Shaojuan Li and Daming He

Water Level Response to Hydropower Development in the Upper Mekong River

Environmental changes and their transboundary influences on the Mekong watercourse system have been an international research focus in recent years, but the opinions and results related to the impacts of upper Mekong River dams are quite different. In this paper, based on the records of water levels from 1960 to 2003 at three mainstream sites in the upper Mekong River, a quantitative examination has been undertaken into characteristics of the mainstream water-level process at multiple timescales and its response to cascade development. The major results are: *i)* Annual mean, wet period mean, and the mean water levels during the period between March and April (PBMA period) exhibit a significant increasing trend at Jiuzhou and Yunjinghong sites, which are influenced by large-scale factors such as climate change and solar activity. *ii)* The interdecadal and interannual variations of annual mean, annual maximum, and wet period mean water levels at three sites show similar features during the dam construction period. *iii)* The interdecadal variations of PBMA period water level show a gradual increase at Gajiu and Yunjinghong sites but a falling trend at Jiuzhou; these trends confirm that there is some regulation on the flow in the dry season caused by the two existing dams. *iv)* The downstream effects of the present dams on water levels are very limited at the annual mean and wet season mean levels, not apparent at the monthly and yearly timescales, and relatively significant at daily and hourly timescales.

INTRODUCTION

The major transboundary issues in international rivers include the reasonable utilization, equitable distribution, and coordinated management of transboundary water resources (1–8). Flowing through six countries, the Mekong River is the most important international river in southwest China and Southeast Asia. Precipitation in the upper Mekong River is strongly influenced by the southwest monsoon. About 70% of annual precipitation is concentrated in the wet season during May–October, which results in unevenly distributed runoff. Runoff in the lower Mekong is much more plentiful than runoff in the upper Mekong (Lancang River) (9–10).

Currently, the Mekong region is at a crossroads in many respects. Development in the region calls for economic growth and investments in large-scale infrastructure and export industries. As a result, there has been a very rapid increase in electricity demand in the Mekong region to drive economic growth and alleviate poverty. According to Cogels (11), “if well designed and operated, hydropower has the potential to meet a significant part of this increasing demand in a much ‘cleaner’ way than other power-generation methods using coal, fuel oil, or natural gas. It has the significant advantage of producing electricity without carbon emissions and the respective impact on global warming.”

By the 1980s, the focus of hydropower development plans in the watershed had moved toward the mainstream of the upper Mekong River. In the early 1980s, an eight-dam hydropower cascade plan was developed. The first dam constructed was Manwan, which started its power generation after infilling in 1993 and was fully operational in June 1995. In October 2003, the second dam, Dachaoshan, reached full operation. The other two dams, Xiaowan and Jinghong, are under construction (12, 13).

Over the past ten years, concerns about the influence of large hydropower dams in the upper Mekong region on ecological and social systems along the river downstream have been the focus of heated debate, but the opinions and results are quite different. Many have suspected that the dams will influence flood control, irrigation, navigation, pollution control, and aquaculture downstream. Others have argued that the dams will obstruct the path of migratory fish, threatening biodiversity and reducing the catches upon which millions of human lives depend (13–17). For example, Quang and Nguyen (15) and Lu and Siew (16) indicated that the low water-level fluctuations in the dry period in the lower Mekong River have been significantly influenced by the operation of the Manwan Dam. Dore and Yu (13) suggested that the negative impacts of dam construction may include increased downstream erosion, serious disturbance to fisheries ecology, and the devastation of annual riverbank gardening enterprises. Other authors, however, have raised concerns that environmental changes (e.g., climatic factors and land use) are the main cause of the hydrological variations in the Mekong River Basin (11, 18–25). Campbell (18–20) showed that the low flows in 2003–2004 were caused by low rainfall in the lower basin, rather than any activities upstream. Mekong River Commission (MRC) (21) and Li et al. (23) indicated that the current dry conditions in the lower Mekong River are influenced by local climatic factors. Cogels (11) stated that the Chinese dams are not responsible for the drought situation faced by downstream countries in recent years. He et al. (22) suggested that the upper Mekong cascade development would increase the dry-period flow volumes and decrease the wet-period flow in the lower Mekong River and Cogels stated that this would be beneficial for drought management in downstream countries (11).

There are three primary reasons for the controversy surrounding dam development (26). *i)* There is a paucity of basinwide research and quantitative data investigating environmental change. *ii)* The existing data and information are usually inconsistent and not unified among different riparian countries in the Mekong region. *iii)* An upstream-downstream dialogue mechanism at multiple levels does not exist.

Based on water-level records from 1960 to 2003 at three mainstream sites, this paper provides a quantitative analysis of characteristics of the long-term water-level variation between the upper and lower reaches of the upper Mekong River at multiple timescales. The cascade development is analyzed to identify how the construction and operation of hydropower dams affect water-level variation. Furthermore, we investigate the main causes of the abnormal fluctuations of water levels (such as low water levels in 1993 and 2004). The results offer scientific recommendations for integrated water resources management (IWRM) in the Mekong River Basin, as well as for evaluations of transboundary effects of cascade hydropower dams in the upper Mekong River on the ecology of the lower Mekong River region.

