Regional Profile | Damming The Senegal River

A regional effort to harness the waters of the Senegal River for hydropower, irrigation, and transportation has resulted in profound environmental changes in the river basin. These environmental changes have, in turn, caused severe health and general welfare problems for the river basin's residents. This case study illustrates the complex relationships that can unfold between people and their environment as societies work to meet their growing needs for energy, agricultural production, and industrial development. Although many of the harmful effects were predicted before the project began, the project's purported benefits—water storage for irrigation, drought, and domestic supply; electrical power for urban areas and industry; and a transportation channel to the sea for land-locked Mali—were deemed too important to forgo. Now, years later, the river basin management authority, national ministries in three riparian countries (Mali, Mauritania, and Senegal), and international agencies financing the project are trying to mitigate some of the most severe problems as they continue work to realize the project's potential benefits.

Background

The Senegal River is the second longest river in West Africa (1). Its principal tributary, the Bafing River, rises in the highlands of Guinea's Fouta Djallon and runs north into Mali, where it joins the Bakoye River at Bafoulabe to form the Senegal River. From Bafoulabe, the Senegal River flows northwest through Mali and down to Kayes, receives waters from the Faleme River, and then flows onto the flood plain starting at Bakel in Senegal. For its remaining length from Bakel to the Atlantic Ocean, the Senegal River forms the border between Mauritania to the north and Senegal to the south.

The upland areas above Bakel, and particularly those in Guinea, receive 700 to 2,000 millimeters of rainfall annually and provide virtually all of the flow in the Senegal River. Annual rainfall below Bakel is typically between 150 and 300 millimeters. Tributaries to the Senegal River are temporary, seasonal systems that function as distributaries when flow is high in the main channel. In its natural state, the Senegal River's annual flood inundated approximately 150,000 hectares in an average year and up to 350,000 hectares in high-flow years. In the dry season, freshwater flow stopped in the lower reaches of the river, and saltwater flow traveling upstream created estuarine conditions from the Atlantic coast to Dagana, approximately 250 kilometers inland. These conditions created a natural division of the river basin into three zones: an upper basin above Bakel; the middle valley from Bakel to Dagana; and the delta, or lower valley, from Dagana to the Atlantic coast.

Approximately 2 million people of several ethnic groups live in the river basin. The predominant groups are the Malinke in the upper basin, the Soninke around Bakel, the Pulaar and Maures in the middle valley, and the Wolof in the delta. All of these groups are agropastoralists, relying for their livelihood on a combination of agriculture, small animal husbandry, and fishing. Herders have historically traveled with their cattle from the valley floor in the dry season to the adjacent Sahelian fringe areas in the rainy season and floods.

Because of their dependence on the river, residents' fortunes have risen and fallen through the years in relation to the availability of water from rainfall and floods. From 1968 to 1973, the region experienced a prolonged and severe great drought that caused extensive famine and focused international attention on the Sahel region.

Development Projects on the Senegal River

Because of its size and regional importance, the Senegal River has long been a target for development projects. There were two international efforts to develop agriculture, navigation, and hydroelectric projects in the four riparian states (including Guinea) during the colonial period in the 1930s and early 1940s. In the 1960s, after gaining independence, the riparian countries created an Inter-Country Committee and a successor organization to pursue an integrated development program for the river basin. However, most of the early attempts at developing the river's resources failed, either for technical reasons or because of tension among the participating states.

In the early 1970s, circumstances finally combined to favor mounting several large-scale projects. In 1970, a U.N.-sponsored study identified several potential sites for hydroelectric dams in western Mali and northeastern Guinea. In 1972, partially in response to the great drought and the resulting attention from international agencies, the governments of Mali, Mauritania, and Senegal created a regional river basin authority, the Organisation pour la Mise en Valeur du Fleuve Senegal (OMVS). Guinea was not included in the OMVS because of its lack of interest and effective participation in the earlier regional organizations. The three member states of the OMVS thought a regional organization would be the best way to prioritize economic objectives for developing resources in the basin, to organize a cooperative effort, and to reach agreement on common responsibilities for financing and managing the major works. Arab oil states also took an interest in financing projects on the Senegal River, a reflection of their prosperity during the oil boom of the 1970s and of their desire to assist other members of the Islamic community and increase Islamic economic and cultural influence in the region.

The OMVS members developed an integrated plan for development of the Senegal River, designed to stimulate economic growth in the three member countries and to moderate the effects of drought on people living in the basin. The plan had six components:

- an upland hydroelectric dam on the Bafing River at Manantali, Mali, for water storage and power production;
- a lowland dam on the Senegal River near Diama, Senegal, to limit saltwater intrusion, regulate water levels in the middle valley, and store water for domestic water supplies;
- facilities and conditions (i.e., locks, channel dredging, and water-level management) to ensure navigability from the Atlantic coast at Saint-Louis, Senegal, to Kayes, Mali;
- irrigation projects and agricultural development in the middle and lower valley;
- urban water supplies using the reservoir created by Diama Dam; and
- development of agroindustry.

The OMVS was given direct authority for building and operating the two dams and responsibility for developing the navigation project. The member states retained responsibility for developing irrigation, water supply, and agroindustrial projects within their own territories.

Politically, the major selling points of the plan were that it would lessen the impact of future droughts and help close the food gap that was emerging as rapid population growth outpaced domestic food production. The OMVS was directed to manage the river's water resources to achieve two objectives that related primarily to agriculture: first, to reduce the large seasonal and annual fluctuations in water availability; and second, to control flooding so that land in the valley could be developed for irrigated agriculture. Senegal and Mauritania would realize most of the benefits from meeting these objectives: of the 375,000 hectares of land that were to be developed for irrigation, all but 9,000 hectares were in these two countries. The hydropower and navigation components were included in the plan primarily to meet Mali's interests.

The expectations of mutual benefit and accelerated development, coupled with the crisis conditions created by the great drought and realistic prospects of international financing, enabled the three countries to overcome entrenched suspicions and proceed with the project. The three member states have maintained a level of cooperation sufficient to complete construction of both dams. Diama Dam was completed and began storing water in 1986. The reservoir behind Manantali Dam began filling in 1987 and reached spillway level in 1991. Other portions of the plan have developed more slowly than first envisioned. Irrigation projects have been completed in the middle valley, and rice and sugar cane production have increased, although not as rapidly as originally predicted. Financing was recently arranged for the hydropower component, which involves installation of turbines and generators at Manantali Dam and building transmission lines to the three capitals (Dakar, Nouakchott, and Bamako) and several points in the basin. Plans for the navigation component have been modified to reflect more realistic water management conditions, shipping systems, and associated development of sea and river ports. Some critics maintain that the navigation project is still unrealistic and will likely never be built. Plans are being developed for water supply projects in Senegal. Most recently, a small amount of industrial development has occurred in the valley, primarily connected with the agricultural sector.

Although the OMVS has implemented portions of its development plan, the projects have not yet generated substantial economic benefits for the member states. Agricultural development has proceeded more slowly than expected, in part because of inappropriate plans for irrigation projects, low yields being experienced in existing projects, and (until recently) centralized control over agricultural planning, production, distribution, and marketing. The power and navigation projects have not yet been implemented. There is some question whether the full plan, even if completed, will ever generate the level of economic benefit originally predicted. The Senegal River dams were initiated in a global economic climate that favored large development projects and a political climate in which the major donors exerted little influence—too little, maintain some critics—over project planning and implementation (2)(3)(4).

Whatever balance may eventually be realized between the economic benefits and costs of the projects for the region and for each country, it is also important to consider the distribution of those costs and benefits and, particularly, the situation of people most directly affected by the projects— those living in the river basin. The completed projects and the OMVS' practices to date in managing water levels in the basin have provided few benefits and serious negative consequences for the basin's residents—some anticipated, and some unanticipated. The ecological, health, and social consequences will be explored in the following sections.

Ecosystem Changes in the Senegal River Basin

The Manantali and Diama dams have changed the river basin ecosystem in several obvious and profound ways. The annual flood has been reduced substantially, because the flow from the Bafing River has been impounded at Manantali Dam. The amount of water available from other tributaries is considerably less than that from the Bafing River. Water has been released from Manantali Dam to provide a managed flood every year since 1987. Unfortunately, the volume of water released each year has been far less than would have been available under natural conditions. And during several years, the period chosen for a water release was poorly timed.

The Senegal River now flows year-round. The region above Diama Dam is now a stable freshwater lake and no longer shifts to estuarine conditions during the dry season. The area below Diama Dam now has a relatively constant estuarine status, as opposed to the previous shifts between freshwater and estuarine conditions that occurred as a result of high freshwater flows in the flood season and low-to-nonexistent freshwater flows in the dry season. The shoreline is increasing as irrigation canals are developed. Weeds and grasses characteristic of a freshwater lake are growing along the banks of the river and canals from Diama Dam to Dagana and could eventually reach another 100 kilometers inland to Bogué. The vegetation, partially submerged along the river's edge, is favorable habitat for the snails that carry schistosomiasis; increasing vegetation is the primary cause of the growing disease problem among the population of the lower basin.

The changes in aquatic habitat and the physical barrier of Diama Dam have greatly affected fisheries in the lower valley, delta, and coastal waters. Before the dams were built, the sediments carried by the annual flood were an important source of nutrients for coastal fisheries, and the flood plains in the upper delta were spawning and feeding grounds for saltwater and freshwater species. A major coastal fishing industry was centered around Saint-Louis, and fish were an important source of protein for people living in the valley. Although the prolonged drought had already reduced annual catches in the valley before the dams were built, a study in 1994 concluded that the dams have generally had a detrimental effect on fish production both in the valley and in the upper part of the delta. People living in the valley maintain that fish consumption has decreased since 1988. They say that the fish now consumed are almost exclusively saltwater species, trucked in from the Senegalese and Mauritanian coastal areas.

Above Manantali Dam, a large, deep freshwater lake now exists in what was previously a forested valley. The dam was designed to store 11 billion cubic meters of water, enough to supply 2 years' flow during a drought. The surface of Lake Manantali now covers 447 square kilometers; its shoreline is approximately 150 kilometers, and it is 65 meters deep at the dam. Studies conducted before the dams were built predicted that fish populations would increase in the lake behind Manantali Dam (stabilizing at around 3,000 metric tons annual production) and decrease below the dam (5). Although the fish population in Lake Manantali did increase after the reservoir was filled, the annual catch has never reached predicted levels and has fallen sharply in subsequent years, to 420 metric tons in 1991 and 285 metric tons in 1993. The decreased catch reflects in part the techniques and equipment used by the fisherman, who were accustomed to fishing in rivers rather than in a deep lake, and also the movement of people away from the area.

Environmental Changes and Health Problems

People living in the Senegal River basin have long suffered from schistosomiasis, malaria, and other infectious and vector-borne diseases endemic in large areas of sub-Saharan Africa. Before dams were constructed, malnutrition was widespread in the valley, and infant and child mortality rates were high, especially during the extended drought. The development plan endorsed by the member states of the OMVS predicted that residents' well-being would improve as agriculture and transportation expanded and people had more income and greater access to food, water, and health care.

The reality has been different. Agriculture is developing, but more slowly than anticipated and in a manner that stretches the financial and human resources of existing landholders. Transportation has not improved. Although some indicators of health have improved in the region, health risks from certain diseases—most notably schistosomiasis, diarrheal diseases, and malaria—have increased, in some cases dramatically. The net impact of the Senegal River development projects on people's health has clearly been negative to this point.

