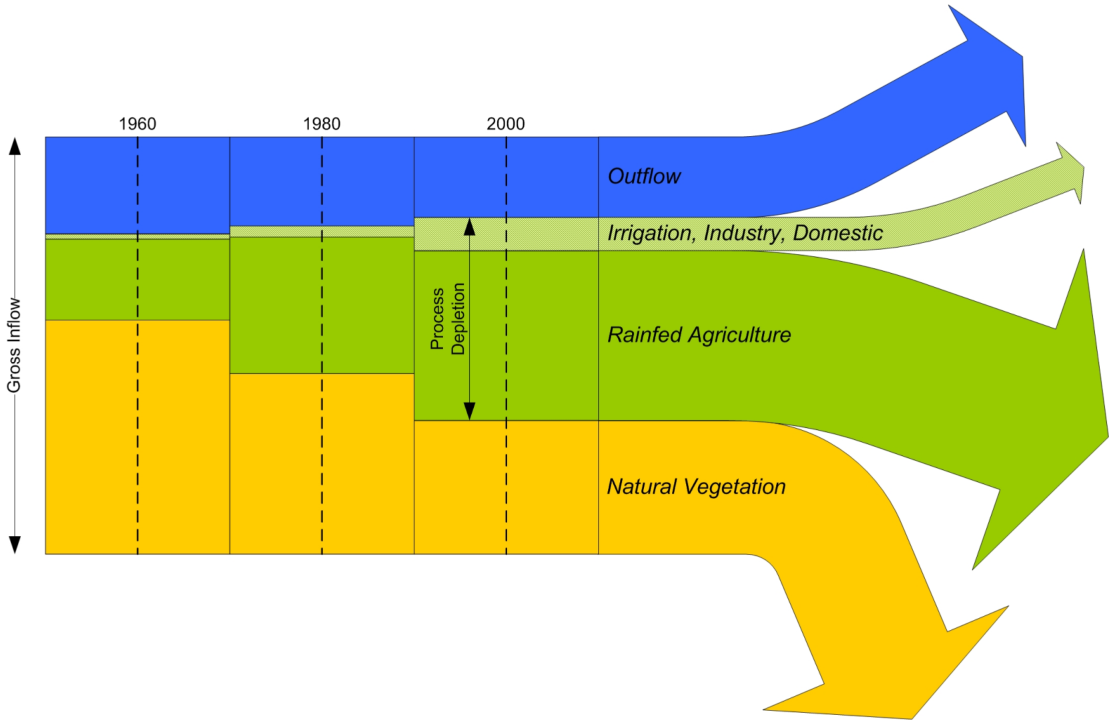
Water Traps: The Elusive Quest for Water Storage in the Chi-Mun River Basin, Thailand

Philippe Floch, François Molle



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Abstract

The closure of river basin, and the process that leads to the depletion of available basin resources, is driven by both state-led initiatives and through local adaptation and resources use. Once a basin closes, users find themselves interconnected through the hydrological cycle, thereby limiting further options of supply augmentation and shifting impacts of additional developments onto other uses and the environment. This paper analyses the process of river basin development in the drainage system of the Chi and Mun rivers in northeast Thailand. We argue that the process of closing the Chi-Mun Basin is significantly influenced both by the large-scale expansion of bunded-field rainfed agriculture, and the overbuilding of irrigation infrastructure. Yet, while the Thai government and planners concerned with the development of the Lower Mekong River Basin, envisioned all possible options to maximize the use of water resources, the adaptation of dry season irrigated agricultural remained marginal, as returns from agricultural production remained low and non-agricultural sectors absorbed larger shares of the rural population. However, we argue that while the basin is so far not closed, irrigation infrastructure in the basin is overbuilt. The dual process of state-led water infrastructure development and local reshaping of the waterscape, together with the current trajectory of farm-level water use, has profound impacts on the logics and justifications of contemporary state-water policy, thoroughly limiting the rationale for further supply augmentation.

Keywords

River Basin Development, River Basin Closure, Water Accounting, Water Resources Planning, Irrigation, Thailand

Introduction

When utilizable river basin outflows in an average hydrological year are either fully committed to existing water users and environmental services, or close to zero, river basins are said to “close”. This closure, in turn, means that water users find themselves tightly interdependent and interconnected through the hydrological cycle. Alongside a physical dimension of disappearing river flows, basin closure is also typically accompanied by pollution peaks around economic centres, calls to farmers not to grow a second crop and politicians calling for further supply augmentation, typically through water imports from neighbouring basins. At the same time, river basin closure implies that re-allocation and demand management policies are gaining importance, as options to augment supply are becoming increasingly unavailable and/or financially and politically costly. It has recently been observed that many drainage basins are closing or experiencing seasonal closure, with an increasing number now beyond a formal state of closure by drawing from additional non-renewable resources to balance supply and demand. Examples of closed river basins include the Colorado, the Yellow River, the Amu-Daria/Syr-Daria, the Jordan, and the Cauvery, with a host of other river being compounded to seasonal closure such as the Ganges, Indus and Krishna river basins in the Indian peninsula.

The processes that lead to the closure of river basins have recently attracted increased scholarly attention (Courcier, et al., 2005; Molle, 2004; Venot, et al., 2008). Founded on a common methodology (Molle, 2003), the studies all point to the intimate interrelations of how societies understand, frame and transform their physical environments, how particular land- and waterscapes shape productive patterns and institutional arrangements, and how changing resources availability at the basin-scale triggers societal adaptations and change with regards to land- and water management. Molle (2003) has also shown, that balancing supply and demand in a basin context has as much of a state dimension, as a local one. This, importantly, contrasts with research that focus solely on envisioning future changes of the hydrological regime as being governed by state interventions only. In fact, basin closure can be governed by both state-sponsored water resources development and bottom-up local responses to shortage of water. In most cases, both state and local responses will equally play their role, with the physical, institutional, socio-economical and political settings governing the importance of each of the two supply response terms. While local responses generally unfold with little awareness of macro-basin hydrological realities, this is equally true for politicians and decision-makers in concerned agencies who are often either non-informed or ignorant of local level adjustments and the dynamics changes of river basins induced by them. This, in turn, has appreciable impacts on formulated water policies in many countries and river basins of the world.

Signs of river basin closure are readily observed in the Chi-Mun Basin, the largest Thai tributary of the Mekong River. Interbasin water transfers have been proposed ever since the 1960s; shortfalls in irrigation water are commonly reported and newspaper articles frequently cover the dearth situation of northeast Thailand farmers in times of drought. Outflows from sub-basins have been shown to be diminishing and pollution peaks in times of low-flow have been recorded around the economic centres of northeast Thailand, most notably Nakhon Ratchasima and Khon Kaen. However, while irrigation in the Chi-Mun basin (and Northeast Thailand more generally) is still seen by many in the government and concerned agencies to be underdeveloped, large tracts of land within command areas of irrigation projects remain uncultivated, especially in the dry season.

Recognizing the importance of the status of river basins in the formulation of sustainable and equitable water policies, this paper will (i) introduce the methodology used and the data sources employed in this study, (ii) present the human and environmental setting of the Chi-Mun river basin in northeast Thailand, including the development of irrigated agricultural and large-scale land-use changes, (iii) quantify the impacts of man-made changes in the study area through an analysis of climatic and hydrological trends in the region, and a series of historical water accountings for 1960, 1980 and 2000, with a more detailed sub-regional focus for the present situation, highlighting the importance of soil water storage in altering the flow-regime, and (vi) provide some conclusions on the processes and dimensions of river basin closure of the Chi-Mun River Basin in northeast Thailand.

Explaining processes of basins closure: Water Accounting methodology and data

To highlight the degree of utilization of basin water resources Molden (1997) introduced a methodology of water accounting. While water accountings have been used in a host of diverse settings to describe the development of river systems, two dominant types of application might be distinguished. On the one hand, water accountings have been used in an attempt to provide a typology of drainage basins. This was aimed at describing the water resources availability in the context of river basins in order to assist policy-makers and planners in making better-informed decisions about available options. On the other hand, water accountings have also been used to contextualize the historical process of river basin development. The reasoning behind utilizing water accounting as a tool to describe the degree of anthropogenization of river basin rests on the empirical evidence of increasing numbers of river basin under significant stress largely due to human activities.

