2 Hydrology as a Policy-Relevant Science in Japan and Monsoon Asia

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INTRODUCTION

There are three basic components that form the hydrological conditions of the world: the climate, the land and human activity. The combination of these components is responsible for the unique nature of the regional hydrology in different parts of the world. In Japan, and a large part of the Asian Monsoon Region, the climate is characterized as warm and humid, the land is characterized as orogenically active, and human activity as rice paddy agriculture. The relations between these factors are unique to the region; that is, the warm humid climate provides the ideal conditions for rice paddy agriculture and therefore rice is the staple diet across Monsoon Asia. However, this means it is necessary for people to live on the flood plains, and accordingly, to live with floods. Since the start of agricultural history, the management of water has been the major concern of the Monsoon Asian people, with particular emphasis on irrigation and flood control. In addition to many non-structural means, structures such as levees, diversions, and sabo sediment control works, have formed unique man–nature co-existence schemes in many basins for thousands of years. Any change in the basin creates a disturbance to the co-existence scheme which takes a long time to adjust itself. Urban concentration of population and industry, transformation of rice paddies into residential areas, expansion of residential areas to steep slopes at the edge of plains, construction of continuous levees, and so on, all change the stability of the hydro–human co-existence scheme (cf. Takeuchi, 2001, 2002). Given the anticipated regional development, it is clear that a serious struggle to seek a new equilibrium with the natural environment will develop. The mutual exchange of knowledge and experience of adjustment efforts towards a new form of living with nature would greatly help all nations in the Asian Monsoon region. So will the International Association of Hydrological Sciences' (IAHS) ten-year Predictions in Ungauged Basins (PUB) project (Sivapalan *et al*., 2003). The Asian Monsoon region shares the common agenda of PUB, a policy relevant hydrology enabling people to live with natural hazards and the expanding population and industry.

REGIONAL CONDITIONS IN JAPAN AND MONSOON ASIA

Japan and the southeast Asian part of Monsoon Asia share numerous common climatic, orogenic and agricultural conditions. Yet each region has different time, space and scale dimensions in those common conditions, such as the onset and offset of monsoons, the magnitude of rainfall, and the severity of dry periods. These differences result in very different hydrological and human co-existence schemes across Monsoon

Asia. This paper mainly describes Japanese conditions and extends the discussion to other parts of Monsoon Asia wherever appropriate.

Climatic and orogenic conditions

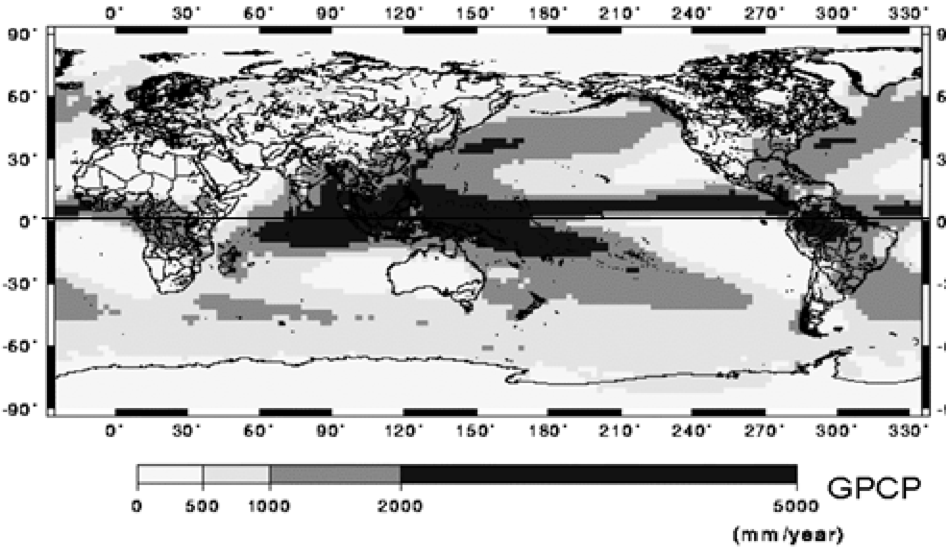
Figure 2.1 shows the annual precipitation estimates over the globe (Musiake, 2003) produced from the GPCP (GEWEX Precipitation Climatology Project) data and calculated using the method of Huffman *et al*. (1997). Southeast Asia, including the Western Pacific Ocean near the Equator, is the world's heaviest rainfall region. The Asian Monsoon region is part of Southeast Asia and the monsoon greatly effects the timing and the extension of rainfall across the region. The semiarid region in China is also strongly influenced by monsoon activities.

