Three Gorges Dam: Into the Unknown

A marvel of engineering, the Three Gorges Dam will start operating at full capacity later this year. Already under way is an epic experiment on how a dam impacts the environment

YICHANG, CHINA—For millions of people along the Yangtze River, the turbid waters of Asia's longest river have long provided an abundance of fish, including one kind that locals are especially fond of: carp. But Yangtze fisheries are harvesting less than half the carp they were 5 years ago. Thanks in no small measure to the completion of the Three Gorges Dam, the world's biggest dam, the outlook for the prized fish is grim.

The Yangtze's four major carp species—bighead, black, grass, and silver—spawn when water levels rise during the summer monsoon rains. "They need this stimulation," says Liu Huanzhang, an ecologist at the Institute of Hydrobiology (IHB) of the Chinese Academy of Sciences (CAS) in Wuhan. Three Gorges reservoir, a 660-kilometer-long serpentine lake that began to fill in 2003, has subtly altered seasonal variations in water levels below the dam. Recent IHB surveys have found a sharp decline in carp eggs and larvae downstream. "It's a very bad sign," Liu says.

Carp are not the only Yangtze species on the ropes. Fishers are hauling in anything with fins and gills that they can net or lay hooks on, including the tiniest of fish to feed aquaculture species such as catfish or mandarin fish, IHB has documented. The central government bans fishing on the Yangtze for 3 months each year, during spawning. But with vast stretches of the river in danger of being fished out, one of China's senior ecologists, IHB's Cao Wenxuan, last month made a bold public plea for a 10-year moratorium for the entire Yangtze.

Other troubles sapping the Yangtze's vitality include industrial effluents, raw sewage, and heavy boat traffic. But by greatly altering ecosystems on the Yangtze's middle reaches, the Three Gorges Dam, which operators plan to bring to full capacity by the end of the year, will complicate attempts to prevent a mighty river from becoming inhospitable to some aquatic life forms.

The Three Gorges Dam is one of several huge projects that are transforming China's environment. They include the recent completion of the world's highest railway across the Tibetan Plateau and a plan to divert billions of cubic meters of water each year from the Yangtze and other southern rivers to China's parched north (*Science*, 25 August 2006, p. 1034). But perhaps no endeavor has generated more debate on the economic and environmental trade-offs of megaprojects than the $25 billion Three Gorges venture in Yichang.

The main justification is flood control. By regulating water flow, the dam is designed to prevent disastrous floods that have occurred every decade or so; the worst in the last century was a flood in 1931 that the government says killed 145,000 people and left 28 million homeless. (Unofficial tallies put the death toll at 3 million people or more.) Also on the plus side, the dam's hydropower station is expected to generate 84.7 billion kilowatt-hours per year of electricity, an amount equal to that produced by burning 50 million tons of coal. And Three Gorges has eased navigation as the rising waters have eliminated treacherous shoals upstream. For these and other reasons, the State Council Three Gorges Project Construction Committee (CTGPC) has hailed the dam as "greatly beneficial" to the environment. According to CTGPC vice director Li Yong'an, "the project has brought more ecological benefit than harm."

But to many critics, Three Gorges is a bête noire. Besides worsening the plight of fish, the dam has fragmented habitats in a

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China's Environmental Challenges

China is waging a war on many fronts to stem environmental deterioration while sustaining rapid economic growth. This special report examines three prominent ventures: **1.** the world's largest dam, which is changing the ecology of a vast and fragile watershed (p. 628); **2.** plans to restore the Qinghai-Tibetan Plateau (p. 633); and **3.** Beijing's efforts to clean its notoriously foul air (p. 636).