In essence, water accountings estimate water depletion from existing uses and highlight the amount of water removed from a drainage basin, rendering it unavailable for further use (Venot et al. 2007). Because water accounting definitions are uniform in terms and meanings, they allow both the comparison of findings between spatial scales (e.g. sub-basins and sub-regions) and between different river basins – at least on the basis of some common parameters. According to mass continuity, the sum of inputs equals the sum of outputs plus the sum of changes in storage; where *RF* is precipitation, *RO* is runoff, *Evap* is evaporation, *Trans* is transpiration and ΔS the change in water storage (both natural / artificial and surface / groundwater):

$$RF = RO + Evap + Trans + \Delta S$$

If we consider the anthropogenic alteration of a drainage system, we can re-write the above formula to account for human-made changes: most particularly increases in storage and net inflow (e.g. construction of reservoirs and tanks, water imports, etc.), and the variations in evaporation and transpiration through changing land-uses, which also affects the basins response, the runoff *RO*, and climate change.

We might therefore write:

$$RF + In = RO + Evap + Trans + Out + \Delta S$$

where *In* and *Out* accounts for other in- and outflows of the respective study area.

Unfortunately – of course – these components vary considerably from year to year. Rainfall over almost any regional scale varies significantly and the temporal distribution of rainfall can change from uniform patterns of precipitation to short and heavy torrential rains with corresponding variable basin responses with regard to runoff. This, in turn, implies that a focus on averaged periods – representative of the general trend of basin development – provides more reliable estimates of mean flows and variability (Perry 2007). Water accounting, due to its focus on water depletion, also rests heavily on the landuse data that supports the water balance model. The importance of land cover is enhanced in eco-environments that are primarily utilized by rainfed agricultural and/or support high levels of natural vegetation. Equally important, in many cases long-term measurements of rainfall over large-river basins is only available in a selected number of locations, making the interpolation and regionalization of average rainfall difficult, and resulting in considerable inaccuracy.

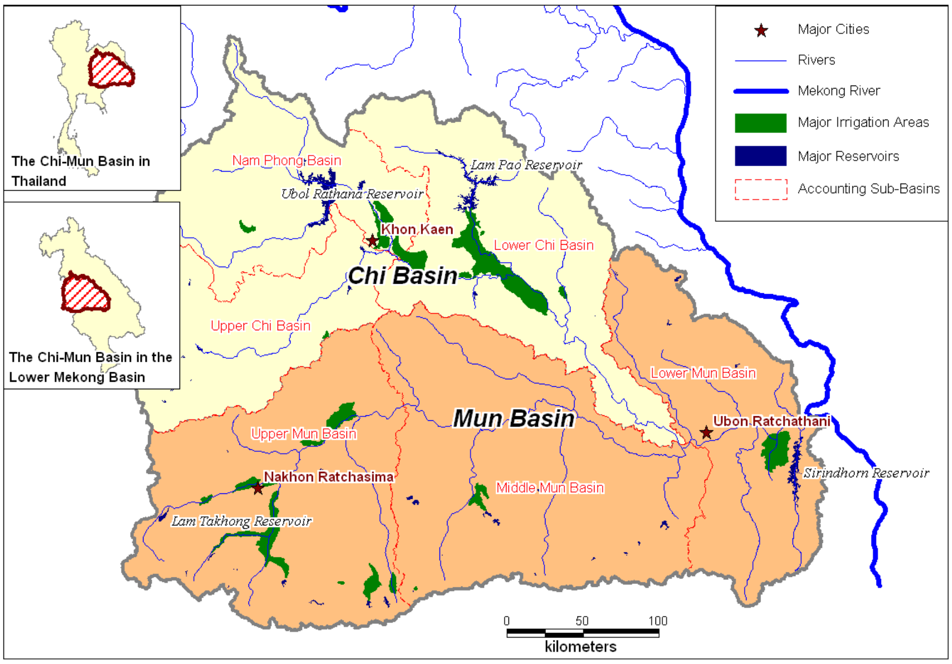
The following depleted fractions will be used for describing changes in water use in the basin: (1) surface irrigation, (2) rainfed agriculture, (3) domestic process and industries; (4) depletion from natural vegetation (forests, bush land and fallows) and (5) depletion from bare land and reservoirs. Categories (1) to (3) are further classified as process (voluntary) while all other are non-process depletion. The depleted water can further be disaggregated into beneficial, low-beneficial and non-beneficial depletion. What is "beneficial", however, requires a value-judgement which, although “offer[ing] a good entry point for stakeholder consultation” (Molden et al. 2001), is not discussed in this study, since it is beyond the scope of this paper to balance “values” of depletion from agricultural land, forest areas and wetland ecosystems.

Records of historical landuse data on the Chi-Mun basin are often conflicting, at times contradictory. To estimate landuse and agricultural production from the 1960s to present, we have analysed sub-district level data on agricultural production and related parameters of four agricultural census reports (1963, 1978, 1993 and 2003) published by the National Statistics Office of Thailand. This was complemented by annual agricultural statistics from the Office of Agricultural Economics Agricultural Statistical Year Book published since 1951. Further data, especially on the decline of forest, has been collected from reports on land and water resources in northeast Thailand, redigitized historical maps, and data provided by the Mekong Commission's Spatial and Time-Series data set. Climate and discharge data has been obtained both from the Royal Irrigation Department and from data sets of the Mekong River Commissions.

The Chi-Mun River Basin: Introducing the Study Area

The Chi-Mun river basin is a right-hand tributary of the Mekong River, located in northeast Thailand. The region borders Lao PDR in the north and east (with the Mekong River as a border), Cambodia in the south, and Thailand's central plains in the west. The drainage area of the Chi and Mun rivers covers roughly 120,000 km², and contains or overlaps with 15 of the 19 provinces of the north-eastern region. Among all the drainage areas discharging into the Mekong River from Thai territory, the Chi-Mun basin is the largest both in area and annual runoff. The two major rivers of the study area are the Mun River and its largest tributary the Chi River (Figure 1), draining both in west-east direction from the mountainous western drainage divide.

Figure 1: The Chi-Mun River Basin at a glance



The topography of the river system is dominated by the Korat Plateau, varying in height between 170m and 300m , with boundary mountain ranges between 500m and 1000m. Physiographically, the landscape of the region is characterised by a succession of hilly areas, undulating land, non-floodplains, floodplains and river levees, forming a succession of mini-watersheds that provide distinct eco-environments for agricultural production (KKU-FORD 1982, Limpinuntana 2001). Precipitation is characterized by a wet season from May to October, transitional periods in the months of April and November, and scant to zero rainfall in the remainder of the year. Temperature peaks in the months of March and April and drops to its annual lows in November and December. Potential Evaporation is constantly high with an annual average of 1600 mm. Soils are mostly sandy with high rates of percolation and low organic matter and soil fertility; features which both constrain on-farm water management and the suitability/fertility of land resources for agricultural production and irrigation development (Srisuk et al. 2001). Saline soils, as a product of both the dominant rock salt that underlies a large part of the plateau and secondary salinization induced by irrigation and other water uses, are an important feature of the basin (Srisuk 1997).

According to the Population and Housing Census reports published every ten years, the population of northeast Thailand rose from around 8.8 million in the 1950s to over 20 million in 2000. This also holds true for the Chi-Mun Basin, with the basin's population climbing from roughly 7 million in 1960, to almost 16 million in 2000. By the mid-twentieth century, the population of northeast Thailand was concentrated around the economic centres of that time (most notably Nakhon Ratchasima, Khon Kaen and Ubon Ratchathani) and the middle reaches and lower terraces of the Chi and Mun rivers. Today, the highest densities are still found around these economic centres, but population, and agriculture, have gradually expanded into higher terraces.