SCHISTOSOMIASIS

Schistosomiasis results from infection by species of the trematode *Schistosoma*. The parasite has a complex life cycle with a stage that infects freshwater snails, which then release larvae into the water. Humans come into contact with the larvae when they wade in shallow waters (for example, when collecting water, washing clothes, or, for children, playing); they become infected when larvae penetrate the skin. Larvae migrate through the host's circulatory system and lungs while developing into mature male and female worms; they eventually migrate to blood vessels in the abdomen and form permanent reproductive pairs, after which the females may produce large numbers of eggs for many years.

There are two main species of *Schistosoma* that infect humans in Africa; they rely on different snail hosts, settle in different tissues of their human hosts, and produce different forms of the disease. *S. mansoni* settle in blood vessels near the liver or intestines and cause intestinal schistosomiasis; *S. haematobium* settle near the bladder and cause urinary schistosomiasis. The severity of the disease in each individual depends on the position and size of the egg load and the host's cellular response to it. Intestinal schistosomiasis causes diarrhea and bloody stools in moderate cases and, in heavy infections, permanent organ damage that can lead to death. Urinary schistosomiasis causes blood in the urine; severe cases involve serious damage to the urinary tract, sometimes leading to bladder cancer.

Before 1986, urinary schistosomiasis was endemic in the Senegal River basin, with relatively low rates of infection in the lower valley and moderate to high rates in the middle and upper valleys. Since the construction of Diama Dam, the snail hosts of *S. haematobium* have extended their range and increased their number in the lower valley, especially along the Lampsar River (a southern branch of the Senegal River in Senegal). Infection rates in humans have also increased. A 1994 survey found the prevalence of urinary schistosomiasis was moderate (11 to 12 percent) among schoolchildren surveyed along the Mauritanian shore of the Senegal River at Rosso, Baghdad, and Jidrel Moghuen. That year, the snail host was found for the first time in the Taouey canal in Senegal, near its outfall to Lake Guiers. There was no evidence at that time of infection among schoolchildren in Mbane, a town on the eastern shore of the lake, although the presence of the snail host suggests that future increases in disease rates in this area are possible.

The net impact of the Senegal River development projects on people's health has clearly been negative to this point.

In the upper valley around Lake Manantali, the prevalence of urinary schistosomiasis was high (69 to 95 percent) in several lake shore villages and in a village just downstream of the dam, according to the 1994 survey. Prevalence decreased with greater distance from the dam (to 49 percent and 7 percent in two villages further downstream). In at least one place in the middle valley, in the irrigation projects around the Foum Gleita Dam in Mauritania, the prevalence of urinary schistosomiasis has been reduced to less than 5 percent by a combination of mitigation measures and natural conditions. The former includes switching from rice to other crops on some of the land and keeping irrigation canals free of weeds. These efforts are aided by the naturally flat terrain of the lake bed behind the dam, which results in large fluctuations in the location of the water line along the shore as water levels fluctuate in the lake. These fluctuations disturb the growth of marginal vegetation along the lake shore and reduce the amount of favorable habitat for snails.

The most dramatic health impact of the Diama and Manantali dams and the new water management regime has been the introduction and rapid spread of intestinal schistosomiasis in the lower valley. Before 1986, *S. mansoni* was not present in the lower and middle valleys and had been reported at only a few locations in the upper valley. In 1988, soon after the completion of Diama Dam, a new focus of intestinal schistosomiasis was reported in a sugar cane project area in Richard-Toll, on the Senegal side of the river. Prevalence reached epidemic levels the following year in Richard-Toll and, by 1993, had climbed to nearly 100 percent in the nearby village of Ndombo and 70 percent in Ngnith, a village on Lake Guiers. In 1994, disease prevalence was 82 percent among schoolchildren at Mbane on Lake Guiers and 47 percent at Dagana, the easternmost boundary of Lake Diama. These Senegalese children had heavy infections with very high egg counts.

In the Mauritanian portion of the lower valley, intestinal schistosomiasis was first reported in 1994 with prevalence rates of 25 to 32 percent in children in three towns from Rosso to Jidrel Moghuen; these children had infections of light to moderate severity. However, the snail host of *S. mansoni* was found in large numbers with high infection rates along the Mauritanian shore of the Senegal River and spreading northward into the Garak canal at Tougene and the Sokam canal near Lake Rkiz. These findings suggest that the extent and intensity of the epidemic will likely increase in Mauritania, possibly following the same course as in Senegal.

As of 1994, the problem with intestinal schistosomiasis had not extended into the middle valley and had not increased greatly in the upper valley. Under the current operating regime, Lake Diama ends at Dagana; above Dagana, the Senegal River is still within its original banks. There is little or no growth of marginal weeds in this region and, therefore, no habitat for the snails.

The introduction of intestinal schistosomiasis and the increases in urinary schistosomiasis are due to a combination of human factors. First, Diama Dam eliminated saltwater intrusion into the lower river and maintained nearly constant water levels, creating conditions favoring the growth of marginal vegetation along the river edges and the spread of the snail hosts of *Schistosoma* species. Second, *S. mansoni* was probably introduced to the lower valley by people migrating into the region, possibly from the upper valley. Population in the region has increased rapidly, especially around the irrigation projects at Richard-Toll, as people move there to take advantage of new jobs. Water supply and sanitation facilities have not kept up with this rapid growth. As a result, the increased contamination of surface waters, and their greater use by residents, has contributed to higher transmission rates for schistosomiasis and increased risks for other waterborne diseases as well. The increased prevalence of urinary schistosomiasis around Lake Manantali—as well as the increased number of the type of snails associated with intestinal schistosomiasis—are due to the year-round presence of water in the lake and its nearly constant water level.

RIFT VALLEY FEVER

Rift Valley Fever is a mosquito-borne viral disease that is most often benign in humans but can occasionally lead to blindness, encephalitis, and fatal hemorrhagic fever. Epidemics are common in livestock and can cause high rates of stillbirths and abortions. The virus is transmitted to humans by biting insects (mosquitoes, sand flies, and, possibly, ticks) or by direct contact with blood or organs of infected animals after slaughter.

An outbreak of Rift Valley Fever occurred near Rosso, Mauritania, in 1987 soon after the completion of Diama Dam and the initial filling of Lake Diama. It began during the rainy season in pastoralist groups in Mauritania and spread to Rosso, eventually appearing on both sides of the river. The outbreak was the first known epidemic of Rift Valley Fever in humans west of Uganda and reportedly killed more than 200 people (6). The disease had been observed only once before in epidemic form in humans, in Egypt in 1977 near the Aswan High Dam on the Nile River. Although the exact ecological conditions conducive to rapid transmission of Rift Valley Fever remain unclear, the initial filling of a nearby reservoir may be a factor, since this was a common condition in the events at Aswan in 1977 and Mauritania in 1987 (7). Filling the Diama reservoir created more standing water—a location preferred by the *Aedes* mosquito, the probable vector of Rift Valley Fever in Mauritania (8).

The potential for such an outbreak in the Senegal River basin had been identified in pre-dam construction health assessments in 1980, 1984, and just before the onset of the rainy season in 1987 (9). Despite these warnings, authorities in the basin did not take necessary precautions to prevent an outbreak.

MALARIA

Malaria occurs in most parts of the Senegal River basin. Most reported cases are due to malaria tropica (*Plasmodium falciparum*), which can cause severe disease and death. The risk of infection is greater in the upper valley than in the lower areas because the rainy season is longer and the amount of rainfall is higher, creating better conditions for the mosquito vector (*Anopheles* species). *Falciparum* malaria has become a serious concern in Africa because of the parasite's growing resistance to antimalarial drugs.

Evidence is conflicting regarding whether the new water management regime on the Senegal River and the expansion of irrigated areas in the lower valley are causing an increase in malaria infection rates. Reliable evidence shows that *A. gambiae* population densities have increased during the rainy season (August to December) in the middle valley, and that malaria transmission is continuing later into the dry season (December to April). Routine surveillance data from health service facilities in Rosso, Richard-Toll, and Podor reflect an overall increase in the number of malaria cases, although most of the reported cases were not confirmed by microscopic analysis. In contrast, longitudinal studies conducted in the delta region at Kasak-Nord and the middle valley at Podor, and an unpublished study performed in 1991 by the OMVS throughout the basin, do not show increased malaria.

MALNUTRITION

Malnutrition has been widespread in the Senegal River valley for a long time; it was particularly severe during the droughts before construction of the dams. The Senegal River development projects were expected to improve the nutritional status of valley residents as irrigated agriculture catalyzed economic development and brought significant improvements in peoples' socioeconomic status, giving them more income to spend on nutrition and health. Although the situation is complex and no authoritative studies exist with which to compare nutritional status before and after dam construction, the available information suggests that overall, the quality of peoples' diet and their nutritional status have not improved significantly, and may have declined, since construction of the dams.

Before the dams were built, valley residents grew and consumed a wide variety of food crops grown in family plots and small fields in the river's flood plain. Construction of the dams, interruption of the annual flood, and expansion of irrigation projects has reduced traditional agriculture and has increased rice and sugar cane cultivation. In the lower and middle valley, residents' diets now appear to include more rice, a smaller variety of vegetables in most villages, and lower consumption of meat, dairy products, and freshwater fish. This change may reflect the financial strain on family resources caused by low rice yields and farmers' attempts to grow two crops of rice each year, and also the reduced livestock production and fish catch in the valley. For rice-producing families, rice is the predominant food in the diet and is usually eaten at least once or twice a day. Rice is less nutritious than millet and sorghum, which used to be staples in the diet but are now more difficult to find in the markets.

Several studies of nutritional status in towns along the Senegalese shore of the Senegal River in 1990–91 found the prevalence of chronic malnutrition in children at levels between 20 percent and 36 percent. One study concluded that levels of malnutrition observed in 1992 were comparable to those in 1983, before construction of the dams (10). The same study found the prevalence of nutritional stunting to be 22 percent and wasting to be 11 percent in 1990 among children aged 0 to 5 years old, with somewhat lower levels observed in 1992 (16 percent and 5 percent, respectively). On the Mauritanian side of the river, a 1986 study in the Trarza district (around Rosso) found chronic malnutrition to exist among 25 percent of children younger than 5 years of age. In a 1994 study, rates of chronic malnutrition among children in the same region were estimated at 36 percent, with 11 percent of children showing evidence of nutritional wasting.

DIARRHEAL DISEASES

Changes in water management practices and voluntary migration into the lower valley have affected the rates of diarrheal diseases in basin residents. Development plans for the region called for improvements in water supply, sanitation, and health services, but few improvements have been made to date.

In the lower valley, modest improvements have been insufficient to deal with population movements. In Richard-Toll, an influx of workers to serve the sugar cane industry added an additional 50,000 people to the population, overwhelming improvements in the town's water supply and sanitation facilities. There is an increased risk of cholera and other waterborne diseases in the Richard-Toll area, and there was a cholera epidemic near Rosso, Mauritania, in 1987. Because future improvements to the water supply systems of Dakar and Saint-Louis will draw on water from Lake Diama and Lake Guiers, the quality of those water bodies may soon affect these large population centers as well.

In the middle valley, the regulation of water levels in the river has allowed the development of wind-powered water pumps. These pumps draw water from aquifers bordering the river, resulting in an improvement of water supplies for these villages. Further away from the river, however, the absence of the annual flood has interrupted the previous cycle of aquifer recharging, resulting in a gradual decline in the water table and reduced water availability. The result has been a rise in the reported rates of diarrheal disease. Along the river in the upper valley, diarrheal disease has continued to be a severe problem despite regulation of the river, and health authorities in Kayes, Mali, report that conditions have worsened.

