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# Three Gorges Dam and Its Impact on the Potential Transmission of Schistosomiasis in Regions along the Yangtze River

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**Abstract:** Large-scale hydroprojects have a propensity for incurring schistosomiasis epidemics by altering the environments of their vicinities. As the construction of the Three Gorges Dam, one of the world's largest hydroprojects to date, draws near its conclusion, an assessment of the dam's capacity in causing schistosomiasis becomes more urgent and pressing. This article reviews recent investigations into the possible effects of the dam on schistosomiasis in the Three Gorges region and areas along the Yangtze downstream from the dam. Data used in this article were extracted from peer-reviewed papers found in *PubMed, Chinese Journal of Parasitology and Parasitic Diseases*, and *Chinese Journal of Schistosomiasis Control*. Results indicate that the Three Gorges Dam is capable of inducing a wide variety of environmental and ecological changes both within the Three Gorges region and in downstream areas. These changes, however, carry ambivalent implications for the reproduction of *Oncomelania* snails and the spreading of schistosome infections. Furthermore, major changes in the demographics and agricultural practices of the Three Gorges and downstream Yangtze areas caused by the dam could also exert significant influence on the transmission of schistosomiasis in these regions. Major conclusions of this review include the need for further ecological simulations of the Three Gorges Dam and the need for deploying monitoring and intervention systems to provide successful prophylaxis of the Three Gorges Dam-associated schistosomiasis emergence.

**Keywords:** *Schistosoma japonicum*, *Oncomelania hupensis*, Three Gorges Dam, Yangtze River, hydroproject, China

## Introduction

The Three Gorges Dam is one of the world's largest hydroproject aimed at controlling and developing the Yangtze River (Government of China, 2006). Although instrumental to the alleviation of flooding in areas surrounding the Yangtze River, the dam nevertheless creates many environmental changes. In particular, the potential impact of the dam on the transmission of *S. japonicum* both within its vicinity and in downstream Yangtze regions has invoked concerns from researchers worldwide (Maszle et al., 1998;

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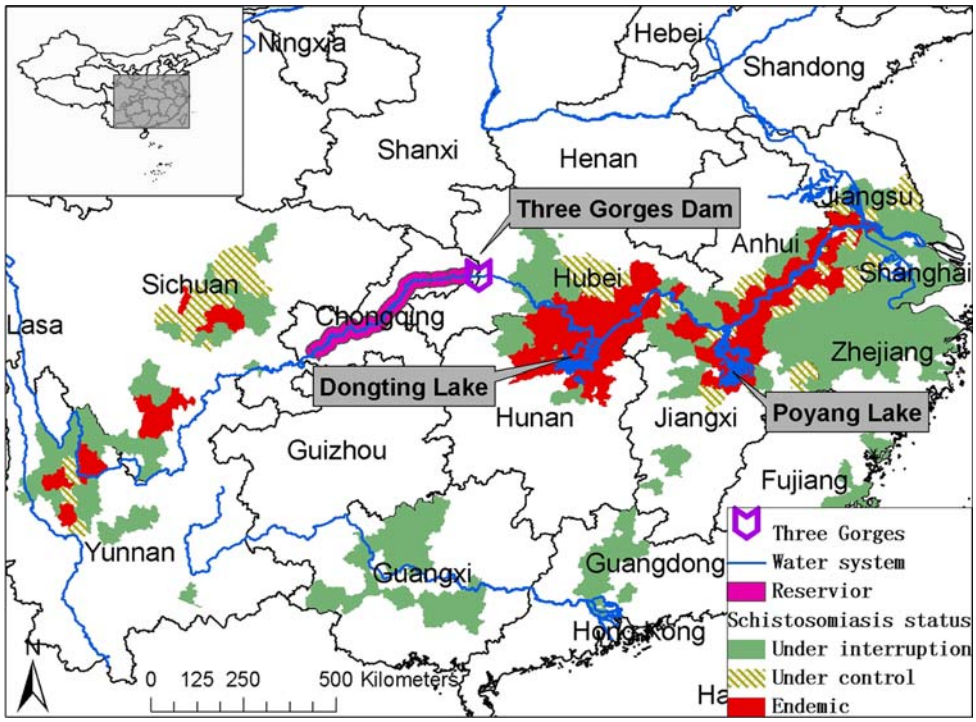


**Figure 1.** A map of the Three Gorges Dam showing schistosomiasis endemic foci and names of various geopolitical divisions used in the article.

Engels et al., 2005; Winter, 2005). In the last century, schistosomiasis emergences or re-emergences resulting from large-scale hydroprojects have been reported for the Sudanese Gezira-Managil Dam (Omer, 1978; Amin, 1977; Fenwick, 1989), the Egyptian Aswan High Dam (Khalil, 1949; Strickland, 1982), and the Ethiopian Melkasadi Dam (Teklehaimanot and Fletcher, 1990). In China, the Danling Dam in the province of Sichuan and the Huangshi Dam in the province of Hunan have all had adverse effects on local schistosome transmission (Guo and Zheng, 1999; Zhang and Guo, 2006). However, not all dam regions suffer from schistosomiasis. For example, when the Ertan Dam in the province of Sichuan became operational, local schistosomiasis control centers collaborated with dam management office and government ministries to actively monitor and prevent the spreading of schistosome worms. As a result of these efforts, potential schistosome transmissions in the Ertan region were successfully averted (Gu et al., 2001).

Currently, the Three Gorges region is a non-endemic area for schistosomiasis. However, regions of the Yangtze River both upstream to and downstream from the Three Gorges area form schistosomiasis endemic foci (Fig. 1) (Xu et al., 2000a; Wu CG et al., 2005a). Therefore, one primary focus of our exposition is the possible introduction of *S. japonicum* to the Three Gorges region through environmental changes caused by building the Three Gorges Dam. The rest of this review is organized as follows: Section 2 briefly summarizes the environmental and geographical characteristics of the Three Gorges region. Section 3 presents some possible environmental changes induced by building the Three Gorges Dam. Section 4 discusses the influences these changes may have on the transmission dynamics of *S. japonicum* in the Three Gorges region. Section 5 examines the impact of the Three Gorges Dam on the transmission of schistosomiasis in downstream regions of the Yangtze River. Finally, Section 6 concludes the entire review with some additional recommendations.