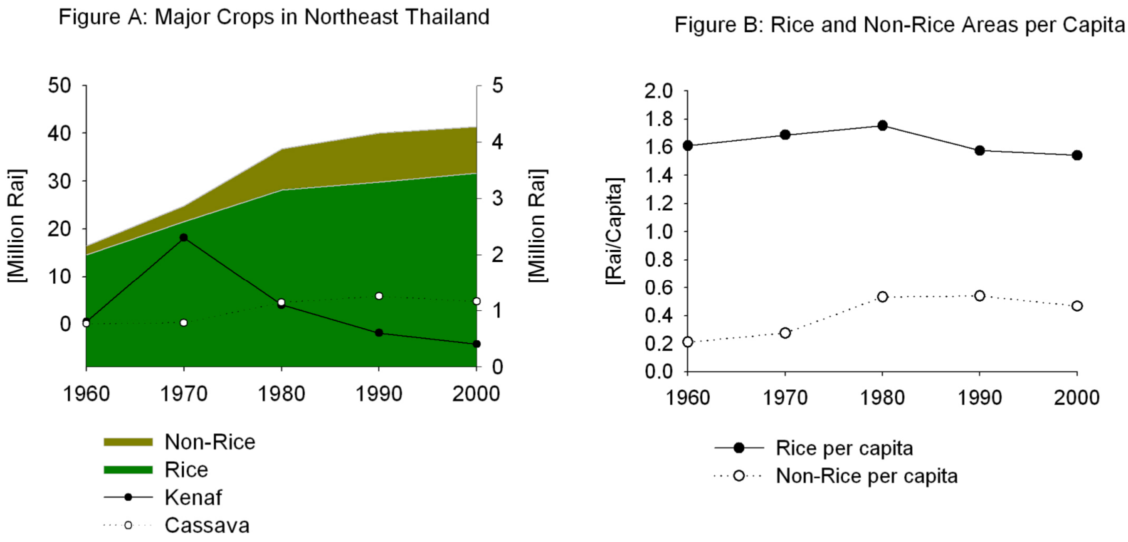
Agriculture and Forests

Early into the years of agricultural expansion – what Siamwalla (1996) called the *Indian Summer* of agricultural expansion in Thailand – only 29 % of the land in northeast Thailand was cultivated, with the remainder covered with forest, grassland and 'waste'-land (USBR 1965). Agricultural land expanded from the lower terraces, most suitable for the cultivation of rice, towards increasingly marginal lands in the middle and upper terraces. We estimate that farmland increased from 12,000 km² in the 1940s, to 60,000 km² by 2000. By 1963, farmland already exceeded 30,000 km² in the Chi-Mun basin (our estimate) and just over 40,000 km² in Northeast Thailand. Between 1961 and 1973/74 the area of farmland more than doubled; at least in the records presented in the Agricultural Statistical Yearbooks. This increase is largely accounted for by the increase in paddy rice and by the increase in field or upland crops, while the area under fruit and rubber trees was halved during the same period (IOH 1982). Between 1990 and 2000, agricultural expansion markedly declined, as a result of both the increasing importance of non-agricultural economic sectors (Coxhead and Southgate 2000) and the closure of the land-frontier (Rigg 1985); the 2003 Agricultural Census points to a decline in agricultural production compared with the 1993 Agricultural Census.

Among the cultivated agricultural crops, rice was, and still is, overwhelmingly dominant. But while the percentage of the area devoted to rice was estimated to be as high as 90 % in the 1960s (Platanius 1961, NEDB 1961, USBR 1965), this figure declined to around 70 % (Figure 2). In absolute terms, the area under cultivation in the Chi-Mun basin in the 1960s was about 34,000 km² with about 26,000 km² committed to rice, about 4,700 km² to field crops, some 2,000 km² to permanent and tree crops, and the remainder either other agricultural landuse classes or non-cultivated. By 2000, land committed to rice cultivation climbed to around 44,500 km² (some 5,900 km² potentially irrigated), and areas under field crops totalled over 11,000 km². Spatially, the major expansion of rice cultivation in the Chi-Mun Basin was concentrated in the Middle and Lower Parts of the Basin, with particularly high increases in paddy land in the Middle Mun. Conversely, the Upper Chi and the Upper Mun Rivers with their dominantly higher terraces and larger parts of mountainous terrain saw higher increases in the cultivation of upland crops; while also higher degrees of remaining forest.

At the same time, forests in northeast Thailand and the Chi-Mun basin (as in the rest of the country) were diminishing fast. In the 1960s, still over 71,000 km² were under forest in northeast Thailand and over 53,000 km² in the Chi-Mun basin; roughly 45 % of the basins surface area. By the early 1970s, this forest cover was already reduced to just over 30,000 km². This trend in deforestation continued until the 1980s, when the rates of deforestation slowed down. At present, undisturbed forest area has declined to 16,100 km² in the Chi-Mun basin, mostly consisting of mixed deciduous forest, dry evergreen forest, and deciduous dipterocarp forest. In addition another 6,000 km² are classified by the Land Development Department as disturbed forests, totalling just over 22,000 km² of land in forest. Evidently, already in the 1960s and 1970s, considerable parts of forests were already degraded (e.g. USBR 1965). By the 1970s, Van Liere, in his assessment of land potentials in northeast Thailand (Van Liere and Kawai, 1973) noted that "the Northeast is subjected to a quasi complete destruction of natural vegetation cover" and that "only very limited areas, mostly situated on protected and isolated slopes in the mountain ranges still contain forests, while all other areas have degenerated to either an open savannah type of vegetation or are completely denuded."

Figure 2: Agricultural Production in Northeast Thailand



Irrigation Development

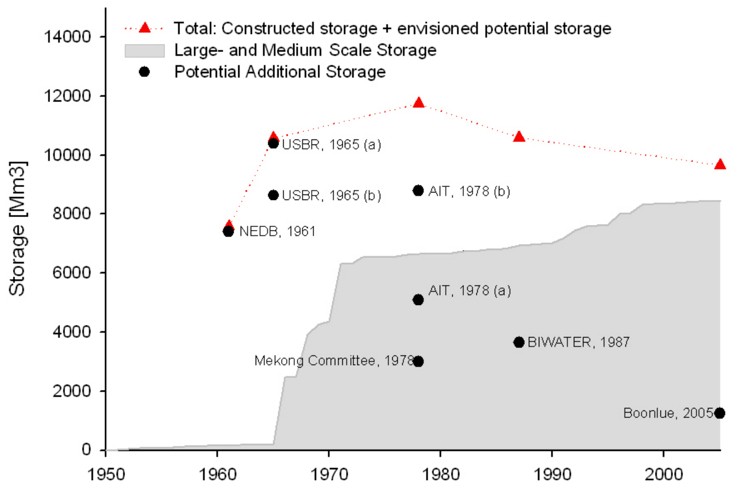
Irrigation development, and state-sponsored water resources developments, in the Chi-Mun basin started in 1939, with the Thai government commissioning the Royal Thai Irrigation Department (RID) to implement pilot tank irrigation and run-off-river diversion schemes in northeast Thailand. From a technical perspective, investments into irrigated agriculture in northeast Thailand has (for the last 50 years) been a continuous attempt to balance the seasonality of rainfall, make wet season production less risky through supplementary irrigation, and allow for dry season agricultural production. Contextually, the development of irrigation infrastructure has been embedded in many other governmental and societal policies: food security and self-sufficiency, the fight against insurgency and the spread of communism, the creation of rural employment opportunities along with the support of agribusiness development, and a counter-strategy against migration from the rural northeast to the economic centres of the country (and abroad)(Floch et al. 2007). During this period, the drive to implement irrigation infrastructure took all possible forms: small-scale ponds, weirs and pumps, medium-scale dams and pumping stations, wells, and large-scale gravity and pump irrigation schemes.

The core of the storage projects in the Chi-Mun basin were conceptually shaped in the late 1950s and implemented in the 1960s. Comprehensive regional master planning of water resources in the northeast unfolded both through the National Economic Development Board (which was established in 1960 to guide developmental policy planning and formulation) and embedded in larger development plans for the Mekong River Basin. The Ubol Ratana dam, the largest man-made storage in the Chi-Mun basin and in Northeast Thailand, was closed in 1966; the Lam Pao reservoir (within the drainage area of the Chi river) in 1968, Lam Takhong and Lam Pra Plerng projects (both located in the upper reaches of the Mun) in 1969 and 1970 respectively. This surge in infrastructure development meant that by the 1970s most attractive places for irrigation development through gravity-storage development had been developed (Figure 3).

