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The Yangtze is the third longest river in the world. Originating from 5,800-meter-high Mount Tanggula on the Tibet Plateau, the Yangtze follows a sinuous west-to-east route for more than 6,000 kilometers before emptying into the East China Sea at Shanghai. The river has 3,600 tributaries and drains almost 2 million square kilometers, almost 19 percent of China's land area.

During flood season, the water level in the river can rise as much as 15 meters, affecting 15 million people and threatening 1.5 million hectares of cultivated land. Historic floods have been devastating. The flood of 1870 is still talked about along the middle reaches of the river, and the flood of 1954 inundated 3 million hectares of arable land and claimed 30,000 lives. Altogether in the 20th century, as many as half a million people may have died in the Yangtze's flood waters.

The Yangtze also has some of the most beautiful scenery in the world in the region known as the Three Gorges, with spectacular cliffs and steep mountains rising as high as 1,500 meters. Interspersed with gently rolling hills and long sloping riverbanks, the gorges have been compared in majesty to the Grand Canyon. Cruising the river through the Three Gorges is considered a classic travel experience, as each bend in the river reveals a new perspective on the marvels that geological change has wrought.

Making Choices

Balancing the desire to preserve the river in all its natural glory against that to tame it to control flooding, generate power and provide more reliable shipping conditions presents a classical dilemma involving engineering and society. When nationalist leader Sun Yat-Sen proposed a Three Gorges Dam in 1919, the ecological costs were overshadowed by the economic benefits for China. In the mid-1940s, a preliminary survey, along with planning and design efforts, was carried out by the U.S. Bureau of Reclamation under the direction of John Lucian Savage, designer of the Hoover and Grand Coulee dams. In his exploratory role, Savage became the first non-Chinese engineer to visit the Three Gorges with the thought of locating an appropriate dam site. Savage's work is the likely inspiration for John Hersey's novel, *A Single Pebble*, whose opening sentence is, "I became an engineer." In the story, the unnamed engineer travels up the Yangtze in a junk pulled by trackers in the ancient and, once, the only way to make the river journey upstream.

Chairman Mao Zedong was a staunch supporter of a Three Gorges Dam, which he felt would provide a forceful symbol of China's self-sufficiency and ability to develop its resources without Western aid. As early as 1953, Mao expressed his preference for a single large dam rather than a series of smaller ones, and he suggested that he would resign the chairmanship of the Communist Party in China to assist in the design of the project. Mao's poem about being at ease swimming across the turbulent Yangtze reflects on how all things change, like the swift river and the gorges through which it flows. He knows that Goddess, a prominent peak in the middle reaches of the Three Gorges, will marvel at the accomplishment of a dam.

In 1992, the Chinese government announced officially its determination to tame the Yangtze with what would be the world's largest hydroelectric dam, ultimately to be fitted with 26 generators rated at 700 megawatts each. The total of 18,200 megawatts is equivalent to the output of approximately 15 of the largest nuclear-power plants operating in the world today. Since one of China's most pressing environmental problems is pollution from burning fossil fuels, the prospect of a clean hydroelectric dam generating about 10 percent of the country's power is very appealing to the Chinese leadership. In addition to providing flood control and power generation, the dam will open up the Yangtze as far upriver as Chongqing to 10,000-metric-ton ships, providing an opportunity for China to develop container ports almost 2,000 kilometers inland. This purpose goes hand in hand with China's

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Bob Sacha/National Geographic Society

Figure 1. Three Gorges Dam will contain the world's largest hydroelectric plant when completed, with generators expected to provide 10 percent of China's electricity. The impoundment will prevent flooding, yet the project is not without detractors on environmental grounds.

plan to soon become a full partner in world trade operations.