## Environmental and Geographical Characteristics of the Three Gorges Region

The Three Gorges Dam is located in the Three Gorges region in the upper reaches of the Yangtze River (Fig. 1). It is situated upon Sandouping Island in the province of Hubei, China. The reservoir associated with the dam occupies a total area of approximately 1084 km$^2$. It is a narrow and long reservoir about 600 km in length and 1.1 km in width. Its maximum water reservation level is 175 m (Hong, 1992). The reservoir stretches from 106° E to 111° E and from 28°50′ N to 32° N, which places it in between two major schistosomiasis endemic regions—the Jianghan Plains of the province of Hubei and the Chengdu Plains of

the province of Sichuan (Fig. 1). No noticeable differences exist between the temperature and precipitation levels of the dam region and the two surrounding schistosomiasis endemic regions. The lifestyles of people living around the dam and those living in the endemic regions are not significantly dissimilar (Wang and Zheng, 2003). A investigation performed in 1983 revealed that the species spectrum of mollusks distributed in the Three Gorges region is not significantly different from that found in the endemic regions. Some species of snail other than *Oncomelania hupensis* are in fact identical to those found in endemic regions in western Sichuan. However, the presence of many cliffs, precipices, and jagged shores formed by the rapid flowing waters of the Three Gorges segment of the Yangtze River, along with the lower temperature of the water, discourages *Oncomelania* snail life and reproduction in the Three Gorges region. Hence, the Three Gorges is currently a non-schistosomiasis endemic area because of neither a suitable place for *Oncomelania* breeding nor for transmission of *S. japonicum* (Gu et al., 1987).

## Possible Environmental Changes Associated with the Three Gorges Dam

Guo and Zheng (2000) predicted that the Three Gorges Dam's environmental adjustment capacities allow for significant changes to the Yangtze River's water and sedimentation levels in its mid and lower reaches. These changes, in turn, will significantly alter the environments and ecologies of numerous regions and provinces from mid to lower reaches of the Yangtze River. Before discussions on their implications for schistosomiasis could begin, the environmental changes brought about by the dam must be made more clear and concrete. This section enumerates some of these changes, and quantifies them in such a way as to facilitate further discussions in subsequent sections.

### Water Level

When the Three Gorges Dam becomes operational, the natural river course lying within the dam will be submerged and changed into a lake-like reservoir whose water level is adjusted on a seasonal basis. The flood season alone the Yangtze River lasts from June to September, and during this period the operational water level within the Three Gorges Dam will be maintained at 145 m above sea level to prevent flooding in the mid to lower Yangtze River. Water intake commences in October, and a normal water reservation level of 175 m will be kept throughout November and December. Hydroelectricity generation lasts from January to April. To ensure the generation of adequate electricity, reservoir water level from January to April is kept higher than the seasonal basal level of 155 m. By the end of May, reservoir water level falls back to 145 m in preparation for the new flood season (Zhang and Guo, 2006). Thus, the Three Gorges Dam operates in a so-called Winter-Water, Summer-Land (WWSL) cycle, where water levels rise in winter and fall in summer. WWSL will cause the formation of marshlands between water levels of 145 and 175 m.

### Silt Deposition

The Three Gorges Dam will change the environment of many marshlands and rapid flowing waterways in the Three Gorges segment of the Yangtze River. Rapid flowing waters will slow down and sedimentation will increase. Silt from six major tributaries of the Yangtze River will merge at the entrance of the Three Gorges Dam to form an alluvial plain. Zheng et al. (2001) predicted that, in the 200 km river segment above Peiling's backwater change area, marshlands will form in 10 to 14 years after the dam becomes operational. In 30 years, more than 60 marshlands will emerge. In 100 years, 27 large-scale marshlands with a total area of 34 $km^2$ will form. The elevations of these marshlands will range from 149 to 175 m above sea level.

### Climate

The latitudes occupied by the Three Gorges Dam (28°50′ N to 32° N) fall within China's schistosomiasis endemic latitudes (Xu et al., 2004). *Oncomelania* snails in China are found mainly in zones with average temperatures >14°C, average January temperatures >0°C, and annual precipitation levels >750 mm (Xu et al., 2004). Peng et al. (2006) applied statistical analysis to spatial airflow distribution data collected using Geographic Information System (GIS) to more accurately evaluate the meteorological characteristics of schistosomiasis endemic zones in China. Their analyses placed 95% confidence intervals for the average temperature of January at 0.9°–12.4°C, and for the average annual temperature at 9.4°–21.1°C—ranges that are most compatible with the lifestyle of snails. Studies by Zheng et al. (2001) and the Yangtze River Committee on Water Conservancy revealed that the Three Gorges region's average temperature in January is 3.9°–7.5°C. Its average annual temperature is 16.4°–18.8°C. Its annual precipita-

**Table 1.** Temperature, Precipitation, and Cumulative Temperature of Various Cities and Towns in the Three Gorges region[a]

| Location name | Annual average temperature (°C) | Average temperature in January (°C) | Annual precipitation rate (mm) | Cumulative temperature of days ≥10°C (°C) |
|---|---|---|---|---|
| Dangyang | 16.4 | 3.9 | 996.8 | ≥5000 |
| Fengdu | 18.2 | 7.1 | 1087.3 | 5892.7 |
| Jiandong | 17.2 | 5.9 | 1091.2 | 6985.3 |
| Peiling | 18.1 | 7.1 | 1073.5 | 5903.8 |
| Wanxian | 18.1 | 6.7 | 1185.4 | 5757.9 |
| Wushan | 18.4 | 7.1 | 1049.4 | 5694.0 |
| Youyang | 18.2 | 3.7 | 1389.4 | 4651.5 |
| Yichang | 16.8 | 4.5 | 1031.0 | ≥5000 |
| Yunyang | 18.8 | 7.5 | 1145.1 | 5994.1 |
| Zigui | 18.0 | 6.8 | 1028.7 | ≥5000 |

[a]Source: Zheng et al. (2001).

tion is >1000 mm. These climate traits match well with the confidence intervals established by Peng et al. (2006) for schistosomiasis endemic regions in China (Tables 1, 2). Furthermore, Jia et al. (2005) showed that submersion within the dam's perimeters will increase the surface area of available water in the Three Gorges region. Due to water's greater heat capacity, the average winter and spring temperatures of the Three Gorges region will increase by 0.3°–1°C, while the summer and autumn temperatures will decrease by 0.9°–1.2°C. Three Gorges' annual precipitation level will also increase by 3 mm with a corresponding increase in soil water content. These climate changes will cause the environment of the Three Gorges region to gradually evolve in a direction more suitable for the survival of snails.

