Pets
1.	16-27	Chieng Mai	16	1	2,099	10,140	6	151	204	33,242	2,847	248,000	four injured persons, 2621 flooded houses
2.	15-27	Phatchabon	1	1	—	—	—	—	1	12	—	—	—
3.	16-17	Lumchun	3	—	473	2,365	1	—	36	10,907	—	27,040	—
4.	23	Nan	8	3	300	1,500	5	4	2	—	109	25,000	—
5.	17-24	Phrae	4	—	—	—	2	—	13	1,950	—	4,000	—
6.	22-26	Suchotnai	3	—	5,694	28,470	—	—	8	26,300	—	15,600	—
7.	24-25	Phayao	4	—	—	—	—	—	12	4,320	—	3,985	—
8.	22	Chiang Rai	2	—	89	346	1	—	—	—	—	104,841	89 flooded houses
9.	23-26	Tak	3	1	—	—	1	29	16	996	100	28,364	—
10.	23	Uttaraidit	1	—	—	—	—	—	—	—	—	2,065	—
Total			45	6	8,645	42,821	16	184	292	77,727	3,056	458,895	

*Department of Public Works.
1 US\$ = 25 bahts.

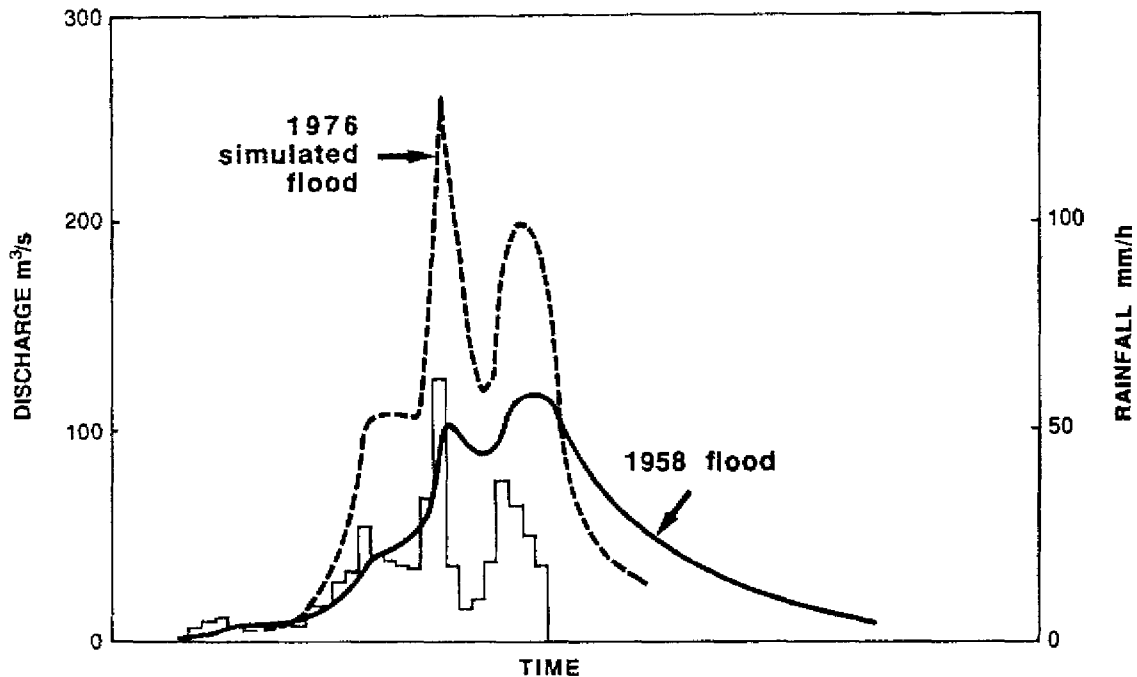


FIGURE 5 Flood flow changes due to urbanization, Shakujii river, Japan (Uehara, 1987)

increased by up to 2.5–3.0 times that in 1958 (Figure 5). This increase corresponds to an increase of residential area from 33% to 52% of the catchment (Uehara, 1987). Results of a similar study of the Thurumi river basin (235 km²) are shown in Figure 6 (Kinoshita *et al.*, 1986).