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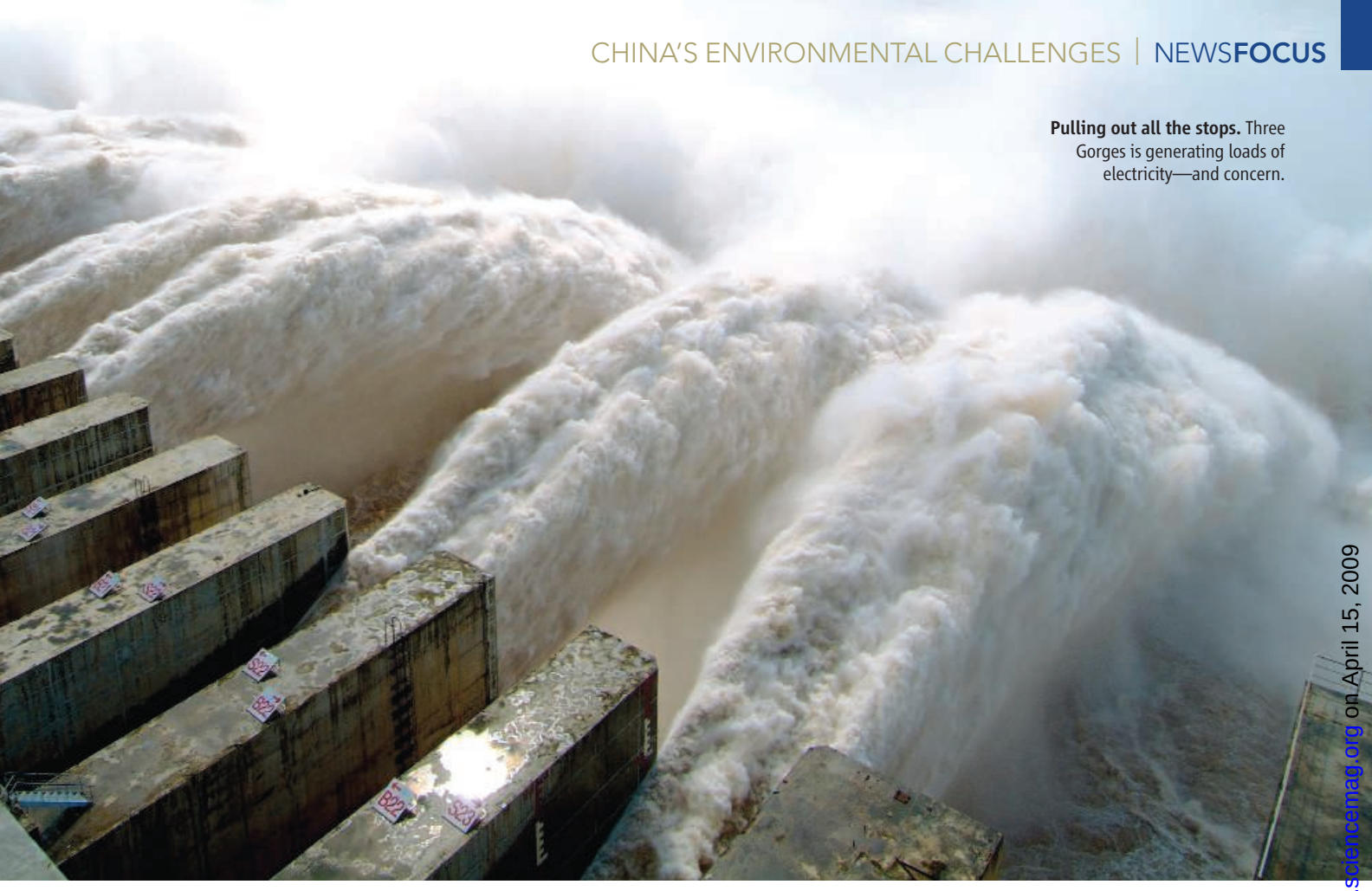

Pulling out all the stops. Three Gorges is generating loads of electricity—and concern.

biodiversity hot spot, and it could erode inhabited islands in the Yangtze River delta. The impoundment of 39.3 billion cubic meters of water has destabilized slopes, heightening risk in a landslide-prone region, while the sheer weight of all that water has heaped strain on seismic faults. The rising waters have also uprooted more than 1 million people and submerged entire communities. Another 4 million of the 16 million people living in the reservoir area may have to be relocated in coming years, officials revealed last fall.

In China, public debate about the dam's dark side is muted. But for scientists, the myriad effects of Three Gorges are fair game. The government has sanctioned an ambitious program to monitor the Yangtze and the Three Gorges reservoir area, which at 58,000 square kilometers is bigger than Switzerland. "We're studying the changing landscape," says Wu Bingfang, whose team at CAS's Institute of Remote Sensing Applications (IRSA) in Beijing is using satellite imagery to follow how the dam impacts its surroundings. They also intend to estimate how much methane and other greenhouse gases the reservoir area emits as submerged vegetation rots.