© Royal Swedish Academy of Sciences 2008
http://www.ambio.kva.se

DATA AND METHODS

Data

The water-level data used in the paper are based on records of daily, monthly, and seasonal change at three mainstream hydrological stations in the upper Mekong (Fig. 1): *i)* at the Jiuzhou site (upper Manwan Dam) from 1960 to 2003; *ii)* at the Gajiu site (below Manwan Dam) from 1960 to 2001; and *iii)* at the Yunjinghong site (the last one before the upper Mekong River flows out of China) from 1960 through 2003. The three sites are located in stable reaches. Even the Gajiu site, the nearest gauging station below Manwan Dam, is located in a rocky reach, the morphology of which is unaffected by the outflow of the dam. Thus, the records at the three sites are consistent because the cross sections of the measurements stations have been stable over the study period.

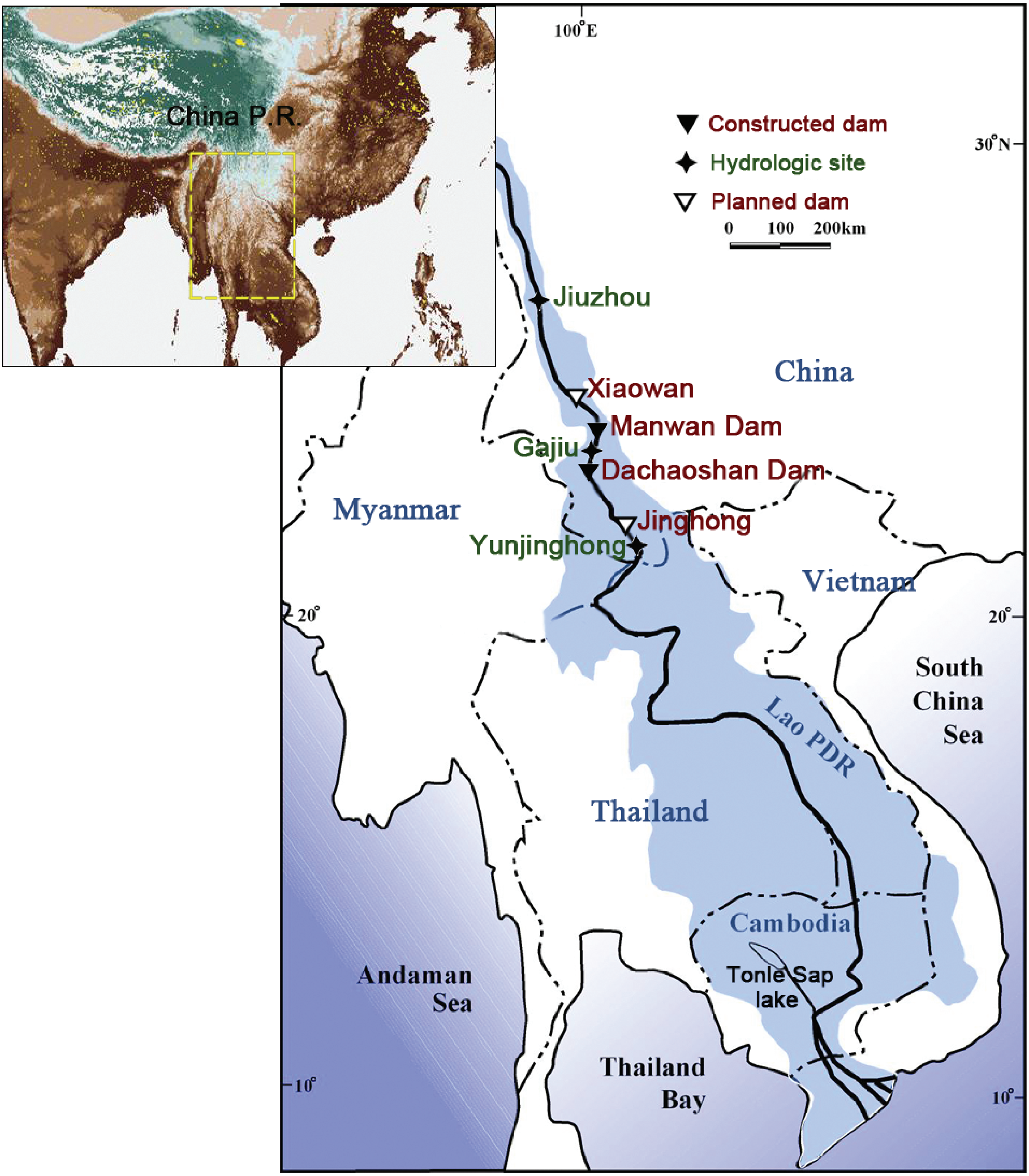

Figure 1. The location of three gauging sites in the main stem of the upper Mekong River and the relevant dam sites.

© Royal Swedish Academy of Sciences 2008

Methods

Generally, the observed water level can be divided into three factors: trend, interdecadal variation, and interannual variation. Trend is often influenced by large-scale environmental variation (such as climate variation), and other factors, including interdecadal and interannual variation, are influenced by human activities (e.g., dam construction, irrigation, or other water consumption activities). The moving-average method can be useful in smoothing time series. However, it has the significant drawback of reducing the length of time-series data available for analysis, which makes one-to-one analysis difficult, especially for terminal points in the time series. To overcome this problem, we employed the binomial coefficient weighted average method (27). The method has the following merits: *i)* the output data set has the same length as the original; *ii)* the major characteristics of one variable and its setting can be retained; *iii)* the trend and cycles of data series can be displayed clearly; and *iv)* it can smooth the high-frequency oscillation and reflect long-term variability. Using this method, water-level variations can be divided into trend, interdecadal, and interannual variations. From the three variations, the influences of climate factors and human activities on water-level variation can be shown.

