

WWF INTERNATIONAL
RESEARCH PAPER

DAMS AND FLOODS

Fred Pearce

June 2001

For further information contact: Biksham Gujja, Head - Freshwater Programme, WWF International, Ave du Mont-Blanc, 1196 Gland, Switzerland, Tel: +41 22 364 90 31, Fax: +4122 364 05 26, E-mail: bgujja@wwfint.org

DAMS AND FLOODS

SNATCHES

May 1998:

Thawing snow pours down hillsides in the Suzak district of southern Kyrgyzstan, bursting a 100-metre wide dam on the River Kugart. More than a thousand homes are swept away by the swollen river. [BBC]

July 1998:

Water from melting glaciers smashes through a dam on the Kuban-Kel lake in the mountains of central Asia. As the lake empties, water levels rise by 4 metres on the river below. Forty-three people in Uzbekistan are killed and six villages destroyed. [AP]

August 1998:

Ten people die and 100 000 are evacuated after heavy rains topple the Benanga dam near Samarinda in the Indonesian state of East Kalimantan. [DPA]

October 1998:

A series of dam bursts and overflows in the hills around the Honduran capital Tegucigalpa add significantly to the 8000 death from Hurricane Mitch. [USGS]

September 1999:

At least 48 people die during floods in northern Ghana after engineers in neighbouring Burkina Faso open spillways to relieve water pressure on the Bagre Dam. Local reports say three other dams burst their banks. Forty villages are reported completely submerged. [BBC]

September 1999:

Thirty-nine die and 80 000 are made homeless as Nigerian authorities make emergency releases from three dams, including the giant Kainji, during floods on the River Niger. [BBC]

October 1999:

A hundred die and thousands are left homeless in floods in the Mexican state of Hidalgo. A significant cause is water released from the La Esperanza dam, which floods two rivers. [CINDI]

March 2000:

Rushed water releases from the Kariba dam on the River Zambezi in southern Africa flood a district occupied after the dam's construction made it "safe". [New Scientist]

July 2000:

Floodwaters swamp towns in central Luzon, Philippines. Parts of Manila are submerged after power authorities open the gates of four hydroelectric dams north of the capital to prevent water overflowing. {Dartmouth floods register}

August 2000:

Monsoon floods in the Indian state of Andhra Pradesh crack the Roxsagar dam near the state capital Hyderabad. Thousands of workers rush to mend the breach, but were forced to retreat as water gushes towards the capital. Nearly 40 000 people are evacuated from their flooded homes. [BBC]

September 2000:

Emergency releases from at least four dams in West Bengal add to floods that cross the border into Bangladesh, killing more than a thousand. [BBC]

INTRODUCTION -- The downside of dams

Worldwide there are an estimated 45 000 large hydroelectric dams more than 15 metres high. Their reservoirs cover an area as large as France. A recent study suggests that the total number of man-made reservoirs -- whether used for electricity generation, irrigation, water supply or other purposes -- is much higher, covering an area three times larger than France. Collectively they hold back an estimated 5000 cubic kilometres of water, enough to raise sea levels worldwide by 13 millimetres. Most have been built in the past half-century -- an era that has seen the tributaries and main stems of most of the world's largest rivers barricaded by dams. The largest yet, China's massive Three Gorges dam now under construction on the River Yangtze, will plug the world's third largest river.

In the early heroic years of dam construction, many environmentalists as well as engineers hailed them as a new clean form of renewable electricity generation. Other dams improved river navigation, held back dangerous floods and supplied water to cities or new irrigation projects to boost food production. But this enthusiasm has faltered as evidence has grown of the downside of large dams. Many do more harm than good -- in social, environment and economic terms.

The charge sheet against large dams is long. They typically flood rich, fertile river valleys, forcing inhabitants -- often tribal communities already marginalised in highland areas -- into unsatisfactory resettlement programmes. They disrupt the natural downstream flows of water and silt that sustain fisheries, fertilise soils and irrigated crops. They generate significant amounts of greenhouse gases -- in some cases hydroelectric reservoirs may give off more gases than a fossil-fuel power plant of similar capacity. And as they grow older and their reservoirs fill with silt, they do ever less good and run ever greater risks of catastrophic collapse.

Politically, they have become a weapon for the rich, urban and powerful to take control of water resources away from the poor, rural and dispossessed. The large contracts and draconian scale of dam construction has made them a favourite of dictatorial and corrupt regimes as well as giving considerable power over national affairs to large international corporations.

And they have done considerable ecological harm to wetlands, rivers and estuaries. Dams are a major cause of the degradation of many of the world's wetlands. A recent study of 91 dams in 30 countries by the WWF identified 250 species, from sturgeon and dolphin to birds such as the Siberian crane, that have been directly harmed by dam construction -- a figure that is likely to be the tip of the iceberg.

THE FLOOD PROBLEM

Events round the world in recent years have revealed another, largely unexpected, menace from large dams. Though most are built with the promise that they will reduce flooding downstream, many have had the reverse effect. This is most marked during times of heavy rains, when reservoirs become swollen.

Initially, dam managers attempt to capture the water. This is their natural instinct, usually backed up by operating manuals. The primary purpose of their dams is to capture water in order to generate hydroelectricity and/or provide water for cities and irrigation projects. To release the water into the river downstream is normally to "waste" it. As Bryan Davies, a river ecologist from the University of Cape Town, puts it: "The tendency everywhere is to store like hell when you can."