"Now that the dam is a reality, I hope we can manage it well," says Niu Wenyuan, chief scientist of China's sustainable development strategy program and a counselor of the State Council. A wealth of data on the Yangtze's fragile condition has been posted to a CTGPC-run Web site, www.tgenviron.org. The findings are expected to guide priorities of a $7.3 billion monitoring and mitigation program over the next 12 years.

"Humanity deserves the opportunity to learn some lessons from this engineering exercise," says Chen Jiquan, a landscape ecologist at the University of Toledo in Ohio. In 2000, Chen led a 12-person delegation from the Society for Conservation Biology to China to assess Three Gorges. The group offered recommendations to a dozen bodies in China and at the United Nations but did not receive a single response. "It was a sad story," says Chen.

Chinese scientists insist they are open to outside views and determined to confront the colossal project's mixed legacy. "Researchers want to tell the truth," says Wu.

Well bred. A female jiangzhu and her two babies at IHB.

CREDIT: COURTESY OF WANG DING

A fading pulse

In the 1930s, engineers identified the picturesque Three Gorges region straddling Hubei and Sichuan provinces as an ideal spot for a dam to dwarf all others. The original idea was to tame the Yangtze's periodic floods, but planning sputtered until the early 1980s, when China's energy needs grew more intense. "They thought this large dam would solve a lot of problems," says Chen. Then-Premier Li Peng, a water engineer by training, pushed hard for Three Gorges, and in 1984 CAS began an environmental impact assessment. After weighing the pros and cons, the 8-year-long review gave Three Gorges the thumbs-up. Construction started in 2003—to the dismay of many scientists. "I felt there were serious problems. My opinion was to wait 20 or 30 years," says Niu.

In May 2006, some 26,000 workers completed a Great Wall for the Yangtze: a concrete

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barrier 185 meters tall and 2.3 kilometers long. The reservoir had begun filling 3 years earlier and has risen from its original low water mark of 62 meters to the present 156 meters. By December, engineers expect to have finished installing the last five of 26 hydropower turbines.

For ships to move upstream, they must traverse five locks stacked like a staircase at the dam's northern end that raise craft more than 100 meters. Migratory fish don't have a chance. "There was serious debate about whether to build a passage for fish," says Liu. In the end, he says, authorities abandoned the idea because migratory fish can't pass the Gezhouba Dam spanning the Yangtze just 38 kilometers downstream, and it would have been "impossible" to build a big enough passage for the primary species that would have benefited from it, the Chinese sturgeon (*Acipenser sinensis*).

It turns out, however, that Chinese sturgeon may still have a future on the Yangtze. The ancient species spends much of its life at sea, migrating upriver to spawn. The original sturgeon spawning areas were hundreds of kilometers upstream of Three Gorges. The fish has been blocked from reaching those areas since Gezhouba Dam rose in 1981. But the sturgeon is now observed to spawn downstream of Gezhouba, and fishing for it is banned in China.

Although millions of lab-bred fingerlings have been released into the Yangtze in the past 2 decades, most young sturgeon captured in the Yangtze delta are wild, suggesting that the wild population is coping reasonably well, Liu says. Over the past 3 years, the Yangtze River Fisheries Research Institute in Jingzhou has released sturgeon into the Three Gorges reservoir to see if the fish can thrive exclusively in fresh water. Early results are discouraging, says the institute's Wei Qiwei, because the reservoir ecosystem is changing as the river slows and silt accumulates. "The lake now is not suitable for a benthic feeder," he says. Such upheavals threaten 40 other endemic fish

FEARS OVER WESTERN WATER CRISIS

ÜRÜMQI, CHINA—The Tarim River is the lifeblood of Xinjiang Province, providing more than half the irrigation water for this Alaska-sized region in western China. The largest inland river in Asia, the Tarim is also a green-fringed stockade keeping the vast Takla Makan Desert from advancing northward into rugged grasslands and fertile oases inhabited by the majority of the province's 20 million people. With Xinjiang's fortunes riding on the Tarim, officials watched with growing dismay last winter as the river's volume fell 28% below average and 300 kilometers of its 1321-kilometer-long course ran dry. After enjoying 2 decades of robust flow, water managers in May ordered strict rationing through September.

One group of researchers saw the crisis coming. Based on past flow rates and weather conditions anticipated for 2007–08, Chen Yaning and colleagues at the Chinese Academy of Sciences' Xinjiang Institute of Ecology and Geography in Ürümqi forecast a sharp drop in runoff feeding the Tarim. Their report in the 20 March issue of *Hydrological Processes* predicted that the river will bounce back this coming winter. But if their numbers are correct, another—and worse—crisis will happen in 2009–10, when the Tarim's inputs are predicted to be 12% less than the past year's poor flow. "Most farms will not be able to irrigate their crops," says Chen, who calls the looming threat "a big conflict between ecology and the economy."