The binomial coefficient weighted average method is given as follows:

Suppose we have N groups of random variables: $X_1, X_2, \ldots, X_i, \ldots, X_N$. The serial is weighted averaged by using a binomial coefficient of n, and the new serial, $Y_1, Y_2, \ldots, Y_i, \ldots, Y_N$, is obtained, where n must be an odd number. First, we set $m = n - 1$ and calculate the coefficient of $C_i = C_m^{i-1}$, where $i = 1, n$. Next, let $L = m/2$. The weighted average formula is defined as:

$$Y_i = \sum_{i=1}^{n} C_i X_k / 2^m,$$

when $i > L$, and $i \leq N - L$;

$$Y_i = \left(\sum_{i=a}^{n} C_i X_k \right) / \sum_{i=a}^{n} C_i,$$

when $i \leq L$; and

$$Y_i = \left(\sum_{i=1}^{b} C_i X_k \right) / \sum_{i=1}^{b} C_i,$$

when $i > N - L$; where $k = i - L - 1 + i$, $a = 2 + L - i$, $b = n - i + N - L$, and N is the number of the groups of random variables.

INTERANNUAL VARIATIONS OF WATER LEVELS AT MULTIPLE TIMESCALES

Figure 2 shows the annual mean, annual maximum, wet period (June–October) mean, and dry period (November–April) mean at Jiuzhou, Gajiu, and Yunjinghong sites from 1960 to 2003. Furthermore, the mean water levels during the period between March and April (PBMA period) are also chosen to illustrate the impact of dam construction. A lower water level has appeared a few times in the lower Mekong, which has been recognized in previous research (13, 15–17) as the influence of the upstream dams.

In Figure 2a, the annual means at three sites exhibit a relatively similar feature in most years during 1960 to 2002. The annual mean water levels at the three sites increase at the same time in the wet years (e.g., 1991) and decrease at the same time in the dry years (e.g., 1992). Even after the construction of the dams in 1992 in the mainstream of upper Mekong River, the variation of annul means shows similar features.

As for annual maximum, it can be noted that a similar feature exists in most years at the three sites, especially in the wet years (e.g., 1966, 1979, 1991, 1993, and 1998 in Fig. 2b). The years between 1967 and 1988 represent a stabilization period, characterized by smaller fluctuations in water levels. In the period from 1988 to 2002, however, a trend of increasing fluctuations can be seen (Fig. 2b).

Variations of mean water levels in the wet period, dry period, and PBMA period (Fig. 2c,d,e) reveal that there is no obvious difference among the three sites in most years, which indicates that the construction of the dams has not influenced long-term water- level variations. The water levels at Jiuzhou and Yunjinghong decreased in 2003, which was an extremely dry year, with annual precipitation reduced by 10%–20% from the long-term mean precipitation in the lower Mekong River (22). This may be one reason that the water-level trend at Yunjinghong is contrary to the other sites, except in PBMA period in this year.

CORRELATIONS OF WATER LEVELS IN DIFFERENT PERIODS AT MULTIPLE TIMESCALES

Table 1 shows the correlation coefficients for water levels at three sites in the first phase (before dam construction from 1960 to 1992) and the second phase (after dam construction from 1993 to 2003) on multiple timescales based on correlation analysis.

From Table 1, three results can be summarized:

i) During the PBMA period, the correlation coefficients for the mean water level decreased in the second phase, except for the correlation between Jiuzhou and Gajiu.

ii) For annual maximum water level, the correlation coefficient between sites at Jiuzhou and Yunjinghong in the second phase is significantly higher than that in the first phase. It is probably influenced by the dams' regulation for flood control during the wet period, which needs to be assessed further based on the daily records between the upper Mekong and the lower Mekong sites.

iii) For annual mean and wet-period mean water levels, there are no obvious changes in the correlation coefficients between two of these three sites during the two phases. For example, the correlation coefficient of annual means between Gajiu and Yunjinghong in the second phase is 0.023 higher than that in first phase. This means that the dams' operations have little regulating effect on annual mean and wet-period mean water levels downstream.

Figure 3 shows the scatter plots of the mean water level at annual maximum and PBMA period at the three gauging sites. The scatter plots support the results of the analysis. The fitted regression lines during the first and the second phases are marked in the plots, as are the years escaping from the fitted line and the special operational years of dams.

During PBMA periods, the correlations of mean water levels between the sites decrease a little in the second phase. This reduction is likely a result of the construction and operation of the dams (Fig. 3b).

THE CHARACTERISTICS OF WATER-LEVEL VARIATIONS AT MULTIPLE TIMESCALES

As stated, at multiple timescales, water-level variations can be divided into trend, interdecadal, and interannual variation curves (Fig. 4). From interdecadal, and interannual variation curves, the influences of human activities (such as dam construction, irrigation, or other water consumption activities) on water-level variation can be more directly shown, which can help us to evaluate how the operation of hydropower dams in

