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Research initiatives in Thailand on Predictions in Ungauged Basins

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Abstract Thailand is severely affected by water related problems and disasters. Due to frequent water related disasters and high stress on available water resources by ever increasing demands in various sectors, short-term forecasting and long-term predictions of hydrological characteristics of different river basins are urgently needed in Thailand. So far, the success of predictions has been very limited due to uncertainties associated with inadequate data and inefficient tools and techniques. With the realization that the new decadal initiative of the International Association of Hydrological Science (IAHS) for Predictions in Ungauged Basins (PUB) can contribute significantly towards improving the hydrological predictions, which is very timely and relevant for Thailand, a group of researchers from several institutes of Thailand took the initiative to bring together interested researchers, practitioners and decision makers in the fields of hydrology and water resources to work together in areas of hydrological predictions in Thailand. The first official meeting for initiating PUB related research in Thailand was held at the Asian Institute of Technology (AIT), Bangkok, on 9 September 2004. It generated enormous interest among the participants and the message spread very fast to various institutions. Within a short time span, the members of the group involved in PUB Thailand have become more than 30 from 10 institutions. This paper presents an overview of the PUB activities in Thailand and briefly describes some of the on-going research projects under the two working groups that have been formulated to coordinate the PUB research in Thailand.

Key words Thai PUB; hydrological prediction; water resources; Thailand

INTRODUCTION

Thailand is a tropical country located in the southeastern region of the Asian Continent with a land area of 512 000 km^2 and a population of 65 million (as of 2000) (Fig. 1). The annual average rainfall varies widely from north to south and east to west ranging from 1240 to 2720 mm year^{-1}. The heterogeneous rainfall pattern affects the water resources distribution in Thailand. The country can be divided into five major regions for water resources distribution as shown in Table 1. Thailand had an abundance of water resources in the past. It embarked on water resources development 100 years ago, which can be divided into three stages as follows:

– 1st stage: construction and dredging of canals for irrigation, drainage and navigation;

Fig. 1 Map of Thailand.

Table 1 Distribution of water resources in different regions of Thailand.

Region	Area in km^2	Area in % of total country area	Annual runoff in MCM	in % of country runoff
North	148 868	29.1	36 440	18
Northeast	168 846	33.0	43 469	22
Central	78 459	14.3	21 804	10
East	36 448	11.0	21 218	10
South	84 450	16.5	75 660	38

– 2nd stage: construction of reservoirs, diversion weirs, hydropower plants and large scale irrigation projects; and
– 3rd stage in the last 20 years: small-scale water resources development projects to provide basic water supply for rural populations.

During this period, 392 large and medium scale reservoirs have been built with a total capacity of 68 000 MCM and 10 000 small-scale projects including dams, weirs,

ponds, shallow and deep wells were constructed. About 21% of total farming areas (4.5 million ha) are irrigated and more than 80% of the rural population gets a basic water supply. Together with the positive contributions that these developments have made to the overall economic progress and prosperity of the country, many negative consequences have also resulted from these developments, such as water quality degradation, water shortages due to changes in climate and over-use, and the lack of an appropriate institutional framework for the proper planning and management of water resources. Most of the development plans in the past have been short-term goal oriented without adequate focus on long-term developments in various sectors and their consequences (Tingsanchali, 2003).

Thailand is located in the Asian monsoon region. The Asian monsoon is one of the most vigorous circulation systems in existence over the globe. Its seasonal changes dominate the local climate over the Asian continent. The Asian Monsoon region is seen as a hot spot in the context of global climate changes. There is increasing evidence that demonstrates the Asian monsoon's important role in global climate changes such as the El Nino (Murakami, 1992). Flood and drought problems in Thailand are perennial and produce tremendous losses, as shown in Fig. 2. In recent years, floods and droughts have been rapidly increasing in different parts of the country and their magnitudes and impacts are escalating. Thailand shows a higher rate of increase of flood frequency compared to its neighbouring countries in the last 15 years (Dutta, 2003). Land-use change and urbanization are the main causes of the increasing floods in Thailand and it is further influenced by climate change in recent years. Between 1976 and 1989, Thailand lost 28% of its forest cover mainly due to illegal logging. Kanae *et al.*, 2001 showed that deforestation has greatly influenced the changes in rainfall patterns in Thailand. Effects of climate change, especially the rise of sea level, are going to be significant in the coastal belt of Thailand (Dutta & Niu, 2005).