## Impact of Dam on Schistosome Transmission in the Three Gorges Region

The Three Gorges Reservoir is based in an area consisting of three consecutive narrow water passageways on the Yangtze River known collectively as the Three Gorges. Yangtze water found in these passageways is rapid flowing and collides with the many precipices, cliffs, and sandbars that flank the river. This makes Three Gorges' environment extremely hostile to the reproduction of snails. Indeed, studies conducted toward the end of the 1980s have confirmed that the Three Gorges region does not form an endemic focus for schistosomiasis (Gu et al., 1987). However, many environmental changes take place in the Three Gorges region both during and after the construction of the Three Gorges Dam. The possible impact of these environmental changes on the distribution of *Oncomelania* snails and *S. japonicum* worms in the Three Gorges region will be discussed in this section.

### Snail Survival and Reproduction

Xiao et al. (1998) proposed that the Three Gorges Dam's WWSL cycle of operation contradicts with the snails' "winter-land, summer-water" (WLSW) breeding cycles. Therefore the conditions present in the Three Gorge Dam will not be ideal for the reproduction of snails. However, He et al. (1999) concluded that the Three Gorges Dam will decrease the population environmental capacity of the Hubei segment of the Yangtze River. According to the rules of resettlement, some migrants from the Three Gorges are resettled near their original homes but away from the reservoir; the slope lands adjacent to the Three Gorges Dam will be increasingly reclaimed by the resettled farmers. This reclamation causes soil erosion which increases the rate of silt arrival into the Hubei segment. Furthermore, the flow rate of the Yangtze River and its silt-carrying capacity will both decrease due to the Three Gorges Dam. Together, these changes will cause sedimentation and formation of marshlands conducive to the reproduction of snails. Comparative ecological studies by Lai et al. (2000) showed that marshlands situated at higher than 175 m above sea level in the Three Gorges Reservoir are exposed above the normal winter water reservation level of the reservoir. This will create an opportunity for snails to live through the winter on land. During summer, although the water level is

**Table 2.** Monthly Survival Rates of Snails in Simulated Three Gorges Dam Environment in Yiling (%)[a]

| Experimental area type | Snail type | 2002 | | | | | | | | 2003 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May |
| Control area | Rib-shelled | 63 | 51 | 32 | 31 | 19 | 46 | 21 | 14 | 11 | 25 | 36 | 43 | 37 |
| Sedimentation area | Rib-shelled | 95 | 95 | 78 | 66 | 68 | 62 | 62 | 33 | 27 | 32 | 55 | 85 | 53 |
| | Smooth-shelled | 99 | 98 | 78 | 75 | 62 | 41 | 33 | 40 | 25 | 35 | 43 | 54 | 51 |
| Irrigation area | Rib-shelled | 92 | 97 | 79 | 86 | 40 | 74 | 57 | 55 | 33 | 30 | 57 | 65 | 41 |
| | Smooth-shelled | 98 | 97 | 87 | 71 | 53 | 63 | 41 | 22 | 42 | 21 | 58 | 59 | 46 |

[a]Source: Zheng et al. (2001), Xu et al. (2004), Jia et al. (2005).

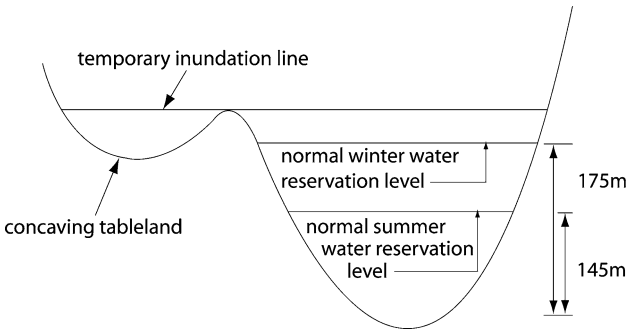


**Figure 2.** A cross-section diagram of the reservoir showing an adjacent concaving tableland, the various water reservation levels, and the temporary inundation line.

lowered, thereby taking those marshlands further above water and making them unfavorable for snail dispersal, but flooding will repeatedly raise the water level for a period long enough to provide an adequate water source for an underwater habitat for the young snails. Furthermore, the concaving tablelands found in the reservoir also possess geographic characteristics similar to the marshlands (Fig. 2). Therefore Lai et al. (2000) concluded that the belt above 175 m and below the temporary inundation line, along with the concaving tablelands in the reservoir, could form the main potential habitats for *Oncomelania* snails.

## Snail Dispersal

The modes of dispersal employed by *Oncomelania* snails were categorized as *active* or *passive* (Wu CG et al., 2005b). Active dispersal is accomplished via young snails exploiting surface water current as a means of locomotion to spread themselves to other places. Active dispersal could also be achieved in adult snails by their suspending themselves below the water surface and taking advantage of surface water currents. Passive dispersal is accomplished via snails attaching themselves to other waterborne objects to spread to new places. Hence, passive dispersal takes on more diverse forms than active dispersal. Gu et al. (1987) and Xu et al. (2000b) found that schistosomiasis endemic regions along the upper Yangtze River are situated far from the Three Gorges region (Fig. 1). The nearest such endemic region is 299 km away from the Three Gorges region. The maximal distance traversed by snails under favorable currents is 168 km. Therefore it is very difficult for snails from endemic regions along the upper Yangtze River to migrate to the Three Gorges region via active dispersal. Although endemic regions in lower Yangtze River are nearer to the Three Gorges region (Fig. 1) (Xu et al., 2000a), a study by Xiao et al. (1998) showed that it is very difficult for snails in lower Yangtze River to spread to the Three Gorges region via passive dispersal. This is because snails adhering to the bottom of boats cannot travel countercurrent for more than 30 km to reach the Three Gorges region. The Three Gorges Dam will make it harder still for snails to expand into the Three Gorges region because they will need to pass through two sets of dam gates in order to enter into the reservoir itself. Li and Lin (1998) investigated correlations between the morphology of various species of snail intermediate hosts and the prevalence of schistosomiasis in various hydroprojects. The authors concluded that the thin, broad, and light shells of African snails facilitate their migration through active dispersal. On the other hand, the *Oncomelania hupensis* snails (in particular, adult *O. hupensis* snails) are prone to sinking due to their relatively smaller volume and greater density (Zhang and Guo, 2006). Since the *O. hupensis* snails form the sole vector of schistosome transmission in mainland China (Mao and Shao, 1982; Ross et al., 1997b), it is highly improbable for the Three Gorges Hydroproject to facilitate the active dispersal of upstream *O. hupensis* snails to the Three Gorges region.