© Royal Swedish Academy of Sciences 2008
http://www.ambio.kva.se

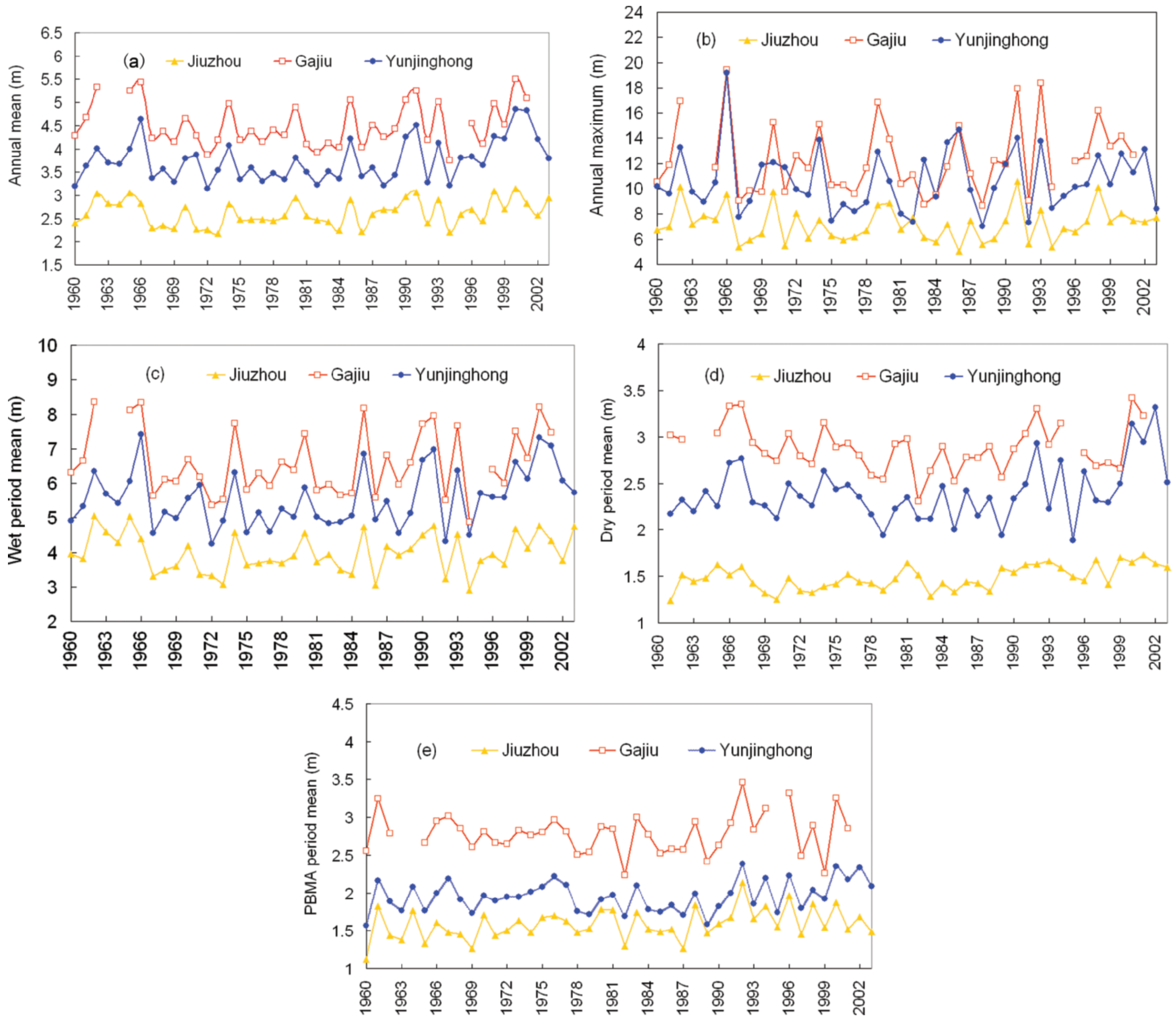

Figure 2. The variations of water levels at multiple timescales at three sites in the mainstream of upper Mekong River (a: annual means; b: annual maximum; c: wet-period means; d: dry-period means; e: PBMA period means).

the upper Mekong River affects the water level in the lower reach of the upper Mekong River.

From Figure 4, four results can be shown:

i) Annual mean and PBMA period mean water levels exhibit a significant increasing trend at Jiuzhou and Yunjinghong sites. The wet-period mean also shows a significant increasing trend at Yunjinghong. Such trend variations are influenced by large-scale factors such as climate change.

ii) A 9 y or 10 y cycle in annual mean water level exists at the three sites over the past 40 y; this coincides with the periodic oscillation pattern of solar spot activity (28). This implies that the annual mean transboundary runoff in the upper Mekong River may be related to the supply of solar energy, and the whole water-level evolution of this river is direct influenced by the solar activity.

iii) The interdecadal and interannual variations of annual mean, annual maximum, and wet-period mean water levels at the three sites show similar features during the dams' construction period (1993–2002), which means that present human activities (including dam construction) have little

Table 1. Correlation coefficients of water level at multiple timescales between three sites (all of them pass 95% confidence verification).

	Annual mean		Annual maximum		Wet-period mean		PBMA period mean	
	Pre-impact	Postimpact	Pre-Impact	Postimpact	Pre-impact	Postimpact	Pre-impact	Postimpact
Jiuzhou-Gajiu	0.882	0.955	0.807	0.808	0.93	0.983	0.778	0.84
Gajiu-Yunjinghong	0.903	0.926	0.78	0.926	0.917	0.96	0.883	0.809
Jiuzhou-Yunjinghong	0.732	0.845	0.53	0.823	0.76	0.932	0.731	0.678

Pre-impact: before construction of dams (1960–1992).
Postimpact: after construction of dams (1993–2003).