Approximately 76% of the total 9.2 million ha of rice growing areas in Thailand are under rainfed conditions. Of the three rainfed rice ecosystems, upland, lowland and deep water, rainfed lowland occupies 6.8 million ha (OAE, 2001). Most areas of rainfed lowland rice in northeast (NE) and northern (N) Thailand are classified as

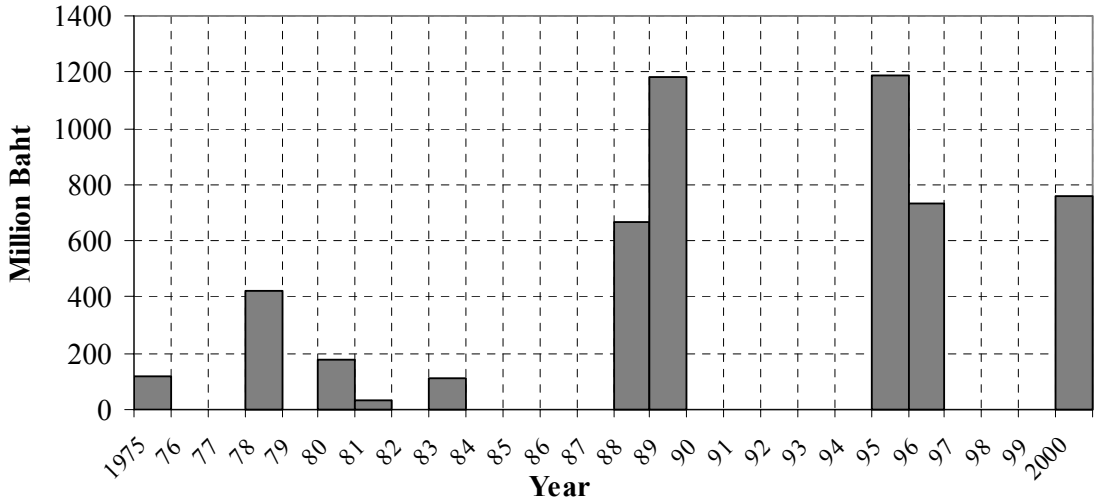

Fig. 2 Total direct tangible flood damage in Thailand during 1975–2000.

shallow favourable and shallow drought-prone (IRRI, 1996). Several constraints limiting production of rainfed lowland rice in NE and N have been recognized. Early-season drought occurs in most areas, affecting timely transplanting of seedlings and the growth of direct seeded rice. Late season drought develops in most years at the end of the rainy season before crop maturation, particularly for paddy rice in a high toposequence position (Jongdee, 2001; Jongdee, *et al.*, 2004).

An integrated water resources management approach with structural and non-structural measures for basin-wide development is needed to tackle complex issues of water management and water related natural disaster risk reduction. Short-term and long-term predictions of hydrological characteristics of different river basins are necessary for that. There have been several studies conducted with various tools for prediction of flows in river basins by some researchers but in an *ad hoc* manner. So far, the accuracy of predictions has been very limited due to the uncertainties caused by inadequate data and inefficient tools and techniques. There has been a growing realization of the need for collaborative and concerted efforts amongst hydrologists and meteorologists affiliated with government agencies and academic institutions of the country towards reduction of predictive uncertainties.

PUB INITIATIVES IN THAILAND

In 2003, the International Association of Hydrological Sciences (IAHS) initiated a decade long programme for Predictions in Ungauged Basin (PUB). Predictions of Ungauged Basins (PUB) is the most recent initiative of the IAHS, a celebrated policy-relevant science initiative that arose out of free discussion by IAHS members based on recognition of current needs of the world, especially of developing countries, and a scientific readiness to make a new commitment. (PUB SSG, 2003; Sivapalan *et al.*, 2003). It addresses challenging and exciting scientific problems and addresses an urgent practical problem, of immediate relevance to society, dealing with questions such as the impacts of land use and climate changes, biodiversity and sustainable development (Sivapalan, 2003).