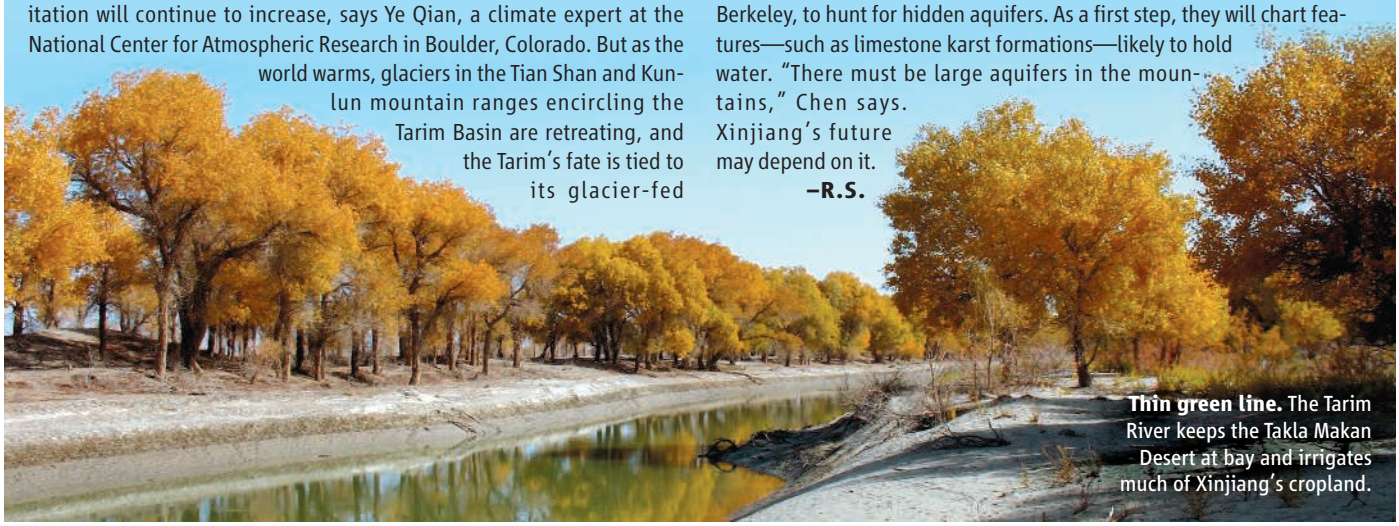
The long-term prognosis is cloudier. On one hand, Xinjiang has been getting wetter over the past half-century, and models suggest that precipitation will continue to increase, says Ye Qian, a climate expert at the National Center for Atmospheric Research in Boulder, Colorado. But as the world warms, glaciers in the Tian Shan and Kunlun mountain ranges encircling the Tarim Basin are retreating, and the Tarim's fate is tied to its glacier-fed tributaries. "If the glaciers disappear, so will the source of the Tarim's water," says Liu Changming, a hydrologist at the Institute of Geographical and Natural Resources Research in Beijing. Rising temperatures will also increase freshwater loss through evaporation.

This is not the first water crisis to grip Xinjiang. In recent decades, the Tarim's nine historical tributaries have dried up one by one, leaving just three: the Aksu, the Yarkand, and the Hotan rivers. (Last winter, the Yarkand and Hotan stopped flowing altogether, only resuming in May with spring runoff.) Worried by the high evaporation rates as the Tarim neared its terminus, Chinese engineers in the early 1970s dammed the river to create the Daxihaizi Reservoir. The amputation dried up the Tarim's final 321 kilometers, turning villages downstream into ghost towns. In the meantime, the "green corridor"—a marshy vegetation belt extending 800 or so meters on either side of the Tarim—began to wilt as water diversion to Daxihaizi and smaller reservoirs drew down the water table. Since 2000, the central government has spent roughly $15 million shoring up this line of defense against the Takla Makan.

All signs indicate that provincial authorities must act fast to conserve water. Unbridled irrigation in the Tarim's upper reaches, Chen says, sucked the life from tributaries and caused rampant salinization that has ruined 1.1 million hectares of farmland, a quarter of Xinjiang's total. Water-saving steps could include switching from ditch irrigation to drip irrigation and moving away from water-intense crops.