© Royal Swedish Academy of Sciences 2008

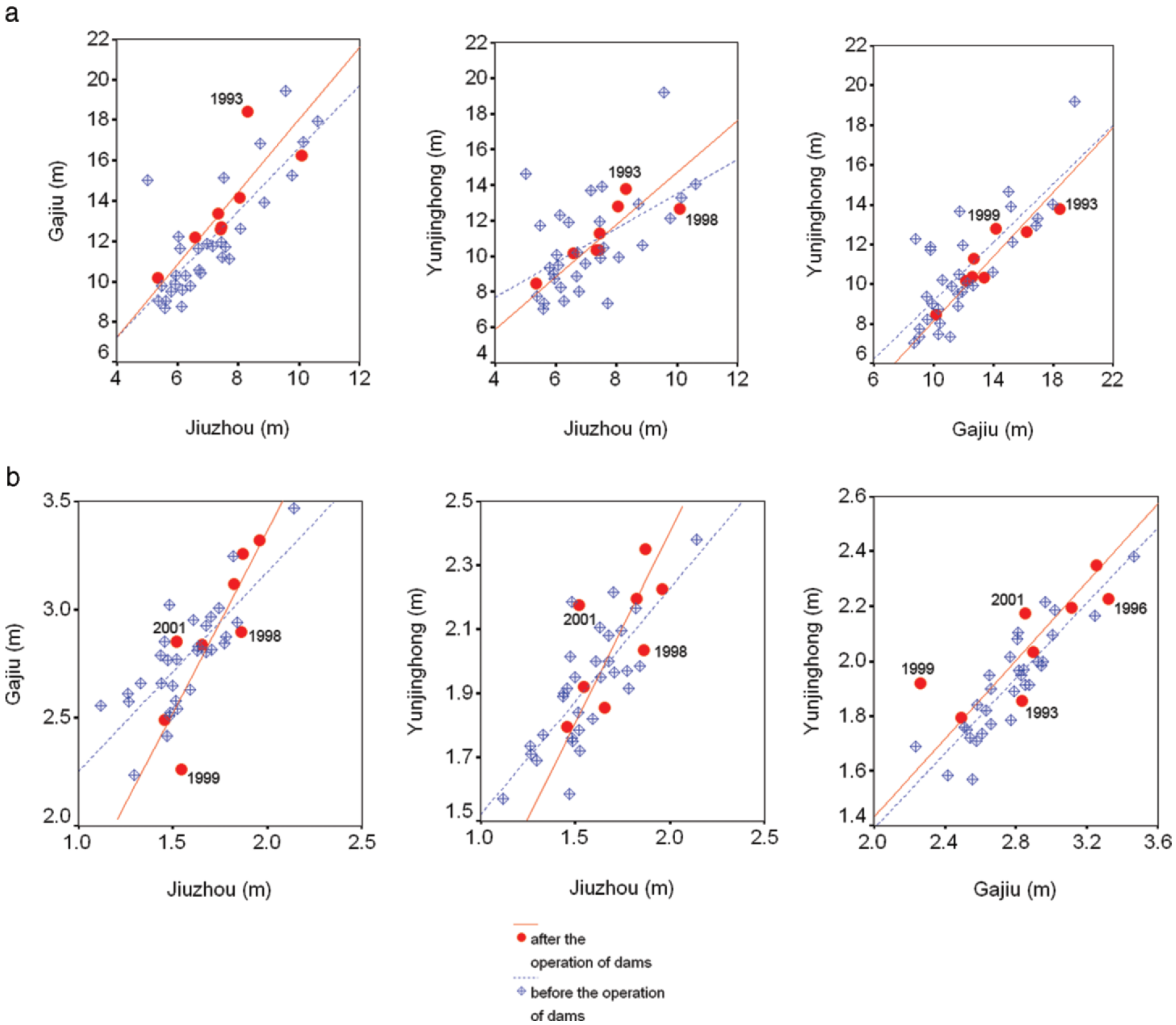

Figure 3. Scatter plot of different timescale water levels between three sites (a: annual maximum, b: PBMA period mean).

influence on the whole upper Mekong River water-level variation. Furthermore, the differences in the water-level variations are usually on smaller timescales and are more similar on larger timescales.

iv) The interdecadal variations of PBMA period water level increase gradually at Gajiu and Yunjinghong, while they show decreasing characteristics at Jiuzhou site, especially from 1996 to 2000. This means that the upper Mekong cascade development will increase the flow of the upper Mekong River reaches during dry periods, confirming the research of He (12, 22): there is some regulation on the flow in this period caused by the two existing dams

INFLUENCES OF DAMS ALREADY CONSTRUCTED ON MONTHLY WATER-LEVEL ALLOCATION

Figure 4 compares monthly water-level allocations at the three sites during the periods preceding and following construction of Manwan and Dachaoshan Dams.

Before the construction of Manwan Dam, variations of monthly water-level allocation at the three sites were consistent (Fig. 4a). During construction of the dam, however, changes of

Men mending a fishing fence of the large-scale fishing lot in the Tonle Sap Lake of Cambodia (Photo: M. Keskinen).