Social Changes and Conflict

The environmental and health changes seen in the Senegal River basin have not happened in isolation; the change in water management and the growth of irrigated agriculture have also brought broad-based social changes, including tensions between pastoralists and farmers and among ethnic groups as well. The dam projects resulted in the relocation of roughly 10,000 people in more than 40 villages and hamlets in Mali. The Malian government, the U.S. Agency for International Development (USAID), and the World Health Organization moved these populations from the area inundated by the Manantali Dam and resettled them in new sites on the plateau above the lake and downstream along the Bafing River. One year after being resettled, villagers reported in a 1989 USAID study that they had insufficient land for cultivation and grazing and insufficient water for gardening. Housing and personal water supplies were considered adequate at that time, because the additional external funding that accompanied the dam projects ensured that these basic items were supplied to the displaced populations. Health problems are common in resettled populations, and increases in diarrheal illnesses and allergies, a measles epidemic, and an outbreak of livestock disease were reported among some of the resettled villages. Some health indicators did improve for the residents of some resettled villages, where residents had been guaranteed health centers and one water point for every 100 inhabitants. Two years after their displacement, residents continued to receive additional support, such as supplemental nutrition programs funded by the donor governments.

Traditional systems of livestock production have been altered in the middle valley. Construction of the dams was expected to foster an increase in livestock production, but herders have had to cope with a decrease in pastureland due to the persistent drought, the reduction in the annual flood, and the expansion of irrigated land. The increased difficulty of gaining access to the river for watering animals and the reduction in grazing land has led to tensions between pastoralists and farmers.

The development of irrigation along the Senegal River also disturbed patterns of land use and land tenure, exacerbating ethnic conflict among groups in the region. Tens of thousands of people lost their property rights, and massacres occurred in both Mauritania and Senegal (11).

Looking Forward

Dam building will continue to be an important element of economic development plans in many countries. The potential benefits for agriculture, water supply, power production, transportation, industrial development, and flood control are obvious and desirable. Given this expectation, what lessons can be drawn from the experience of Mali, Mauritania, and Senegal in developing the Senegal River?

This case study illustrates the many secondary impacts that a dam project may have on the health, livelihood, social structure, and general welfare of people living in the area. Many of these impacts can be predicted—indeed, most of the impacts of the Senegal River dams were predicted in preconstruction studies.

If many of the negative impacts of the Senegal River dams were predicted, then why were they not avoided? The answer is complicated. First, the financing consortium could have required changes in the project's design but did not. The financing agreements for the dams were reached in the late 1970s, at a time when most participants were not especially sensitive to environmental impacts and, in any case, were eager to participate in the project and would not have been inclined to force changes to which the borrowing countries objected.

Second, the people who have been hurt by the project lack political power and were not represented effectively either in the project design or in its operation. Measures that would have reduced the project's negative impacts on valley residents were not implemented because they were perceived to be adverse to the project's objectives. In the Senegal River basin, more attention should have been paid to how benefits and costs would be distributed among various groups. Generally speaking, even when the overall balance of benefits to risks is positive and a project is justifiable at the level of national interest, the distribution of benefits and costs may be quite unfair. This situation was certainly apparent with the Senegal River dams project. The benefits of the project—income from irrigated agriculture and electrical power from Manantali Dam—will be enjoyed primarily by the people living in the capital cities, while people living in the valley pay the price for the project in terms of poorer health, changed livelihoods, relocation, and disrupted social relationships.

Third, even if the OMVS had the political will to reduce the negative impacts resulting from construction of the Senegal River dams, the organization does not have the technical capability to do so. Many of the negative impacts could be reduced even now by making operational changes in the project. For example, more water could be released to restore an annual flood. Planned variations in the water levels of Lake Manantali and Lake Diama could be used to control snail populations and reduce the spread of schistosomiasis. Yet, if the OMVS were to decide that such measures have merit, it would need greater capabilities in terms of water resource modeling, planning, and operations; genuine expertise in other disciplines (e.g., health and social sciences); and improved mechanisms for communicating with national agencies of its member states.

The experience with the Senegal River dams, therefore, points to at least the following five lessons:

- More effort is needed to evaluate the environmental, health, and social impacts of dams systematically in order to predict their varied impacts more accurately and with greater certainty.
- The design reviews and evaluations conducted by international funding agencies represent a critical juncture at which to make modifications that would reduce negative impacts.
- Dam projects should include funding for measures needed to mitigate their environmental, health, and social impacts as an integral part of the project.
- Institutional arrangements created for managing such projects should include representatives of affected populations in positions of real authority.
- These institutions need funding and technical assistance to develop adequate technical capacity and a multidisciplinary staff that understands and can address the broad range of potential negative impacts.

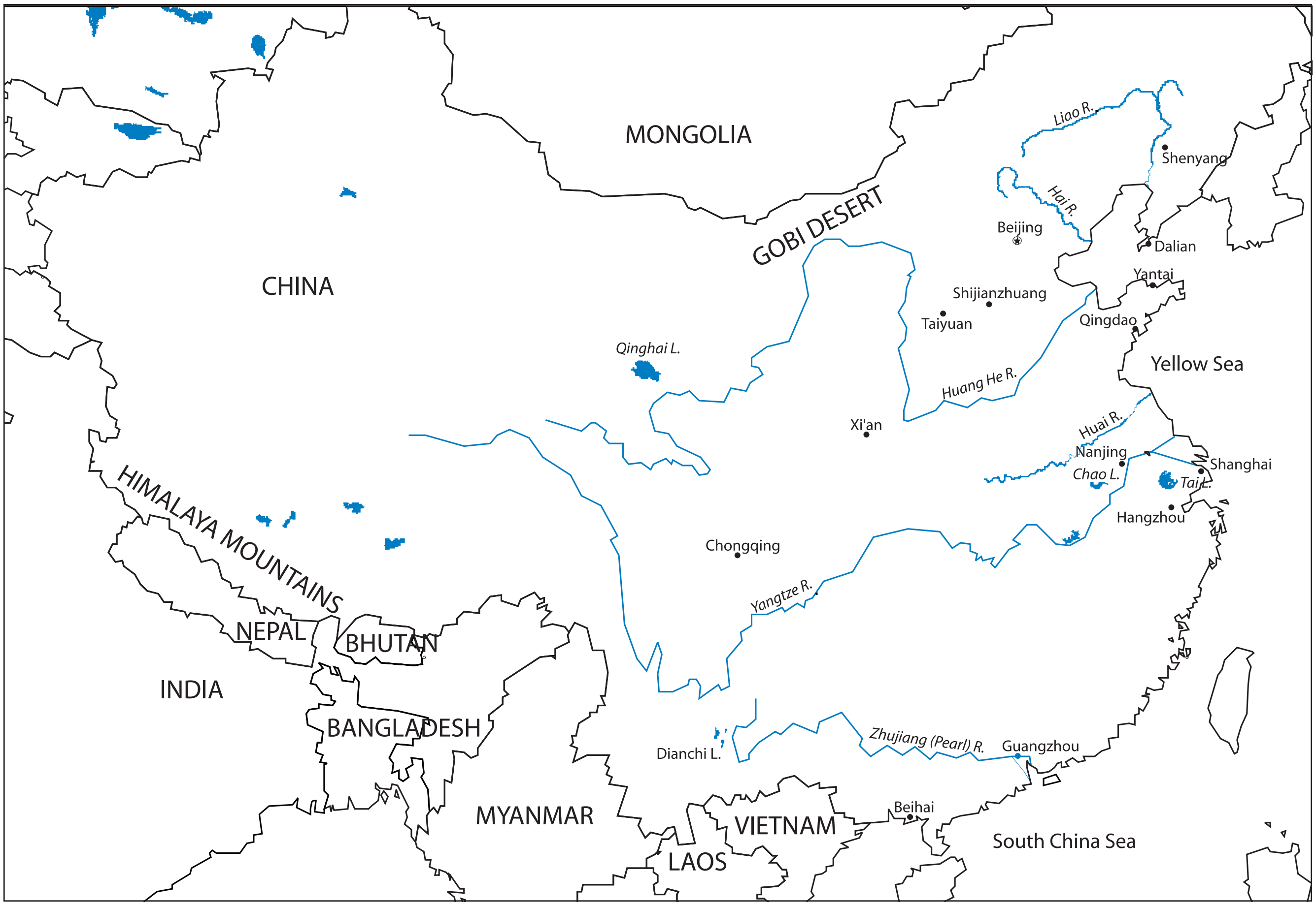
There is some hope that conditions will improve in the Senegal River valley as a result of international attention to the problems. An international consortium has recently concluded negotiations with the OMVS for the purchase and installation of turbines and hydroelectric generators at Manantali Dam and power distribution lines from Manantali to the national capitals and several locations in the valley. The project includes funding for a study of alternative water management regimes at Manantali Dam and, specifically, for evaluating options for manipulating water levels to reduce schistosomiasis transmission and other impacts. The World Bank, which is a member of the power project consortium, is also developing health sector projects in Senegal and Mauritania that will improve health services and disease surveillance. The World Bank is also developing water supply and sanitation projects in Senegal that will improve facilities and reduce the population's exposure to schistosomiasis.

References and Notes

1. Unless noted otherwise, information in this article is taken from Diop *et al.*, *Senegal River Basin Health Master Plan Study* (Water and Sanitation for Health (WASH) Field Report No. 453, December 1994, reprint ed.).
2. Construction costs for the two dams amounted to US$637 million. The funds came principally from the governments of Saudi Arabia, Kuwait, Abu Dhabi, the Federal Republic of Germany, France, Iran, and the African Development Bank. The United States (U.S.Agency for International Development) and the World Bank declined to provide capital funds for the projects, but supported environmental assessments and other research related to the projects and provided financial and technical assistance for relocating villages that were displaced by the Manantali Dam.
3. Anne Guest, "Conflict and Cooperation in a Context of Change: A Case Study of the Senegal River Basin," in *Boundaries in Question: New Directions in International Relations*, John Macmillan and Andrew Linklater, eds.(Pinter Publishers, London, 1993), pp. 163–173.
4. *Ibid.*
5. Gannett Fleming Corddry and Carpenter, Inc., "Assessment of Environmental Effects of Proposed Developments in the Senegal River Basin," prepared for the Organisation Pour La Mise en Valeur du Fleuve Senegal, 1977.
6. John Walsh, "Rift Valley Fever Rears Its Head," *Science*, Vol. 240 (June 10, 1988), pp. 1397–1399.
7. William R. Jobin, "Rift Valley Fever: A Problem for Dam Builders in Africa," *Water Power and Dam Construction* (August 1989), pp. 32–34.
8. *Op. cit.* 3.
9. J.P. Digoutte and C.J. Peters, "General Aspects of the 1987 Rift Valley Fever Epidemic in Mauritania," *Research in Virology*, Vol. 140, No. 1 (1989), pp. 27–30.
10. E. Benefice and K. Simondon, "Agricultural Development and Nutrition Among Rural Populations: A Case Study of the Middle Valley in Senegal, 1993," *Ecology of Food and Nutrition*, Vol. 31, No. 1–2 (1993), pp. 45–66.
11. Thomas Homer Dixon, *Environmental Scarcity and Violent Conflict: Evidence from Cases*, Peace and Conflict Studies Program, University of Toronto. Available online at: http://ut1.library.utoronto.ca/disk1/www/documents/pcs/evid1.htm (January 1998).

Eugene P. Brantly and Karen E. Ramsey, Environmental Health Project of the U.S. Agency for International Development, Washington, D.C.