Research activities related to flood forecasting in the tropical cyclone countries range from a very advanced level in Japan to only a very basic level in some other countries. In densely populated and built-up areas, the approach to flood forecasting has been considerably intensified in time and space. For example, from the results of studies of physiographic characteristics, flood-risk mapping and drainage systems in Tokyo, flood impacts are predicted using assumed values of rainfall intensity such as those shown in Figure 7 for Hong Kong. Japanese meteorologists are developing systems for forecasting rainfall for a 1 km × 1 km mesh at about five- to 10-minute intervals. From this information the hydrologists should be able to issue a more accurate and precise forecast of floods (Kinoshita, 1987).

Other countries are making special efforts to develop flood forecasting and warning systems. For example, Tingsanchali (1987) has reported on the experience of calibrating and applying the SSARR model for flood forecasting on the Pong, Chi and Mun river basins in Thailand since 1981. The forecast of rainfall remains the most critical factor in the accuracy of these flood forecasts.

A significant impetus to research in flash flood forecasting was given during the Typhoon Operational Experiment (TOPEX). The hydrological component of TOPEX was implemented on the basis of three water-years starting in March 1981. The objective was to reduce the risk of loss of life and damage

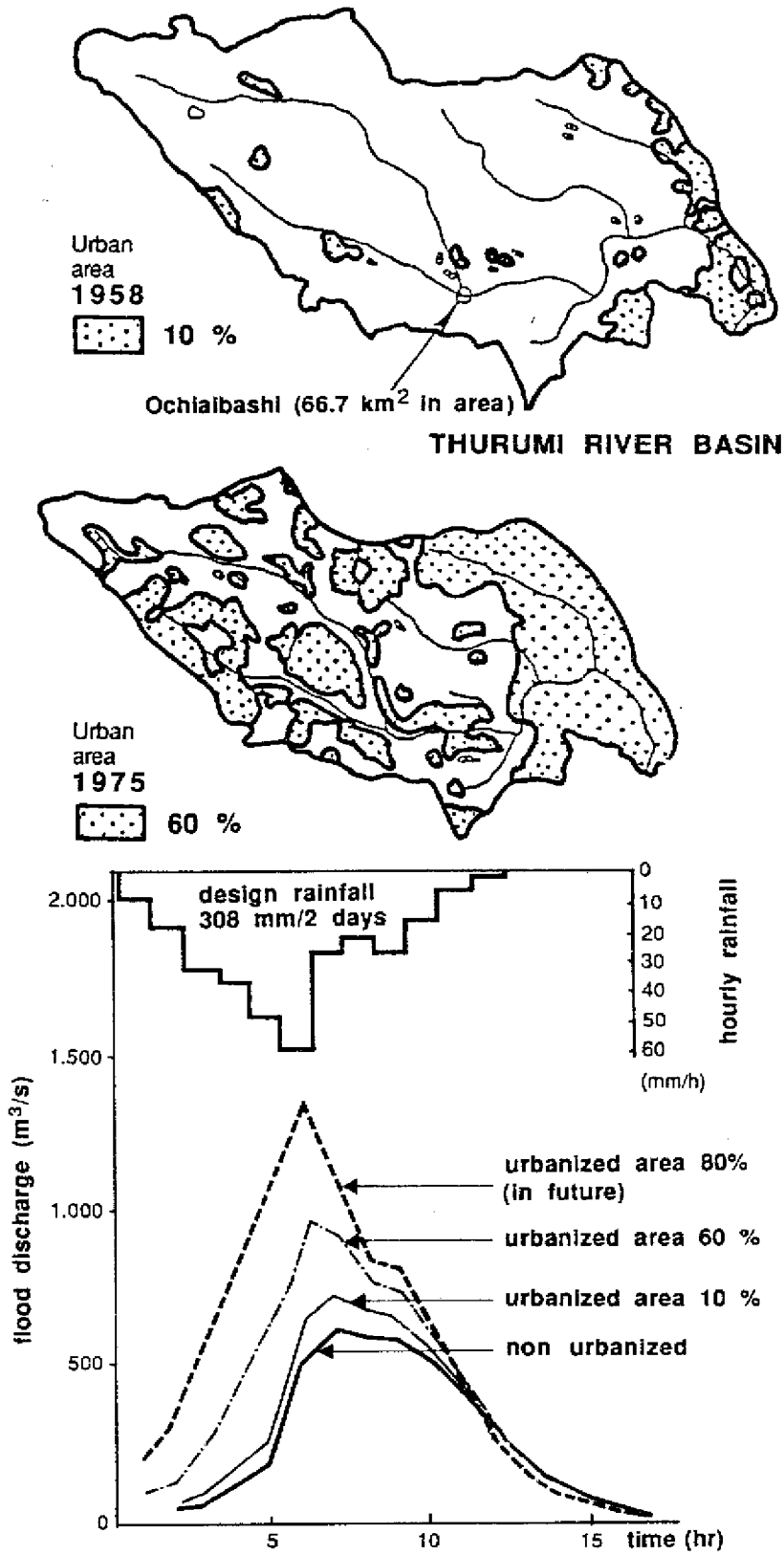


FIGURE 6 Effect of urbanization on flood flows at Ochiaibashi (Japan) (Kinosita et al., 1986)

THE HYDROLOGY OF DISASTROUS FLOODS IN ASIA

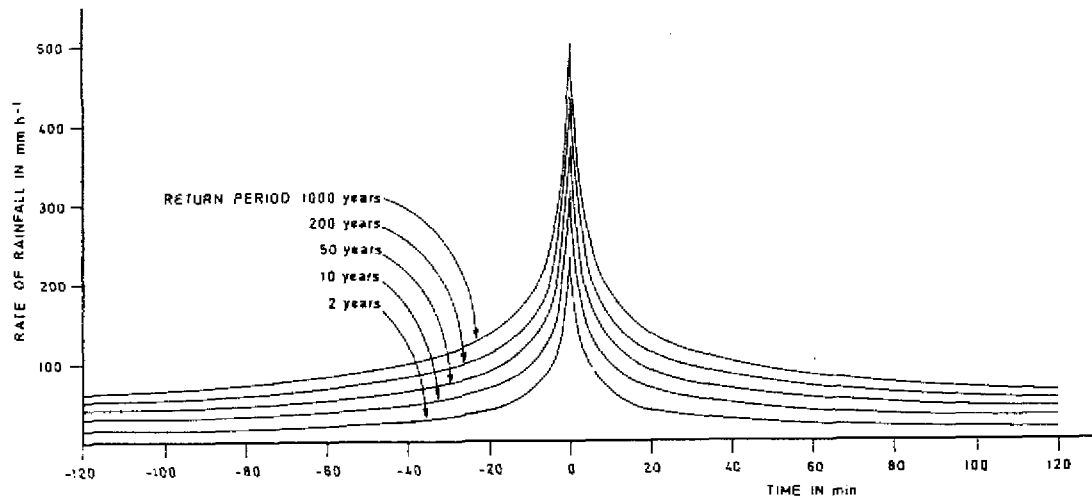


FIGURE 7 Storm profiles for engineering applications in Hong Kong (Royal Observatory, 1986)

from typhoon-related floods by improving the forecasting and warning capabilities of countries. Six countries designated nine river basins whose flood forecasting systems were evaluated during the three years (WMO, 1985).