However, past research had considered biological factors to the exclusion of economic and social factors that tie in closely with the migration and dispersal patterns of snails. There have been reports of paper-making reeds carrying schistosome infested snails (Wei et al., 2004). Dead snails have also been found within warehouses of paper-making factories in the Three Gorges region. This shows that there exist other venues through which snails could make their way into the region. Xu et al. (1999) found that many different types of plants from schistosomiasis endemic regions are imported into the Three Gorges region every year in large quantities. The possibility thus exists of snail and snail egg-carrying soil being taken with the imported plants into the Three Gorges region. Furthermore, the Three Gorges Dam will improve the existing Yangtze River transportation infrastructure, thereby greatly enhancing the flow of materials and merchandise and facilitating the introduction of more snails into the Three Gorges region.

## Sources of Transmission

Goldsmith and Hildyard (1985) showed that environmental impacts on intermediate hosts are closely related to statistical socioeconomic and population variations. After the Three Gorges Dam starts its normal water intake, 21 prefectures, 356 towns, and 1711 villages will be submerged (Zhang and Guo, 2006). Gu et al. (1988) predicted that, in 2020, the average farmland-to-farmer ratio of the 19 rural counties in the Three Gorges region will be greatly reduced due to submersion, migration, and the construction of new cities and towns. Thus, agriculture alone could no longer sustain the economic development of the Three Gorges region. Export of labor, real estate, tourism, and business activities are needed to ensure the continued economic prosperity of the Three Gorges region. However, these activities will cause influxes of people from nearby schistosomiasis endemic zones and greatly increase the prevalence and intensity of schistosome infections in the Three Gorges region.

Zhang et al. (2000a) reviewed that the Three Gorges Dam will lower the immigration capacity of the Three Gorges region. Approximately 1.13 million migrants from the reservoir areas need to be settled in other places (Li and Yin, 1992). Of the 1.13 million people, approximately 250,000 will enter schistosomiasis endemic regions to work (Zhang and Guo, 2006). According to recent reports from hospitals and Centers for Disease Control and Prevention (CDC) in the Three Gorges region, incidences of acute schistosomiasis occurred frequently among residents originally from the Three Gorges region after they started to work in schistosomiasis endemic regions. Every year, there are approximately 100,000 people acting as potential sources of infection for schistosomiasis and returning to the Three Gorges area (Xu et al., 1999). These people have the potential for causing schistosomiasis emergence in the Three Gorges region if *Oncomelania* snails exist there at the same time. According to data reported by the Sichuan Parasitic Disease Prevention Research Center, every year approximately 85,000 schistosome-carrying people from endemic regions enter the Three Gorges region to travel and work. Wei et al. (2004) performed seroanalysis on 175 merchants from Badong and Zigui counties near the Three Gorges Dam and obtained at least one seropositive case for schistosomiasis. Furthermore, a recent investigation of 372 people working in three districts of Wanxian, Fengdu, and Yubei in the Three Gorges, who came from endemic regions, revealed 14 cases of historical infections with *S. japonicum* and 5 cases of seropositivity (Wu CG et al., 2005a). Another investigation on 133 Three Gorges natives returning from endemic areas revealed 56 cases of contact with infested water and 2 cases of seropositivity (Wu CG et al., 2005a). These evidences show that the potential human transmission sources for schistosomiasis may have been introduced into the Three Gorges region. Fortunately, no local transmission foci have been found because no *Oncomelania* snail has been detected up to now.

In addition to humans acting as sources of *S. japonicum* transmission, cattle, sheep, pig, mouse, and many other types of livestock and wild animals also harbor schistosome worms (Mao, 1990). In fact, the definitive host range of *S. japonicum* spans more than 40 species belonging to 34 genera in 18 families extending across seven mammalian orders (Ross et al., 1997a; Li et al., 2000), making it a true zoonosis (Ross et al., 1997a; Zhou et al., 2001). A study by Zhang and Guo (2006) showed that 89.7% of Three Gorges region's population consists of farmers, and a great majority of these farmers raise cattle and sheep for a living. Due to the zoonotic nature of *S. japonicum*, these livestock have the potential to act as significant sources of infection for schistosomiasis. Furthermore, some of the livestock introduced to the Three Gorges region come from schistosomiasis endemic regions and may already be infected. Although there are currently no reported cases of schistosomiasis infection in animals, livestock introduced from endemic areas nevertheless pose a clear and present danger to human health in the Three Gorges region.

## Impact of Dam on Schistosome Transmission in Regions along Middle and Lower Reaches of the Yangtze River

Flowing eastwards from the Three Gorges, the Yangtze River passes through the provinces of Hubei, Hunan, Jiangxi, Anhui, and Jiangsu, and joins many other rivers and the Dongting and Poyang Lakes before emptying into the East China Sea (Fig. 1). Zheng et al. (2001) showed that the Three Gorges Dam will decrease the probability of flooding in mid and lower reaches of the Yangtze River from once every 10 to 20 years to once every 100 years. This much-reduced probability of flooding will effectively deter the dispersal of both snails and schistosome worms. Some scholars also believe that the WWSL operation cycles of the Three Gorges Dam contradict with the WLSW life cycles of snails in regions along mid and lower reaches of the Yangtze River (Liang et al., 2002a). Therefore, the Three Gorges Dam will not create conditions favorable to the long-term survival of snails. Structural and enzyme chemistry research has also shown that water submersion in winter suppresses catalytic activities of snail enzymes, thereby decreasing snails' membrane enzyme solubility and reducing their long-term survival rates (Liang et al., 2002b). However, the Three Gorges Dam will not completely alter the WLSW environment of marshlands in mid and lower reaches of the Yangtze River. Furthermore, the Three Gorges Dam increases the rate of silt deposition in the Three Gorges region. This increased rate of silt deposition leads to expansion of marshlands, blockage of river passages, and alteration of exposure times of downstream marshlands. These environmental changes caused by the Three Gorges Dam could affect the transmission of schistosomiasis in regions along the Yangtze River downstream from the dam.

