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Water Budgets and Water Regions: Planning and Managing Water Resources Development in Thailand

Donald Alford* addresses some long-held notions about water supply and water use, gives hydrological analyses of the Chao Phraya river system, and provides recommendations for improved water planning and management in Thailand

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***"It is important to distinguish between what 'everybody knows' and what is empirically established. 'Everybody knows' that ... population pressure has been increasing rapidly; that people need fuel and animals need fodder; that too many trees have been felled and that, as a result, runoff rates have accelerated, silt loads have increased, downstream canals and rivers have been clogged, flooding has had greater destructive effect, and the topsoil of the mountains has been washed into the seas...... In a few places, no doubt, all of this is true. Yet much of what 'everybody knows' is not scientifically documented, and some of it is probably not true"* (Cool, 1983).**

Water, together with soil, is a life support resource. As long as both are protected and conserved, a country retains options for future development. When either, or both, are degraded by misuse, a country loses these options. Water enters into all aspects of human life—social, cultural, economic, legal, and technical, and is thus perceived by various segments of society in very different ways, depending upon the primary interest of the various user groups. The technical aspects of water are commonly viewed from the perspective of engineers, who have a responsibility to design and build structures to store and divert water, so that it will be available at places and times of need. In the process of storing and diverting water to specific places for specific uses, society often loses sight of the fact that the total amount of water available for all uses is fixed. While both seasonally and annually the amount of water may fluctuate widely about a long term average, for the purposes of planning and management, it must be assumed that the volume of water available for all uses within a river basin will only decrease with use. To the extent that such uses may be consumptive - i.e., a use wherein all water withdrawn from a river system is consumed by the use, and none is returned to the river, such as is common in irrigated agriculture, effective planning must assume that such a use at one point in the system, will decrease the availability of water for all other uses in the same system.

Historically, water use in Thailand has been mainly agricultural—primarily for the growing of rice. In recent history, this water intensive activity was concentrated in the lower Chao Phraya basin, centered on Ayutthaya, and was designed to exploit the natural flooding of this region during the rainy season. Rice cultivation in the lower Chao Phraya river basin evolved in harmony with the natural cycle of flooding and drought; there was little upstream competition for the water of the Chao Phraya basin, and consequently, little need for institutional management of the water resources.

In recent decades, a number of developments have occurred to alter this historical relationship of water supply and use:

- There has been an explosive growth of the Bangkok Metropolitan Region near the mouth of the Chao Phraya River, requiring a considerable increase in the domestic water supply;
- The increase in water use near the headwaters of the river has created an upstream-downstream competition for water;

- Increasing industrial development has placed increasing demands on the water resources of the basin, as well as added substantially to the contaminant loading of the river;
- The construction of the Bumiphol and Sirikit reservoirs in the northern headwaters of the Chao Phraya basin has substantially decreased the annual flood crest of the river, thereby decreasing the availability of the historical source of irrigation water in the lower basin.

Thai institutions have been slow to respond to these rapid changes affecting water supply and use. While this lack of response to rapidly changing conditions is undoubtedly due to a complex of factors, it is felt that there are a number of predominant reasons why planning and management of water resources are inadequate today:

- Traditionally, for the purposes of water resources planning and management, Thailand has been viewed as being composed of a number of differing geographical regions - the north, northeast, central, east, and south (e.g., Tawatchai, 1991). While these regions have a great deal of historical and cultural significance, they are only marginally useful as geographic descriptors, and they have no demonstrated relevance for water resource analysis. In spite of this, virtually all planning and management of water resources in Thailand use the "hydrologic region" as a basic unit;
- There is a strong focus on the construction of water storage and diversion projects, with little attention given to alternative forms of water management;
- Water resources planners and managers are concentrated in Bangkok, and tend to view the water problems of the country as being those of Bangkok, rather than a complex mosaic of local problems representing a wide mix of supply and use characteristic;
- There is, for all practical purposes, no water resources research being conducted today in Thailand. Thailand is completely dependent upon imported technical methodologies and concepts in developing options for the utilization of the country's water resources. These may not always be appropriate.