Climate is, however, not the only natural factor controlling the Asian Monsoon region. This region is also in the orogenically active zone, indicated in dark grey in Fig. 2.2 (Strahler & Strahler, 1992). Due to the orogenically active nature of the region, basins are mountainous and narrow, with steep slopes, extensive sediment production and regular slope failures. Obviously, living in an orogenically active region has a major effect on the way humans adjust to co-exist with nature. Due to the reliance on rice paddy agriculture, people live on the flood plains and therefore expose themselves to a high risk of flooding and major flood hazards when floods do occur, due to the high river gradients, which in turn are due to the orogenic conditions. Such conditions are common in many countries in Southeast, South and East Asia.

Extreme precipitation

As is seen in Fig. 2.1, Japan receives more precipitation than most other nations at similar latitudes. The main sources of Japan's precipitation are the "Baiu", typhoons and snowfall. Baiu is a Japanese pronunciation of the Chinese term "Meiyu" meaning "rain at the time of plum fruits", which is due to the Asian Monsoon. On average, the onset of Baiu is early June in Southern Kyushu (the southernmost main island of Japan) and the middle of June in Northern Honshu (the main island of Japan). The offset of Baiu usually occurs during the middle of July in Kyushu and towards the end of July in Northern Honshu (National Astronomical Observatory, 2004). The Baiu is not distinctly identifiable in Hokkaido (the northernmost main island of Japan) as it is too northern for the monsoon to dominate. The onset and offset dates are declared by the Japan Meteorological Agency (JMA) according to the position of the stationary front over the Japanese archipelago and the synoptic fields. The dates of Baiu and the amounts of rain vary a great deal every year. In extreme cases, there is almost no rain or conversely there are disastrous torrential rains.

Typhoons are tropical low pressure systems formed in the Northern Pacific Ocean west of the 180 meridian, with wind speeds of more than 17.2 m s^{-1}. According to the 1951–2004 records, the number of typhoons varied from 16 to 39 per year, of which about 11 came within 300 km of Japan and an average of 3 per year (range: 0 to 10 per year) actually passed over Japan. In 2004, a record number of 10 typhoons passed over Japan. This is more than triple the 1951–2004 average and almost double the previous record of 6 typhoons per year. There are two types of typhoon effects in Japan—wind and rain. When a typhoon passes over the Japan Sea (west of Japan), strong winds often hit Japan as the southeast part of typhoon vortex is accelerated by the typhoon



(Japan: 1,718mm (1971-2000) by AMeDAS)

Fig. 2.1 *Global distribution of mean annual precipitation (1979–1999) by GPCP (Musiake, 2003).*