### Jianghan Plains

The Three Gorges Dam will cause changes in the flow rate, water level, and water quality of lower Yangtze River, and effect environmental changes in lakes both north and south of the Jin segment of the Yangtze River (Cai et al., 1987). The Chinese Academy of Science and many other research agencies have made long-term observations of underground water levels in the Jianghan Plains (Xu et al., 2000b). These observations show that water percolates from the Yangtze River into natural underground water reservoirs in a process of lateral transfer. During flood seasons, the farthest point of lateral transfer is 15 km. During dry seasons, the farthest point of lateral transfer is 7 km. Areas within 2–3 km of the Yangtze River are sensitive to water-level changes in the Yangtze River. Therefore, Xu et al. (2000b) concluded that water percolation from the Yangtze River into underground reserves will cause the underground water level of the Jianghan Plain to rise. The increased water level will cause the degeneration of rice paddies into marshlands, thereby providing new habitats for *Oncomelania* snails in the region.

### Lake Dongting

Lake Dongting is situated on the southern shores of the Jin segment of the Yangtze River. Here, part of the Yangtze River forks into the Songci, Ouchi, and Taiping creeks that flow into the lake (Cai et al., 2000). Prior to the construction of the Three Gorges Dam, water from the Yangtze River entering the lake contained high quantity of silt and mud. Every year 154 million metric tons of silt enters the lake. This leads to yearly increases in the elevation of the lake bed (Li et al., 2000). In order to predict the impact of sedimentation rate changes on the transmission of schistosomiasis in regions surrounding the lake, Cai et al. (2000) took soil samples from several marshlands in the lake. A comprehensive analysis of these samples allowed Cai et al. (2000) to make the following predictions regarding the effects that Three Gorges Dam will have on schistosome transmission in the Dongting region:

(1) The rate of growth of snail-harboring marshlands in the lake will decrease. Fifty years after the completion of the Three Gorges Dam, silt entering from the Yangtze River into the lake will decrease by 80% due to the extra silt deposited within the dam itself. Decreased silt input greatly decreases the rate of marshland formation in the lake, which effectively curbs the reproduction of snails. In 80 years, the Three Gorges Dam will reach its maximum silt containment level. At that point, extra silt will be displaced from the dam. The extra silt will enter Dongting and restore its sedimentation and marshland formation rate to pre-dam times.

(2) Large numbers of schistosome-infested snails inhabit marshlands lying within 1000 m of the shores of Dongting. Agricultural activities taking place on these marshlands place both humans and livestock in jeopardy from contracting schistosomiasis (Wu and Wen, 1988). Sedimentation rate changes in the lake caused by the Three Gorges Dam will not alleviate this situation. In fact, these changes will cause the regression of reed-type marshlands

within 1000 m of the shores of Dongting into grass-type marshlands or mixed grass–reed marshlands. Since humans and livestock will make use of the vegetative blankets found on these regressed marshlands, the probability of humans and livestock coming into contact with cercariae-infested waters around the marshlands will greatly increase. Furthermore, miracidia hatched from eggs in the stool left behind by infected livestock will initiate new rounds of schistosome infections in snails. In this respect, schistosomiasis epidemics in regions surrounding Lake Dongting will be made worse by the Three Gorges Dam.

## Lake Poyang

Research data concerning Lake Poyang are provided mostly by the Yangtze River Committee on Water Conservancy and an on-site investigation conducted by Zheng et al. in 2001. Zheng et al. (2001) predicted that after the Three Gorges Dam becomes operational, Lake Poyang's water level will rise by 0.11–0.90 m in January, February, and March. It will lower by 0.07–0.13 m in December. Regardless of the annual precipitation levels, the water level of Lake Poyang has always been lower than 13 m above sea level. Snails at Poyang live in places that are higher than 13 m above sea level (Zheng et al., 2001), with a majority of snail infested marshlands located at a height of 14–16 m above sea level (Ning et al., 2003). Therefore, snail reproduction will not be affected by changes in Lake Poyang's water level caused by the dam. From April to June, Poyang's water level will experience different degrees of increase. Yet these changes also have very limited effects on the epidemiology of schistosomiasis in and around the lake. Zhang et al. (1995) showed that the water level of Lake Poyang from April to June is critical for the survival of its snails. The Three Gorges Dam will cause the water level of Lake Poyang to rise slightly in April. This slight rise in water level will cause flooding of Poyang's marshlands 15 days earlier than the corresponding flooding times in pre-dam years. However, the premature flooding takes place after peak periods of snail reproduction have passed, thus the distribution of snails in Lake Poyang will remain unaffected (Wang and Zheng, 2003). On the other hand, the early flooding will lengthen shallow-water periods on Poyang's marshlands. The longer periods contribute to an increase in the number of shallow-water areas formed on Poyang's marshlands. This increases the density of schistosome-harboring snails by 20% and expands the schistosomiasis infection zones in Lake Poyang by 20%.

## Anhui Segment

The 416 km-long Anhui segment of the Yangtze River has 200,000 hectares (ha) of river marshlands, lake marshlands, and lake beaches. Out of the 200,000 ha, more than 26,000 harbor snails. Of the three types of marshlands, lake marshlands have the highest snail-coverage ratio at 45.69% of their total area. Lake beaches have the lowest snail coverage ratio at 5.6%. Lake marshlands and beaches are more susceptible to water submersions. Data were provided by the Yangtze Committee on Water Conservancy concerning monthly water levels measured by Datong hydrometric station (located at the western end of Anhui segment) and Nanjing hydrometric station (located at the eastern end of Anhui segment). These data project a higher water level from January to June, and a lower water level from October to December, for the Anhui segment after the dam becomes operational. Water levels will not change noticeably from July to September; while in February, March, and November, the most significant changes in water levels will be observed after the dam is built (Table 3). Zhang et al. (2000b) predicted that the changes in water level in autumn will advance the exposure times of marshlands on the Anhui segment and allow for early planting of crops like wheat and rape (Chinese canola). This will prolong the period of agricultural development and suppress snail activities on the marshlands. On the other hand, farmers spending long periods of time working on the marshlands will have an enhanced chance of contracting schistosomiasis from the surrounding bodies of water. This problem is greatly exacerbated by the increased water levels in spring, when farmers spend prolonged periods of time harvesting the wheat and rape they have planted in autumn.