Recently, a series of TDRI research papers (Thitinan, 1994; Thanet, 1994; Amnat, 1994) has focused on water conflicts at the scale of the local community and sub-catchment basin. These papers serve to point up the increasingly local nature of water resources problems, whether they involve conflicts among agriculture, hotel, golf course, and urban users in the Ping river basin, inter-basin transfers in the Mae Klong basin, industrial pollution in the Mun river basin, or urban and industrial water supplies in Bangkok. In every case, there is a need for a better understanding of the complex interactions between the biophysical water environment, and human modifications of that environment, if such conflicts are to be resolved equitably in the future.

It is the purpose of this paper to consider briefly some of the underlying causes of the conflicts described by these authors, and to propose options that may help in dealing with such problems in the future. These causes are felt to be linked to problems associated with a reliance upon conventional wisdom similar to that described by Cool for the Himalayas a decade ago, coupled with a lack of general conceptual models to describe the supply and use of water in Thailand. This paper will deal primarily with the technical aspects of water supply and demand, particularly from the perspective of the supply and demand relationship in portions of the Chao Phraya river basin. The data on which this paper is based are presented here primarily in graphical and tabular form. Only the most salient points are discussed in the text.

PLANNING AND MANAGEMENT UNITS AND CONCEPTS

From a technical standpoint, the planning and management of water resources development involves an understanding of the relationship between water supply and water use, an understanding of how that relationship is determined by the water budget, and an understanding of the important role played by the river basin in defining the geographic scope of potential impacts of misuse of water resources. The great variability of water availability and use over the surface of any river basin must be understood, if planning and management are to be realistic.

THE UNITY OF THE RIVER BASIN

The Water Budget

The *water budget* is the primary analytical approach used in determining the relationship between water supply and demand. The water budget of an unmodified catchment basin expresses the quantitative relationship among elements of *input* (as rainfall and condensation), of *storage* (as lakes, groundwater, or reservoirs), and of *output* (as stream flow and evaporation). Seasonally, the water budget equation may have either a positive or a negative value, but annually the value is zero. In Thailand, the water budget equation is strongly positive during the wet season, and strongly negative during the dry season. *An accurate water budget—relating input to output, or supply to use—is not possible unless all inputs and outputs are defined in the context of a single river basin.*

The River Basin

A *river*, or *catchment*, *basin* is a topographic, bowl-shaped, depression which directs the flow of surface drainage. It has only a single outlet, the *mouth* of the river flowing in the basin. The major river system within the basin is formed from numerous *tributaries* which join to form the main river. It is a basic tenet of hydrology that the topographic unit of measurement is the river basin. All mathematical modeling of water budgets for the purposes of calculating water and energy exchange, or of supply and use relationships, are dependent upon being able to isolate the processes of precipitation, infiltration, evaporation, stream flow, and human use, the major components of the water budget equation, within the confines of the catchment basin. Without this constraint, these terms become largely meaningless insofar as they provide insights into water supply and use relationships. The importance of the river basin as the basis for water supply and use calculations is straightforward. Alteration of the quality or quantity of water at any point within a river basin will spread downstream like ripples on a pond, ultimately affecting all downstream water users.

The Hydrologic Region

Virtually all water resources planning in Thailand has been undertaken in terms of *hydrologic regions*, e.g., TDRI, 1988; Tawatchai, 1991 (see Table 1). These regions, defined in terms of political subdivisions, generally are composed of portions of several river basins. The use of political, rather than physical, subdivisions produces information that is very difficult to interpret when used for water resources planning. Recognizing this fact, the National Water Resources Commission (NWRC, 1990) subdivided the country into 25 *river basins*. While the river basins represent a major improvement over the hydrologic regions, they leave a number of issues unresolved. At least three of the river basins defined by NWRC are actually only small portions of much larger international river systems—the Salween and Mekong basins. Several river basins have been subdivided into upper and lower portions. The two most notable are the Chao Phraya River, which, in the NWRC scheme, is defined as being composed of seven distinct river basins. In fact, it is only one—the Chao Phraya river system. The Bang Pakong river basin has been separated from the Prachinburi river basin, even though the Prachinburi is a tributary to the Bang Pakong.