© Royal Swedish Academy of Sciences 2008
http://www.ambio.kva.se

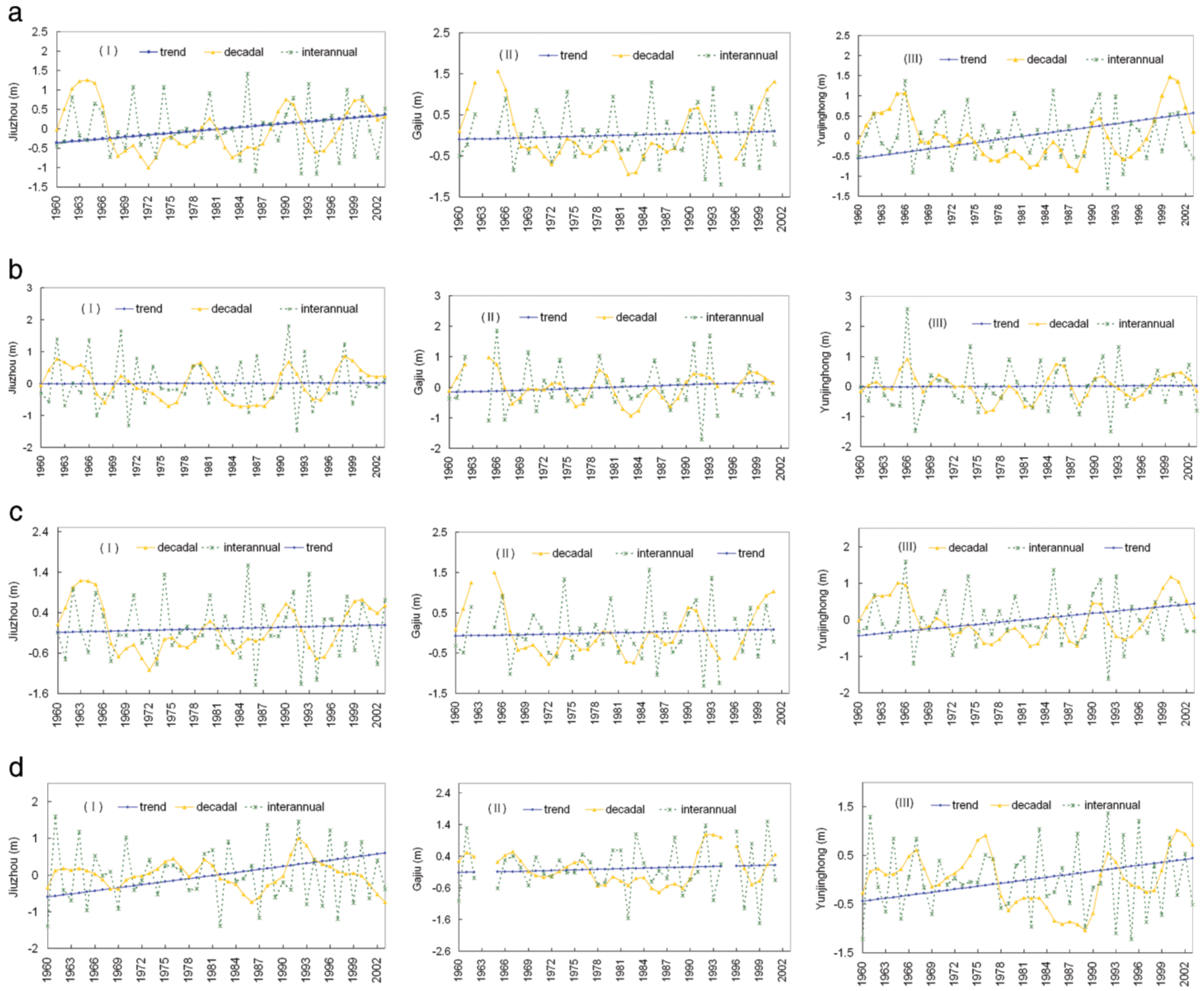

Figure 4. The trend, interannual, and interdecadal variations of multiple-timescale water levels (a: annual mean water level; b: annual maximum water level; c: wet-period mean water level; d: PBMA period mean water level).

monthly water-level allocation at the three sites became evident (Fig. 4b); clearly, construction of the dam had an influence on the distribution of water-level allocation at monthly timescales within the year at the Gajiu site and the Yunjinghong site. After the reservoir at Manwan Dam began filling, the allocation at the three sites returned to be more consistent (Fig. 4c). However, in 2000, when both Manwan Dam was under operation and Dachaoshan Dam was close to finishing, the water-level allocation again appeared more or less consistent at the three sites (Fig. 4d).

Currently, then, when the two dams are operating under normal operating conditions, the influences on downstream monthly water-level allocation during year are not obvious. However, at timescales shorter than a month, especially daily and hourly, influences of the dams on water-level variation are more significant.

DISCUSSION

Annual Minimum Water Levels in 1993 and 2004

An important factor that must not be overlooked is the movement of Chiang Saen station, located in Northern Thailand, in 1993. The Chiang Saen gauging station was moved downstream 500 m on 15 December 1993, and the zero reference showed a difference of 0.62 m from the previous site (29). Therefore, conclusions of downstream impact of hydropower dams in the upper Mekong based on the lowest water level observed at Chiang Saen station should be further analyzed. More detailed data from the hydrological record in the lower Mekong will be found, and this issue will be analyzed and discussed in future research.

In response to abnormally low water levels observed in the lower Mekong in February and March 2004, several environmental nongovernmental organization (NGOs) hurried to claim that the upper Mekong dams were the cause (30–32). After conducting its own analysis, the MRC Secretariat (21) announced that "The upstream dams in China are not the reason for the low water level in Mekong but the continuous drought of the last year in the river basin." Campbell (21) noted that "If the low water level in the lower Mekong was caused by the water stor[age] in China dams, we could find that the drought in the channel close to China border would be more serious. But in fact, it was found that the drought in Mekong channel at Pakse Station is more serious than that at Chiang Saen station."

As He et al. (22) showed, the reality of the 2004 droughts is that annual precipitation in the upper Mekong watershed in 2003 was 10%–20% less than the multiyear mean at the county

© Royal Swedish Academy of Sciences 2008
http://www.ambio.kva.se

level. In Ximeng County, for example, which normally receives the highest levels of rainfall annually, the decrease was nearly 45%. Similarly, rainfall from January to March of 2004 was 36%–81% less than the multiyear mean from previous years for the same time period. Thus, the uncommonly low water levels in early 2004 resulted mainly from drier climatic conditions, excepting the influence from the construction and operation of the upper Mekong dams. Arguments to the contrary simply do not hold up to scientific scrutiny.