Regional Profile | **China's Health and Environment**



No country better typifies the confluence of trends discussed in this report—nor the challenges they pose to environmental quality and public health—than does modern China. Since the economic reforms of 1978, China has experienced dramatic industrialization and rising energy use against a backdrop of population growth and unprecedented urbanization. China's astounding industrial growth over the past two decades has created a country poised to become a major economic power in the 21st Century. Per capita, China is still one of the world's poorest countries, yet the future looks promising—incomes are rising, poverty rates are falling, and life expectancy is up. Yet, along with these gains, China is grappling with some of the most serious environmental problems on the planet, which in turn could prevent China from sustaining high levels of economic growth in the coming decades.

Recognizing the urgency of these problems, the Chinese Government has endorsed a suite of policies to curb air and water pollution. The extent to which these policies are successful has direct bearing on not only the health of the Chinese people and the local environment but the global environment as well.

Encompassing a geographically vast area with a number of distinct ecological zones, China extends from the massive and sparsely populated Gobi Desert and the mountains of the southwestern Himalayas to the densely inhabited valleys of the eastern coast. As the world's most populous country, with more than 1.2 billion people, China's economic growth is the fastest and most sustained of any major country in the world, rising an average of 10 percent annually over more than a decade (1). In fact, some autonomous regions in the golden southeastern coastal zones have grown nearly 20 percent annually, doubling in less than 4 years (2).

Industry is China's largest productive sector, accounting for 48 percent of its gross domestic product (GDP) and employing 15 percent of the country's total labor force (3). In the 1990s, the output of China's 10 million industrial enterprises has increased by 18 percent annually (4). Without a doubt, Chinese industry is largely responsible for lifting many millions of people out of poverty. It also underlies a huge and growing demand for energy.

China's demand for high-grade energy such as oil and natural gas will increase rapidly, although coal will continue to dominate the energy structure, accounting for more than 75 percent of total energy production. From 1990 to 1995, China's oil demand grew at 4.3 percent annually, while oil production increased only 1.2 percent each year. As a result of these trends, China has become a net oil importer (5).

Along with industrialization has come rapid urbanization, especially in what is known as the southern coastal crescent that runs from Guangzhou to Shanghai. The proportion of the population living in cities has grown about 50 percent since 1980. Some 370 million people now live in cities, and this number is expected to grow to 440 million by the turn of the century (6). A World Bank model predicts that by the year 2020, 42 percent of China's population, more than 600 million people, will live in urban areas overwhelmingly concentrated in the eastern and southern coastal provinces (7).

Since the political transformation of 1949, dramatic and extensive social improvements have accompanied China's growth. In 1949, the new People's Republic of China faced a massive burden of nutritional deficiency and infectious and parasitic diseases. More than half the population died as a result of infectious and other nondegenerative diseases before reaching middle age—a pattern still common throughout much of the developing world. Since 1949, the average life span in China has risen from 35 years to the current 70. The infant mortality rate has dropped from 200 per 1,000 to 31 per 1,000. Infectious diseases, while still a serious problem in some parts of the country, claim the lives of a mere 0.0004 percent of the population each year (8). The decrease in morbidity and mortality rates associated with infectious diseases in China is a remarkable achievement for the world's most populous country. This decline can be attributed to an aggressive campaign to improve primary health care and tackle infectious diseases (9).

However, over the coming decades, China's deteriorating environment threatens to undermine the gains that rising incomes would otherwise bring. China's rapid industrialization, urbanization, and economic growth are contributing to respiratory diseases and chronic illnesses such as cancer. Levels of particulate air pollution from energy and industrial production in several of China's megacities, such as Shanghai and Shenyang, are among the highest in the world, leading to corresponding problems of lung disease in their populations. Water pollution in some regions, such as in the Huai River Valley, is also without parallel.

In 1996, the government annual report, *State of the Environment*, noted that environmental pollution was expanding into the countryside, and that ecological destruction was intensifying (10). Environmental problems are seriously affecting overall social and economic development in the country. *China Environment News*, a national newspaper of the National Environmental Protection Agency (NEPA), reported that in recent years, economic costs associated with ecological destruction and environmental pollution have reached as high as 14 percent of the country's gross national product (GNP) (11). More recently, the World Bank estimated that air and water pollution cost China nearly 8 percent of its GNP, around US$54 billion (12). Although solid scientific data are lacking, the government has identified environmental factors as one of the four leading factors influencing the morbidity and mortality of China's people today (13). The importance of environmental factors is well understood by some, as shown by a 1994 opinion survey about risks. Respondents who hold science or engineering degrees ranked risk from pollution ahead of natural disasters (14).

Responding to growing public concerns about the environment, the Chinese Government has officially named the environment as one of its top priorities and has committed itself to reversing the trend of environmental deterioration (15). Over the past decade, China has increased environmental spending, adopted market incentives, strengthened lawmaking and enforcement, and promoted nationwide environmental education. Decisions made in the next decade or two about energy, transportation, and agricultural technologies will largely determine how successful China will be in achieving its goal of sustainable development.

This case study describes the initial findings of an ongoing project between the World Resources Institute (WRI) and the Chinese Government to evaluate the links between environment and health in China. The goal of this collaborative project is to develop information and indicators that will enable decisionmakers to make informed choices about the environment, energy, infrastructure, and related issues.

The first section of this profile focuses on air pollution trends and the impact of air pollution on human health. Routine monitoring of air pollution and good hospital and health records have enabled researchers to gain a fairly clear picture of air pollution's impact on human health and what the future will hold if air pollution continues to worsen. Water pollution also presents a major threat to public health, although data in this area are less complete. Although data limitations prevent a comprehensive review, the second section reviews the most recent evidence concerning the extent of health problems associated with water pollution. The third section reviews China's laws and policies to protect the environment and health.

Air Pollution and Health Effects

POOR AMBIENT AIR QUALITY PREVAILS

"The residents of many of China's largest cities are living under long-term, harmful air quality conditions," Zhao Weijun, deputy director of the air pollution department of NEPA, reported in 1997 in *China Environment News* (16). China has long recognized air pollution as a critical problem. Ambient concentrations of total suspended particulates (TSP) and sulfur dioxide (SO_2) are among the world's highest. (See Figure China.1.) In 1995, more than one half of the 88 cities monitored for SO_2 were above the World Health Organization (WHO) guideline. All but two of the 87 cities monitored for TSP far exceeded WHO's guideline. Some cities such as Taiyuan and Lanzhou had SO_2 levels almost 10 times the WHO guideline (17).

Largely because of controls at power plants and within households, particulate emissions have not risen as much as might have been expected with the doubling of coal consumption. Overall, particulate emissions in China have remained relatively level since the early 1980s (18). In fact, in some large cities, ambient particulate concentrations have decreased markedly since the 1980s (19). In contrast, SO_2 emissions have roughly paralleled the increase in coal consumption, reflecting heavy coal burning and inadequate sulfur control measures.

Coal burning, the primary source of China's high SO_2 emissions, accounts for more than three quarters of the country's commercial energy needs, compared with 17 percent in Japan and a world average of 27 percent (20). China's consumption of raw coal increased annually by 2 percent between 1989 and 1993 (21). (See Figure China.2.) Meanwhile, SO_2 emissions increased by more than 20 percent and TSP increased by approximately 10 percent (22). The country is expected to burn 1.5 billion metric tons of coal annually by the year 2000, up from 0.99 billion metric tons in 1990 (23). Without even more dramatic measures to control emissions than are currently in place, the deterioration of air quality seems inevitable.

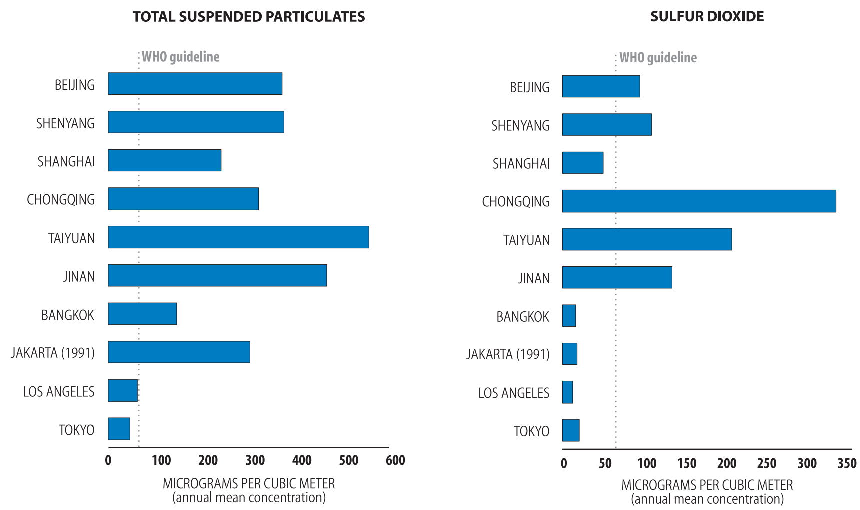
Particulates and SO_2 are the ambient air pollutants of greatest concern; both are byproducts of coal combustion. While industrial emissions of heavy metals and toxics are also significant contributors to air pollution in China, they are not routinely monitored and will not be addressed in this section.

The extent and type of air pollution in China vary dramatically by geographic region. SO_2 and particulate emissions are highest in the northern half of China, where coal is used to heat homes and other buildings for several months of the year and where industrial centers also depend heavily on coal burning. Yet, air pollution in the North would be much worse if not for the higher quality, cleaner coal that is available there. By contrast, the coal mined in the South is high in sulfur and extremely polluting, contributing to serious problems with acid precipitation, especially in the southwest provinces of Sichuan, Guizhou, Guangxi, and Hunan (24) (25).

Industry accounts for two thirds of China's coal use—industrial boilers alone consume 30 percent of China's coal. These boilers are usually highly inefficient and emit through low smoke stacks, contributing to much of China's ground-level air pollution, especially small particulates

China's Air Pollution Levels Are Among the World's Highest

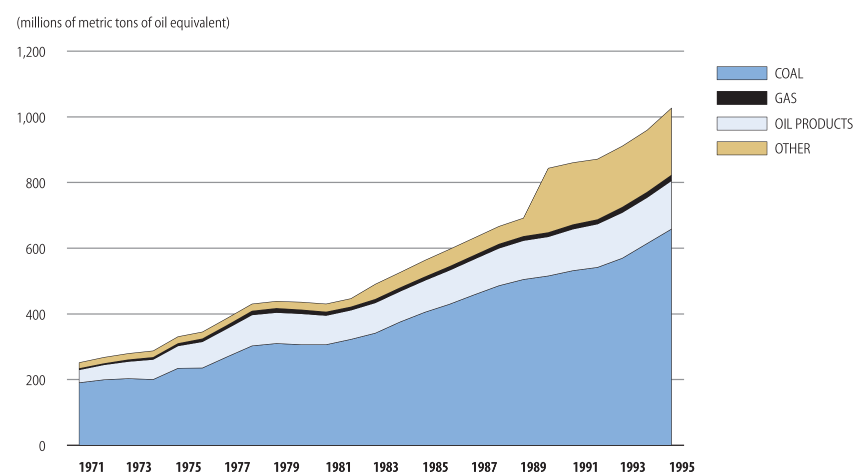
FIGURE CHINA.1 Ambient Concentrations of Air Pollutants, 1995



Source: The World Bank, *Clear Water, Blue Skies: China's Environment in the New Century* (The World Bank, Washington, D.C., 1997), Figure 1.1, p. 6.