The Water Resources Region

If not interpreted with great care, this subdivision into 25 river basins may create a false impression of the true water supply and use situation in Thailand—for a variety of reasons. Most importantly, there are actually at most eight major river basins contained completely within the borders of the country. These are: (1) the Chao Phraya; (2) the Mun; (3) the Bang Pakong; (4) the Mae Klong; (5) the Petchaburi; (6) the Tapi; (7) the Thale Sap; and (8) the Pattani. All of the remainder of those defined by NWRC are either minor basins, draining directly into the Gulf of Thailand, the Andaman Sea, or are small portions of international river basins—the Salween and Mekong. For the purposes of realistic water resources planning and management, it is most useful to consider Thailand as being composed of eight *water resources regions*, rather than five *hydrologic regions*, or 25 *river basins* (see Table 1 and Figure 1).

The way in which a river basin is perceived influences the way in which it will be managed. If, for example, the Chao Phraya river basin is perceived as being composed of seven separate river basins, it is not inconceivable that seven distinct, disparate, management plans will evolve for the waters of the river basin.

If, on the other hand, the Chao Phraya river basin is recognized as a single water resource region, in which modification of water supply and use characteristics at any point will affect all other points within the basin, then a much more holistic management approach is made possible. Within a water resources region, the trade-offs and impacts of major water resources projects, such as dams, irrigation systems or inter-basin transfers of water, are made explicit. Within any given water resources region, both active management, involving engineering modifications such as dams or inter-basin transfers, and passive management, involving primarily water conservation such as improved methods of managing irrigation water, are possible.

THE IMPORTANCE OF SCALE

While Thailand develops water supply and use estimates on the regional, or macro scale, intermediate, or meso, scale water supply patterns are the most relevant to the development of planning and management options, since they are closest to the human scale of water usage. The meso scale is the scale at which urban and industrial water supply problems must be evaluated. It is the scale of irrigation districts. It is the scale at which conflicts are most easily perceived, and resolved. For water budget analysis, it is the scale of catchment basins where long term stream flow measurements exist, where consumptive withdrawals are measured, or may be estimated with some confidence, and where the most reliable water budgets may be determined.

The recent TDRI papers by Thanet (1994), Thitinan (1994) and Amnat (1994) highlight some existing problems at an intermediate scale that are not apparent from the macro scale analysis provided by Tawatchai (1991), who, based on an analysis of water supply and use patterns within the hydrologic regions of Thailand, concluded that only the central region would face serious water problems during the remainder of this century. These authors present a picture of serious conflicts among water user groups throughout the country today, at the scale of the small catchment basins rather than a large excess of supply over use, as found by Tawatchai (1991).

At the same time, such problems have considerable relevance for Bangkok and the lower Chao Phraya river basin (the central region). The ultimate source of much of the water available for use in Bangkok originates in the headwater catchment basins, such as that described by Thanet (1994), the Mae Taeng catchment in the upper Ping river basin. The water supply and use conditions existing in the Mae Taeng basin ultimately help to determine the amount of water available for use by all users of the waters of the Chao Phraya basin, from Chiang Mai to Bangkok. Water that is consumed in the Mae Taeng catchment is not available for use in the Ping river basin. Water that is consumed in the Ping river basin is not available for use in the Chao Phraya river basin. If the water in the Chao Phraya river basin declines, the water available for use by Bangkok residents declines. This is a "zero sum" situation. Water consumed at any point within a river basin, from the small headwater tributary to a major irrigation district near the mouth, must be subtracted from the water available for any other use within the basin. As will be shown below, water use in the headwaters of the Chao Phraya basin are cumulative, and have a much greater impact on the Bangkok water supply than may be presently appreciated.