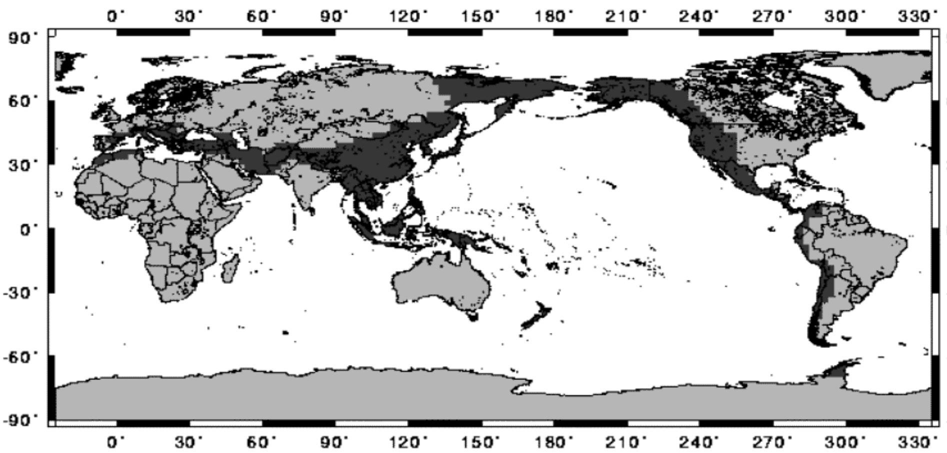


Fig. 2.2 *Global distribution of tectonic zones (indicated in dark grey) (Strahler & Strahler, 1992).*

translation to the north. However, when typhoons pass over the Pacific Ocean side of Japan, much rain is often brought to Japan, especially when low pressure activities over the islands are stimulated while the typhoon is approaching Japan. The heavy rainfall and powerful winds caused by typhoons result in many disasters across Japan.

The Japan Sea side of Honshu is the world's heaviest snowfall region. The accumulated snow pack sometimes reaches over 6 m. An example record was 6.62 m at Rokujuri-yama Snowfall Observatory, Yamagata, in 1963. People often have to use second floor windows to enter and exit their houses. Figure 2.3 shows how the heavy snow develops on the Japan Sea side of the islands. Siberian westerly winds in winter are moistened over the Japan Sea, then uplifted by the mountain ridges of the Japanese islands and this produces heavy snowfall. The stream of air continues to flow beyond the mountain ridges where very dry weather is brought to the Pacific Ocean side of Japan in winter.

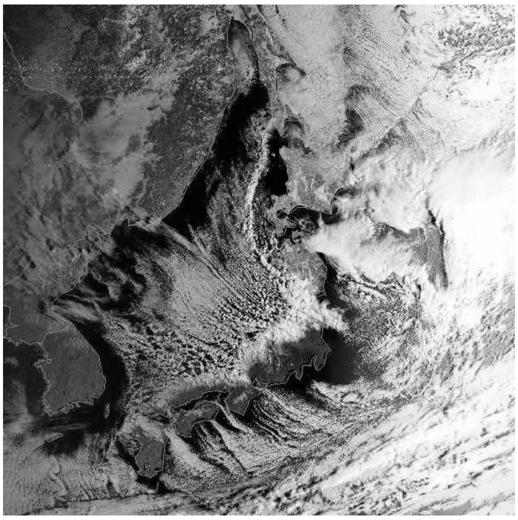


Fig. 2.3 *Typical winter cloud development over the Japan Sea and snowfall over Honshu Island. NOAA15, 08:00, 29 February 2000. (http://www.info.nara-k.ac.jp/~asai/hrpt_sample1.html)*