China's Growing Consumption of Coal

FIGURE CHINA.2 Energy Demand in China, 1971–95



Source: International Energy Agency, *Energy Statistics and Balances: Non-OECD Countries, 1971–1995*, on diskette (Organisation for Economic Co-Operation and Development, Paris, 1997).

Outdated Vehicles Degrade Urban Air Quality

TABLE CHINA.1 Percentage of Emissions in Selected Chinese Cities Attributable to Motor Vehicles

	PERCENTAGE ATTRIBUTABLE TO MOTOR VEHICLES			
	CARBON MONOXIDE	HYDROCARBONS	NITROUS OXIDES	CATEGORIES
Beijing	48–64	60–74	10–22	District
Shanghai	69	37		District
Shenyang	27–38		45–53	District
Jinan	28		4–6	District
Hangzhou	24–70			Road
Urumqi	12–50			Road
Guangzhou	70		43	

Source: He *et al.*, "Status and Development of Vehicular Pollution in China," *Environmental Science*, Vol. 7, No. 4 (August 1996).

and SO_2. Inefficient and dirty boilers are particularly problematic because many of the industries that use them are located in densely populated metropolitan areas, placing populations in these areas at high risk of exposure. The residential sector accounts for approximately 15 percent of total coal use, yet is estimated to contribute to more than 30 percent of urban ground-level air pollution (26)(27).

Although the energy and industrial sectors are now the biggest contributors to urban air pollution in China, the transportation sector is becoming increasingly important. The number of motor vehicles on China's roads has tripled since 1984, climbing from less than 2.4 million in 1984 to 9.4 million in 1994 (28). By 2020, the urban vehicle population is expected to be 13 to 22 times greater than it is today (29). This trend will likely have a major influence on the future of China's air quality. The shift toward vehicle use is most apparent in China's big cities. For example, from 1986 to 1996, the number of vehicles in Beijing increased fourfold, from 260,000 to 1.1 million. Although this is only one tenth of the number of vehicles in Tokyo or Los Angeles, the pollution generated by Beijing motor vehicles equals that in each of the two other cities (30).

The problem stems not just from the growing size of the vehicle fleet but also from low emissions standards, poor road infrastructure, and outdated technology, which combine to make Chinese vehicles among the most polluting in the world (31). Vehicle emissions standards in China are equivalent to the standards of the developed world during the 1970s, and some domestic companies are manufacturing vehicles modeled after vehicles from 20 years ago. Actual emissions often exceed these standards: Chinese vehicles emit 2.5 to 7.5 times more hydrocarbons, 2 to 7 times more nitrous oxides (N_2O), and 6 to 12 times more carbon monoxide (CO) than foreign vehicles (32). In Beijing, Shanghai, Hangzhou, and Guangzhou, up to 70 percent of CO emissions have been attributed to motor vehicles. Cars also contribute a large share of hydrocarbons and N_2O in the cities where data are available (33). (See Table China.1.) As a result, although China's vehicle fleet is small compared with the developed countries, its large cities are already blanketed with smog.

A recent study in Beijing revealed that at all monitoring points within the Third Ring Road—a rough boundary separating downtown Beijing and its outskirts—the CO levels exceeded the national standard (4 micrograms per cubic meter per day). During the summer, ozone concentrations repeatedly exceeded the national standard, which is set on an hourly basis—often several times per day. In addition, concentrations of N_2O have almost doubled over the past decade (34).

Compounding these pollution problems is the fact that the burgeoning Chinese motor vehicle fleet is largely fueled by leaded gasoline. Although lead exposure is known to be a significant health hazard in China, no routine monitoring of environmental concentrations or blood-lead levels is performed. A few studies have been conducted and are described below. These scanty data suggest that ambient lead levels in the urban area of major cities such as Beijing are usually 1 to 1.5 micrograms per cubic meter—the national standard is 1 microgram per cubic meter. In some areas, ambient lead levels can reach as high as 14 to 25 micrograms per cubic meter (35). The health effects, described below, are significant, although recent and dramatic government actions to phase out leaded gasoline will likely have a major impact on this problem. Beijing and Shanghai as well as other cities have already begun to act, and the countrywide phaseout is expected to be complete by the year 2000.

HEALTH EFFECTS FROM AMBIENT AND INDOOR AIR POLLUTION

Air pollution is thought to be one of the leading risk factors for respiratory diseases, such as chronic obstructive pulmonary disease (COPD), lung cancer, pulmonary heart disease, and bronchitis, diseases that are the leading causes of death in China. The fact that men and woman have similar rates of these diseases, despite women's much lower smoking rates, provides evidence that this high disease burden is related to pollution (36).

Although only a limited number of epidemiologic studies have been conducted, air pollution has clearly contributed to both excess mortality and morbidity in China. At this stage, however, it is extremely difficult to tease apart which sources of air pollution have the greatest impact on human health, indoor or outdoor. In urban areas, there is a great deal of exchange between outdoor and indoor air, both of which are polluted from different sources—indoor primarily from the burning of coal for cooking and heating. Summaries of selected recent estimates of health impacts are presented to provide a more complete understanding of the complex relationship between air pollution and human health.

Environmental Change and Human Health

Based on dose-response functions from studies conducted within China and in other countries, the World Bank has estimated the number of deaths and diseases associated with air pollution among urban populations. Using the Chinese standards as a benchmark, they estimate the number of deaths that could be prevented if air pollution were reduced to those levels. According to their calculations, approximately 178,000 deaths, or 7 percent of all deaths in urban areas, could be prevented each year. Another measure of air pollution's impact on health is the number of hospital admissions from respiratory diseases. This study found 346,000 hospitalizations associated with the excess levels of air pollution in urban areas. Table China.2 summarizes the estimated health impact of both ambient and indoor air pollution in China (37).

In China, the effects of outdoor air pollution are compounded by those of indoor air pollution. Households using coal for domestic cooking and heating are especially at risk because coal emits very high levels of indoor particulate matter less than 2.5 microns in size—the size believed to be most hazardous to health. (These concentrations can be more than 100 times the proposed U.S. ambient air 24-hour standard.) Exposure to these small-sized particles is especially harmful because they persist in the environment and reach deep into the lungs (38).

Indoor air pollution affects both urban and rural populations. Nor is it simply a problem indoors: numerous studies have shown that intense indoor coal burning can affect ambient air quality as well. For instance, rural neighborhoods are generally unaffected by urban sources of air pollutants but can be extremely polluted from the burning of coal indoors. Table China.3 shows the extremely high levels of particulates in both rural and urban indoor environments (39). Indoor air pollution causes as many health problems as smoking, with the effects concentrated among women and children (40).

Although the proportion of China's households that burn polluting biomass fuels indoors for cooking and heating remains significant, it has been declining with the proliferation of alternative energy sources. Largely as a result of government investments, about one third of urban Chinese now have access to gas for cooking, and coal-burning households are increasingly turning to the use of cleaner, more efficient briquettes (41).

Perhaps the most compelling example of the health impact from indoor air pollution is the extremely high lung cancer rates among nonsmoking women in rural Xuan Wei County. Studies conducted by the United States Environmental Protection Agency (U.S. EPA) report that in the three communes with the highest mortality rates, the age-adjusted lung cancer mortality rate between 1973 and 1979 was 125.6 per 100,000 women, compared with average rates of 3.2 and 6.3 for Chinese and U.S. women, respectively, for the same time. Because surveys showed that virtually no women (in the county) smoked tobacco products, other sources of potent exposure must have contributed to these troubling rates. Analyses of indoor air and blood samples from the women indicate that fuel burning inside the home was largely responsible for the lung cancers. The U.S. EPA studies found a strong association between the existence of lung cancer in females and the duration of time spent cooking food indoors. The levels of carcinogenic compounds present in smoky coal (a local type of coal that smokes copiously) were found to be much higher in the women who used smoky coal for cooking (42)(43).

Since the 1980s, a number of studies examining the relationship between ambient air pollution and health effects in China have been conducted. It is important to remember that although the studies measured only ambient air pollution levels, in reality people are exposed to a combination of indoor and outdoor air. One of most definitive of these studies examined the relationship between air pollution and mortality in two residential areas of Beijing. According to this study, the risk of mortality was estimated to in-

Air Pollution's Toll

TABLE CHINA.2 Estimates of Respiratory Damage That Could Be Avoided by Meeting Class 2 Air Quality Standards in China

PROBLEM	NUMBER OF CASES AVERTED
Urban air pollution	
Premature deaths	178,000
Respiratory hospital admissions	346,000
Emergency room visits	6,779,000
Lower respiratory infections or child asthma	661,000
Asthma attacks	75,107,000
Chronic bronchitis	1,762,000
Respiratory symptoms	5,270,175,000
Restricted activity days (years)	4,537,000
Indoor air pollution	
Premature deaths	111,000
Respiratory hospital admissions	220,000
Emergency room visits	4,310,000
Lower respiratory infections or child asthma	420,000
Asthma attacks	47,755
Chronic bronchitis	1,121,000
Respiratory symptoms	3,322,631,000
Restricted activity days (years)	2,885,000

Source: The World Bank, *Clear Water, Blue Skies: China's Environment in the New Century* (The World Bank, Washington, D.C., 1997), Table 2.1, p. 19.

Air Quality May Be Worse Indoors

TABLE CHINA.3 Indoor Particulate Air Pollution from Coal Burning in China (Sample Studies)

PLACE	URBAN/ RURAL	PARTICULATES (micrograms per cubic meter)
Shanghai	Urban	500–1,000
Beijing	Urban	17–1,100[a]
Shenyang	Urban	125–270
Taiyuan	Urban	300–1,000
Harbin	Urban	390–610[a]
Guangzhou	Urban	460
Chengde	Urban	270–700[a]
Yunnan	Rural	270–5,100
Beijing	Rural	400-1,300
Jilin	Rural	1,000–1,200[a]
Hebei	Rural	1,900–2,500
Inner Mongolia	Rural	400–1,600[a]

Source: World Health Organization (WHO), *Health and Environment in Sustainable Development: Five Years after the Earth Summit* (WHO, Geneva, 1997), p. 86.

Note: a. Particles less than 10 micrometers in size.

crease by 11 percent with each doubling of SO_2 concentration, and by 4 percent with each doubling of TSP. When the specific causes of mortality were examined, mortality from COPD increased 38 percent with a doubling of particulate levels and 29 percent with doubling of SO_2. Pulmonary heart disease mortality also increased significantly with higher pollution levels. Levels of air pollution measured often exceeded WHO guidelines, particularly in winter when ambient air pollution was exacerbated by indoor fuel burning and climatic conditions. Yet, what was striking is that excess mortality was associated with pollutant levels below WHO guidelines, suggesting that the guidelines cannot be perceived as a safe limit (44).

Respiratory diseases, hospitalization, or doctor visits are often a more sensitive measure of the impact of air pollution on human health than mortality. One recent study confirmed that as concentrations of SO_2 and TSP rose in Beijing, so did visits to the emergency room. This increase in unscheduled hospital visits occurred both when air pollution levels were extremely high (primarily in the winter) and when the levels were below WHO's recommended guidelines, bolstering studies in developed countries that have shown excess respiratory disease and mortality at lower doses (45). Although Beijing has been the focus of many studies, it has no monopoly on bad air. Chongqing, the largest and most recently declared autonomous zone, has a higher concentration of SO_2 than any of China's five other largest cities (46). A recent study found that several symptoms of compromised health, including reduced pulmonary function and increased mortality, hospital admissions, and emergency room visits, were correlated with higher levels of air pollution in Chongqing (47). A study conducted in another of China's largest cities, Shenyang, estimated total mortality increased by 2 percent with each 100 micrograms per cubic meter increase in SO_2 concentration, and by 1 percent for each 100 micrograms per cubic meter in TSP (48).