This exciting scientific initiative inspired researchers from several leading academic institutions of the country to initiate joint research activities to improve hydrological predictions in Thailand. With the realization that the IAHS PUB could contribute significantly towards improving the existing knowledge and techniques for hydrological predictions in Thailand, the group led brainstorming discussions to explore the possibility of organizing a group of researchers to work on it. After several rounds of discussions and brainstorming, a meeting was called at the Asian Institute Technology (AIT) to discuss the formation of a Thai PUB research group. The main objectives of the first meeting were to discuss the needs of IAHS PUB related research in Thailand and in the region, and to find out common areas of research interests that can be undertaken under the umbrella of PUB in Thailand and the region. The meeting was attended by a total of 14 researchers from seven universities and organizations of Thailand, and an invited speaker from the University of Tokyo, Japan. The need for PUB and its relevance to Thailand were debated at length in the meeting. At the end of the discussion, there was unanimous agreement that the IAHS PUB was a timely,

important and relevant initiative and that there was a definite need for PUB in Thailand. The team identified several thematic areas of research interests that were highly relevant, not only to Thailand but also to the other countries of the southeast Asian region. Follow-up discussions were carried out in the second meeting that was held at the Thammasat University (TU) on 15 October 2004. The number of participants in the second meeting was almost double that of the first meeting and generated tremendous enthusiasm among the participants towards the formation of a focused and independent research group to work together on urgent issues of water resources management in Thailand under a changing environment. In the meeting, discussions were carried out regarding formation of PUB working groups and long-term objectives, agenda and goals for these working groups.

FORMULATIONS OF WORKING GROUPS

After long deliberations in the first and second official meetings, several thematic areas were identified as focused areas of research and implementation under this initiative. Based on the similarities and objectives, these thematic areas were lumped into two broad themes to focus on the reduction of uncertainties in data and to improve the predictive capabilities of existing tools and techniques. Two working groups were formulated to work on these areas. The Working Group 1 (WG1) was formed to work on the reduction of "Uncertainties in Data and Prediction of Extreme Events" that included five thematic areas: (1) data uncertainty; (2) rainfall predictions; (3) extreme events; (4) optimization; and (5) stochastic modelling. The Working Group 2 (WG2) decided to focus on reduction of uncertainties in "Hydrological Modelling and Impact Analysis" that included the seven themes: (1) physically based hydrological modelling; (2) climate and land-use change and society; (3) nonpoint source pollution; (4) anthropogenic effects; (5) conceptual modelling/innovative modelling; (6) top-down approach to modelling/downscaling; (7) urbanization.

AIT was identified as the central node to coordinate the overall activities of PUB Thailand, including the networking and research collaboration with international organizations and IAHS PUB teams from other countries in Asia.

Subsequently, research frameworks for the two WGs were developed in the WG meetings to cover various themes and two team leaders were identified to coordinate the activities of the WGs under the frameworks developed. The summary report of the working groups, participating members and their research plans are presented in the next sections.

Working Group 1 (WG1): uncertainties in data and prediction of extreme events

The main objectives of the WG1 are to:

- quantify the uncertainty inherent to the observed records of hydrological phenomena; and
- propose innovative prediction and optimization techniques that can reduce the uncertainties of existing methods.

The WG1 consists of nine participants from four institutes, namely: AIT, Mahanakorn University of Technology (MUT), Thai Meteorological Departments (TMD) and TU and the group activities are coordinated by TU.

The research topics that are identified under WG1 research activities are as follows:

- Data uncertainty: Spatial heterogeneity
- Rainfall prediction: RS radar
- Extreme events
- Optimization
- Stochastic modelling

The detailed research topics and synopsis prepared by several WG1 members to carry out research covering some of the aforementioned themes are as follows:

A Dynamic Programming (DP) for searching the optimal rule curves of a reservoir system (by TU) Rule curves of a reservoir system are necessary monthly guides to those responsible for reservoir operation. Often, reservoir simulations compare several trial rule curves and specified water demands are used to search for the optimal rule curve. Unfortunately, depending on the experience of the engineer who chooses the curves, its solutions are often approximate. To obtain optimal solutions, this study thus considers the search for the rule curve as a staged problem, and formulates it using dynamic programming (DP). The principle of progressive optimality (PPO) is proposed to find the solution of the formulated DP problem because the PPO algorithm avoids the searching of unnecessary or infeasible states, and thus reaches a global optimum faster. The PPO algorithm will be examined in terms of its feasibility for a system of reservoirs in the Chao Phraya River basin. The results of a preliminary study related to this topic were presented in a technical seminar held on 30 August 2004 at TU. Many participants attended the seminar, and staff from the Electricity Generating Authority of Thailand (EGAT) expressed their interest and willingness to collaborate on this research topic.