In 1987 the Typhoon Committee carried out a survey of the hydrological research activities of Asian countries, and the results were reported by Sea (1987). In China, a number of flood forecasting models have been applied, tested and adapted for local use. A combination of the Xinanjiang model and the Constrained Linear System (CLS) has resulted in a Synthesized Constrained Linear System (SLCS) which is now being used operationally (Wang *et al.*, 1987).

Development of Flood Forecasting Systems

Flood forecasting is the real-time estimation of stage, discharge, time of occurrence and duration of flooding, especially of peak discharge, at a specific point, resulting from precipitation and/or snowmelt (WMO, 1974). In Asia, as in many other parts of the world, floods are not only a curse but also at times a blessing. Flood forecasting combined with flood-plain management can reduce the curse while retaining the blessing.

Until recently, flood forecasting in tropical cyclone- and typhoon-affected countries was considered to be less important than flood preventive structural measures. All countries recognize that while structures try to 'keep the water away from people', it is almost impossible to 'keep people away from water'. In this connection, Sugawara (1978) has the view that flood control reservoirs are effective for small- and medium-sized floods but are of little value for the control of large, very infrequent events, especially when the populations they protect have attained full confidence in the security provided by the control. It

TABLE 3 *Major flooded forecasting projects implemented by WMO*

Country	Phase	Duration	Rivers	Assistance in US\$
Bangladesh		1980-86	—	3,040,000
Burma	I	1979-84	Irrawaddy (upper)	330,000
	II	1986-89	Irrawaddy (lower)	1,056,000
China		1981-85	Yellow (lower)	700,000
		1983-86	Yangtze (middle)	900,000
India	I	1980-85	Yamuna	1,255,000
	II	1985-88	Yamuna	261,000
Indonesia		1987-90	—	998,000
Nepal		1982-87	—	1,031,000
Pakistan	II	1985-88	Indus	595,000

seems that flood disaster prevention measures, including flood forecasting, have this unfortunate characteristic: they increase the damage from large disasters. This is so because the increase of private and public properties in the flood-prone areas not only raises the damage potential but also increases the difficulty in providing flood control facilities.