Wang et al. (1998) found that water level changes in the Anhui segment of the Yangtze River caused by the Three Gorges Dam will occur at elevations below those necessary for the formation of snail-harboring marshlands. Thus, the Three Gorges Dam will not greatly increase areas of snail reproduction. However, with the formation of new marshlands and blockage of Yangtze tributaries, it is predicted that the number of available snail habitats in the Anhui segment will increase after the completion of the Three Gorges Dam (Wu CG et al., 2005b). More frequent spring water submersions caused by the Three Gorges Dam will also increase the probability of fishers coming into contact with cercariae-infested water and contracting schistosomiasis. Early water recessions caused by the Three

**Table 3.** Monthly Changes in Water Levels of Typical Years at Datong and Nanjing Hydrometric Stations before and after the Construction of the Three Gorges Dam[a]

| Typical years | Monthly average differences between water levels before and after construction of the Three Gorges Dam (in m) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| *Datong hydrometric station* | | | | | | | | | | | | |
| Year of high precipitation | 0.09 | 0.26 | 0.30 | 0.14 | 0.35 | 0.58 | 0.30 | 0.01 | 0.00 | −0.49 | −1.34 | −0.96 |
| Year of average precipitation | 0.21 | 0.53 | 0.67 | 0.37 | 0.08 | 0.21 | 0.08 | 0.00 | 0.00 | −0.75 | −1.26 | −0.10 |
| Year of low precipitation | 0.39 | 0.59 | 0.61 | 0.48 | 0.12 | 0.34 | 0.08 | 0.03 | 0.00 | −1.00 | −1.20 | −0.07 |
| *Nanjing hydrometric station* | | | | | | | | | | | | |
| Year of high precipitation | 0.05 | 0.35 | 0.18 | 0.08 | 0.09 | 0.34 | 0.06 | 0.01 | 0.00 | −0.29 | −0.07 | −0.04 |
| Year of average precipitation | 0.12 | 0.37 | 0.40 | 0.21 | 0.04 | 0.12 | 0.05 | 0.00 | 0.00 | −0.44 | −0.75 | −0.06 |
| Year of low precipitation | 0.31 | 0.30 | 0.37 | 0.28 | 0.07 | 0.25 | 0.04 | 0.03 | 0.00 | −0.59 | −0.71 | −0.03 |

[a]Source: Zhang et al. (2000b).

Gorges Dam in autumn will lengthen the amount of time humans and livestock spend on marshlands. This will greatly increase the chance of livestock ingesting schistosome-infested snails. Zhang et al. (1998) found that the Three Gorges Dam will cause the Anhui segment marshlands to shift upwards by 0.5 m. This increase in marshland elevation will advance the marshlands' agricultural development by half a month to one month, and lengthen the time cattle spend plowing the marshlands to plant crops. This increases the chance of cattle contracting schistosomiasis. It also increases the exposure time of marshland snails to miricidia and, hence, the density of schistosome-infested snails.

### Jiangsu Segment

According to data from Nanjing Hydrometric Station (Table 3), upon completion of the Three Gorges Dam, the Jiangsu segment of the Yangtze River will not experience any water-level change from August to September. Small changes in water level are predicted for January, May, June, July, and December. Water-level increases of 0.15–0.40 m are predicted for February, March, and April. Water-level decreases of 0.29–0.75 m are predicted for October and November. Experiments conducted by Liang et al. (1999) have shown that advanced flooding of the Jiangsu segment caused by the Three Gorges Dam from February to April will increase the mortality rate of adult snails and decrease their fecundity. Therefore, the density of snails in Jiangsu segment's marshlands will decrease by approximately 80%. On the other hand, advanced flooding will make conditions more favorable for the maturation of larval snails. This increases the chance of miracidia penetration of marshland snails and results in the formation of new schistosomiasis endemic zones in the Jiangsu segment. In October and November, the larval snails will have already developed into adult snails, thus early water recessions caused by the Three Gorges Dam will not have any effect on the prevalence of schistosomiasis due to larval snail infections (Wang and Zheng, 2003). However, the number of miracidia-infested snails will nevertheless increase to a certain extent. Advanced water recessions in the fall season will increase incidences of schistosome infections among people and livestock, leading to additional marshland contamination by livestock manures harboring schistosome eggs.

## Conclusions

From the review above, we have three conclusions. 1. The Three Gorges Dam will cause the environment of the Three Gorges region to gradually evolve towards one that is more favorable to the reproduction of *Oncomelania* snails and the emergence of a schistosomiasis epidemic. Concurrently, environmental and socioeconomic changes increase the probability of snail introduction into the Three Gorges region. 2. For regions along mid and lower reaches of the Yangtze River, the Three Gorges Dam will alleviate floods, limit the dispersal of snails, and decrease the chance of human and livestock coming into contact with water infested with infected snails with *S. japonicum*. 3. On the other hand, water level and silt deposition changes brought

about by the Three Gorges Dam will increase the exposure time of marshlands along mid and lower reaches of the Yangtze River regions and cause blockage of Yangtze's tributaries in those areas. These changes create opportunities for the reproduction and dispersal of snails, and increase the chance of humans and livestock contracting schistosomiasis.

Further investigations of the relationships between the Three Gorges Hydroproject and transmission of *S. japonicum* in the Three Gorges and other related regions are warranted. These investigations present numerous exciting research opportunities and new research prospects. In particular, research in the following areas is needed in order to obtain conclusions that are reliable, long-term, and systematic in their treatment of the future outlook of schistosomiasis in the various regions along the Yangtze River:

### Simulation

Ecological simulations for the many different environments that will exist in the Three Gorges region and regions along mid and lower reaches of the Yangtze River after the completion of the Three Gorges Dam need to be performed. Long-term research on snail ecology in the reservoir areas is needed in order to identify all potential reproduction factors.

### Socioeconomics

Investigations of the relationships between socioeconomic changes caused by the Three Gorges Dam and the epidemiology of schistosomiasis in the Three Gorges region need to be carried out.

### Monitoring and Prevention Systems

Although the GIS technology had been used in previous research projects, it should be employed further to dynamically monitor and accumulate data regarding water level, silt deposition, marshlands, lake and river floodplain formations, human and livestock activities, and snail dispersal patterns in the Three Gorges region and regions along mid and lower reaches of the Yangtze River (Maszle et al., 1998; Zhou et al., 2001). These data could then be used to further investigate the temporal–spatial relationships between environmental changes caused by the Three Gorges Dam and schistosomiasis transmission in areas surrounding the Yangtze River.