For all its practical benefits to China, the Three Gorges Dam project has been opposed by numerous groups both domestic and international. Especially vocal have been human-rights advocates, environmentalists and historians. Among the most persistent opposing voices has been Dai Qing, who was educated as an engineer but became disillusioned during the Cultural Revolution and finally turned to investigative journalism. Her 1989 book, *Yangtze! Yangtze!*, was highly critical of the idea of a Three Gorges Dam and led to her temporary imprisonment. That book and her subsequent one, *The River Dragon Has Come!*, published in 1998, state the fundamental case against the project but seem to have had little, if any, effect on the progress of the dam.

When complete, Three Gorges Dam, which will stretch about 2 kilometers across the Yangtze at Sandouping, will be 185 meters high and will create a reservoir 600 kilometers long, reaching all the way to Chongqing. The filling of the reservoir will displace on the order of a million people, inundate almost 50,000 hectares of prime farmland, submerge archaeological treasures and forever alter the appearance of the Three Gorges.

The project has been described as "perhaps the largest, most expensive, and perhaps most hazardous hydroelectric project ever attempted." Vocal protesters and international politics have no doubt influenced the World Bank's refusal to finance the project. Bowing to pressure from environmental groups, the Clinton Administration opposed competitive financing through the Export-Import Bank, effectively discouraging American companies from participating. The Chinese government has nonetheless been resolute.

As in all large dam projects, choosing the site was of fundamental importance. Of 15 locations seriously considered, the final choice was made on the basis of geological foundation conditions and accessibility to construction equipment and materials. The chosen dam site is 28 kilometers upriver from Yichang, where the Yangtze runs wide between gently sloping banks that provide staging areas for the construction project. The geology in the area is ideal, in that it is underlain with solid granite for some 10 kilometers surrounding the dam site, providing a stable construction base.

The project was planned to be completed in three stages. Phase I, stretching from 1993 to 1997, consisted of building coffer dams within which the river bottom could be excavated and the foundation of the dam begun. A temporary ship lock was also constructed during this phase in order to allow shipping to pass the construction site throughout the project. Phase II, extending from 1998 to 2003, involves the construction of a good part of the dam proper. Concrete is being poured 24 hours a day to complete the spillway of the dam, the intake portions of the dam designed for the power generation and the initial

Figure 2. Yangtze River, although offering spectacular scenery, may have claimed a half-million lives during the 1900s in devastating floods. (Photograph courtesy of Alan R. Miller, New Mexico Tech.)

stage of the power plant itself. At the end of Phase II, the reservoir will be filled and the dam will begin to generate power, which will produce revenue to fund the final phase of the project. Phase III, stretching from 2004 to 2009, will involve the completion of the dam across the river, including additional powerhouse units. According to the China Yangtze Three Gorges Project Development Corporation (CTGPC), the government-authorized entity created to own the project, construction is on schedule for the completion of the present phase in 2003.

A First-hand Perspective

I was invited recently to lead a civil engineering delegation from the United States to visit the Three Gorges Dam construction site and talk with Chinese engineers about the project. The delegation would have the opportunity to see first-hand the scale and technical nature of this gargantuan engineering project and to visit the areas along the Yangtze that will be permanently altered by the creation of the reservoir. The delegation would see the towns that will be submerged and from which so many people will be displaced. Our group would also have an opportunity to experience China in this time of rapid emergence as a full player on the world economic scene.

Figure 3. Lock at Gezhouba Dam, completed in 1981, provides shipping access above Yichang. (Photograph courtesy of Alan R. Miller.)

Our delegation consisted of 40 engineers. They were mostly civil engineers, some with extensive experience in dam construction and power generation, but there were also a number of electrical and mechanical engineers, among others, as well as a geologist, reflecting the inherent interdisciplinary nature of large engineering projects. About 25 guests traveled with the delegation. Most were spouses of the delegates, but there were also a half-dozen professional sociologists who were interested in the relocation problems associated with the Three Gorges Project.

The conventional wisdom in the United States about the project is that it is technologically risky, environmentally unsound, sociologically devastating and economically unwise for China at this time. Thus, the overall view of the project that is held by most Americans is that it is ill-advised at best and a disaster in the making at worst. Different members of the delegation took different preconceptions with them to China, and some brought home altered perceptions.