Respiratory diseases are not the only health impacts of concern associated with air pollution. Lead exposure, for instance, leads to neurological damage, particularly in children. China has no comprehensive national data on blood-lead levels, a reliable biomarker of exposure, but some studies show that blood-lead levels are far above the threshold associated with impaired intelligence, neurobehavioral development, and physical growth. (The U.S. standard is 10 micrograms per deciliter.) Between 65 and 100 percent of children in Shanghai have blood-lead levels greater than 10 micrograms per deciliter. Those in industrialized or congested areas had levels averaging between 21 and 67 deciliters (49). In Shanghai, prenatal exposures to lead from urban air were associated with adverse development in the children during their first year of life (50).

Water Scarcity, Water Pollution, and Health

China's rapid economic growth, industrialization, and urbanization—accompanied by inadequate infrastructure investment and management capacity—have all contributed to widespread problems of water scarcity and water pollution throughout the country. China has some of the most extreme water shortages in the world. Of the 640 major cities in China, more than 300 face water shortages, with 100 facing severe scarcities (51). As discharges of both domestic and industrial effluents have increased, clean water has become increasingly scarce. The impact of China's dual problem of water scarcity and water pollution exacts a costly toll on productivity. Water shortages in cities cause a loss of an estimated 120 billion yuan (US$11.2 billion) in industrial output each year. The impact of water pollution on human health has been valued at approximately 41.73 billion yuan per year (US$3.9 billion), which is almost certainly an underestimate (52). Although Chinese decisionmakers are increasingly concerned about the damages associated with water pollution, years of neglect and a lack of funding for research have resulted in limited data on water pollution and even fewer epidemiologic studies on the links between water pollution and human health effects.

China has a total of 2,800 billion cubic meters of annually renewed fresh water; the world's most populous country is fourth in the world in terms of total water resources (53). Considering per capita water resources, China has the second lowest per capita water resources in the world, less than one third the world average. Northern China is especially water-poor, with only 750 cubic meters per capita; this geographic region has one fifth the per capita water resources of southern China and just 10 percent of the world average (54).

The distribution of groundwater is similarly skewed: average groundwater resources in the South are more than four times greater than in the North. Dramatic shifts in annual and monthly precipitation cause floods and droughts, which further threaten economic growth.

As surface water quality has worsened, the Chinese have increased their extraction of groundwater to meet water demand. As a result, overextraction of groundwater has become a serious problem in a number of cities including Nanjing, Taiyuan, Shijiazhuang, and Xi'an. Groundwater depletion is most problematic in coastal cities, including Dalian, Qingdao, Yantai, and Beihai, where saltwater intrusion is on the rise (55). Although there is no comprehensive monitoring of China's groundwater, studies suggest that groundwater quality, not just quantity, is severely threatened in many regions. According to one estimate, one half the groundwater in Chinese cities has been contaminated (56).

INDUSTRIAL AND MUNICIPAL WASTEWATER THREATENS CHINA'S WATER QUALITY

Each year, large amounts of pollutants are dumped into China's water bodies from municipal, industrial, and agricultural sources. China is the world's largest consumer of synthetic nitrogen fertilizers (57). As a result of these activities, pollution is widespread in China's rivers, lakes, and reservoirs. Except for some inland rivers and large reservoirs, water pollution trends in China have worsened in recent years, with the pollution adjacent to industrially developed cities and towns being particularly severe (58).

Some of the major threats to water quality stem from inadequate treatment of both municipal and industrial wastewater. In 1995, China discharged a total of 37.29 billion cubic tons of wastewater, not including wastewater from township-and-village enterprises (TVEs), into lakes, rivers, and reservoirs. Approximately 60 percent was released from industrial sources, the rest from municipal. With only 77 percent of industrial wastewater receiving any treatment in 1995, nearly one half of the industrial wastewater discharged failed to meet government standards (59). Industrial discharges usually contain a range of toxic pollutants including petroleum, cyanide, arsenic, solvents, and heavy metals (60).

Although the amount of wastewater discharged from regulated industries has leveled off since the early 1990s, discharges from TVEs and municipal sources have increased rapidly (61). The increase from TVEs can be traced to the rising proportion of total industrial output from these enterprises and to a lack of pollution control over these enterprises because of their widely scattered geographical distribution. In addition, local authorities are reluctant to tighten control over pollution when pursuit of economic benefits is their first goal.

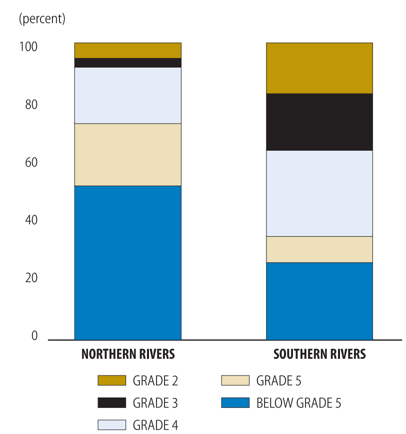
Treatment of municipal sewage lags far behind that of industrial wastewater. In 1995, China had only 100 modern wastewater treatment plants (62). Beijing had only one secondary sewage treatment plant, with a capacity of 500,000 metric tons, which cannot keep pace with the increasing amounts of sewage in the city (63). Treatment should improve rapidly, however, following the amendment of the Water Pollution Prevention and Control Law (64), which set more restrictive regulations, as well as a recent government decision requiring all cities with a population of more than 500,000 to have at least one sewage treatment plant (65).

Water bodies near urban areas are generally the most severely polluted, and the situation is deteriorating. Many urban sections of rivers are polluted by toxic and even carcinogenic compounds, such as arsenic. Although most Chinese attempt to protect themselves from bad water by boiling it, boiling does not affect many of the toxins.

Biological contamination remains a problem as well. Indeed, fecal coliform, mostly from sewage, has become the most challenging drinking water pollutant in the country. In 1994, 54 out of 134 rivers tested did not meet Grade 4 and 5 surface water standards, indicating that the water was deemed unsuitable for even industrial or agricultural use. About 90 percent of the sections of rivers around urban areas were found to be seriously polluted. Because heavy industry is concentrated in northern China, the major river systems in the North are more heavily polluted than those in the South (66). (See Figure China.3.)

Polluted Rivers

FIGURE CHINA.3 Water Quality Is Low at 135 Monitored Urban River Sections, 1995



Source: The World Bank, *Clear Water, Blue Skies: China's Environment in the New Century* (The World Bank, Washington, D.C., 1997), p. 14.
Note: Grades 4 and 5 are deemed unsuitable for direct human contact.

HEALTH IMPLICATIONS

Access to Safe Drinking Water is Key to Protecting Public Health

The health of China's people depends, to a great extent, on the quantity and quality of its drinking water supply. Drinking water quality is largely determined by sources of incoming water, modes of water supply, and the level of water treatment. The majority of Chinese urban and some suburban residents now have access to tap water, while the largest portion of the rural population still relies on hand- or motor-pumped wells, or they fetch water directly from rivers, lakes, ponds, or wells, with little or no treatment at all. Large rivers are the most common source of urban drinking water, as well as the major source for rural residents in many parts of the country.

In only 6 of China's 27 largest cities does drinking water quality meet state standards, according to one recent study. Groundwater did not meet state standards in 23 of these cities (67). The problem is more pronounced in rural China. In some rural areas, the fecal coliform in the drinking water supply exceeds the maximum level by as much as 86 percent; in towns and small cities, the rate is about 28 percent. Currently, around 700 million people in China drink water that fails to meet state standards for fecal coliform (68).

Over the past decade, the government has launched a major initiative to improve access to safe drinking water in rural areas. From 1991 to 1995, the government spent 14.45 billion yuan (US$1.35 billion) to improve the drinking water supply in rural regions (69). Although the rural population with access to tap water more than doubled between 1987 and 1995, when it reached 47 percent, more than one half of those people still drank water that failed to meet safety standards (70).

Infectious Diseases Associated with Poor Water Quality

Despite an overall decline in mortality from infectious diseases in China, the population still suffers from a number of diseases associated with inadequate drinking water quality and sanitation. For the past two decades, diarrheal diseases and viral hepatitis, both diseases associated with fecal pollution, have been the two leading infectious diseases in China. In 1995, the incidence of hepatitis was 63 per 100,000, a 46 percent decrease from 1991. After a sharp drop from 1991 and 1992, the incidence of dysentery has risen since 1994, in part because of the deterioration of water quality. A sudden upswing in the incidence of typhoid fever in 1991 and a large outbreak in some provinces in 1992 were also partly attributed to the poor drinking water quality in rural areas. In 1991, typhoid fever incidence reached as high as 10.6 per 100,000. Although the incidence of waterborne diseases is still high compared with many other countries, effective medical care has kept mortality low, averaging less than 0.1 per 100,000 (71).

It is more difficult to establish the impacts of industrial and chemical water pollution on human health than pollution by human waste. However, recent epidemiological studies suggest that exposure to organic and inorganic chemicals in drinking water may significantly contribute to chronic disease. Liver and stomach cancers are the leading causes of cancer mortality in rural China. Many studies in China and abroad have shown a strong association between drinking water pollution and cancer incidence and mortality. An example is a study conducted in Lujiang County, Anhui Province, where mortality rates for stomach and liver cancers were associated with the high levels of inorganic substances in surface water (72). Although diet and alcohol consumption may play some role in the increases of these cancers, environmental causes cannot be dismissed (73). Since the 1970s, deaths from liver cancer have doubled—China now has the highest liver cancer death rate in the world (74).

In southern China, where some of the population has long depended on ponds for drinking water, the rates of digestive-system cancers are very high. An investigation of 560,000 people in 23 villages and towns showed that between 1987 and 1989, cancer mortality was 172 per 100,000, which is much greater than the average mortality rates in rural China (75). Gastric, esophageal, and liver cancers accounted for 85 percent of all cancers. Other studies reported that the high incidence of liver cancer in Jiangsu's Qidong and Guangxi's Fushun regions is highly correlated with drinking water pollution (76)(77). Further research is needed to confirm this link and identify the specific pollutants at fault.

Impact of Wastewater Irrigation on Health

Irrigation with wastewater has been a common practice in many parts of China throughout its 2,000-year-old agricultural history. In the past several decades, however, the age-old practice of using night soil has been supplemented by the use of industrial wastewater as well, leading to problems with both biological and chemical contaminants. Irrigation with industrial wastes is especially common in the northern regions, where water is scarce. Pollutants, including some organic pollutants, heavy metals, and carcinogens, enter the food chain in the irrigation process and can affect human health.

Numerous studies since the 1970s have shown significant increases in cancer rates and deaths, as well as birth defects, in areas that rely on wastewater for irrigation. For example, research in Shenyang and Fushun showed that the incidence of intestinal infections and enlargement of the liver was, respectively, 49 percent and 36 percent higher in the irrigated areas than in the control area. There were twice as many cancer patients in the sewage-irrigated area. In Fushun, in Liaoning Province, more than 13,000 hectares of farmland are irrigated with water polluted with oil. The adjusted rate of malignant tumor mortality was almost twice that of the control area, and the incidence of congenital malformation was double the rate in the control area (78). Although these associations raise alarms, they do not prove that wastewater is to blame.