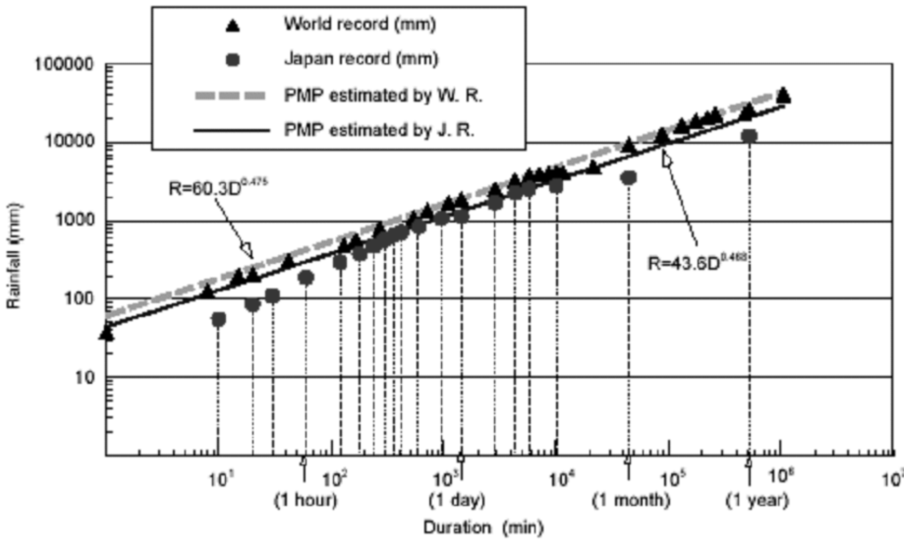


Fig. 2.4 *Maximum precipitation over different time periods for the world and Japan (Takara, 2002).*

The three sources of precipitation mentioned above are not only the cause of disasters but also provide water resources in Japan. If the precipitation is high, floods occur over any flat land. If the precipitation is low, drought and water shortage occur in many urban areas, especially in the western part of Japan. Takara (2002) produced Fig. 2.4 which shows Japanese records of rainfall intensity in relation to world records. Japanese rainfall intensity is very close to the highest in the world. It is especially high in the several hours to several days range, which is the most influential time length for flooding in Japan as rivers are short and basins are small due to the orogenic conditions of the region.

Precipitation observation and forecast

The observation and forecasting of rainfall is very important in Japanese flood management. The current progress in weather forecasting with 1–2 days lead time is remarkable, and based on current research, further improvement is expected in both short-term (i.e. a few hours to several hours) and long-term (i.e. a few weeks to several months) forecasts (JMA, 2005).

According to Nakao (2005), daily precipitation is measured at 8390 stations in Japan (as of 1 March 2005) of which 1321 are AMeDAS (Automated Meteorological Data Acquisition System) stations operated by the Japan Meteorological Agency (JMA), 2011 are operated by the River Bureau of the Ministry of Land, Infrastructure and Transport (MILT) (of which records at 393 stations are published by the River Bureau, MILT, 2001a), 3919 are operated by local governments, and 976 by the Highway Bureau of MILT. All the stations are integrated into FRICS (Federation of River Integrated Communication Service) and precipitation information is disseminated all over Japan.

Snowfall observations are difficult. Snowfall is measured by a tipping bucket, heated up to 5 ± 1°C (JMA, 2002). The snowfall is generally underestimated mainly because of wind but, to a small extent, also due to evaporation that occurs during heating. Kinosita (2000) examined the distribution of runoff ratios over Japan. Northern Japan, as well as the Japan Sea side, have distinctly higher runoff ratios with the majority being greater than 1 (i.e. discharge is greater than precipitation). This is partly because the AMeDAS observations stations are mostly distributed in low altitude areas where there is not as much precipitation as in high, mountainous areas. It is also because snowfall is not completely captured by the 20 cm tipping bucket gauges due to wind. No reliable correction method is available except the empirical formula developed by Yoshida (1959):

$$CR = 1/(1 + kU)$$

where CR is the fraction of snowfall captured by the tipping bucket over the corrected snowfall amount (corrected snowfall = measured snowfall/CR), U is wind speed (m s^{-1}) and k is an empirical coefficient of between 0.14 and 0.24 for most AMeDAS raingauges (Ohno *et al*., 1998).

There has been much effort to improve snow measurements utilizing radars to measure snowfall and ultrasonic or laser equipment to measure snow depth. However, radar measurements are not yet reliable, despite the extensive use of polarized radars (Yoshino, 2002).

Regarding discharge observations, according to Nakao (2005), there are 5088 river stage observation stations in Japan, of which 1760 are operated by the River Bureau of

MILT (records from 373 of these stations are published by Ryuryonenpyo; River Bureau, MILT, 2001b) and 3248 by local governments. There are a number of problems in quality assurance, such as poor maintenance of height staffs, poor measurement procedures, and errors in rating curve estimates, especially in the transition from low to high flow stages. Low flow is measured by propeller-type instruments and high flow by floats, which are totally different methods (Kinosita, 2005).