Radar rainfall forecasting for Bangkok Metropolitan area (by MUT) Bangkok is known as one of the cities with a high flooding risk because of several reasons. These include: the city's rapid urbanization, the Chao Praya River inflow from the north of Thailand, an inadequate drainage capacity, backwater from the tidal effects of the Gulf of Thailand and increase of groundwater consumption causing more land subsidence and subsequent reduced drainage capacity. Flooding in Bangkok has high negative socio-economic and environmental impacts. The efficiency of the flood forecasting system of Bangkok Metropolitan area needs to be improved for minimizing the negative impacts. Rainfall forecast is an important part of the flood forecasting. The flood forecasting system will only be successful in providing vital early warning if rainfall forecast inputs are sufficiently accurate and definitive. Weather radar can sense spatial and temporal distributions of rainfall in real time, and when properly calibrated with raingauge data, can provide the hydrologist with reasonably accurate spatial and temporal patterns of storm events. It also has the potential to improve rainfall forecasting for a few hours ahead (nowcasting), and consequently to improve warnings of severe storms and floods. For this reason, it is useful to link radar rainfall forecast model with rainfall runoff models into an integrated forecast system. This research

focuses on investigating a procedure to improve the radar rainfall estimation system so that it is capable of quantitative rainfall estimation and to develop an end-to-end rainfall forecasting system for Bangkok.

Synthetic daily streamflow for ungauged basins in Thailand (by TU): Insufficient streamflow gauging stations in Thailand causes difficulty in hydrological analysis for water resources development, planning and management, particularly in remote urban areas. In order to overcome such difficulty, the study aims to develop a model which is able to synthesize daily streamflow for ungauged basins by using model parameters estimated from physical characteristics of a basin. A synthetic storage routing model coupled with loss mechanisms was selected for simulation of rainfall runoff relationships since this model is quite practical for engineering purposes with only three parameters to be estimated and providing quite satisfactory results in many river basins in Japan. Relationships between optimum model parameters and physical characteristics of a basin will be investigated in order to formulate simple model parameter estimation formulae. Some river basins in Thailand will be selected for further study as a part this research. Finally, verification of model applicability will be conducted in some river basins in Thailand.

Quantitative spatial rainfall estimation by using geostationary meteorological satellite (by TMD): Thailand is located in the N–S elongated direction over the tropical Indo-China peninsula and is influenced by rainfall from monsoons and tropical storms. The sparseness of the ground-based rainfall observational network is one of the reasons for difficulties in disaster monitoring, prediction and mitigation. TMD has established a radar network with a footprint tentatively covering the whole country, however, the frequent malfunctioning of the system and its limitation over the mountain terrain regions hinder its utilization in conventional operations. A predictive kind of rainfall forecasting in ungauged basins with remote sensing using satellite technology is the most important and attractive new opportunity for the region. The Tropical Rainfall Measuring Mission (TRMM) satellite project has established the first Active Microwave Precipitation Radar (PR) on-board as the first space weather surveillance radar station. The main objective of this study is to establish a relationship between rainfall intensity and cloud top temperature using TRMM and utilize it to investigate the quantitative rainfall characteristics derived from the Geostationary Meteorological Satellite. The outcomes of the study will be useful to generate a database of rainfall of high spatial resolution that can be utilized for water resources analysis and disaster monitoring in Thailand.

Working Group 2 (WG2): hydrological modelling and impacts

The main objectives of WG2 are to:

- seek for the better understanding of runoff response to contribute to a more reliable assessment of the impacts of climate and land-use changes (e.g. anthropogenic, deforestation, urbanization);
- obtain more accurate prediction of the effects of the above mentioned changes on the catchment responses; and

– improve process understanding to assist in dealing with the PUB problem and the extrapolation of flood, drought and salinity intrusion to ungauged catchments

The WG2 is coordinated by the Mahanakorn University of Technology (MUT). At present, the group consists of 13 members from eight institutes, namely: AIT, Kasesert University (KU), King Mongkut Institute of Technology (KMIT), MUT, Suranaree University of Technology (SUT), Kasesert University (KU), Royal Irrigation Department (RID), TMD and TU.

The research topics that are identified under WG2 research activities are as follows:

– Physically based hydrological modelling
– Climate and land use change and society
– Non-point source pollution
– Anthropogenic effects
– Conceptual modelling/Innovative modelling
– Top-down approach modelling/downscaling
– Urbanization

Some of the research subjects and synopsis proposed by several WG2 members to carry out research covering the above mentioned topics are presented below.