Township-and-Village Enterprises: Lack of Regulation Poses Major Threat to Health and Environment

The rapid development of TVEs will have an enormous impact on China's water quality in the coming years. Although their development can be traced back to the late 1950s, these enterprises boomed in the past 10 years. The economic success of the TVEs has reduced poverty for millions of farmers, but they have also inflicted severe damage on the environment in rural China. Even though the Chinese Government has enacted a number of laws and policies to control and regulate industrial discharges (79), the government has not yet effectively regulated TVEs (80).

By 1995, more than 7 million TVEs existed throughout China, with a total output of 5.126 trillion yuan (US$671 billion), accounting for 56 percent of the total industrial GDP—considerably more than the contribution of state-owned enterprises. The number of TVEs is expected to continue to grow. A conservative estimate holds that the TVEs discharge more than half of all industrial wastewater in China—more than 10 billion metric tons. Most TVEs have no wastewater or hazardous waste treatment facilities, and since TVEs are widely scattered across vast rural areas, wastes from TVEs have the potential to affect the health of many people (81).

A 1989–1991 investigation of the 10 leading TVE industries in seven provinces and municipalities showed that industrial wastes were discharged without any treatment and control. An analysis of the health of 860,000 people in the area revealed that the incidence rate of chronic diseases was between 12 and 29 percent, much higher than the national average for rural areas, which is approximately 9 percent. The total mortality in polluted areas averaged 4.7 per 1,000, higher than the average 3.6 in the control area. Life expectancy in the polluted areas was 2 years lower than in the control area. Although not definitive, evidence suggests that industrial pollution from TVEs could become a major threat to human health in China (82).

Laws and Policies to Protect the Environment and Health

China's achievements in health and life expectancy over the past four decades have far exceeded what could be expected for a country at its stage of economic development, according to a recent World Bank evaluation. Behind these dramatic gains in public health was an extraordinary campaign for the Chinese people carried out by the central government, which provided family planning, childhood immunization, accessible primary health care (particularly for mothers and children), improved nutrition, infectious disease control, better education, and improvements in housing and sanitation. (See Table China.4.) Morbidity and mortality from infectious diseases continue to decline on average in most areas of China, although in remote and poor regions, the levels of communicable disease remain much higher than the national averages. The overall success of these programs can be attributed to the central government's approach of adopting the best of traditional methods and wedding these with modern methods. For instance, a campaign to eradicate major public health scourges, such as diphtheria and syphilis, succeeded in large part because it involved vast numbers of traditional doctors in the rural areas (83).

Along with rising income and improved literacy rates, the era of reform has brought more environmental awareness to the Chinese people. A few recent studies in China showed that as communities have become wealthier and better educated, the public has begun to push for stronger regulations and enforcement (84). The increase in media coverage of pollution accidents has contributed to the public's awareness. A popular saying in China's developed eastern region is, "The house is new, the money is enough, but the water is foul and the life is short" (85).

How will China set priorities to prevent environmental exposures and protect public health? Although the government has already begun to address particulate and SO_2 emissions, much remains to be done. While regulatory standards will likely reduce emissions from power plants and state-regulated industries, smaller residential sources and TVE industries will continue to threaten air quality. Residential coal burning for cooking and heating will continue to be a major source of exposure until there is more universal adoption of cleaner fuels. Even though the government has focused some attention on mobile source pollution, it will be a difficult problem to address, given the rapid expansion of the fleet of vehicles.

Most Chinese Have Safe Water and Sanitation

TABLE CHINA.4 Access to Safe Drinking Water and Sanitation Among Selected Countries in Asia, 1990

	PERCENTAGE OF THE POPULATION WITH ACCESS TO					
	SAFE DRINKING WATER			SANITATION [a]		
COUNTRY	URBAN	RURAL	TOTAL	URBAN	RURAL	TOTAL
China	87	68	72	100	81	85
India	86	69	73	44	3	14
Indonesia	35	33	34	79	30	45
Sri Lanka	80	55	60	68	45	50
Japan	100	85	96	100	100	100

Source: The World Bank, *Clear Water, Blue Skies: China's Environment in the New Century* (The World Bank, Washington, D.C., 1997), Table 2.2, p. 20.

Notes: a. Assumes that residents have access to water for washing and that sewage is removed from the house through outdoor latrines, night-soil collection systems, or flush toilets.

ENVIRONMENTAL LAWS AND REGULATIONS

Since the promulgation of the Environmental Protection Law in 1979, the first of its kind in China, 5 pollution-control statutes and 10 natural resource conservation statutes have been enacted. The Environmental Protection and Natural Resources Conservation Committee of the National People's Congress, the lawmaking arm, submitted a 5-Year Legislative Plan to the National People's Congress in 1993. According to the plan, approximately 7 key environment and natural resource statutes will be created or amended by 1998, and more than 17 such statutes will be created or amended by the end of this century. The United States, by comparison, has passed approximately 21 major environmental acts in the last four decades.

The Energy Conservation Law was passed on November 1, 1997, and came into force on January 1, 1998. The scope of this law extends to energy from coal, crude oil, natural gas, electric power, coke, coal gas, thermal power, biomass power, and other energy sources. This law may be the harbinger of strengthened efforts by the Chinese Government to prohibit certain new industrial projects that seriously waste energy and employ outmoded technologies.

Despite the complex system of legislative and policy tools in place and the network of environmental officials throughout China, compliance with environmental regulations remains low, essentially because economic development remains the country's priority at all levels of society.

As part of its efforts to strengthen environmental law enforcement, the government revised its criminal code to punish violations against the environment and resources. This step may provide law enforcement agencies with some power. However, the vagueness of standards in many laws and regulations, coupled with the lack of a comprehensive enforcement regime, has led to a situation where many environmental laws still reflect deals cut between the local environmental protection agencies, NEPA, other ministries, local government bodies, and the polluting enterprises. Thus, the degree of actual compliance and enforcement depends on the region concerned and the personalities involved. Often, the richer the potential investor, the more strictly environmental policy will be applied (86).

For the next decade or so, China's rapid development will likely lead to further uncertainty in the regulatory regime. In the meantime, an increasing array of resources are being devoted to enforcement, and discussions are currently underway to elevate NEPA to ministerial status, which may give NEPA more leverage and authority in law enforcement. Nonetheless, many Chinese officials adamantly hold that economic development must come before environmental protection. They also disagree about how stringent environmental initiatives need to be to protect the health of billions of citizens while maintaining economic growth. This internal struggle enhances the paradoxical quality of Chinese environmental law, which may at once appear both simple and complex, or lenient and severe (87).

USING ECONOMIC INSTRUMENTS—HARNESSING THE MARKET

In its transition from a command to a market economy, China is trying to harness the market to work for the environment rather than against it. Continued and accelerated economic reform is a prerequisite to reorient state enterprises so that they respond to environmental penalties. Liberating international trade will give Chinese industry access to the latest environmental technology. The development of capital markets is necessary to provide financing to firms and municipalities supplying environmental infrastructure. Adjustments of the pricing system are needed to ensure that it reflects true environmental costs.

Despite the fact that China is resource-poor, it prices its energy and water far lower than the actual costs. However, great strides are being made to rectify this situation. Over the past 3 years, the government has raised and partly deregulated coal prices; in most areas, coal prices now cover the costs of production and delivery. In addition, many cities and provinces are currently preparing to increase sewage and water charges to consumers and industries. In Taiyuan of Shanxi Province, for instance, the price bureau has announced that water prices will quadruple over the next 5 years in order to recover supply costs (88). Shanghai recently increased tap water prices by between 25 and 40 percent to fund water quality improvement programs and to make sewage self-financing. Guangzhou and Chongqing are eager to do the same (89).

The increasing market orientation of the industrial sector offers an opportunity to use market-based pollution controls more effectively. Achieving pollution control objectives will require increasing pollution charges. NEPA has proposed a 10-fold increase in the air pollution levy; this increase would go a long way toward reducing air pollutant emissions. Higher levies are needed both to lower current emissions and to finance the large investment required to achieve desired ambient air quality in Chinese cities. Currently, the pollution levies are assessed only on discharges that exceed the standard; in other words, emissions cost the polluter nothing until the standards are breached. Moreover, effluent charges are based on the pollutant that exceeds the standard by the greatest amount and do not reflect the risks posed by other pollutants. The World Bank has been working with NEPA to overcome these shortcomings. These two organizations are developing a system that incorporates both maximum discharge rates for all pollutants as well as incentives to encourage emissions at levels below the maximum allowed (90).

INCREASING ENVIRONMENTAL INVESTMENT

Environmental protection demands more spending. The Chinese Government has attributed the continued deterioration of the environment largely to lack of funding. Despite extremely ambitious 5-year plans to control environmental pollution in the past, insufficient investment has prevented realization of these goals. Now in its Ninth 5-Year Plan period, the government has adopted the Trans-Century Green Plan, which sets targets for environmental protection for the year 2010. In conjunction with other environmental protection plans, NEPA is striving to stabilize the emissions of several pollutants at 1995 levels by the year 2000. The percentage of SO_2, particulates, untreated sewage, and heavy metals sewage treated would be increased from its current 19 percent to 25 percent, and treatment of industrial wastewater would be expanded by about 70 million metric tons. This ambitious plan, which NEPA estimates will cost 450 billion yuan (1.3 percent of China's GNP) to achieve, accords top priority to certain areas, especially along the east coast and in some parts of its inner land: the Hai, Huai, and Liao rivers; the Chao, Dianchi, and Tai lakes; and two areas in southwest China with pronounced problems with SO_2 levels and acid rain (91).

Industries and local governments are increasingly looking for new sources of funding, through the "polluter pays" principle, urban environmental infrastructure funds, and even bank loans. The central government is playing a more supportive role in seeking loans and foreign investment and implementing economic policies. The government intends to increase the proportion of GNP spent on controlling pollution from the current 0.8 percent to more than 1 percent at the turn of the century, or approximately 188 billion yuan (US$17.5 billion) (92). Some cities are investing in an even higher proportion. For instance, Beijing, Shanghai, and Xiamen have decided to allocate up to 3 percent of their GDP to pollution control. Tianjin will set aside up to 2 percent (93). In the meantime, China also hopes that foreign investment will continue to provide funds supporting its ambitious plans to address pollution. A recent World Bank report noted that investing about 1 percent of GDP each year gradually rising to 2.5 percent over the next 25 years—divided roughly equally between air and water investment—would greatly reduce pollution in China by 2020 (94). The report also noted that the operating and the average investment costs each year of such a program would gradually rise to about 2.5 percent of GDP by the end of the period. According to the World Bank, the benefits of these measures exceed the costs by large margins, and these measures are essential if China is to redirect its development toward a more sustainable path.

Changhua Wu, Michelle Gottlieb, and Devra Davis, Health, Environment, and Development Program, World Resources Institute, Washington, D.C.