Influence of Cascade Hydropower Development on Downstream Flows

The downstream effect of dam construction and operation is extremely complex because it is strongly connected with the conditions of socioeconomic and environmental systems in the downstream area. This is why the precise nature of the impact of such construction and operation of such projects on downstream regions is frequently overlooked, avoided, and remains a subject of much uncertainty (33). The Mekong River is among the few major rivers in the world running in a north-south direction, and extremely diverse ecological and socioeconomic environments prevail along the entire length of the river. River-flow variation is particularly subject to the influences of climate change and human activities, yet the upper Mekong dams are but one of many drivers of change.

The influence of the present upper Mekong dams is, for the most part, limited to middle stretches of the river valley, making them a minor influence in the hydrology of the overall river system. The total volume of water that can be stored behind the two existing dams, Manwan and Dachaoshan, is at least 30 times smaller than the total volume of water flowing annually out of China in the Mekong River. Furthermore, these dams are not used for irrigation, but mainly for power generation, they do not "consume" water and tend to increase the river flow in the dry period while reducing the flow in the flood period. As Cogels (11) said, "The overall downstream impact of hydropower dams on the Upper Mekong in China is often exaggerated in the public opinion."

Moreover, as this research has shown, the primary influence of present upper Mekong dams on variations in lower Mekong water level is seen at the timescale of one to several days and is concentrated in the gorged mainstream channel of the river upstream of Vientiane. At timescales of more than month, the primary influence on water-level variations is usually climatic factors.

Once Xiaowan and Nuozhadu, the two largest upper Mekong dams, are completed, the seasonal regulation capacity of upper Mekong discharge within China will reach 100%, with yearly regulation capacity at 23%. This will have an obvious effect on the distribution of water volumes throughout any given year, which will have comprehensive effects on hydrological process. The increase of regulated runoff, for example, will be benefit for the irrigation and navigation in the lower Mekong River. The measures or decisions for reducing the downstream impacts, like practicing integrated operation based on downstream ecological hydrology processes, have been studied recently in China (7, 10, 12, 18–24). The real effects in the future from the construction and operation of the dams, however, need to be further analyzed and assessed based on detailed information, such as the daily hydrological records from both the upstream sites and the downstream sites.

CONCLUSIONS

The following conclusions can be drawn:

Annual mean, wet-period mean, and PBMA period mean water levels exhibit significant increasing trends at Jiuzhou and Yunjinghong sites, which are influenced by large-scale environmental influences such as climate change. It is also noticed that a 9 yr or 10 yr cycle of annual mean exists at three sites during past 40 y, which implies that the whole water-level evolution of this river is direct influenced by solar activity.

The interdecadal and interannual variations of annual mean, annual maximum, and wet-period mean water levels at three sites show similar features during the dam construction period, which means that present human activities (including dam construction) have little influence on the whole upper Mekong River water-level variation.

The interdecadal variations of PBMA period water level increase gradually at Gajiu and Yunjinghong but show a falling trend at Jiuzhou, which confirms that there is some regulation on the flow in the dry season caused by the two existing dams.

The downstream effects of operation of the present dams on the water levels are very limited at the annual mean and wet-season mean levels, not apparent at monthly and yearly timescales, and relatively significant on the daily and hourly timescales.