### Intervention Measures

Dams such as the Ertan Dam in China (Gu et al., 2001) have successfully controlled snails and schistosome worms found in their surrounding environments. The experiences of these dams could be worked into researching policies that prevent the Three Gorges Dam from transforming its vicinities into schistosomiasis endemic zones.

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## References

Amin MA (1977) Problems and effects of schistosomiasis in irrigation schemes in the Sudan. In: *Aridland Irrigation in Developing Countries*, Worthington EB (editor), Oxford, UK: Pergamon Press, pp 407–411

Cai SM, Guan ZH, Zhou BK (1987) Three Gorges Dam and its impact on the environment of lakes north and south of the Jing River [in Chinese]. In: *Collected Works of Ecology and Environment Impact and Study on Strategy after Three Gorges Dam Construction*, Chinese Academy of Sciences—Three Gorges Ecology and Environment Research Group (editors) Beijing, China: Sciences Press, pp 277–296

Cai KP, Zuo JZ, Ho HB, Zhuo SJ, Hu G (2000) Impact of changes in mud siltation of Dongting Lake on the endemic factors of schistosomiasis after building Three-Gorge Dam [in Chinese]. *Practical Preventive Medicine* 7:1–3

Engels D, Wang LY, Palmer KL (2005) Foreword: Control of schistosomiasis in China. *Acta Tropica* 96:67–68

Fenwick A (1989) Irrigation in the Sudan and schistosomiasis. In: *Demography and Vector Born Diseases*, Service MW (editor), Boca Raton, FL: CRC Press, pp 333–351

Goldsmith E, Hildyard N (1985) *The Social and Environmental Effects of Large Dam, Volume 1: Case Studies*, Camelford, Cornwall, UK: Wadebridge Ecological Centre

Government of China (2006) *The Background of Three Gorges Project: The World's Largest Concrete Dam* [in Chinese]. Available: http://www.gov.cn/jrzg/2006-05/20/content_286285.htm [accessed November 26, 2007]

Gu YG, Xia LF, Li ZW, Zhao MF, Yang HY, Luo QY, et al. (2001) Study on schistosomiasis control strategy in Ertan Reservoir [in Chinese]. *Chinese Journal of Parasitology and Parasitic Diseases* 19:225–228

Gu XG, Zhao WX, Xu FS (1987) Study on the effects of Three Gorges Dam construction on schistosomiasis prevalence [in Chinese]. In: *Collected Works of Ecology and Environment Impact and Study on Strategy after Three Gorges Dam Construction*, Chinese Academy of Sciences—Three Gorges Ecology and Environment Research Group (editors) Beijing, China: Sciences Press, pp 8582–8671

Gu XG, Zhao WX, Xu FS (1988) Study on the effects of Three Gorges Dam construction on schistosomiasis prevalence [in Chinese]. In: *Collected Works of Ecology and Environment Impact on Three Gorges Project*, Hu CL (editor), Beijing, China: China Water Power Press, pp 176–207

Guo JG, Zheng J (1999) Impact of water resources development on the transmission of *S. japonicum* [in Chinese]. *Chinese Journal of Parasitology and Parasitic Diseases* 17:252–255

Guo JG, Zheng J (2000) Schistosomiasis endemic and control in China [in Chinese]. *Chinese Journal of Disease Control and Prevention* 4:289–293

He CH, Pan HM, Guo SL (1999) Effects of ecological environmental changes caused by Three Gorges Dam on breeding of snails in Hubei section of the reservoir [in Chinese]. *Chinese Journal of Parasitic Disease Control* 12:281–284

Hong Q (1992) *The Great Project [in Chinese]*, Beijing, China: China Water Power Press

Jia QL, Xiao BZ, Liao WF, Wu CG, Ji HQ, Wu GH, et al. (2005) Effects of ecological changes in the Three Gorges Reservoir area on Yangtze River on the prevalence and countermeasure of schistosomiasis japonica [in Chinese]. *Acta Academiae Medicinae Militaris Tertiae* 27:160–163

Khalil BM (1949) The national campaign for the treatment and control of bilharziasis from the scientific and economic aspects. *Royal Egyptian Medicine Association* 32:820

Lai J, Gu XG, Xu FS, Wen S, Liang S (2000) Study on the development of snail habitat in Three Gorges Reservoir area inundated temporarily by flood [in Chinese]. *Journal of Practical Parasitic Diseases* 8:102–105

Li Y, Lin J (1998) Effects of Three Gorges Dam construction on control of water level in Yangtze River and schistosomiasis prevalence [in Chinese]. *Medical Philosophy* 19:372–373

Li YS, Sleigh AC, Ross AGP, Williams GM, Tanner M, McManus DP (2000) Epidemiology of *Schistosoma japonicum* in China: morbidity and strategies for control in the Dongting Lake region. *International Journal for Parasitology* 30:273–281

Li B, Yin Z (1992) *On the Settlement of Migrants from Three Gorges Dam Construction Site [in Chinese]*, Beijing, China: China Water Power Press

Liang YS, Huang YX, Song HT (1999) The construction of the Three Gorges Dam on the transmission of schistosomiasis in Jiangsu, China. II. Observation on effect of advanced spring flooding on snail population [in Chinese]. *Chinese Journal of Parasitic Disease Control* 12:210–213

Liang YS, Xiao RW, Ye JF (2002a) Three Gorges Dam and its impact on the environment of schistosomiasis endemic regions around middle and lower Yangtze River—on-site studies [in Chinese]. In: *Schistosomiasis Prevention Research*, Chinese Academy of Science and Technology (editors), Beijing: Science and Technology Press, pp 59–62

Liang YS, Xiao RW, Ye JF (2002b) Three Gorges Dam and its impact on the environment of schistosomiasis endemic regions around middle and lower Yangtze River—structural chemistry, enzymatic structural chemistry and transmission electron microscopy studies [in Chinese]. In: *Schistosomiasis Prevention Research*, Chinese Academy of Science and Technology (editors), Beijing: Science and Technology Press, pp 63–66

Mao SP (1990) *Biology of S. japonicum and the Prevention of Schistosomiasis [in Chinese]*, Beijing, China: People's Health Press

Mao SP, Shao BR (1982) Schistosomiasis control in the People's Republic of China. *American Journal of Tropical Medicine and Hygiene* 31:92–99

Maszle DR, Whitehead PG, Johnson RC, Spear RC (1998) Hydrological studies of schistosomiasis transport in Sichuan Province, China. *The Science of the Total Environment* 216:193–203