References and Notes

1. The World Bank, *World Development Indicators 1997*, on CD-ROM (The World Bank, Washington, D.C., 1997).
2. Jonathan Sinton, ed., *China Energy Databook*, *1996 Revision* (University of California at Berkeley, Berkeley, 1996), p. x-12.
3. International Labour Organization (ILO), *Economically Active Population, 1950–2010: Vol. 1, Asia* (ILO, Geneva, 1996), p. 205.
4. The World Bank, *World Development Indicators 1997* (The World Bank, Washington, D.C., 1997), p. 130.
5. International Energy Agency, *Energy Statistics and Balances: Non-OECD Countries, 1971–1995*, on diskette (Organisation for Economic Co-Operation and Development, Paris, 1997).
6. United Nations (U.N.) Population Division, *Urban and Rural Areas 1950–2030 (The 1996 Revision)*, on diskette, (U.N., New York, 1997).
7. Li Junfeng *et al*., *Energy Demand in China: Overview Report*, Issues and Options in Greenhouse Gas Emissions Control Subreport Number 2 (The World Bank, Washington, D.C., 1995), p. 17.
8. China Ministry of Public Health, *Selected Edition on Health Statistics of China 1991–1995* (China Ministry of Public Health, Beijing, 1996), p. 3.
9. Chen Junshi *et al*., *Diet, Lifestyle, and Mortality in China: A Study of the Characteristics of 65 Chinese Counties*, published in the U.K. by Oxford University Press, Oxford; in the United States by Cornell University Press, Ithaca; and in China by the People's Medical Publishing House, Beijing (Oxford University Press, Oxford, 1990), p. 73.
10. National Environmental Protection Agency (NEPA), *1996 Report on the State of the Environment* (NEPA, Beijing, 1997) (Chinese language edition).
11. Qian Chen, "Improve the Eco-Environment and Rebuild the Beautiful Mountains and Rivers," *China Environment News* (September 13, 1997), p. A.
12. The World Bank, *Clear Water, Blue Skies: China's Environment in the New Century* (The World Bank, Washington, D.C., 1997), p. 23.
13. *Op. cit.* 10.
14. Zhang Jianguang, "Environmental Hazards in the Chinese Public's Eyes," *Risk Analysis*, Vol. 14, No. 2 (1994), p. 165.
15. Outlined in National Environmental Protection Agency (NEPA), *The National Ninth 5-Year Plan for Environmental Protection and the Long-Term Targets for the Year 2010* (NEPA, Beijing, 1996).
16. Fang Cai, "Stare Into the Sky—When Will It be Clear?," *China Environment News* (January 21, 1997), p. 1.
17. National Environmental Protection Agency (NEPA), *National Environmental Quality Report, 1991–1995* (NEPA, Beijing, 1996), pp. 5, 15.
18. *Op cit.* 12, pp. 8–9.
19. China Environment Yearbook, *China Environment Yearbook*, various issues (China Environment Yearbook Press, Beijing, various years) (Chinese language editions).
20. International Energy Agency, *Energy Statistics and Balances: Non-OECD Countries, 1971–1995*, and *Energy Statistics and Balances: OECD Countries, 1960–1995*, both on diskette (Organisation for Economic Co-Operation and Development, Paris, 1997).
21. *Op. cit.* 2, p. iv-11.
22. *Op. cit.* 19.
23. *Op. cit.* 7, p. 43.
24. *Op. cit.* 2, p. viii-2.
25. *Op. cit.* 12, pp. 21–22, map 1.
26. *Op. cit.* 12, pp. 8, 46.
27. *Op. cit.* 2, p. v-4.
28. American Automobile Manufacturers Association (AAMA), *Motor Vehicle Facts and Figures* (AAMA, Washington, D.C., 1996), pp. 44–47.
29. Stephen Stares and Liu Zhi, "Motorization in Chinese Cities: Issues and Actions," in *China's Urban Transport Development Strategy: Proceedings of a Symposium in Beijing, November 8–10, 1995*, World Bank Discussion Paper No. 352 (The World Bank, Washington, D.C., 1996), p. 50.
30. Liu Xianshu and Xiao Yunxiang, "How to Enjoy and Use Automobiles," *China Environment News* (January 28, 1997), p. 1.
31. Michael Walsh, "Motor Vehicle Pollution in China: An Urban Challenge," in *China's Urban Transport Development Strategy: Proceedings of a Symposium in Beijing, November 8–10, 1995*, World Bank Discussion Paper No. 352 (The World Bank, Washington, D.C., 1996), pp. 118–122.
32. He Kebin *et al*., "The Status and Trend of Urban Vehicular Pollution," *Environmental Science*, Vol. 17, No. 4 (1996), pp. 80–83 (in Chinese).
33. He Kebin *et al*., "Status and Developments in China's Vehicle Emissions Pollution," *Environmental Science*, Vol. 7, No. 4 (1996), pp. 15–17 (in Chinese).
34. *Ibid.*
35. *Op. cit.* 31, p. 120.
36. *Op. cit.* 12, pp. 17–18.
37. *Op. cit.* 12, Table 2.1, p. 19.
38. World Health Organization (WHO), *Health and Environment in Sustainable Development: Five Years After the Earth Summit* (WHO, Geneva, 1997), p. 82.
39. *Ibid.*, pp. 83–86.
40. *Op. cit.* 12, p. 19.
41. *Op. cit.* 12, p. 19.
42. Robert S. Chapman *et al*., "Assessing Indoor Air Pollution Exposure and Lung Cancer Risk in Xuan Wei, China," *Journal of the American College of Toxicology*, Vol. 8, No. 5 (1989), pp. 941–948.
43. Judy L. Mumford *et al*., "DNA Adducts As Biomarkers for Assessing Exposure to Polycyclic Aromatic Hydrocarbons in Tissues from Xuan Wei Women with High Exposure to Coal Combustion Emissions and High Lung Cancer Mortality," *Environmental Health Perspectives*, Vol. 99 (1993), pp. 83–87.
44. Xu Xiping *et al*., "Air Pollution and Daily Mortality in Residential Areas of Beijing, China," *Archives of Environmental Health*, Vol. 49, No. 4 (1994), pp. 216–222.
45. Xu Xiping, Li Bauluo, and Huang Huying, "Air Pollution and Unscheduled Hospital Outpatient and Emergency Room Visits," *Archives of Environmental Health*, Vol. 103, No. 3 (1995), pp. 286–289.
46. China Environment Yearbook, *China Environment Yearbook, 1996* (China Environment Yearbook Press, Beijing, 1997), p. 193 (Chinese language edition).
47. *Op. cit.* 12, p. 18.
48. Xu Zhaoyi *et al*., "The Effect of Air Pollution on Mortality in Shenyang City," *Journal of Public Health in China*, Vol. 15, No. 1 (1996), p. 61.
49. *Op. cit.* 12, p. 20.
50. Shen Xiao-Ming *et al*., "Prenatal Low-Level Lead Exposure and Infant Development in the First Year: A Prospective Study in Shanghai, China," paper presented to the International Society for Environmental Epidemiology, University of Alberta, Edmunton, Canada, August 1996.
51. *Op. cit.* 10.
52. *Op. cit.* 12, pp. 23, 87–88.
53. See Data Table 12.1.
54. *Op. cit.* 12, p. 88.
55. *Op. cit.* 10.
56. Zhang Weiping *et al*., eds., *Twenty Years of China's Environmental Protection Administrative Management* (China Environmental Sciences Press, Beijing, 1994), pp. 215–217.
57. Food and Agriculture Organization of the United Nations (FAO), *FAOSTAT Statistical Database* (FAO, Rome, 1996–1997).
58. Vaclav Smil, "China Shoulders the Cost of Environmental Change," *Environment*, Vol. 39, No. 6 (1996), p. 33.
59. *Op. cit.* 10.
60. *Op. cit.* 46.
61. *Op. cit.* 10.
62. China Environment Yearbook, *China Environment Yearbook, 1996* (China Environment Yearbook Press, Beijing, 1997), p. 215 (English language edition).
63. Xiaoke Jiang, Former Director, Beijing's Environmental Protection Bureau, Beijing, 1998 (personal communication).
64. The Water Pollution Prevention and Control Law, initially adopted in 1984, was amended in 1996.
65. This is a decision announced at the 4th National Conference on Environmental Protection, which was convened in Beijing in September 1996.
66. *Op. cit.* 10.
67. Vaclav Smil, *Environmental Problems in China: Estimates of Economic Costs*, East-West Center Special Report No. 5 (East-West Center, Honolulu, 1996), pp. 2, 24.
68. Cai Shiwen, "China's Environmental Pollution and Health Problem," paper presented at the Second Conference of the China Council of International Cooperation and Development, Beijing, 1993.
69. China Ministry of Public Health, *China Yearbook of Public Health 1996* (People's Medical Publishing House, Beijing, 1997), pp. 416–417.
70. Zhang Feng *et al.,* "Status and Analysis of Rural Drinking Water Quality," *Journal of Hygiene Research*, Vol. 26, No. 1 (1997), pp. 30–32.
71. China Ministry of Public Health, *Selected Edition on Health Statistics of China, 1991–95* (China Ministry of Public Health, Beijing, 1996), pp. 69–70.
72. Guili Chen, "The Warning of Huai River," *Contemporary Magazine*, Vol. 2 (1996).
73. Howard Frumpkin, "Cancer of the Liver and Gastrointestinal Tract," in *Textbook of Clinical Occupational and Environmental Medicine* (W.B. Saunders Co., Philadelphia, 1994), p. 576.
74. Feng Rukang, "China Maps Out Geographical Belt of Liver Cancer," *China Environment News* (October 15, 1997), p. 8.
75. Su Delong, "Drinking Water and Liver Cancer," *Journal of Chinese Preventative Medicine*, Vol. 14, No. 2 (1990), pp. 65–73.
76. Liang *et al*., "Epidemiologic Investigation of Relationships Between Drinking Water Types and Liver Cancer," *Cancers*, Vol. 6, No. 3 (1987), p. 177 (in Chinese).
77. Tang He and Lin Nianfeng, "The Relationship Between Organic Water Pollution and Liver Cancer at Fushui in Guangxi," *Journal of Environment and Health*, Vol. 12, No. 5 (1995), pp. 193–195 (in Chinese).
78. Yuan, "Etiologic Study of High Stomach Cancer Incidence Among Residents in Wastewater Irrigated

Areas," *Environmental Protection Science*, Vol. 19, No. 1 (1993), pp. 70–73 (in Chinese).
79. Such policies include pollution levies and permits.
80. Cao Fenzhong, "Air and Water Pollution Problems in TVEs," a policy paper prepared for the Chinese National Environmental Protection Agency (NEPA) (NEPA, Beijing, 1997), p. 1.
81. *Ibid.,* pp. 1–5.
82. Xu Fang *et al.,* "Economic Analysis and Countermeasure Study of TVEs Pollution's Damage to Human Health," *Journal of Hygiene Research*, Vol. 21, Supplement (1992), pp. 1–23.
83. "Decision on Public Health Reform and Development by the Central Committee of the Chinese Communist Party and the State Council," *People's Daily* (February 18, 1997, Beijing), p. 1.
84. *Op. cit.* 12, p. 13.
85. *Report of the 4th National Conference on Environmental Protection* (China Environmental Sciences Press, Beijing, 1996), p. 32.
86. *Op. cit.* 83.
87. Richard J. Ferris Jr., "The People's Republic of China: An Environmental Law Briefing for Corporate Council," *The Metropolitan Corporate Counsel* (December 1997), p. 13.
88. *Op. cit.* 12, pp. 95–96.
89. Shuping Lu, Director, Shanghai Environmental Protection Agency, 1998 (personal communication).
90. Dr. Hua Wang, Consultant and Principal Economist in the Environment, Infrastructure, and Agriculture Division, Policy Research Department, The World Bank, Washington, D.C., 1997 (personal communication).
91. *Op. cit.* 15, p. 12.
92. *Op. cit.* 15, p. 4.
93. Wang Yi, Professor/Senior Scientist, Eco-Environment Research Center of the Chinese Academy of Sciences, 1997 (personal communication).
94. The World Bank, *Can the Environment Wait? Priorities for East Asia* (The World Bank, Washington, D.C., 1997), p. 1.