References and Notes

1. Dalby, S. 2002. *Security and Ecology in the Age of Globalization*. Environmental Change and Security Program Report, Woodrow Wilson International Center for Scholars, Washington DC, pp. 95–108. (http://www.wilsoncenter.org/topics/pubs/Report_8_Dalby.pdf)
2. Jacobs, J.W. 1994. Toward sustainability in lower Mekong River basin development. *Water Int. 19*, 43–51.
3. Jacobs, J.W. 1995. Mekong Committee history and lessons for river basin development. *Geograph. J. 161*, 135–148.
4. Sandra, P. 1996. *Dividing the Waters: Food Security, Ecosystem Health, and the New Politics of Scarcity*. World Watch Institute, New York, pp. 35–45.
5. United Nations Economic and Social Commission for Asia and the Pacific. 1997. Guidelines on water and sustainable development: principles and policy options. *Water Resour. Ser. 77*, 1–20.
6. He, D., Liu, C. and Yang, Z. 1999. Study for the sustainability of international rivers in China. *Acta Geograph. Sin. 54(Suppl.)*, 1–10 (In Chinese).
7. Feng, Y., He, D., Gan, S. and Gu, Y. 2006. Linkages of transboundary water allocation and its eco-thresholds with international river. *Chin. Sci. Bull. 51(Suppl.)*, 25–32 (In Chinese).
8. Motoyuki, S. 2001. Promoting academic debates for sustainable management of international rivers: the role of the UNU. In: *Towards Cooperative Utilization and Coordinated Management of International Rivers*. Daming, He, et al. (eds). Science Press, New York, p. 1–3.
9. He, D. 1995. The analysis of hydrographic characteristic in Lancang-Mekong River, Yunnan. *Geograph. Envir. Res. 7*, 58–73 73 (In Chinese).
10. Liu, H. 2001. Water resources simulation model of the Lancang River (Yunnan Portion). In: *Towards Cooperative Utilization and Coordinated Management of International Rivers*. He, D., Zhang, G. and Hsiang-te, K. (eds). Science Press, New York, pp. 208–215.
11. Cogels, O. 2007. Mekong hydropower development is good. *Bangkok Post,* 9 January 2007. (http://www.greengrants.org.cn/read.php?id=1353)
12. He, D. and Chen, L. 2002. *The Impact of Hydropower Cascade Development in the Lancang-Mekong Basin, Yunnan. Mekong Update & Dialogue*. Sydney University, Australia, pp. 2–4.
13. Dore, J. and Yu, X. 2004. *Yunnan Hydropower Expansion*. Chiang Mai University's Unit for Social & Environmental Research & Green Watershed working paper. Chiang Mai University, Kunming, PR of China, pp. 18–27.
14. Roberts, T. 2001. Downstream Ecological Implications of China's Lancang Hydropower and Mekong Navigation Project. (http://www.irn.org/programs/lancang/index.asp?id=021112.ecoimplications.html)
15. Quang, M. and Nguyen, P.E. 2003. Hydrological impacts of China's upper Mekong dams on the lower Mekong River. (http://mekongriver.org/publish/qghydrochdam.htm 21)
16. Lu, X.X. and Siew, R.Y. 2006. Water discharge and sediment flux changes over the past decades in the lower Mekong River: possible impacts of the Chinese dams. *Hydrol. Earth Sys. Sci. 10*, 181–195.
17. The Chinese dams are blamed for the abnormal discharge in the Mekong River (*Reuters,* 25 March 2004).
18. Campbell, I. 2007. Perceptions, data, and river management: lessons from the Mekong River. *Water Resour. Res. 43*, W02407.
19. Campbell, I. 2004. *The Present Low Flows in the Lower Mekong Basin*. Mekong River Commission Report No. 3/04. (http://www.mrcmekong.org/MRCnews/press04/26-mar-04.htm)
20. Campbell, I.C. and Manusthiparom, C. 2004. *Technical Report on Rainfall and Discharge in the Lower Mekong Basin in 2003–2004*. Mekong River Commission Secretariat, Vientiane, 7 pp.
21. Mekong River Commission Secretariat. 2004. Mekong's low flows linked to drought. *News & Events 3*. (http://www.mrcmekong.org/MRC_news/press04/26-mar-04.htm).
22. He, D., Feng, Y., Gan, S., Magee, D. and You, W. 2006. Transboundary hydrological effects of hydropower dam construction on the Lancang River. *Chin. Sci. Bull. 51(Suppl.)*, 16–24.
23. Li, S., He, D. and Fu, K. 2006. The correlations of multi-timescale characteristics of water level processes in Lancang-Mekong River. *Chin. Sci. Bull. 51(Suppl.)*, 50–58.
24. Fu, K., He, D. and Li, S. 2006. Response of downstream sediment to water resource development in mainstream of the Lancang River. *Chin. Sci. Bull. 51(Suppl.)*, 119–126.
25. Mekong's low flow no link with Chinese dams, *China View,* 26 March 2004. (http://news.xinhuanet.com/english/2004-03/26/content_1387097.htm)
26. He, D. 2007. Integrated assessment of dam's impacts—a case of upper Mekong hydropower development and its impact to the lower Mekong. In: *Symposium on Modeling of Dams,* 11–13 April 2007. Skamania Lodge, USA.

© Royal Swedish Academy of Sciences 2008
http://www.ambio.kva.se

27. Wei, F.Y. 1999. *The Diagnosis, Analyses and Forecast of Modern Climate*. Meteorological Press, Beijing, pp. 42–61 (In Chinese).
28. She, C.Y. and David, A.K. 2004. Impact of natural variability in the 11-year mesopause region temperature observation over Fort Collins, CO (41°N, 105°W). *Adv. Space Res. 34*, 330–336.
29. Lu, X.X. 2005. The research on suspended sediments in lower reach of Lancang-Mekong river, presented at the Conference of Ecosystem Changes in Longitudinal Range-Gorge Region and Transboundary Ecological Security in Southwest China, held by Yunnan University, 25–26 March, Kunming, China.
30. Low water levels in Mekong caused by Chinese dams (*Bangkok Post,* 15 February 2004).
31. Chinese dams cause water level to recede (*Bangkok Post,* 15 February 2004).
32. China's dams linked to low water levels (*The Nation,* Bangkok, 3 March 2004).
33. Adams, W. 2000. *The Downstream Impact of Large Dams*. Working paper prepared for World Commission on Dams, Vlaeberg, Cape Town, Africa, pp. 7–14.
34. Acknowledgments: The authors would like to thank the anonymous reviews for their constructive comments, and extend thanks to Matti Kummu, Sam Buchanan, Hu Jinming, Lu Xixi, Fu Kaidao, and Marko Keskinen for their great help in exchanging information and revision for the work. This work was supported by funding from the National Key Project for Basic Research of P.R. China (also called 973 Program) (project No. 2003CB415105). This work has received funding from the Academy of Finland project 211010.

Shaojuan Li is a PhD candidate at Asia International Rivers Center, Yunnan University, China. She has experience in climate change of East Asia, hydrologic processes, and transboundary ecological security of the Lancang-Mekong River. Her address: Asia International Rivers Center, Yunnan University, Kunming 650091, China.
E-mail: lsj@mail.ynu.edu.cn

Daming He is a senior researcher at Asian International Rivers Center, Yunnan University. He has broad and interdisciplinary experience on water use, environmental change, and ecological conservation, focusing on international rivers. His address: Asia International Rivers Center, Yunnan University, Kunming, 650091, China.
E-mail: dmhe@ynu.edu.cn.

© Royal Swedish Academy of Sciences 2008
http://www.ambio.kva.se

Copyright of AMBIO - A Journal of the Human Environment is the property of Allen Press Publishing Services Inc. and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.