FLOOD MANAGEMENT IS THE MAJOR CONCERN

Floods are the major hazard in Japan and many other East, Southeast and South Asian countries that are affected by the Asian Monsoon, as well as typhoons and cyclones. Figure 2.5 (Takeuchi, 2001) indicates the death tolls and economic losses due to large floods during the 1990s across the world. The majority of large floods with large death tolls occur in Asia (dark circles), including China (grey squares). In China and Bangladesh especially, the death tolls are often many more than one thousand. In an extreme case, flooding caused by a storm surge from the Gulf of Bengal (Baba, 1991a,b) resulted in a death toll of 140 000 in Bangladesh in 1991. The two largest economic losses were experienced in China in 1996 and 1998, affecting more than two hundred million people on both occasions.

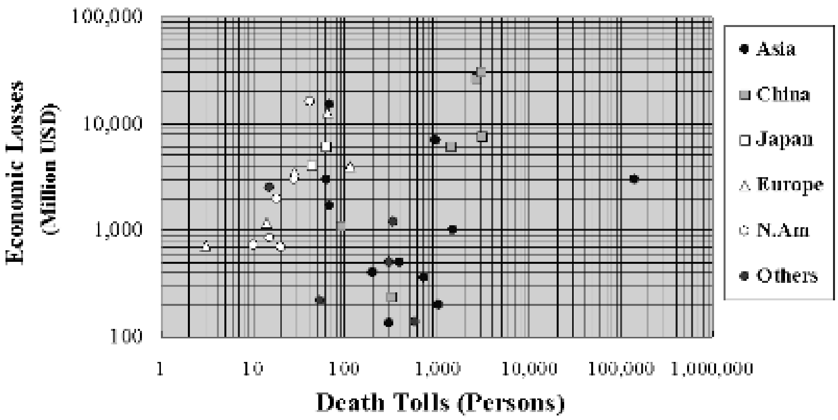


***Fig. 2.5** Human and economic losses of large floods in the 1990s based on data from Munic Re (1998) (Takeuchi, 2001).*

It should also be noted that Japan (white squares in Fig. 2.5) has many floods with less than a hundred deaths but high economic losses. It is true that even if extensive economic investment in flood control works reduces the death tolls, such structures cannot substantially reduce the economic losses. This is because the area protected by flood control works is considered “safe”, and so becomes populated and economic activity intensifies. In other words, the damage potential of the flood plain increases. If floods occur under such circumstances, either due to extremely high precipitation or some failure of control works, even if the flooding is only minor, the ensuing damage is quite often greater than would have been the case without flood control in the first place. Many developed countries (all white symbols in Fig. 2.5) continue to suffer severe flood-caused economic losses (and still many deaths) for precisely this reason. In addition, the frequency and severity of flooding seem to be magnified by the current intensification of global warming.

The Japanese experience with flood management in the last century provides many lessons, both good and bad, for other Monsoon Asian countries, especially those which are rapidly developing their population, economy and urbanization, as Japan did over the last century. As is seen in Fig. 2.6, immediately after World War II, Japan was hit by a series of large floods, each causing catastrophic damage. The reasons were considered to be at least three-fold. Little flood control investment was made during the war. The period after World War II in the late 1940s and 1950s was abnormally wet, with a number of large typhoons hitting the Japanese archipelago. Less advanced weather forecasting and the lack of effective information dissemination also greatly contributed to the flood damages during the immediate post-war period extremely high. Since the most devastating flood in 1959, which took more than 5000 lives, the annual death tolls have decreased and have never been more than 1000 per year since. This is because the three problems identified above (i.e. lack of flood control investment, climatically wet period and poor weather forecasts/information dissemination) were all tackled, especially the better dissemination of weather information by television and other mass media, supported by advances in weather forecasting.