The installation of irrigation- and on-farm infrastructure, however, took considerably longer and in the late 1970s the Thai government adopted a water policy in which the focus was directed towards the completion and upgrading of distribution systems and on the rapid development of small-scale irrigation infrastructure. This “two-pronged” Water Policy (AIT 1978) guided both funding and decision-making for the years to come (Bruns 1991). Also, the “two-pronged” water policy was consistent with the observation that, despite large-scale investments, little benefits had accrued to the residents of the northeast and potential beneficiaries of the available storage in the basins. Additional, pump irrigation was increasingly seen as an attractive, scattered (and fast to be implemented) technology to serve rapidly spreading irrigation areas along the banks of the main rivers. Between the years 1980 and 2000, over 650 electric pump irrigation projects were implemented in the Chi-Mun basin, potentially supplying water to close to 160,000 ha of agricultural land.

Additionally, planners and decision-makers – in the 1980s – increasingly started to look into options of storage in the vast floodplains of the Chi-Mun Basin. NEDECO (1982) looked at storage options in the floodplains of the lower Mun, and Gibb and Partners (1988) contemplated a cascade of in-stream storage weirs. Also, the Interim Mekong Committee claimed they had found a solution to augment storage in the area through their concept of in-stream storage (Mekong Secretariat 1989). This change in planning focus was mostly a result of the increasing resettlement problems that had plagued earlier (and more classical) storage/gravity irrigation projects.

Figure 3 : Trajectory of Constructed Storage and Envisioned Potential Storage



In 1992, the Thai government, embarked on an ambitious plan to increase irrigation areas in the Chi-Mun basin, and Northeast Thailand more generally, as it started construction on the Khong-Chi-Mun irrigation project. This project was foreseen to add 4.98 million hectare of irrigated land in northeast Thailand over a period of 42 years. It rested firmly on the technical option of floodplain storage along the main rivers of the northeast associated with large-scale pump irrigation schemes, and on the idea to divert water from the Mekong to meet the water requirements of the full-development project. Implementation, however, was hampered from the onset, and though weirs are now dotting the courses of the Chi-Mun river basin, 15 years after the start of construction irrigation infrastructures are still in the stage of implementation. And the transfer of Mekong waters to supply the Khong-Chi-Mun irrigation schemes has not materialized.

Accounting for all types of irrigation projects, potential irrigable areas have reached 1.2 million ha in Northeast Thailand and about 0.9 million ha in the Chi-Mun Basin (Boonlue 2005). According to the same author, storage capacity totals 10 Bm^3 in the whole north-eastern region, including almost 9.0 Bm^3 in the Chi-Mun drainage area (Mun Basin: 4.9 Bm^3, Chi Basin: 4.0 Bm^3). Storage in the Chi-Mun Basin, which was technically estimated at around 12 Bm^3 (in large-scale, medium-scale and small-scale irrigation projects), appears to be – in all current studies – now close to exhaustion, with most theoretically possible large-scale storage sites discredited. Additional potential storage is now seen to lie mostly in medium and small scale-projects and estimated at 1.4 Bm^3 (Boonlue 2005).

However, Euroconsult (1998) reported that in the large-scale Lam Pra Plerng and Lam Pao schemes, dry season cultivation was only 10 – 15 % of the irrigation area, with less than 50 % of farmers cultivating any crops because of high labour costs or a complete lack of labour. Likewise, figures provided in 2001 by the Royal Irrigation Department indicated that only 16 % of the total irrigable area was planted during the dry season. In 2002, the same figure was reduced to 13 %. This indicates that the majority of irrigation schemes in northeast Thailand are utilized primarily for supplementary wet season irrigation, while irrigated agriculture in the dry season is essentially confined to very small areas of the total installed potential. In line with this, Kamkongsak and Law (2001) estimated that total dry season cropping around small-scale pumping stations is stagnant at around 10 to 15 percent

Quantifying the Anthropogenization of the Chi-Mun River Basin

Changes in population, land use, agricultural production, industrialization and storage in the Chi-Mun Basin are bound to have an impact on the water regime of the region: the development of dry season cropping through the implementation of storage infrastructure leads to a seasonal redistribution of water resources; clearance of forest areas and the corresponding transformation of these areas into agricultural areas both impacts the consumptive fraction of water use and changes surface runoff and the recharge of groundwater bodies; and the rise of population, urbanization and industrialization increases water consumption in non-agricultural sectors. Investigating macro-level changes in the basins water regime, we will first analyze changes in precipitation, potential evaporation and runoff in the Chi-Mun basin, then look – in more detail – into the changes in runoff at the basin and sub-basin levels and into possible explanations for changes in rainfall-runoff relationships, and finally carry out successive water accountings for the last 40 years, with a closer examination of the current status of the Chi-Mun Basin. Through this exercise, we aim to build an hydrological understanding of the transformations that have taken place during the last half century in northeast Thailand and clarify the status of the Chi-Mun basin (open, closing or closed).

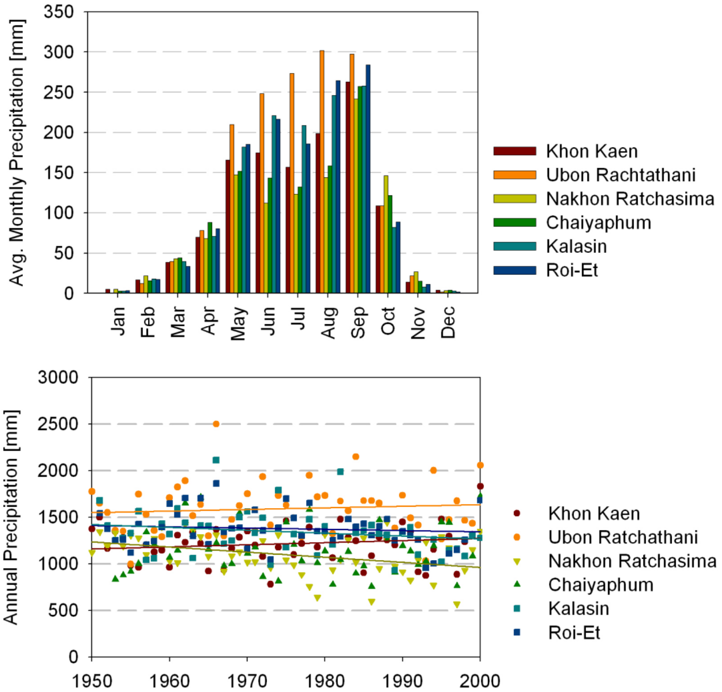
Climate and Precipitation: the last 50 years and trends

Northeast Thailand is characterized by a semi-arid tropical climate. Temperature in the region shows both daily and seasonal fluctuations. While mean annual air temperature is estimated at 26 degree in the region, lowest average daily air temperature range between about 16 degree Celsius in December to around 24 degree Celsius in June, to average highest daily temperatures from 30 degree Celsius in December and 34 degree Celsius in June (values for Ubon Ratchathani). At the same time, potential evaporation (ET_p), which determines the possible maximum depletion from natural vegetation, water bodies and other surface areas, shows seasonal corresponding fluctuations, with peaks during the dry season in the months of March and April, and the lowest mean monthly values found in the month of September. In absolute terms, average daily potential evaporation is approximately 4mm/day. Spatially, though variations exist, evaporation is a much more regionally uniform parameter than rainfall (see below), which is little surprising, considering its determinant parameters (solar radiation, sunshine duration, Temperature, relative humidity …) are more uniform, both spatially and seasonally. For the last 50 years, temperature regimes in the Chi-Mun basin have not changed significantly, and though rising temperatures and corresponding climate changes potentially has profound impacts on the water regime, for the purpose of analysing past changes we assume regional climatic parameters to be sufficiently unchanged not to have an impact on water balance calculations.