While considerable effort and resources have been expended in Asia to establish flood forecasting services in major river basins, only a start has been made in providing effective flash flood forecasts. Table III shows the major technical assistance projects implemented by WMO since 1980 to set up flood forecasting services.

The total technical assistance so far given represents but a small fraction of the total national effort. Malaysia, for example, has a well organized flood forecasting service covering all the main rivers which is being extended gradually on a selective basis. Since 1971, four peninsula rivers have been equipped with mainly locally manufactured automatic telemetry and transmission systems. Flood forecasts are prepared by the Hydrological Forecast Unit using the Sacramento and Tank models. For other rivers, forecasts are made by a stage-correlation procedure. On a few rivers, dams which were not constructed specifically to control floods do help in mitigating flood disasters. However, no other major river control structures are planned for the near future. It is planned to upgrade the flood forecasting services for the entire country. Flood Warning Boards have been established at the local level to issue forecasts and warnings in each dangerous river. In addition, basin-wide hydrological studies have been initiated. In short, Malaysia has already acquired considerable experience in flood forecasting and warning procedures and has a sound infrastructure, as shown in Figure 8.

THE HYDROLOGY OF DISASTROUS FLOODS IN ASIA

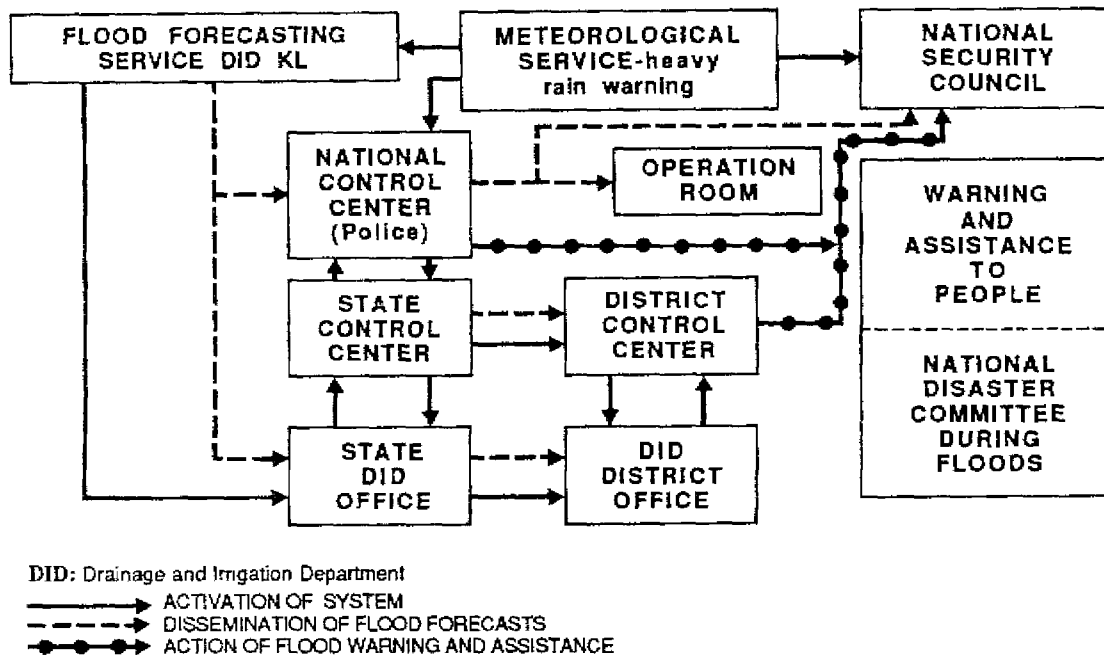


FIGURE 8 *Flood warning and forecasting information service system (Malaysia)*

In neighbouring Thailand only a few flood forecasting efforts have been made independently by various national agencies. Recent severe flash floods have sharpened the awareness of the authorities concerned of the need for provision of an efficient nationwide flood forecasting and warning service. There already exist considerable facilities and equipment which need to be fully exploited. For example, in addition to a dense network of meteorological and hydrological observing stations, the entire country is monitored by a system of eight weather radars (Figure 9). There is an immediate need for national planning and development authorities to evaluate the hydrological and meteorological facilities, the experience and the expertise available in the country, in order to mobilize the resources required to mitigate flood disasters.