The grand challenge is to find alternative water sources. Chen's group plans to team up with Wang Chi-Yuen of the University of California, Berkeley, to hunt for hidden aquifers. As a first step, they will chart features—such as limestone karst formations—likely to hold water. "There must be large aquifers in the mountains," Chen says. Xinjiang's future may depend on it.

–R.S.



Thin green line. The Tarim River keeps the Takla Makan Desert at bay and irrigates much of Xinjiang's cropland.

CREDIT: CHEN YANING

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species, IHB and other researchers say. "Species that cannot adapt to the reservoir will gradually disappear," says Liu.

Subtle changes to Yangtze hydrology have had unforeseen effects. "These changes hit the carp on several fronts," says Brian Murphy, a fisheries researcher at Virginia Polytechnic Institute and State University in Blacksburg. In April and May, Three Gorges Dam operators dump water from the reservoir to make room for summer monsoon rain surges. The modest spike in flow stimulates adult carp to leave floodplain lakes and start spawning runs before they have stored enough energy and before eggs have matured, says Murphy. The colder water they encounter on the river further retards egg maturation and suppresses hatching rates and development of fry. Dam operations in the fall reduce water flow, stimulating carp to migrate back to the floodplain earlier than normal, again reducing their chances to accumulate energy stores, Murphy says. Drift sampling at Jianli, 350 kilometers downriver from the dam, has revealed a precipitous fall from an estimated 2.5 billion eggs and larvae in 1997 to 100.5 million in 2005, Murphy, Xie Songguang of IHB, and others reported in *Fisheries* in July 2007.

It's unlikely that the carp can adapt to the new regime. "It seems that any such adaptation could only occur over many generations, and the severe nature of the present spawning reduction yields very few fish for selection to act upon," Murphy says.

For some declining species, it's hard to untangle the dam's impact from other ills. "I doubt that there are enough good 'before and after' data to determine which species have been most affected, nor would it be easy to separate declines due to pollution and overfishing from the dam's effects," says David Dudgeon, an aquatic ecologist at the University of Hong Kong.

A case in point is the Chinese paddlefish (*Psephurus gladius*), a monster known to reach 7 meters in length. Scientists haven't spotted one in years (*Science*, 22 June 2007, p. 1684), suggesting that the fate of this dying breed was sealed long before Three Gorges bisected the Yangtze. Fishers report occasional sightings upstream of the dam, so Wei says he has not given up on the possibility of 11th-hour heroics—artificial breeding—to prolong the species' survival if individuals can be captured.

Two high-profile victims of the Yangtze's many ills are mammals: the river dolphin, or baiji (*Lipotes vexillifer*), and the finless porpoise, or jiangzhu (*Neophocaena phocaenoides asiaorientalis*). A 2006 survey along 1700 kilometers of the Yangtze failed to spot a single baiji, suggesting that the cetacean is down to several dozen individuals and functionally extinct (*Science*, 22 December 2006, p. 1860). CTGPC has claimed that the baiji can be saved and has designated a reserve on the Xinluo stretch of the Yangtze. Experts say CTGPC's plan is either woefully out of date or wishful thinking.