The delegation assembled in Los Angeles in mid-November for a predeparture briefing. The 15-hour flight to Hong Kong was pleasant and uneventful, with most delegates getting a good night's sleep. A five-hour layover in Hong Kong gave some of us an opportunity to ride the new Airport Express into the city that is now one part of but still apart from China.

The world of difference between Hong Kong and the interior of China was emphasized by the fact that our flight from Hong Kong to Wuhan was classified as an international one. Wuhan was created in 1950 out of the merger of three cities separated only by the Yangtze and Han rivers, a region rich in Chinese history. The consolidated city is located midway on a north-south line between Beijing and Canton and an east-west line between Shanghai and Chongqing. In contrast to the bright stainless-steel expansiveness of the new airport at Hong Kong, the dated one at Wuhan was tiny, dingy and drab. Wuhan, one of China's industrial cities, has a population of about 4 million. It was our point of entry into China's interior because it is on the Yangtze River and conveniently connected by a modern toll highway to Yichang, headquarters of the CTGPC and only 30 kilometers downstream from the construction site.

A Land of Contrasts

Although a straight shot on a new superhighway, the bus ride to Yichang took about four-and-a-half hours, so we spent the night in Wuhan. This important river port evokes 19th-century technology as much as Hong Kong does 21st. That is not to say that Wuhan is without its buses and cars, the increase of which throughout China is creating enormous traffic and pollution problems, or its better hotels complete with CNN on television.

Rather, the enormous reliance of the people on muscle power harks back to a previous century. Myriad bicycles have their dedicated lanes, and they carry goods that in America would be found in pickup trucks and delivery vans. It is common to see bicyclists struggling up the slightest incline under a load of reinforcing steel or plastic pipe that extends several meters ahead of and behind the bike. Smaller loads, though not always smaller by much, are carried in bundles hung from the ends of bamboo poles balanced on the shoulders of bearers, who trek along among the bicycles.

The few hours we had in Wuhan were spent riding a bus to and from the Yellow Crane Tower, a restored ancient hilltop pagoda, perhaps the city's most famous tourist attraction. On the ride to and from the Yellow Crane Tower, which was apparently named after a mythic bird—there are no cranes colored yellow in China, our tour guide informed us—we crossed and recrossed a road-and-railroad bridge spanning the Yangtze. Through the haze with which we would become quite familiar, we could glimpse a newer cable-stayed crossing in the distance, one of the many newly constructed modern bridges we would encounter as we crisscrossed the country.

The next day, the bus ride to Yichang was through primitive farmland. In sharp contrast to the new cars and buses traveling the highway on which we rode, the farms showed no sign of mechanization. Those farmers who did not walk behind a water buffalo worked bent over in their fields. During harvest, farmers stay in the tents and tiny shacks that abound beside the fields. Clusters of small run-down farmhouses marked simple villages, with virtually all buildings oriented with their entrance facing south, in the tradition of much-grander Chinese houses. Although in the days of collective farming there was some machinery, our guide told us, that has not survived into the present era when smaller plots of land are worked by individual farmers. That is not to say that they own the land, however, for we were also told that the state owns all the land in China.

Since it was late fall, there were few crops in evidence. The clearly irregular fields followed the contours of irrigation ditches, and some worked-out fields were excavated deeper than their neighbors to allow for fish farming and lotus cultivation. Hubei province's great Jingbei Plain west of Wuhan is extraordinarily flat, and after several hours' riding we had become so accustomed to the flatness of the land that the sudden appearance of hills with terraced fields worked many of us out of a torpor.