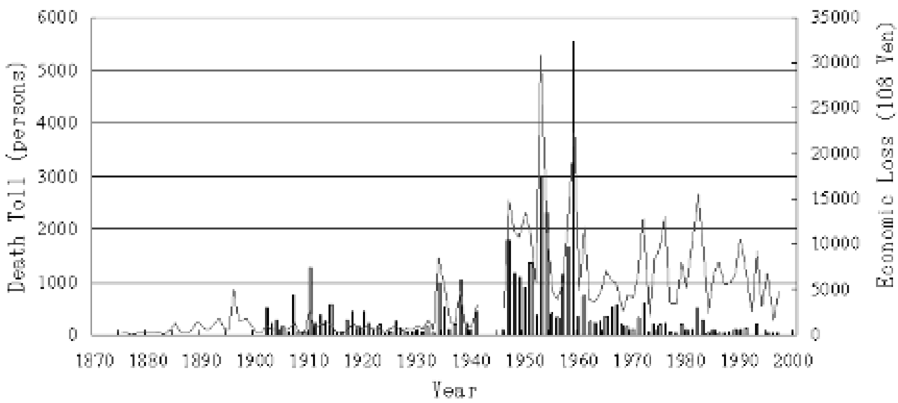


Fig. 2.6 *Human (columns) and economic (broken line) losses due to floods in Japan. Based on data from the Ministry of Construction (1997) (Takeuchi, 2001).*

It should be noted that the death tolls have never been truly eliminated and there are still, quite often, more than a couple of hundred deaths per year. This is because a significant number of deaths occur due to landslides, slope failures and debris flows where urban residential areas have expanded. Unfortunately, neither can readily be predicted nor controlled. Also, new types of urban floods are endangering people and property in city areas. These urban floods include floods in underground shopping malls and train stations, and damage to high-tech lifelines. Large river floods also seem to once again be threatening Japan as global warming develops. Thus we have a number of challenging scientific agenda including the forecasting of typhoons and heavy rains, of slope failures, of urban floods including underground inundation, waste water contamination by sewage, high-tech chemicals, etc.

The other lesson that Japan shares with other countries is the increase in the cost of maintaining high level protection from floods. As reported by Takeuchi (2002), Japanese flood control investments, mainly based on physical means, are 0.8–0.9% of GDP to realize flood damage losses as small as 0.1–0.2% of GDP. Much of that damage is to the control works themselves in rivers and protected areas. This expenditure is fine as long as the national economy can afford it and as long as the control works are ecologically acceptable. However, under budgetary pressures due to increasing welfare and environmental expenditure, the government has to find less costly and more ecologically friendly solutions to flood management. A wise way of living with floods obviously requires more accurate hydro-meteorological information, both in frequency prediction and real time forecasts.

PUB AGENDA RELEVANT TO JAPAN AND MONSOON ASIA

The PUB agenda that Japanese hydrologists and those in Monsoon Asia consider important, are related to the problems of the region described above. Hydrology is supported and relied upon by the nation if it can help to provide solutions to urgent societal problems. Hydrological predictions are the basis for flood damage mitigation, risk management, environmental control, ecological protection and of efforts for man–nature co-existence in the region. The use of the best available technology, monitoring of natural and human activities, and interpretation of theoretical knowledge so that it can be put into practice, are much awaited everywhere in the world. The following are PUB agenda relevant to any hydrologists but in particular, to those in Japan and Monsoon Asia:

Hydro-meteorological prediction Precipitation forecasts are essential to integrated water resources management and especially for disaster management, efficient reservoir operation, etc.

Meteorological regional models, such as NHM, RAMS, MM5, ARPS and WRF, are not only for meteorologists but also for hydrologists, and they can contribute to improving these models by developing better expressions of landscape heterogeneity, raindrop distribution, and various SVAT (soil–vegetation–atmosphere transfer) schemes.

Land surface models (LSM) such as BATS and Sib developed for GCMs are getting closer to the precipitation–runoff models developed for river basin management. The former focuses on the vertical motion of water while the latter on horizontal motion. Their merger with distributed hydrological models improves their respective performance.

Accurate snow measurements Study and measurements are necessary to resolve the fact that discharge from snow-rich areas exceeds the observed precipitation (Kinosita, 2000). New technology is necessary on the ground and in space to measure solid precipitation.