The problems described by Thanet—upstream-downstream competition, conflicts among irrigators, urban dwellers, second home owners, hoteliers and golf course managers for available water supplies—are not unique to Chiang Mai and the upper Ping river basin. They serve as useful paradigms of problems throughout the river basins of Thailand, problems which vary only with respect to the mix of user groups involved in the conflict. Some of the existing, or emerging, conflicts at the scale of the individual river basin are illustrated below with data from the headwaters of the Chao Phraya river basin (see Figure 2).

The Ping River Basin

The Ping River is the western-most of the major tributaries to the Chao Phraya river system. It has a total surface area of approximately 34,000 km^2 and an annual discharge volume of approximately 6,700 $m^3 \times 10^6$ (UN/ESCAP, 1991). The Ping river basin contributes approximately 22 percent of the total annual stream flow volume of the lower Chao Phraya River. The basin has an estimated runoff efficiency of 16 percent, based on a mean annual precipitation of 1200 mm.

From Table 3, it can be seen that runoff efficiency varies by almost a factor of three for the sub-basins considered here, from 39 percent in the Mae Kuang to 9 percent in the lower river basin, below the Bumiphol Reservoir. In the case of the Mae Taeng sub-basin, the area dealt with by Thanet (1994) in his paper on existing water supply and use conflicts, the low runoff efficiency (17 percent) is primarily the result of an irrigation diversion immediately upstream from the gauging station. Without this diversion, the runoff efficiency of the Mae Taeng would be approximately 30 percent. It is doubtful that either rainfall or evapo-transpiration vary by a factor of three over the surface of the sub-basins of the Ping River, as suggested by the variation in runoff efficiency. It is most reasonable to assume that this variation in relative stream flow amounts is related to land use practices, assumed here to be primarily associated with the conversion of land to irrigated agriculture. If the runoff efficiency of the lower Ping River, which is now 9 percent, were raised, through efficient management of irrigated agriculture and other water consumptive land uses, there would be an addition of at least 1,400 million cubic meters annually to the mean flow of the Chao Phraya River available for all other uses within the river system.

The Wang Basin

The Wang river basin is a tributary to the Ping River of the Chao Phraya river system, with headwaters between the Ping river basin, to the west, and the Yom river basin, to the east. The Wang river basin has a surface area of approximately 10,800 km^2, and an annual discharge volume of approximately 1,400 $m^3 \times 10^6$. The Wang River contributes approximately 5 percent of the total annual average stream flow of the lower Chao Phraya River. The runoff efficiency for the entire basin is estimated at 11 percent.

In the Wang river basin, the most striking aspect of the water supply and use patterns in the upper portion of the basin, an area of approximately 7,100 km^2 centered on the city of Lampang, is the extremely low runoff efficiency found there, indicative of high consumptive water use. The headwater sub-basins (Ban Hai and Mae Soi) are typical of most of the sub-basins of the region, with runoff efficiencies of 17 percent and 22 percent, respectively. For approximately 1600 km^2, immediately downstream from the city of Lampang, there is no net increase in stream flow, a runoff efficiency of 0 percent, and for the remainder, to the confluence with the Ping River, the runoff efficiency is only 7 percent. It can only be speculated that these low efficiencies are associated with irrigated agriculture. It would be instructive, however, to investigate water uses in this area, with the objective of determining the source(s) of water use, and the ways of increasing water use efficiency. An increase in the runoff efficiency of the upper Wang river basin to 15 percent would add approximately 1,300 million cubic meters annually to the average flow of the Chao Phraya river system.

The Yom Basin

The Yom basin is a tributary to the Chao Phraya river system, with headwaters between the Wang river basin to the west, and the Nan river basin to the east. The basin has a surface area of approximately 24,000 km^2 and a total annual discharge volume of approximately 1,400 $m^3 \times 10^6$. It has an estimated runoff efficiency of 5 percent, the lowest of the major headwater tributaries which make up the Chao Phraya river system.