In China, the Republic of Korea, Hong Kong and Pakistan the flood forecasting services are rapidly being modernized, while Burma, India, Indonesia and the Philippines have made a good start. In general, the quality of water, which forms a major component of flood disasters, has not yet aroused concern in most of the countries.

Concluding Remarks

Progress towards the orientation of hydrological activities to effectively mitigate the disastrous effects of flash floods in Asia does not seem to correspond to the rapid increase of flood incidents. More funding and greater

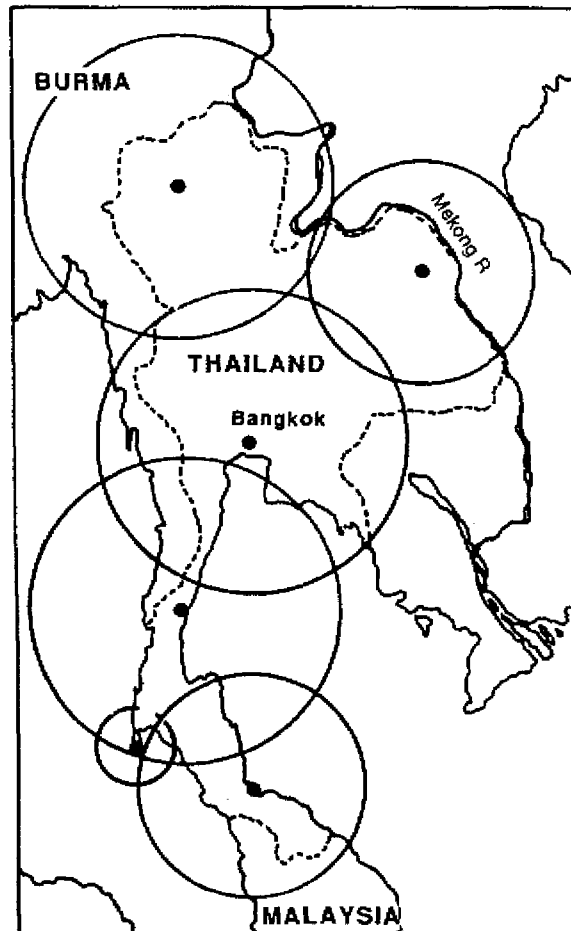


FIGURE 9 *Weather radar coverage of Thailand*

emphasis is required for the establishment of reliable and rapid (computer) systems for data processing and analysis and for the application of forecasts of meteorological conditions, especially the tracks, locations and coverage of rainstorms and tropical cyclones (typhoons). Some countries have recognized and adopted the approach that an efficient flash flood forecasting service should be geared to flood disaster prevention systems in urban areas, as it is becoming increasingly difficult without them to manage and operate the water supply and drainage systems, not to mention pollution control.

The primary task is to identify all densely populated locations which are subject to flash floods, to study their hydrology, to delineate the flood-prone areas and to prepare plans with priorities for the installation of custom-tailored flood forecast/warning systems in each location.

Based on the experience already acquired, flood forecasting services need to be extended to all flood-prone river basins. To do so it is necessary to integrate the meteorological and hydrological data being produced by various agencies in the country, in order to improve the lead time of flood forecasts.

Opportunity should be taken to apply the modern technology needed for upgrading synoptic meteorological and hydrological networks. Based on such techniques as radar-rainfall measurement systems and high resolution satellite sensing, which can provide invaluable information on storm movement, coverage and rainfall intensities even at a relatively small (metropolitan) scale, application of quantitative precipitation forecasts (QPFs) should be promoted. At the same time, more sophisticated hydrological models which will accommodate QPFs should be introduced.