Although the northeast region of Thailand is known to be drought-prone, the total annual rainfall in Northeast Thailand is not much different from that of the central region, with the frequently mentioned drought resulting from the uneven spatial distribution of rainfall, both inter-annually, and seasonally (Limpinuntana 2001). The lowest amount of annual rainfall is found in the western parts of the basin, with the Phetchabun mountain range functioning as a barrier, preventing higher precipitation under the influence of the southwest monsoon. Mean annual precipitation in this area (which covers large tracts of the Nam Phong, Upper Chi and Upper Mun areas) is as low as 1,000 mm per year, constituting the driest regions in northeast Thailand. Further east, precipitations rise continuously and reach up to 1,600 mm in the eastern provinces bordering the Mekong. Annual precipitation also varies considerably from year to year, with annual totals in the wettest years, two to three times the amount in the driest years; the coefficient of variation for annual rainfall is normally about 0.20, but varies typically between 0.15 and 0.23 (Binnie and Partners 1995).

Precipitation in the Chi-Mun river basin shows distinct wet and dry periods. It peaks in the months of June to August and it diminishes from November to March when rainfall is almost non-existent throughout the basin. The start of the wet season is generally characterized by comparably lower amounts of rainfall and it is particularly the later half of the wet season that brings higher rainfall intensities with the built-up of tropical cyclones in the South China Sea. Between the two dominant seasons, the months of April and October are transitional periods, with intermediate rainfall (Figure 4).

Figure 4: Average Monthly and Annual Rainfall in the Chi-Mun Basin (1950-2000)



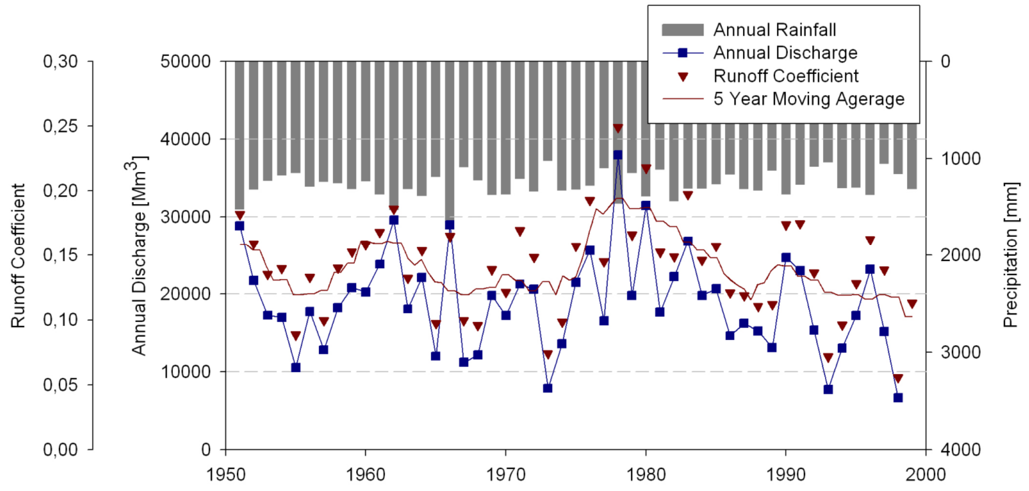
Annual rainfall series (1950 to 2000) do not show coherent trends and while selected stations (e.g. Khon Kaen, Ubon Ratchathani) show long term increases in rainfall quantities, others (such as Roi Et, and Nakhon Ratchasima) show decreasing linear trends (Figure 4). This general pattern, at least for the period from 1950 to around 2000 is confirmed by Wilk et al. (2001) who found no discernible changes in rainfall patterns in the 12,000 km² drainage basin of the Nam Pong (which is part of the Chi Basin in Northeast Thailand)[1]. This is important because since rainfall provides the net inflow into the study domain and the runoff ratio is considerably low, any error in the rainfall term significantly influences the water balance. Moreover, the variability of annual precipitation means that it is important to use a standard period when comparing annual total rainfall totals. If values for different periods are used, some of the observed variability will be due to the period used as well as to spatial or altitudinal variations. This led Binnie and Partner (1995) to conclude that "it is felt that this factor accounts for much of the apparently random variability displayed by some isohyetal maps of mean annual rainfall". This is even more crucial for this study, as annual precipitation constitute the drainage basin gross inflow, and thus has considerable effects on the following water balances.

Basin response to development: runoff and evolution of runoff coefficients

The runoff regime of the Chi-Mun Basin is characterized by its low runoff coefficient, which gradually declines from the upper catchments to the flat and undulating areas of the basin. The region produces an average annual runoff ratio of 0.15, which is considerably lower than the average for the larger Mekong river basin, which generates an average annual runoff ratio of 0.43 (Costa-Cabral et al., 2007). Spatially, the highest regional runoff is generated in the eastern provinces that border to the Mekong River, which also receive higher amounts of rainfall.

[1]Neither were changes found in the water balance terms nor in the dynamics of the recession at the end of the rainy season.

Figure 5: Annual Discharge and Runoff Coefficient at Ubon Ratchathani (1950-2000)



At basin level, the flow station best capturing long term changes in the Chi-Mun river system is located at Ubon Ratchathani (Figure 1). Daily measurements at this station are continuously available since 1950 and the drainage area that is captured by the station is about 87 % of the total Chi-Mun Basin area. A look at time-series of annual discharge and corresponding runoff coefficients at Ubon Ratchathani reveals declining trends for both variables (Figure 5), particularly for the period after 1980. In absolute terms, mean annual discharge at this station declined from around 19 Bm3 for the 10 year period from 1950-1959, to just over 16 Bm3 for the corresponding 1990 to 2001 period. During the same time, the mean annual runoff coefficient (averaged over 10 year periods) decreased slightly from 0.15 to 0.13; which highlights (again) the low runoff generated by the Chi-Mun basin.

Table 1: Evolution of runoff coefficients at selected stations

Station ID	Catchment Area [km²]	1950-1959	1960-1969	1970-1979	1980-1989	1990-2000
M2	4,800	0.10	0.09	0.10	0.10	0.10
M6.A	28,275	-	0.09	0.08	0.06	0.05
M5	44,275	0.10	0.10	0.10	0.09	0.07
E5	4,254	0.19	0.17	0.17	0.18	0.17
E16A	13,171	0.18	0.15	0.11	0.10	0.11
E1	29,788	0.14	0.11	0.10	0.10	0.09
E8A	30,764	0.13	0.11	0.10	0.10	0.10
E20A	47,818	0.14	0.14	0.7	0.12	0.11
M7	106,673	0.15	0.15	0.14	0.14	0.13

Significant declines in average annual runoff-coefficients are also reflected by most other flow-stations on the Chi and Mun rivers. The Upper Mun Sub-Basin, which is best represented by the flow-station at Satuk, saw diminishing runoff coefficients from 0.09 in the 1960s to as low as 0.05 in the 1990s, meaning that only 5 % of the annual rainfall is draining past this point of the river (Table 1).. Further downstream, and along the mainstream of the Chi and Mun Rivers, the average annual runoff has again decreased. However, mainstream runoff measurements on the

Chi and Mun rivers and their changing runoff coefficients are not uniformly found in tributaries of the Chi-Mun Basin which show a much more heterogeneous evolution of generated flows.

Impacts of water resources developments and landuse change

As seen earlier, storage capacity in large- and medium-scale irrigation projects in the basin grew from the 1950s onward to reach over 8 Bm3 at the turn of the century. This development is reflected in the basin's seasonal runoff pattern, which has seen a redistribution of annual runoff between the wet and the dry season. While in the 1950s, around 80 % of the annual discharge passed Ubon Ratchathani in the wet season (defined here as the months from May to October), this ratio has declined to 75 %. The declining runoff during the last 20 years at Ubon Ratchathani corresponds with the inception of the "two-pronged" water policy and the completion of large-scale dams and irrigation infrastructure, alongside the implementation of small-scale developments, most importantly pump irrigation schemes. However, due to the limited storage in the river basin and the nature of wet season flood peaks, the redistribution of water resources from the Wet to the Dry season remained limited.