A situation similar to that found in the Wang river basin exists in the lower Yom basin, except on a much larger scale. The lower Yom basin, with a surface area of approximately 11,700 km^2 has a runoff efficiency of zero. Even with a runoff efficiency of only 15 percent, the national average (FAO, 1969), this portion of the basin should produce more than 2000 $m^3 \times 10^6$ on average each year.

For the Ping, Yom and Wang river basins, an increase in the runoff efficiency only to the average for Thailand as a whole would result in an increase of some 5,500 million cubic meters in the average annual flow of the Chao Phraya River. This is equivalent to the addition of a reservoir the size of the Bumiphol or Sirikit reservoirs. Since much of this increase could probably be achieved by simply increasing the efficiency of irrigated agriculture in these basins, proper management would decrease the cost significantly below that of a third major reservoir in the system.

The Nan River Basin

The Nan river basin is the eastern-most of the major headwaters tributaries to the Chao Phraya river system. It has a surface area of slightly more than 34,000 km^2, and an annual discharge volume of approximately 9,500 $m^3 \times 10^6$. Based on a basin-wide average annual precipitation of 1200 mm, the estimated runoff efficiency of the Nan river basin is 23 percent, the highest of the four major northern tributaries to the Chao Phraya.

In the upper Nan basin, above the Sirikit Reservoir, a very different situation to that found for the Ping, Wang, and Yom basins exists. Here the efficiencies calculated range from 100 percent to more than 160 percent! While there is no theoretical lower limit for runoff efficiency, it is theoretically impossible for this ratio to exceed 100 percent, and, in practice, this ratio is seldom reached in nature. There is, therefore, an error in the basic data used to calculate runoff efficiency in the upper Nan basin. In this case, the error comes from the assumption of spatially uniform rainfall over the surface of the basin. It is clear that at least one small catchment—the Nam Yao—is receiving at least 1800 mm annually on average as a lower limit. Rainfall in the northern headwaters of the Nan river basin could be as high as 3000 mm annually. This illustrates a problem commonly associated with the use of broad regional averages to calculate local water budgets. Unfortunately, the climatological network from which better estimates of local rainfall patterns in areas such as the upper Nan basin might be obtained is inadequate for this task. Only one climatological station in the Nan basin has a period of record of more than 18 years, and all stations are located in valley floors. This gives convenient access, but gives a very biased view of rainfall distribution over the surface of the basin.

DISCUSSION AND CONCLUSIONS

Until Thailand begins to incorporate water supply and use estimates —based upon water budget calculations, and measurements of factors such as irrigation water withdrawals for both rice and golf courses—into the planning and management of water resources, there is little likelihood that the present cycle of drought and flood will diminish. While it is convenient to look for simple, single-cause reasons for this cycle, such as climate change or deforestation, it is clearly much more complex than this. Much of the problem is associated with unplanned and mismanaged water usage, coupled with an incomplete understanding of the functioning of subtropical river systems.

By ignoring the unity of the river basin, the importance of the inter-related nature of water supply and use within a minor sub-basin, and throughout the river basin as a whole, is overlooked. As pointed out by Thanet (1994), there are water supply and use conflicts in the upper Ping river basin. What he did not point out, but could have, is that these conflicts are translated through the flow of the Chao Phraya River to Bangkok. If one assumes that the national runoff efficiency of 15 percent is an achievable management goal, it is possible to speculate that as much as 5,500 million cubic meters could be added annually to the average flow of the Chao Phraya River at Bangkok simply by more efficient management of irrigation water in the Ping, Yom and Wang river basins. Given the extremely low values for the runoff efficiency in the rivers of Thailand compared to the regional values (see Table 2), it is probable that more efficient management of irrigation water could increase the amount of water available for all other uses in the country substantially more than this.