Comparison study in impact of large reservoir developments on flow regimes (by MUT) The impact of large reservoir development to the adjustment of the flow regime was preliminarily investigated using the Sirikit dam in the Nan River basin, north of Thailand, as a case of study. Analysis of pre- and post-dam hydrological records indicated that the impoundment and the amount of rainfall are one of the major causes of change in the flow regime downstream of the reservoir. But, the post-flow annual hydrograph change, especially the reduction of mean monthly peak runoff magnitude and the higher flow during the low flow period, mainly results from the impact of large reservoir development. However, these overall results are based on a single large storage. For better understanding the response of flow to the large reservoir, comparison studies should include a range of dam types and catchment characteristics. Some other factors affected, such as the frequency of flood and drought, shift in low flow, timing of high and low flow or change across different flow duration, should also be further investigated. In addition, the study should include the effect of spatial controls. Without these controls, long-term change in the flow regime caused by change of climate or land use may be incorrectly ignored. To cope with the misleading problem due to lack of spatial control, focus should be made also on the un-impounded river basin.

Space-Time variability of hydrological responses (flood, drought and salinity) and role of catchment water balance: downward approach to hydrological model development (by SUT) Predictions of floods, droughts and salinity, and of water quantity and quality cannot be made without a deep understanding of the climate, vegetation, soil and topographic controls on the water balance. Significant human-induced land use changes currently impact on the water yield of catchments causing high uncertainty of predictive results based on a calibrated model. The understanding of process controls on the catchment water balance is initially necessary and is a prerequisite of flood, drought and salinity problem solving. A systematic "downward"

approach for formulation of hydrological models of appropriate complexity is presented based on an investigation of the climate, soil and vegetation controls on water balance. Starting with a simple model, complexity is added in steps, with the models tested progressively against signatures of runoff variability at each time scale. The movement of soil salinity leads to the expansion of surface salt-affected soil in a catchment which depends on the changing of water flow paths between the surface and subsurface, and within the hillslope. This movement is not only driven by topography but also climate and land-use change.

Analysis of dominant processes and scaling behaviour in river flow simulation in grid based physically-based hydrological modelling in Chao Phraya River Basin (by AIT) Prediction of river flow is important for efficient management of water resources in Thailand. Physically based distributed models can be considered as a suitable tool for river flow simulation and prediction, however, for long-term simulation and prediction of river flow in various parts of a river basin, clear understanding of dominant hydrological processes are important, which vary from region to region. In this research, a distributed hydrological model will be applied for river flow simulation in the Chao Phraya River basin for developing clear understanding of dominant processes in river flow behaviour, and the knowledge will be transferred for flow prediction in ungauged basins in Thailand. The model adopted for this study is a raster-based distributed hydrological model developed at the University of Tokyo, Japan. Scaling behaviours of the grid-based model will be analysed to determine the most effective grid sizes for flow simulation in river basins of different sizes. Utilizing various available and collected datasets, a detailed study will be conducted in the Yom River watershed, a sub basin of the Chao Phraya River basin and a test basin of Thai PUB Research.

Comparative study of different approaches to non point source (NPS) pollution modelling in selected watersheds in tropical environments (by AIT): Watershed models are effective and useful tools in planning, development and management. Recent research carried out at AIT on evaluation of non point source (NPS) pollution models (AGNPS, AnnAGNPS, EPIC, others) developed in the US and Europe indicated that these models, when applied in tropical watersheds in Thailand and Nepal, have performed well with respect to simulating runoff volumes. But, the computed peak flows and sediment yields computed by these models are as high as 2- to 5-fold of the observed values. Satisfactory prediction of sediment and nutrient (N, P and K) transport in watersheds is essential to come up with best management practices and to develop strategies for soil, water and nutrient conservation to improve watershed health.

Researchers in developing countries like Thailand are always affected by chronic problem of limited financial resources to initiate new research projects. Within the limited financial and other resources, the aforementioned topics have been identified by the individual members of the Thai PUB working groups based on their on-going research projects. Research activities in some of these topics have already been initiated and several members of the two groups have presented preliminary research outcomes in a recently held international conference at AIT (Chaleeraktrakoon & Yaklay, 2005; Einfalt *et al.*, 2005; Jothityangkoon, *et al.*, 2005). The group plans to

look for various possible sources of funding to initiate collaborative research in areas identified under the two working groups to address some of the core issues of PUB in the region. After successful completion of the proposed research works in the test basin by the working groups, the tested methodologies and models will be utilized for applications in the ungauged basins in different parts of the country to transfer predictive knowledge and then to other countries of South-East Asia, where most of the basins are ungauged.