The presence of hills soon yielded to mountains, which signaled our land approach to Xiling Gorge, the most downriver of the Three Gorges and thus often referred to as the third gorge. The twists and turns of the highway through the mountains caused the city of Yichang to appear as suddenly as new stretches of river would when we would sail through the gorges a few days hence. The most prominent building to first come into view in the city was the modern China Telecom Building, the city's tallest. It and the headquarters building of the CTGPC dominate the skyline of hilly Yichang, which has come to be known as "dam city" and "electricity city," in recognition of the many hydroelectric power plants in the area.

Our first technical visit was to Three Gorges University, a consortium of several institutions in the area that is the national center for teaching hydraulic and electrical engineering. At our meeting, we received an academic background briefing on the Three Gorges Dam project, which prepared us for our visit to the site the next day.

Before leaving the Yichang area, we visited the Gezhouba Dam, completed in 1981 and a prototype of sorts for the Three Gorges Dam. Located about 30 kilometers downstream from Sandouping, this hydroelectric dam has all the features of the larger structure. In particular, it has sediment-control gates, which by design when opened scour out accumulated sand and silt from behind

Figure 4. Xiling Bridge crosses the Yangtze just downstream from the Three Gorges Dam site. (Photograph courtesy of Catherine Petroski.)

the dam and distribute it in a controlled manner downstream. The issue of accumulating material behind the Three Gorges Dam is an objection raised by opponents, who argue that in time the reservoir will fill with silt and become unnavigable. Impounding silt behind the dam would also deprive the agricultural land downstream of natural replenishment. The reportedly successful operation of Gezhouba Dam, however, appears to have allayed immediate concerns about silt, at least among the engineers.

It was dark when we left Gezhouba Dam and boarded the buses for the ride to Sandouping, the base town for the Three Gorges Dam project. Since it was dark, we could not see the terrain through which we were riding, but the grades of the hills and the rock slopes visible in the bus's headlights made it clear that we were traveling through rough territory. The road was new, constructed in the past few years to serve the project site, and it led through a heavily guarded check station. At

Figure 4. Ship locks for Three Gorges Dam have been carved out of solid granite. (Photograph courtesy of Catherine Petroski.)

one point we passed through a tunnel estimated to be about two kilometers long, suggesting that the mountains above us were too high or steep to put a road over. After maybe 45 minutes of riding without seeing any significant number of lights, we came upon Sandouping, a small town by Chinese standards but a bustling center beside the Yangtze. Our hotel was a relatively new high rise. From its windows we could see the outline of lights on the cables of a major suspension bridge, suggesting that we were beside the river.

In the daylight, we would learn that the graceful structure was the Xiling Bridge. On the way to the dam-construction site, we passed numerous warehouses and dormitories for workers. The latter, we were told, will be converted into tourist accommodations, since the recreational lake to be formed behind Three Gorges Dam is expected to bring large numbers of vacationers to this region. Dominating the route to the construction site was a large pit where granite is being crushed into pieces of aggregate for the concrete. A system of conveyor belts carries the stone over and along the road to the concrete plant.

The Meaning of Big

The construction site is so large, extending well over a kilometer out from the river bank and into the riverbed, that it is hard to encompass it in a single view. Perhaps the dominant first impression is the countless number of tall construction cranes, literally countless because they blend into each other and disappear behind each other. Our guide joked that we were now seeing a real yellow tower crane, as opposed to the mythical source of the name of the Yellow Crane Tower that we puzzled over in Wuhan.

The first stop on the site was at the location of the locks. Twin pairs of five locks are being carved out of solid granite and lined with concrete. They will carry 10,000-metric-ton ships and barges in stages through the difference in water level behind and in front of the dam. Viewed from near their bottom, the scale of this one aspect of the Three Gorges Project is enormous. I certainly have never seen anything like it, and I imagine that it rivals even the construction of the individually larger locks of the Panama Canal. Workers at the bottom of the manmade granite box canyons looked minuscule, and it seemed impossible that these locks were blasted out of the granite in only a few years' time. Our guide told us that the Chinese calligraphy atop a nearby promontory motivated the workers to keep at the task with "first-class management, high-quality workmanship, first-rate construction."