Three major factors determine the effectiveness of water management in virtually all countries:

- The physical availability of the resource is fixed, and varies about a mean value on a seasonal and annual basis. Droughts and floods are recurrent phenomena. What is used consumptively in one portion of a river basin is no longer available for any other uses within that basin;
- There is conflict among various user groups—agricultural, industrial, domestic, recreational, and aquatic ecosystems. The geographical scope of these conflicts is defined by the catchment basin in

which they occur;
- Virtually all problems of water supply and use are local, and can only be resolved within the context of the sub-basin in which they arise.

There are at least three major policy issues associated with the planning and management of water resources development in all river basins of Thailand.

Issue: *No detailed quantitative analysis of all factors determining water supply/use relationships within Thai river basins has yet been completed.*

Structured procedures for auditing and accounting are commonplace in many disciplines. Studies of population dynamics and economics are two primary examples. Continually updated information on population numbers and demographics, as well as a range of economic indicators, are considered essential by most governments today. In many industrialized countries of the world, similar forms of accounting and auditing have been developed for natural resources, and are used increasingly to monitor the shrinking balance between resource supply and use. Until such an auditing and accounting procedure is adopted in Thailand, realistic planning and management of water resource use are not possible.

In spite of the overwhelming dependence of Southeast Asian countries, such as Thailand, on the rivers and groundwater of the region, there are no auditing or accounting systems in use to define the local availability of water, so as to ensure effective planning or management of the resource. The extremely inefficient *ad hoc* system of water resources management, in which water use—primarily irrigation of the annual rice crop(s)—was tied to the seasonal rise and fall of the region's rivers has given way to intense competition for water among an increasing population, industrialization, and explosive urban growth. The development of rational approaches to water allocation among these various sectors has not been possible, given the absence of any system in which such allocations could be quantified or justified.

Issue: *Conceptual models used for water resources evaluation are not always consistent with generally accepted international standards and practices.*

Thailand may be the only technically advanced country in the world to use something other than the river basin as the basic unit for water budget calculations. The 25 river basins now being analyzed by the National Economic and Social Development Board (NESDB) (Personal communication, Potchana Auengpaibul, 1994) is obviously a very positive step in the right direction, but it is only the first step. It is essential that whatever scheme is finally adopted—whether it is the 25 basins proposed by NWRC, the water resources regions proposed in this paper, or some third alternative—that this approach be incorporated into the planning and management of water resource development within the entire country. Without this, the conflicts that are now beginning to emerge as various user groups compete for a fixed amount of water will increase.

Issue: *Hydrological research in Thailand is virtually nonexistent. This has inevitably led to a situation in which imported technologies cannot be evaluated for their applicability to local conditions.*

There is a need for both applied and basic studies of interactions between elements of the water budget equation, and among those elements and human uses of water. While some applied research is being done today in Thailand in conjunction with specific water development projects, there is a lack of basic studies. In the West, most basic research is undertaken by university departments with an interest in some specific aspect of water supply or use relationships. In the United States, each of the 50 states has a water resources research institute within one of the major state universities, the responsibility of which is to promote and facilitate water resources research relevant to the needs of the state. Basic research into water related problems at Thai universities appears inhibited primarily by a lack of available funding. At a minimum, one university in each of the country's major geographical regions should have a center for water resources research, to coordinate efforts to understand the water problems specific to each region.

Two alternative hypotheses are offered to explain the drought and flooding that have become characteristics of the dry and wet seasons in Thailand:

Drought *is not caused primarily by climate change, or by deforestation, but rather by the fact that the water supply during the dry season is not sufficient to meet the increasing use of this supply. As use continues to rise with respect to supply, the imbalance will increase, no matter how much rain falls, or how many trees are planted, or how many dams are constructed.*

Floods *are caused not by deforestation in the headwaters, but by human encroachment into the natural floodplain of the rivers. As this encroachment continues, the severity of the "flooding" will increase, irrespective of land use or reforestation in the headwaters catchments.*

Both these hypotheses, and their alternatives, can be tested by scientific research.

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