Prediction of landslides and debris flows A slope failure type equation should be developed as part of a sediment production formula for the orogenically active region. Extended application of the USLE (Universal Soil Loss equation) in such regions is popular but not proper. Current tank model and snake curve approaches to predict slope failure are too uncertain and need major scientific attention (Terada & Nakaya, 2001; Okada, 2002).

Up-to-date use of flood/drought frequency analyses in this era of climatic change Frequency analyses are still necessary for water management, but the approach is losing its basis due to climatic variation. An effective and up-to-date methodology is needed to utilize the large stock of statistical knowledge relating to flood/drought risk that has been accumulated in the past several decades.

Physically based distributed hydrological (DHM) models There are many ungauged basins in the region, humid or dry, where data are urgently needed for basin management. The use of satellite measurements and their physical interpretation over such ungauged basins should be utilized in DHMs.

In order to make the hydrological simulation useful to basin management, it is necessary for models to simulate the impact of human activities on the natural flow regime. Information regarding the hydrological phenomena and water-use systems peculiar to the Asian Monsoon region, such as flood inundation, paddy fields, flood irrigation, sediment yields, is also necessary. DHMs must simulate those phenomena at any internal points.

Downscaling of the global research products into locally useful information There are an increasing number of global studies but not enough effort is spent transforming the results of these studies into locally useful information. Downscaling can be achieved in several ways, in addition to the use of meteorological regional simulation models as listed above, such as:

– Finer observations by satellites and ground measurements. The GEOSS (global Earth observation system of systems) 10-year implementation plan (2005–2015) will be a good chance to pursue this direction.
– Utilizing DHMs to interpolate large-scale meteorological information to finer scale hydrological information.
– Statistical and geometric interpolation methods such as kriging and co-kriging, often integrated with various GIS information.
– Stochastic data generation methods by preserving the temporal and spatial correlation structure.

Identification of predictive uncertainty Development of a proper indicator to assess the predictive uncertainty by which the performance of prediction models can be measured and compared. Uncertainty analyses of model parameters and model structures are relatively advanced but uncertainty measurement/quantification for input data is the virgin area.

Connection of the Hydro Simulator with the Earth Simulator to interpret global research results and make them useful to local people Recent parallel vector supercomputers of the distributed-memory type, such as the Earth Simulator of JAMSTEC (Japan Agency for Marine-Earth Science and Technology), can run GCMs with DHMs that can directly interpret the global research results to a form useful for people working locally in basins across the world. It has 51 208 vector-type arithmetic processors with 10 Terra byte of memory and the theoretical performance of 40 Terra flops, all targeted at creating a "virtual Earth" within the computer (Earth Simulator Center, 2004).

CONCLUDING REMARKS

PUB is a science driven but policy relevant programme. PUB faces the reality of the world where people are suffering from poverty, disasters, environmental degradation and other sorts of difficulties. Water is a significant factor in their difficulties. Water is essential to sustainable development and politicians are aware of this, as indicated by established international polices such as the UN Millennium Development Goals (UN, 2000) and the implementation plan of the World Summit on Sustainable Development (UN, 2002) (cf. Takeuchi, 2004). PUB has to respond to these political agenda and contribute so that their objectives can be achieved.

For this very reason, PUB needs to be developed with capacity building programmes as it has to close the science gap between the "haves" and "have nots" rather than widen it. An example of an attempt to implement capacity building and PUB is the University of Yamanashi's 21st Century COE (Center of Excellence) "Research and Education on Integrated River Basin Management in the Asian Monsoon Region" Virtual Academy that offers an e-learning course on its DHM to anyone wishing to participate (http://www.coe.yamanashi.ac.jp/~coe/).

Monsoon Asia shares many common problems inherent to the regional climatic, orogenic and societal characteristics. This is an area where experience should be shared and through collaboration water resources management practices can be improved. At the same time, this is the area where hydrological prediction can save many lives and a great deal of properties. The Asian Monsoon area is unique enough in hydrological processes and water use to be able to bring new and useful findings to hydrological science.

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