For American engineers, one notable feature of this Chinese construction site was the freedom with which we visitors were allowed to move among the piles of construction materials and debris. Such traipsing around is unheard of at construction sites in the U.S. Only a simple railing with wide openings separated us from a 30-meter-or-so fall into one of the ship-lock excavations, but neither the Chinese nor the visitors seemed to be bothered by their proximity to the precipice.

After spending some time at the locks, we reboarded our buses and were driven over to the dam proper, which we viewed head-on from its downriver side. The scale of this part of the project was even grander that that of the locks, for it rose higher into the air and stretched over a kilometer wide before us. Under construction to our left was the spillway, with one section of it raised to the dam's final height, giving a sense of how the completed structure will loom over this part of the river. To our right was the power-plants section, which will hold 14 hydraulic turbine generator units capable of generating 9,800 megawatts of power when the dam is completed. (The remaining 8,400-megawatt capacity of the dam's power plant will not be realized until the third phase of the project is completed and all potential generating capacity is in place.)

Behind us stood the batch plant, where concrete was being mixed constantly for the 24-hour-a-day work schedule. One of the major considerations in placing concrete in such a massive structure is how

Figure 6. Large trucks are dwarfed by the rising concrete gravity dam. (Photograph courtesy of Catherine Petroski.)

to dissipate the heat of hydration that is generated in the concrete. If the concrete experiences too much thermal expansion as it sets, cracks will develop when it cools and contracts. Taking the heat away in a controlled and timely manner obviates this unwanted behavior. At the Three Gorges Dam, the thermal problem is being handled in several ways. As with Hoover Dam, cooling pipes are being imbedded into the concrete to carry away some of the heat. The amount of undesirable heat is itself being eliminated at the source by mixing and placing the concrete at the lowest temperature possible. This is accomplished through cooling the aggregate by blowing cold air over it, by using ice water in the mixing process and by ensuring that no concrete comes out of the batch plant at over seven degrees Celsius. The measures appear to be working. So far only one significant crack has appeared in the part of the dam in place, and the Chinese engineers seem confident that it has been satisfactorily repaired.

After the dam itself and the tower cranes—red, white and yellow—the next most prominent feature of the construction site is the conveyor-belt system that rises up to great heights on temporary concrete columns. The conveyor system to deliver the concrete is a crucial component of the job, for the rate at which concrete is placed largely determines if the project can be kept on schedule. The unique Rotec conveyor system is one of the rare American presences in the project (Caterpillar and General Electric being others). Unfortunately, shortly before our visit to the site, there was an accident with one of the conveyors, killing some workers. Before that accident, we were told, the safety record of the project had been excellent. At the time of our visit, the conveyor system was not operating at the desired capacity, which irritated the Chinese, and local papers were carrying stories of a law suit against the conveyor company for breach of contract.

While at the construction site of the Three Gorges Dam, it is hard not to be awed by the enormity of the project and the confidence of engineers working to hold back the legendary Yangtze, building on their experience with Gezhouba Dam and the many other flood-control and hydroelectric projects completed throughout their country in recent decades. (A recent survey by the World Commission on Dams found that 46 percent of the world's 45,000 large dams are located in China. It also reported that, although they have contributed significantly to human development, dams have been the cause of considerable social and environmental damage.)

The convincing official arguments that the Chinese put forth about the multifarious good that the Three Gorges Dam will bring to their emerging economy impress visitors from a country that is what it is today in part because its engineers also tamed great and scenic rivers like the Colorado and the Snake. The preconceived opposition to the Chinese project as being merely irresponsible and antienvironmental that some members of our delegation brought with them from America was allayed as we stood before this monument-in-progress. For the time being, at least, we saw the Three Gorges Dam through Chinese eyes on Chinese ground. The next day we would board a riverboat to cruise past the dam site, up through the storied gorges and past their Goddess Peak, reflecting on the changes the world-class engineering project is bringing to the great Yangtze.