There is also the need to develop the framework and effective interagency-based co-ordination which will permit flood forecasts and warnings to be disseminated to and received by all agencies concerned with flood emergency and relief operations and by the affected people. A programme of educating the public is equally important to ensure that the people concerned clearly understand the significance and meaning of a flood forecast, an advisory, a warning, an alert (WMO, 1988) and the measures they are expected to take in order to minimize loss.

As part of the various operational hydrology activities, it is becoming increasingly important to undertake studies of the effects of deforestation, urbanization and changing land-use on the hydrology of the area concerned, and thus on the intensity and duration of floods.

Finally, international organizations are orientating their programmes in operational hydrology according to the changing needs of countries. In the past the emphasis has been mainly on promoting international co-operation and strengthening the capabilities of the national Hydrological Agencies in a relatively broad sense. Naturally, the guidance material generated by them pertains to large hydrological phenomena. They are now focusing on small-scale facets of hydrology. The operational technology normally applied to flood forecasting in large river basins is not suitable for forecasting flash floods on small basins. This applies equally to the measurement and monitoring the flows in urban areas. In short, it is the operational aspects of the changes in hydrology that the programmes are now aiming at.

Acknowledgements

The author acknowledges with appreciation the kind authorization of the Secretary-General of WMO to submit this paper. The paper is based mainly on the author's mission to six typhoon-affected countries in November/December 1987. The author therefore wishes to express his gratitude to those countries which have given valuable information to ESCAP, which organized the mission, and to other members of the mission for the material they have provided.

REFERENCES

- CHINA (1987) *Brief introduction to hydrological information and forecasting in China*. Ministry of Water Resources and Electric Power, Beijing, China
- DARRYL, D'MORTE (1985) *Temples or tombs*. New Delhi, p. 14
- ESCAP (1986) Environmental issues of water resources development in ESCAP region. *Document E/ESCAP/NR. 13/11*, Bangkok, Thailand
- KINOSHITA, T. *et al.* (1986) *Hydrology of warm humid islands*. National Research Centre for Disaster Prevention, Japan
- KINOSHITA, T. (1987) One-kilometre meteorology (personal communication)
- KOREA (1985) *Flood forecasting and warning system of Han River*. Han River Flood Control Office, Ministry of Construction, Seoul, Republic of Korea
- MEKONG (1987) *Annual report*. Interim Committee for Co-ordination of Investigations of the Lower Mekong Basin, Bangkok, Thailand
- NEMEC, J. (1986) *Hydrological forecasting*. Reidel, the Netherlands
- NRCDP (1983) *Outline of recent activities of National Research Centre for Disaster Prevention*. NRCDP, Japan
- QIAN ZHENGYING (1983) *The problems of river control in China*. Ministry of Water Resources and Electric Power, Beijing, China
- ROYAL OBSERVATORY (1986) *Meteorological research, publications and consultant services*. Pamphlet Serial No. 2-8, Hong Kong
- SEA, C.H. (1987) *Report on research under hydrological component*. ESCAP/ WMO Typhoon Committee, Manila, Philippines
- SUGAWARA, M. (1978) On natural disaster – some thoughts of a Japanese. *WMO Bulletin*, April 1978, Geneva, Switzerland
- TCS (1987) *Flood risk analysis and mapping in some countries*. Mission report, ESCAP/WMO Typhoon Committee Secretariat, Manila, Philippines
- TINGSANCHALI, T. (1987) Development of flood forecasting and warning systems in Chi and Mun river basins – Northeast Thailand. *Water Res J ST/ESCAP/SER. C/154* (Sept. 1987), pp. 31–44, UN, Bangkok
- UEHARA, S. (1987) Prevention of disasters related to rivers. *Technology for disaster prevention*, Volume 11, (Sept. 1987), p. 81, NRCDP, Japan
- WANG JUEMOU *et al.* (1987) *The synthesized constrained linear system (SCLS)*. Ministry of Water Resources and Electric Power, Beijing, China
- WMO (1974) *International glossary of hydrology*. WMO-No. 385, Geneva, Switzerland
- WMO (1981) *Flash flood forecasting*. (By Hall, A.), Operational Hydrology Report No. 18, WMO-No. 577, Geneva, Switzerland
- WMO (1985) *Activities under the hydrological component of TOPEX*. Report No. TCP-20, WMO/TD-No. 37, Geneva, Switzerland
- WMO (1988) *Technical Regulations*. Volume III. WMO-No. 49, Geneva, Switzerland