PUB TEST BASIN IN THAILAND

The Yom River Basin, a sub-catchment of the Chao Phraya River Catchment, which is frequently affected by floods and droughts, is identified as the test basin for conducting research under the two working groups of Thai PUB. The Yom River basin is located in the central-northern part of Thailand between longitude 99.5°E to 100.5°E and latitude 15.6°N to 19.4°N (Fig. 3). The basin is 19 516 km^2 large with an average

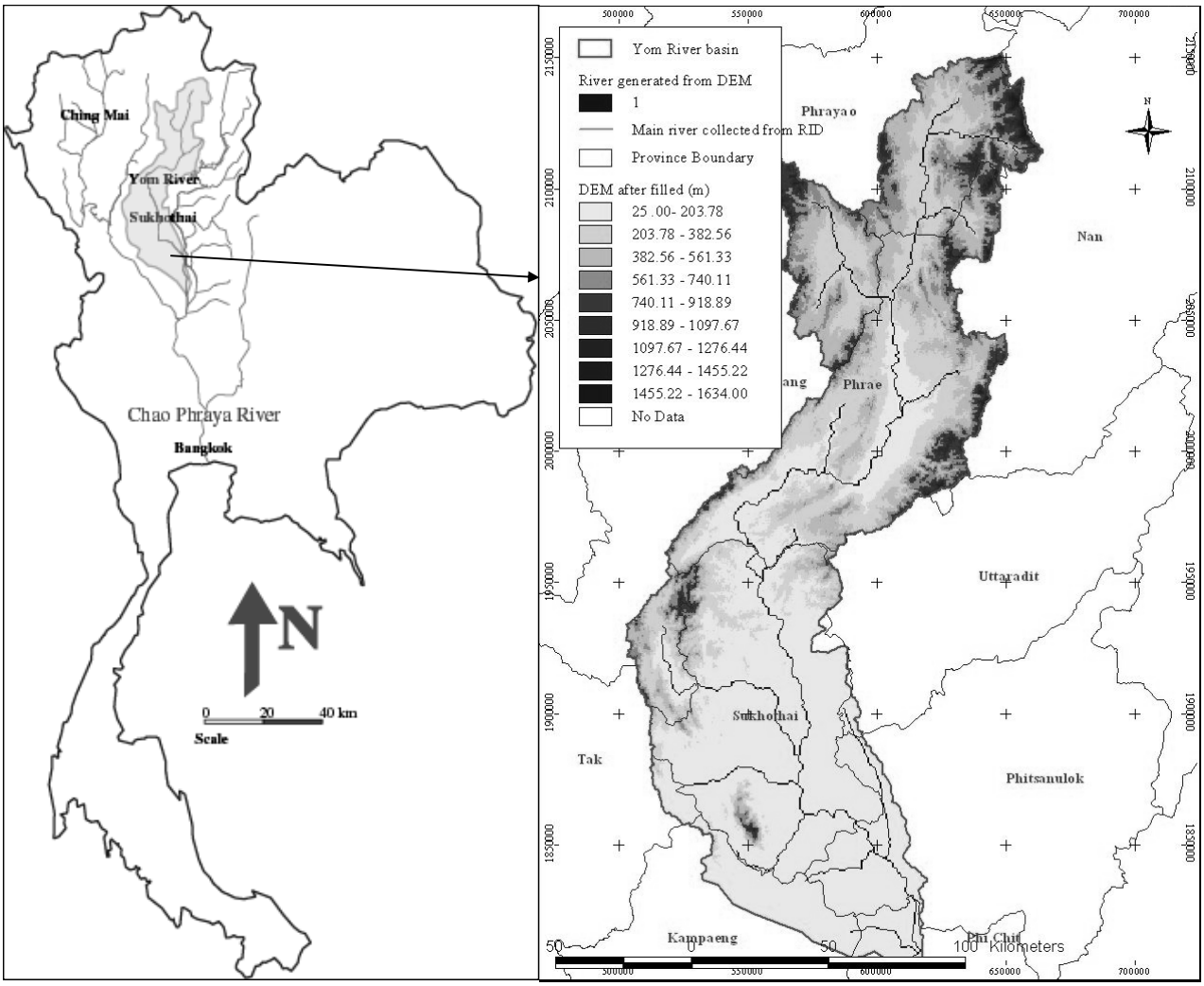

Fig. 3 Location of the Yom River basin.