The history of water resources development in the Chi-Mun basin is also clearly visible from looking at 5-year moving averages of the runoff coefficient in the study area. The 1960 to 1970 period saw most major water infrastructure developments (with corresponding abstractions from the natural runoff regime to fill the reservoirs) and therefore yielded comparably lower runoff coefficient (Figure 5). With the implementation of the "two-pronged water policy" in the late 1970s, annual runoff coefficients for the Chi-Mun basin declined from around 0.15 to as low as 0.10. Also, the introduction of an increasing number of small-scale irrigation projects (weirs, tanks and pumps) contributed to higher intensities of agricultural water use, thereby reducing run-off.

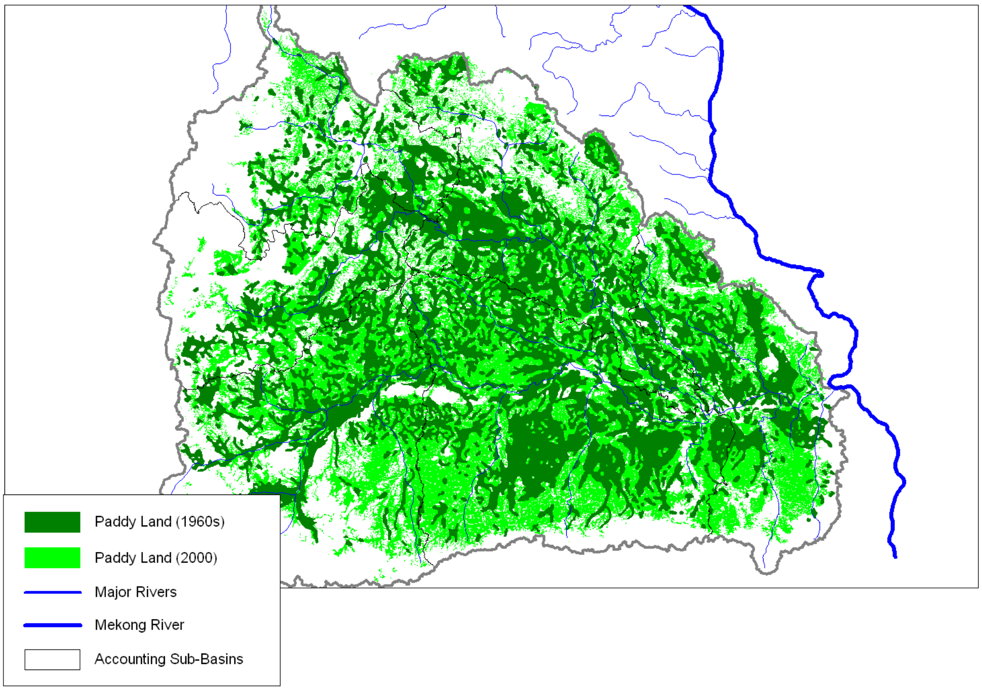
Changes in land-use that have been taking place in the Chi-Mun basin over the last 50 years have attracted scholarly attention from various disciplines including the hydro-sciences. At least since the early 1980s, changes in land-use (most notably the conversion of forest cover into agricultural land), have led to increased concerns about the hydrological impacts of these macro-scale changes. This was accompanied by the perception that the frequency of floods and droughts in the region had been increasing, and that these phenomena were linked to the clearing of upland terraces. A first attempt to analyse the interrelationship of land-use change and runoff in Northeast Thailand was conducted in 1982 by the Institute of Hydrology and Partners (IOH 1982, IOH 1984), but no conclusive evidence could be generated. More recently Weesakul (2005) analysed the impacts of deforestation on stream flow in nine sub-basins of the Chi-Mun Basin, and found no coherent pattern of how deforestation impacts the annual runoff of sub-basins. Wilk et al. (2001) modelled the Nam Pong Basin within the Chi-Mun basin, and found that their model could not reveal any significant change in the water balance due to deforestation. They further showed with a more detailed land-use analysis that shade trees were left on agricultural plots as well as a number of abandoned areas where secondary growth could be expected which they believed would account for the results of their water balance study.

Significantly, however, most studies on the impacts of land-use change on water resources in northeast Thailand have predominantly looked at deforestation, while – at the same time – giving considerably less attention to the re-shaping of the basin through bunding of agricultural areas for agricultural production. Only recently, Costa-Cabral and colleagues (2007) have focused on the relative importance of space-time variability and soil moisture on runoff-generation in the Mekong river basin. The study concluded that "while much of the runoff variability in the Mekong river basin results from the monsoonal precipitation regime and terrain topography [...] a significant portion of this variability is explained by the simulated spatial pattern of soil moisture". This is particularly important for the large extent of bunded paddy fields in the Chi-Mun Basin, since bunded fields are the defining elements of both irrigated areas and rainfed agriculture in large tracts of northeast Thailand (Figure 6).

Because bunded fields retain surface runoff in ponded conditions, allowing re-infiltration and increased evaporation, run-off generation is greatly reduced. As a result, soil moisture in the Chi-Mun basin remains high throughout the rainy season. Costa-Cabral et al. (2007), also found that the practice of irrigation in the area means that the deepest soil layers remain close to saturation throughout the irrigation period (June through October); most markedly in the Chi-Basin above Yasothon which is characterized both by the large-scale irrigation areas of the Nam Pong and

Lam Pao projects, and numerous small-scale irrigation systems that spread along the Chi river in this part of the basin. In addition, the practice of bunding is also reinforced by on-farm developments such as the installation of farm ponds (either individually or through government funds). Small on-farm ponds are an efficient infrastructure to reduce natural risk in rainfed lowland rice (Lacombe et al. 2005, Floch and Molle 2009). There is no reliable estimate of how many farm-ponds exist in the basin but most farmers in the region have access to this type of on-farm storage which captures surface and groundwater flows within the perimeter of fields, and provides them water for cultivation of field-crops (either on the sides of the ponds or through pumping) and for fish breeding and cultivation.

Figure 6: Expansion of bunded paddy fields in the Chi-Mun basin



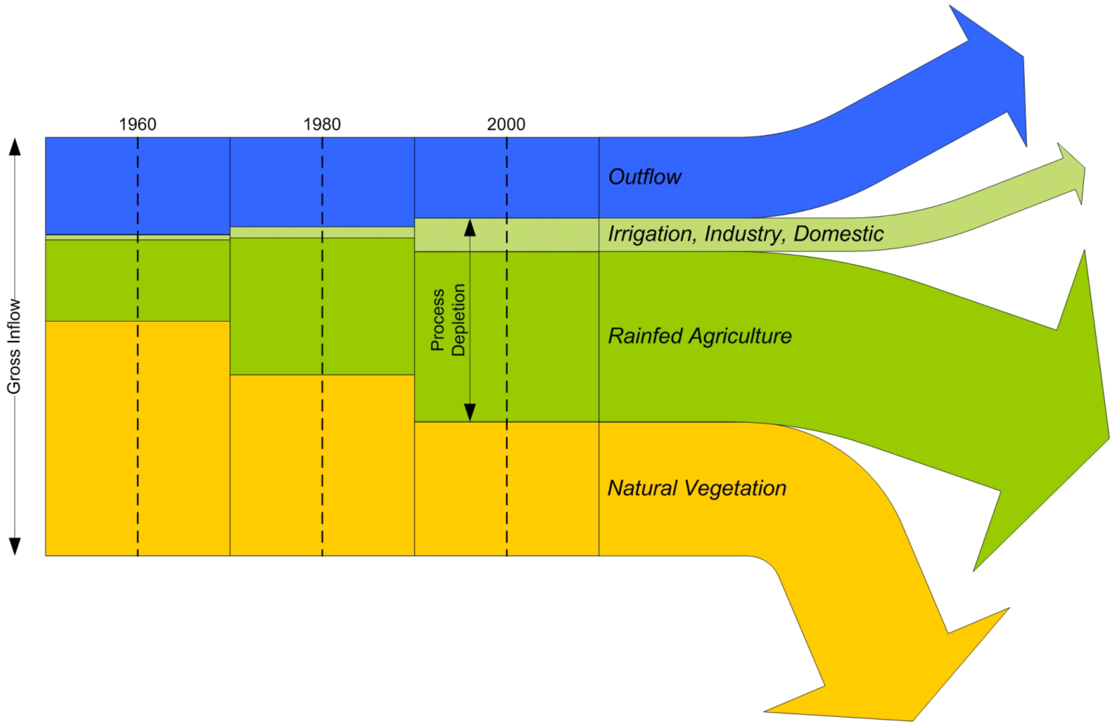
Water Accounting

Historical Water Accountings: 1960, 1980 and 2000

Since area-precipitation and particularly the long-term trends (either increasing or decreasing) are not readily visible from long term data, we have estimated the gross inflow into the Chi-Mun river basin at 138 Bm^3. Since no large-scale water imports into the Chi-Mun river basin have been implemented, and groundwater abstraction (or overdraft) is arguably negligible, the gross inflow is allocated among the various uses and users in the drainage basin.