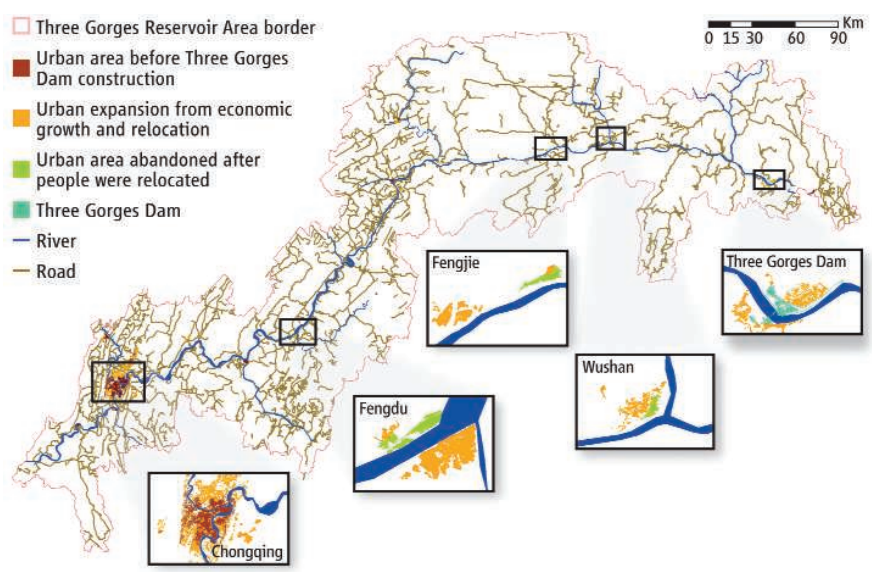
There's still hope for the jiangzhu. Although the 2006 survey recorded fewer than 300 sightings, indicating a maximum population of 1800, IHB's Wang Ding and his colleagues are keeping the species on life support at IHB, where a jiangzhu was born in 2005—the first freshwater cetacean born in captivity in the world. Wang's group is also nurturing a small population in Tian-e-Zhou Reserve, an oxbow of the Yangtze about 250 kilometers east of Three Gorges. But the dam's long shadow may reach there as well. Because water released through the dam tends to carry little silt, the "sour" downstream flow eats away at banks and scours the bottom. Wang's group is monitoring whether erosion will deepen the Yangtze near Tian-e-Zhou. That could sever the connection between river and reserve and prevent water exchange that's critical to the jiangzhu.

To give the Yangtze's aquatic denizens a fair shot at survival, authorities will have to make serious progress in reducing the river's pollution. On an autumn 2000 cruise from Wuhan to Chongqing, a city of 9 million people at the reservoir area's western end, Chen's delegation observed scores of factories and small enterprises "discharging a lot of effluent directly into the river," Chen says. In Chongqing, officials showed off a sophisticated model of water flow—for determining how much waste they could get away with dumping in the Yangtze. "We were speechless," says Chen. "We didn't know if they were joking." It was no joke: That evening, Chen and colleagues saw "mountains of trash" near the Yangtze. "I hope they aren't dumping it anymore," he says.

Perhaps not, after pollution limits and enforcement tightened in 2002. Since then, CTGPC has spent nearly $5 billion on sewage treatment plants and garbage disposal centers. To supplement this effort, the State Environmental Protection Agency last February announced that it will spend $3.3 billion over the next 3 years on 460 projects to improve Yangtze water quality. Despite such measures, the amount of sewage and effluent dumped in the Yangtze in 2006 (the last year for which numbers are available) was nearly 30 billion tons, or more than 4.5 million tons for every kilometer of the river. Experts spar over whether the water is improving or actually getting worse. "People are always fighting, arguing over the data," says one CAS scientist.

By slowing the flow of the Yangtze and nearby tributaries, Three Gorges saps the rivers' ability to detoxify and flush out pollutants. Last week, environmental authorities revealed that they are battling a bloom of blue-green algae along a 25-kilometer stretch of the Xiangxi River—the first outbreak of its kind in the reservoir area. They blamed the bloom on a buildup of pollutants from upstream phosphor mines and chemical plants. In the absence of strict pollution controls, Chen and others fear that the reservoir could become a giant cesspool.

Urban Change in the Three Gorges Reservoir Area



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A warped environment

In the rolling hills above Yichang, two graduate students unearth and examine the data recorder of a seismometer buried near a farmhouse. A team led by geophysicists Zhou Hua-wei of Texas Tech University in Lubbock and Xu Yixian of China University of Geosciences in Wuhan installed a network of 60 seismometers in the vicinity of Three Gorges Dam in mid-May, a few days after the devastating magnitude-7.9 Wenchuan earthquake centered 350 kilometers to the west. They are using recordings of thousands of aftershocks that rippled through the land here to map in detail the local geological structure and the strain placed on it by the reservoir.

The dam's location was carefully chosen in a section of crust called the Huangling core, an upwelling of granitic rock in a sea of unstable limestone. "This is called a weak seismic zone," says Zhou. "But I'm not so convinced." A key unknown is the deep structure of two fault systems skirting the edge of the Huangling core: one 20 kilometers to the west, and one less than 60 kilometers to the east. It's not clear, he says, whether stress propagates between the fault systems and whether the faults link up with each other deep below the surface, beneath the dam. Zhou expects to have preliminary results by the end of the year.

Although the risk of an earthquake powerful enough to bring down Three Gorges Dam is remote, the reservoir's impoundment has undeniably wrought massive changes on its surroundings. Currently, 632 square kilometers of terrain are under water. By the end of the year, engineers plan to begin raising the reservoir from 156 meters to its maximum capacity of 175 meters, which will submerge roughly 400 more square kilometers.