annual discharge of 3684 cumec. It is one of the most frequently flood-affected river basins in Thailand with the absence of any major reservoir. Various hydrological temporal and spatial data are being collected for development of a comprehensive database for utilization in different research activities. Several monitoring stations have been established for measuring rainfalls with high temporal resolutions. The existing spatio-temporal data has been compiled at the central node to make those available to all the members.

INFORMATION DISSEMINATION

A web-based portal has been developed for the Thai PUB for regular communication and exchange of ideas among its members and sharing data and information for research. The internet portal has been established at the web server of AIT (http://www.-sce.ait.ac.th/rnus/pubthai/) (Fig. 4). The website provides a discussion page and a web-based mailing list for regular interactions and exchange of ideas among the members of the group. It provides detailed information on history of Thai PUB, chronology of the activities and the progress of the WG research. All the collected datasets of the

Fig. 4 Front page of the PUB Thailand homepage.

PUB test basin will be uploaded into this website in the near future, for easy access by the members. It is expected that the website will strengthen the networking of the group.

INTERNATIONAL COOPERATION

The Thai PUB is built on the very essence of IAHS PUB to strengthen the regional and international collaboration among the hydrologists to work together on the complex issues of reduction of predictive uncertainties in ungauged basins. The idea of forming a PUB group in Thailand first came up in an informal meeting among several researchers from Thailand and Japan in 2003. The idea was well received at the Australia-Japan PUB Workshop held in Perth in February 2004. The sincere effort of the organizer of the workshop to bring the researchers from Thailand to that meeting sent a strong message of solidarity and encouragement of IAHS PUB to Thailand.

Since its inception, the Thai PUB has been working closing with the Japanese PUB. The first meeting of Thai PUB was attended by a member of Japanese PUB. The IAHS President and the leader of Japanese PUB, Prof. K. Takeuchi attended the third meeting of Thai PUB in December 2003. He gave an overview of IAHS PUB and its worldwide activities and encouraged the Thai PUB to collaborate with Japanese and other PUB groups.

The Thai PUB group has been proactive in its efforts to link it with other Asian PUB groups. Several members of the Thai PUB participated in some of the regional PUB workshops including the PUB Sessions at the "International Conference on Sustainable Water Resources Management in Changing Environment of the Monsoon (WRMinCE)" in Colombo, Sri Lanka in November 2004, and the "Interdisciplinary Workshop on Multi-scale Governance of Forests, Village and Water in the Upper Ping River Basin, Northern Thailand" in Chiang Mai, Thailand in March 2005. These meetings brought the opportunity for the group to interact with the PUB groups of other Asian countries. The two working groups of Thai PUB have already initiated dialogues with Japanese PUB groups for sharing data, tools, knowledge and work together in some issues of common interests.

The VII IAHS assembly brought an important opportunity for the group to put itself in the radar of worldwide PUB. The presentation on the Thai PUB was well received in the conference and it helped the group to interact with the PUB groups of other continents as well. Since the assembly, a discussion has been ongoing to link Thai PUB with the PUB Top-Down modelling Working Group (TDWG).

CONCLUDING REMARKS

In recent years, Thailand has been facing serious problems of water-related disasters and inefficient management of its water resources. The problems have been intensified due to urbanization and climate change. The efficient scientific solutions to tackle the complex issues of water such as long-term predictions of river flows and quantification of the distribution of water resources in changing environments, are essential for sustainable development and environmental management. The present research level in

areas of hydrology and water resources in Thailand is handicapped by limited financial resources and lack of incentives. So far, applied hydrological research in Thailand is dominated by borrowed technology from donor countries and local know-how is not integrated. The IAHS PUB has generated tremendous enthusiasm among the hydrologists in Thailand and that has led to formulation of the PUB Thailand. The group consists of both research and government agencies and has identified some of the most important areas of research that are highly relevant to Thailand and the southeast Asia region. The group aims at overcoming the challenges of hydrological predictions in collaboration with IAHS PUB for socio-economic development and sustainable management of water resources.

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