The massive change in land-use from natural vegetation and forest, to large areas of agricultural land (most notably paddy fields) has doubled depletion from rainfed agricultural (defined here as not under state-sponsored irrigation) from just over 20 % of the total basin consumption to around 40 % of gross inflow. Conversely, depletion by forest and natural vegetation (scrub and bush), which consumed roughly 56 % of the available basin water resources in the 1960s, is now depleting 32 %. At the same time, process depletion – defined here as the sum of all diverted and depleted water to produce an intended product (Molden et al. 2003) including rainfed agriculture – increased from 22.3 % in 1960, to 35.2 % in 1980 to 45.4 % in 2000 (Figure 7).

Figure 7: Water Use Fractions: 1960, 1980 and 2000 (in Percent)



Annually, and in water accounting terminology, this means that the total depleted fraction raised from 77.6 % in 1960, to 78.4 % in 1980 and 79.4% in 2000, meaning that close to 80 % of the gross inflow (138 Bm^3) is now consumed within the boundaries of the basin. Total process depletion from rainfed agriculture, irrigation, domestic and industrial water uses, has doubled from 30.7 Bm^3 to 61.3 Bm^3 in the last 40 years. This is mostly attributable to the consumption of rainfed (wet season) agricultural which now consumes around 55 Bm^3, or 47 % of the Chi-Mun basin's gross inflow: the largest consumer in the basin.

The comparatively low average annual runoff ratio and little available storage means, that irrigation processes are confined to a comparatively little fraction of the overall basin resources. The fraction of water depleted in irrigated agriculture remained modest, and while in the 1960s only 2.1 % of the total process depletion was consumed by irrigation, the corresponding figure in 2000 is 8.2 %. In absolute terms, and considering dry season cropping intensities of 35 % for large-scale irrigation, and 10 % for medium-, small-scale and pump irrigation, we have estimated present annual irrigation water use at 5 Bm^3.

In short, this water use trajectory supports two major observations. Firstly, over the last 50 years the study area has been subjected only to moderate reductions in runoff. This is mostly explained by the failure to increase evapotranspiration in the dry season, as storage opportunities in the basin are limited, and with irrigation water use not adopted at the rate that was envisioned or promised. Secondly, the reduction in water consumption by forests, induced by large-scale deforestation, has translated into consumption within the expanding bunded agricultural areas, as water is trapped and stored for several months, thereby maintaining evapotranspiration close to its potential. This means, at the same time, that water use in the Chi-Mun river basin has shifted from low-beneficial uses from natural vegetation to beneficial depletion in agriculture, while the shift from runoff to evapotranspiration was more limited.

Wet and Dry Season Reallocation: Seasonal Water Accounting

Both large-scale and state-sponsored as well as individual and community level water resources developments aimed at facilitating more stable agricultural production in the wet season and the facilitation of dry-season production by redistributing water resources from the wet to the dry season. Together, these interventions in the hydrological regime of the basin led to a spatial and temporal re-allocation of water resources, shifting water availability from the wet into the dry season. However, constructed storage in water infrastructure projects does not constitute the total available storage of the drainage basin that can be carried over into the first month of the dry season (defined in this study as lasting from November to April). Within the Chi-Mun basin, we identify three dominant storage terms that have changed significantly during the last 50 years, impacting on the basin's water balance:

1. The construction of water resources infrastructure, which was in most cases associated with the facilitation of dry season irrigated agriculture (detailed in the trajectory of water infrastructure development above, Figure 3). Up until present time, the area under irrigation in the Chi-Mun Basin totals 0.9 million ha, and storage capacity reached almost 9.0 Bm^3 in the Chi-Mun drainage area (Mun Basin: 4.9 Bm^3, Chi Basin: 4.0 Bm^3).
2. Based on the extent of rainfed rice cultivation in the 1960 and 2000 (Figure 6), we estimate that additional storage in paddy fields and farm ponds has increased from 2.6 Bm^3 to over 5 Bm^3. This additional water is trapped in the rainy season (both as surface and subsurface water, and as soil moisture) and locally depleted (either through process depletion in the form of a second crop or to water homesteads, beneficially in fish ponds and (although "non-process") for the perennial vegetation that surrounds agricultural areas and homes). And although much of the additionally stored soil moisture is depleted within the wet season, an additional crop of vegetables in early succession after major rainfalls (mostly for home consumption and local markets), is quite common in northeast Thailand (Polthanee 2001); albeit on a small part of the available farm land.
3. The Chi-Mun basin has an impressive floodplain that stretches from the confluence of the Chi and Mun rivers along the middle reaches of these two rivers and many other smaller tributaries in the lower Chi-Mun river basin. After expanding in the wet season, the floodplains and oxbows only start to empty after major rainfall stopped, and are still carrying water into the dry season. Also, when water recedes, utilization of residual soil moisture and beneficial use of floodplain vegetation is observed in northeast Thailand (Blake 2001, Brenner 2003). Based on the extent of the floodplains, we have estimated that roughly 3 Bm^3 are carried over into the dry season in the floodplains. Despite a lack of data we have assumed that floodplain storage was reduced over the last 40 years: both the encroachment into the floodplains (agricultural expansion, settlements) and corresponding dikes probably lessened the extent to which these areas are able to fill during the wet season, while the balance discharge is conveyed downstream through in-stream discharge. Accordingly, we have estimated the 1960 floodplain to be able to carry some 5 Bm^3 and the 1980 storage to be in the order of 4 Bm^3.

Summing up these different storage terms, we estimate total storage and the corresponding transfer of water resources from the wet to the dry season to be in the order of 15 Bm^3 in the 1960s, 18 Bm^3 for the 1980s, and around 20 Bm^3 in 2000. This highlights the fact that (today) state-sponsored development of surface storage constitutes only a fraction of the total storage that is available for productive and environmental uses in the dry season.

This redistribution of water resources from the wet to the dry season means that the wet season depleted fraction in the Chi-Mun basin increased (in relative terms) from 70.9 % in 1960 to 77 % of the net inflow at present. In the same period, process depletion[2] during the wet season increased from 20.1 % to 43.9 % of the net inflow. Within all process depletion, irrigation water use in the wet season (in many instances the largest consumer of water resources in the context of river basins) increased from 3.0 % to 9.5 % of process depletion. In the dry season, 93.5 % of the net inflow was depleted in the 1960s, while this figure is now reduced to 85.5 %. This is mostly explained by the low adaptation of dry season cropping that prevails in the Chi-Mun River Basin and Northeast Thailand more generally.

Basin closure: overall status and discussion

With increases in process depletion from 27.9 % in the 1960s to 57.1 % of the total depleted water resources at the turn of the millennium, the Chi-Mun basin has undergone significant water development, while the outflow from the Chi-Mun River has dropped by about 5 Bm^3 to an

[2] The amount of water diverted and depleted to produce an intended product, e.g. irrigation, domestic and industrial uses.

average of 26 Bm^3 during the same 40 years. Storage in the Chi-Mun Basin, which was technically defined to be in the order of 15 Bm^3 is close to exhaustion, with most theoretically possible storage sites either developed or discredited for technical, financial or socio-economic reasons. Additional storage potential is now seen mostly in medium and small-scale-projects. Because of the exhaustion of additional storage, controllable surface water resources in the river basin are almost fully utilized. If we follow Boonlue (2005), and assume that a maximum of 1.4 Bm^3 could additionally be stored in the Chi-Mun river basin (by itself an optimistic assumption), the totally available water[3] within the basin would be in the order of 110 Bm^3, 55 % (61 Bm^3) of which are currently depleted in agricultural water use. However, with an average of 26 Bm^3 of water draining out of the Chi-Mun river basin, downstream water requirements are currently still met. This, in turn, means that by definition the Chi-Mun is still an open river basin, with initial and sub-regional signs of river basin closure (especially in the upper Mun River). However, and contrary to a narrowly focused definition of an open river basin, this does not imply that there is substantial room for supply augmentation in the Chi-Mun river basin.