One immediate hazard is landslides. At a forum in Wuhan last fall, Huang Xuebin, chief of the Three Gorges' office of geological disaster prevention and control, said that landslides into the reservoir had produced towering waves that crashed into the shore, according to the official Xinhua News Agency. "Frequent geological disasters" threaten lives, Huang argued.

"We are concerned about what will happen when the reservoir level reaches 175 meters," says Qiao Jianping, a geophysicist at CAS's Institute of Mountain Hazards and Environment in Chengdu who has studied landslides in the Three Gorges area. The reservoir's rising waters have weakened slopes by saturating the soil. Qiao's team is developing a method to forecast slides a few days in advance by combining landslide hazard maps and rainfall data, as most slides are triggered by heavy rains. He expects to have a workable system in 2 or 3 years. In the meantime, the government has spent about $2 billion to stabilize landslide zones in the reservoir area by driving steel rods into the ground and building concrete retaining walls. "This work has enlarged the habitable areas along the river," Qiao says.

That's vital, considering that authorities in the past decade have relocated 1.2 million people to newly built towns and cities in the reservoir area. (Another 200,000 were moved to more distant locations.) Last fall, a Chongqing official told Xinhua that another 4 million people may have to be moved in the next 10 to 15 years.

Slim pickings. IHB researchers collect carp eggs and larvae near Chongqing.

CREDIT: LIU HUANZHANG

The Chinese press has featured stories of resolute citizens starting life anew. To get a more systematic view on how people are coping, IRSA has hired a polling firm, Horizon Research Consultancy Group, to interview the displaced. "We want to find out how different generations are responding to the rapid changes," says Wu. The government has allotted $22 billion for resettlement and poverty alleviation in the reservoir area over the next 12 years.

People aren't the only creatures having to move out of harm's way. Scientists have mounted an operation to rescue two evergreen plants found only along the Yangtze's banks in the Three Gorges area. Much of the habitat of a shrub, *Myricaria laxiflora*, and that of a fern, *Adiantum reniforme* var. sinense, was lost when the reservoir's level rose to 156 meters. CTGPC funded a team led by Xie Zongqiang of CAS's Institute of Botany in Beijing to uproot more than 10,000 of the plants before the waters rose and replant them at four conservation centers.

One story only beginning to unfold is how ecosystems will respond to extensive habitat fragmentation after the reservoir's rising waters flooded valleys and turned several dozen hilltops into islands (*Science*, 23 May 2003, p. 1239). Xie and his colleagues are studying how communities of species are changing on several of the islands. They expect to see rapid biodiversity loss. "Such changes may test theories of island biogeography," says Xie. On the plus side, he says, the government has established several new nature reserves in the reservoir area.

A big wildcard is what will happen as silt builds up behind the dam—and as sedimentation is reduced downstream. In the second half of the 20th century, the Yangtze deposited about 40 million tons of sediment in its delta, forming the largest alluvial islands on Earth. Chongming Island, which started out as a sandbar 1400 years ago, now covers more than 1000 square kilometers and has a population of 650,000.

In 1979, authorities sought to consolidate these gains by planting on tidal mud flats *Spartina alterniflora*, a grass native to salt marshes in the southeastern United States. But the invader has spread rapidly and now threatens the Yangtze delta's ecological diversity, Chen and colleagues reported in the June *Journal of Plant Ecology*. Reduced sedimentation is expected to erode the alluvial islands, Chen says. At the same time, filling the Three Gorges reservoir and diverting water to other potential projects in the north will decrease the flow and allow more saltwater intrusion into the delta—spurring *Spartina*'s spread.

The biggest fear of all is a dam breach. "The dam's failure would result in one of the worst disasters in history," says Zhou. Some 75 million people live directly downstream of Three Gorges. One possible—albeit improbable—trigger could be an earthquake that's off the scale for the region. Another potential strain would be huge pulses of water from sustained heavy precipitation or sudden melting of glaciers that feed the Yangtze. "If any catastrophe happens," Chen says, "I'm not sure China—or any nation—could handle it."

A more likely scenario is that some decades from now, the Yangtze and the Three Gorges reservoir area will achieve an ecological equilibrium and the mammoth dam will become a monument to the profound transformation of the land around it.

–RICHARD STONE

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