Ning A, Chen N, Zhong J, Chen H, Lin D, Liu H, et al. (2003) Study on relationship between snail distribution of marshland and changes of water level in Poyang Lake region. *Chinese Journal of Schistosomiasis Control* 15:429–433

Omer AHS (1978) Schistosomiasis in the Sudan: historical background and the present magnitude of the problem. In: *Proceedings of the International Conference on Schistosomiasis*, Cairo, Egypt, 1975: Ministry of Health, pp 121–132

Peng WX, Zhang ZJ, Zhou YB, Zhuang JL, Zhao GM, Jiang QW (2006) Index of air temperature for predicting the distribution of *Oncomelania* snails [in Chinese]. *Chinese Journal of Schistosomiasis Control* 18:182–184

Ross AGP, Li YS, Sleigh AC (1997a) Epidemiological features of *S. japonicum* among fishermen and other occupational groups in the Dongting Lake region (Hunan Province) of China. *American Journal of Tropical Medicine and Hygiene* 57:302–308

Ross AGP, Li YS, Sleigh AC, McManus DP (1997b) Schistosomiasis control in the People's Republic of China. *Parasitology Today* 13:152–155

Strickland G (1982) Providing health services on the Aswan High Dam. *World Health Forum* 3:297–300

Teklehaimanot A, Fletcher M (1990) A parasitological and malacological survey of schistosomiasis mansoni in the Beles Valley, northwestern Ethiopia. *Tropical Medicine & International Health* 93:12–21

Wang TP, Ge JH, Zhang SQ (1998) Schistosomiasis transmission and ecological environmental changes in Anhui reach after construction of Three Gorges Reservoir [in Chinese]. *Journal of Practical Parasitic Diseases* 6:157–163

Wang RB, Zheng J (2003) Three Gorges Dam project and the transmission of schistosomiasis in China [in Chinese]. *Chinese Journal of Schistosomiasis Control* 15:71–74

Wei FH, Wang RB, Xu XJ, Liu JB, Fu Y, Zheng J (2004) Investigation on import way of schistosomiasis and *Oncomelania* snails in Three Gorges Reservoir areas [in Chinese]. *Chinese Journal of Schistosomiasis Control* 16:118–121

Winter A (2005) Breeding snail fever—Three Gorges Dam boosts parasitic infections. *Scientific American*, July, pp 21–22

Wu ZD, Wen S (1988) A study of schistosomiasis endemic regions in the marshlands of the province of Hunan [in Chinese]. *Hunan Medicine* 5:83–85

Wu CG, Xiao BZ, Liao WF, Yan W (2005a) Analysis of the epidemiological factors of schistosomiasis in the Three Gorges

Reservoir areas [in Chinese]. *Journal of Tropical Medicine* 5:774–776

Wu CG, Zhou XN, Xiao BZ (2005b) A comprehensive summary of the relationship between the ecological changes in the construction of the Three Gorges Dam and the transmission of *S. japonicum* [in Chinese]. *Foreign Medical Sciences—Parasitic Diseases* 32:224–228

Xiao RW, Ye JF, Tao LF (1998) Study on *Oncomelania* snail breeding and spreading in the Three Gorges Reservoir region [in Chinese]. In: *Collected Works of Ecology and Environment Impact on Three Gorges Project*. Beijing, China: China Water Power Press, pp 159–175

Xu XJ, Wei FH, Cai SM, Liu JB, Fu YB, Zheng J, et al. (2004) Study on the risk factors of schistosomiasis transmission and control strategy in the Three Gorges Reservoir areas [in Chinese]. *Chinese Journal of Epidemiology* 25:559–563

Xu XJ, Wei FH, Yang XX, Dai YH, Yu GY, Chen LY et al. (2000a) Possible effects of the Three Gorges Dam on the transmission of *Schistosoma japonicum* on the Jiang Han Plain, China. *Annals of Tropical Medicine and Parasitology* 94:333–341; DOI:10.1080/00034980050034581 [Online March 14, 2000]

Xu XJ, Yang XX, Dai YH, Lü GY, Chen L, Su Z, et al. (2000b) Study on environment impact in endemic area of schistosomiasis in Jianghan Plain following the Three Gorges Dam project [in Chinese]. *Chinese Journal of Schistosomiasis Control* 12:333–336

Xu FS, Wen S, Qian XH, Mao Y, Zhong B, Lai J, et al. (1999) The impact of social factors on schistosomiasis prevalence at the Three Gorges Reservoir areas [in Chinese]. *Journal of Practical Parasitic Diseases* 7:74–75

Zhang SQ, Ge JH, Zhang GH (1998) The impact of water level change in Anhui Province caused by Three Gorges Dam construction on behaviours of people and cattle and schistosomiasis prevalence [in Chinese]. *Chinese Journal of Parasitic Disease Control* 11:118–120

Zhang HJ, Guo JG (2006) Impact of the Three Gorges Dam construction on transmission of schistosomiasis in the reservoir area [in Chinese]. *Chinese Journal of Parasitology and Parasitic Diseases* 24:236–240

Zhang AH, Guo SL, He CH, Nie SF, Liu ZC, Pan HM, et al. (2000a) Study on the effects of social and economic changes on the spreading of schistosomiasis in Hubei area of the reservoir after construction of Three Gorge Dam [in Chinese]. *Medicine and Society* 13:6–8

Zhang S, Wang T, Ge J, He J, Tao C, Zhang G, et al. (2000b) The impact of the Three Gorges Dam construction on the exploitation and utilization of marshland and the prevalence of schistosomiasis in Anhui Province [in Chinese]. *Chinese Journal of Parasitic Disease Control* 13:276–278

Zhang SJ, Yu ZH, Wu ZD (1995) The impact of water level change in Jiangxi Province caused by construction of the Three Gorges Dam on the transmission of schistosomiasis in Poyang Lake [in Chinese]. *Journal of Jiangxi Preventive Medicine* 3:13–16

Zheng J, Gu XG, Xu YL, Ge JH, Yang XX, He CH, et al. (2001) The relationship between the ecological changes in the construction of the Three Gorges Reservoir and the transmission of *S. japonicum* [in Chinese]. *Journal of Tropical Medicine* 1:112–116

Zhou XN, Malone JB, Kristensen TK, Bergquist NR (2001) Application of geographic information systems and remote sensing to schistosomiasis control in China. *Acta Tropica* 79:97–106