Over the last half-century, irrigation projects supplying water to a potential 1.2 million ha have been installed in Northeast Thailand, and the total irrigable area in the Chi-Mun River Basin exceeded 0.9 million ha. Development of dry season irrigation in the Chi-Mun river basin, however, never reached substantial levels (see above). Reasons for this low utilization are, of course, numerous, but there is a clear indication that cultivating during the dry season is uneconomical in the marginally fertile soils that cover most of Northeast Thailand (Nesbitt 2005). Euroconsult (1998), for example, reported that in the large-scale Lam Pra Plerng and Lam Pao schemes less than 50 % of farmers were cultivating any crop because of high labour costs or a complete lack of labour, and Floch and Molle (2009) confirmed that off-farm economic opportunities have increasingly drawn farmers away from pump irrigation schemes in the lower Chi-Mun river basin, leaving much of the installed pumps idle during the dry season. Hence, irrigation infrastructure, which was largely installed on the premises of double cropping, is significantly underutilized.

On the other hand, a study of the Mun river basin explained that "after developing existing schemes to their full potential, and introducing a fully diversified cropping pattern away from the existing dominance of rice, the basin's water resources will be able to support an average of 11 % dry season cropping" (Binnie and Partners 1995). This suggests that the Chi-Mun river basin has been physically overbuilt; implying that in the case that irrigation facilities would be used at a rate close to their intended potential, water uses in the basin would be competing intensely for water resources.

Moreover, while the river basin is (still) open, the reason for this has to be understood as the result of the marginal utilization of existing infrastructure, rather than in terms of underdevelopment of water resources. Although the lack of storage does make it impossible to irrigate a large part or the whole of the public irrigation schemes, even the limited current potential is underutilized. The wider socio-economic trajectory has led to significant agrarian change (rural-urban migration, increasing off-farm employment opportunities) with low returns in dry season agriculture leaving irrigation infrastructure untouched. Irrigation, as the consumptive use which could potentially deplete available basin resources, was therefore mostly restricted to supplementary irrigation during the wet season, while full utilization never occurred[4].

Summary and Conclusion

At current levels of irrigation water use, domestic and industrial usage and extent of rainfed agriculture, the Chi-Mun river basin is not yet a closed river basin. The process of river basin development in this mostly rainfed-dominated ecosystem was fuelled by a two-fold mechanism: (i) the capturing of most feasible surface storage from the 1960s to the 1980s, and (ii) the

[3] Available water is the net inflow minus both the amount of water set aside for committed uses and the non-utilizable uncommitted outflow. It represents the amount of water available for use at the basin, service or use level. It includes process and non-process depletion plus utilizable outflow.

[4] This, of course, meant that much of the irrigation infrastructure that has been put in place on the argument of facilitating double cropping, has performed poor in economic terms.

massive expansion of rainfed cultivation (with the introduction of bunded fields). Together with local water storage, this reduced surface run-off throughout much of the basin. This process has meant that runoff out of the Chi-Mun river basin has been reduced by 5 Bm^3 during the last 40 years, while the remaining discharge cannot be easily captured without massive environmental and social disruption because of the lack of available storage. A traumatic example of such disruption within the Chi-Mun river basin are found in the Khong-Chi-Mun Irrigation Project and other in-stream storage weirs (such as the Pak Mun dam) along the Chi and Mun rivers, and most of their tributaries. By encroaching into parts of the floodplain ecosystem, these projects interfered with local water use, and disrupted the sensitive ecological balance of fish-migration, thereby creating massive popular protest (see e.g. Missingham 2003, Foran 2006).

The process of gradual closure of the Chi-Mun basin, unlike other more dramatic cases of basin closure (e.g. the Colorado, Yellow or Jordan River …) has played out much more quietly. This can be attributed to both the pace of expansion of rainfed agricultural and the lack of dry-season utilization of medium- and large-scale irrigation infrastructure. The low development of dry season cultivation, on the other hand, has prevented massive over-exploitation of surface water resources in parts of the basin, and our water accounting confirms that the potential demand of actual irrigation infrastructures outstrips by far available supplies. This, at the same time means, that the Chi-Mun river basin is de-facto overdeveloped. The process by which overdevelopment of irrigation infrastructure has played out mirrors experiences in other parts of the world. The political drive to benefit the largest possible constituency from large-scale hydraulic infrastructure has led planners and consultants to over-optimistically estimate water availability and it has been argued that “the potential for agricultural development [in the Chi-Mun river basin] has previously been overly optimistic, with an average of less than 5 % dry season cropping across the basin” (Binnie and Partners 1995).

The development of the basin, alongside its dual dynamics, is also the context under which contemporary state water policies – especially policies in favour of further supply augmentation (e.g. the Thai “Water Grid”, Molle and Floch 2008a) – have to be looked at. The dearth situation of farmers, scarce and erratic rainfall, and low actual irrigation water use, is frequently reflected against possibilities of massive transbasin diversions and further construction of storage and irrigation infrastructure, often through the implementation of pump-irrigation. Little, however, is published about the apparent underutilization of existing infrastructure, and the fact that over the course of the last 50 years, the Chi-Mun river basin irrigation infrastructure has already been overbuilt, fuelling calls for bringing in distant water through interbasin transfers. This is particularly true for the countless small-scale projects that scatter the Chi-Mun basin, and we have argued elsewhere that it is safe to assume that no one in the water bureaucracies is interested to know about the underutilisation of these projects (Molle and Floch 2008b).

Also, and quite remarkably, it has only been very recently that changes in runoff have been linked to the expansion of bunded rainfed agriculture, against earlier studies that solely looked at the impacts of deforestation and landuse change on the hydrology during the last 30 years. Giving basinwide attention to local storage and especially to soil water moisture and how it is artificially kept at high levels through local farm-level interventions highlights the importance of looking more closely at the management of water resources captured in the soil column. The recharge of soil and groundwater bodies in the Chi-Mun basin is equally dependent on the vast floodplains that annual fill and empty, a domain with currently little available research on the hydrological functions of this ecosystem on the basin, and the changing face of it. This, in turn, would be needed to better understand the recharge of adjacent tracts of land which are utilized for productive and environmental uses. In addition, there is little analysis of the cumulative impacts of local water storage (both in farm ponds and in soil moisture) on the wider hydrology of the Chi-Mun basin.

Molle (2003) has shown that balancing supply and demand in a basin context has as much a state as a local dimension. This, importantly, contrasts with research that focus solely on envisioning future changes as being governed by the state. Conversely, basin closure can both be governed by state-sponsored water resources development and bottom-up local responses to shortage of water. This is the case in the Chi-Mun Basin where local development of farms and on-farm storage – not as visible as large-scale developments in the basin – have significantly contributed to the local depletion of water, thereby efficiently capturing water to supply the “rainfed” agro-ecosystem that spreads throughout most of northeast Thailand. In view of this, talking of purely rainfed production appears to be misleading, as the availability of multiple water sources that farmers outside large-scale irrigation schemes can tap for productive purposes in the dry season is considerable.

Importantly, at first glance, and looking at the discharge that leaves the basin, planners and decision-makers are likely to assume potentials for further development, either through storage or through increases in efficiency. However, as we have shown elsewhere (Molle and Floch 2008a), current water policies, which focus on significantly augmenting areas under irrigation in Northeast Thailand, are in neglect of at least four distinct dimensions that currently limit the possible returns on investment: (i) the availability of storage in the basin, (ii) the lack of available labour for agricultural development, (iii) the environmental constraints that limit agricultural production, and (iv) the limited markets. Equally important, as the Chi-Mun river basin is already physically overbuilt, any attempt to increase production from irrigated agricultural should, first and foremost, target the utilization of existing infrastructure.

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