Dam managers also often have a remit to guard against flooding downstream by capturing the flood flows of rivers. During moderate floods this usually works well. But in times of very high rainfall and exceptional river flows, the dam's very capacity to capture water becomes a menace. As the reservoir becomes full, its operators are faced with the choice of risking the catastrophic failure of their dam as it overfills, or of making emergency releases of water down spillways. Anxious not to cause downstream flooding, they often leave it too late to make the fateful decision. The result is emergency releases that are far greater and more sudden than flows that would have occurred during the natural river flooding.

Moreover they are unexpected. People living below dams expect that the huge structures will save them from flooding. Round the world, with or without official support, people invade floodplains downstream of dams -- in the expectation that with the dam in place they will be safe. All too often, they are not safe at all.

Dams are often designed on the basis of a very poor knowledge about the long-term hydrology of the rivers they block. There is little historical data on rainfall or river flows in much of the world. Hydrologists know little about the potential for extreme flood events. And where there is data, it may not accurately reflect current risks.

River catchments that have been deforested or cleared of scrub, or where their wetlands have been drained, develop very different hydrological regimes. The loss of these natural sponges for floodwaters within the catchment increases the risk of extreme floods.

Moreover, climate change appears to be affecting rainfall patterns and timing and making eventual rainfall more erratic. According to Mark Jury, a climatologist from the University of Natal in South Africa, the maximum daily rainfall recorded in the catchment of the Limpopo, a river badly hit by floods in 2000, has risen from 200 millimetres a day in the early 20th century to around 300 millimetres today. This, he says, "is attributable to global warming and locally higher sea temperatures which feed the rainbands of tropical cyclones".

A frequent problem is that dams are often built without adequate spillways to cope with extreme floods. During a 1995 study of 25 Indian dams, World Bank engineers calculated the amount of water that the dams should have been able to release at the height of a flood. In each case, they found they expected floods were greater than those that the dams had been built to discharge over their spillways.

Two of the dams could cope with only one seventh of the expected peak discharge. At two others -- the Hirakud in Orissa and the Gandhi Sagar in Madhya Pradesh, both among India's largest -- the investigators wrote that "the consequences of dam failure during a major flood would have to be described with some adjective beyond disastrous." The risk is real. In India's worst dam failure in 1979, the Machu II dam in Gujarat unleashed floodwaters in which 2000 died.

There is no reason to believe Indian dams are unusual. The risks are if anything even greater in China. In a series of articles in 1998, the China Daily, the country's official news agency, reported that thousands of the country's dams were at risk of catastrophic failure. Quoting experts, the article said that "most of the old dams built in the 50s and 60s are seriously deformed [and] are all threatened by the hidden danger of dam collapse." It suggested that politicians were too keen on building "new star dams dazzling people's eyes" than in repairing old ones, which "have been forgotten".

"Since 1949, 322 [Chinese] dams have failed," the agency said. As recently as 1993, some 300 people died when a small reservoir in northwest China's Qinghai province gave way during floods. But the worst case by far, which was not known about in the outside world for more than a decade, was the collapse of the Banqiao dam during floods that followed a typhoon in August 1975. The catastrophe "killed more than 200 000 people", it said.

During floods in 1998, many dykes collapsed along the River Yangtze, while dams failed to fulfil their flood protection role. While no dams are known to have failed, many had over the years lost much of the capacity to siltation and were forced to make emergency releases earlier than they should have.

CASE STUDIES

Except during some catastrophic engineering failure, dams are rarely the sole cause of floods. But in a number of recent flooding disasters round the world, dams have been heavily implicated in making the floods worse, and causing many deaths.

Nigeria, September 1999

In late September 1999, large areas of central Nigeria were under water as the worst floods in more than a generation surged down West Africa's biggest river, the Niger, which drains six countries. The rains were heavy, certainly. They would have caused flooding at any time. But what caused the massive devastation in Nigeria was that, at the height of the floods, the operators of three large dams were forced to open sluice gates to protect their structures.

Poor transmission from a local radio station meant that many villages received no warning as water surged from the Kainji, Shiroro and Jebba dams. The governor of Niger state, Abdulkadir Kure, told reporters: "The flooding is catastrophic. There are hundreds of villages under water." He estimated 80 000 people were in need of food and shelter, including the populations of riverside towns such as Pategi and Lafiaji, and some 100 000 hectares of millet, rice and wheat were under water. The death toll, never finally established, was at least 39.

The UN's West African office reported that "the disaster [was] caused largely by the spillage of water from the Kainji dam" -- a vast concrete and rock structure 85 metres high and 5 kilometres across. Two weeks later, with the waters still high, the BBC reported that villagers in one small part of the flood zone were demanding \$16 million compensation from Nigeria's National Electricity Power Authority, responsible for the releases.

Kure said the operators of the dams had no choice but to release the water from the three dams. But, at least in the case of the 30-year-old Kainji dam, evidence soon emerged that defects in the dam were at least partly to blame. As the floods raged down the Niger in an extended monsoon season, the 136-kilometre long reservoir was full. It contained 15 cubic kilometres of water. And its operators were worried. Just a year before, the dam had come close to a major disaster after spillways malfunctioned and water poured over the top of the dam running the risk of washing away the town of Kainji. Its engineers had said a record of poor maintenance meant that "it may soon give way". When the floods returned in 1999, they took no chances. They opened the spillways.

Bengal, September 2000

Heavy monsoon rains in the rivers of West Bengal in western India filled reservoirs to bursting point during September 2000. So much so that engineers organised emergency releases from several dams, creating water surges into four

rivers: the Damodar, Barakar, Mayurakshi and Ajoy. The floodwaters surged on into the giant river delta system that covers much of both West Bengal and neighbouring Bangladesh. They contributed to a disaster that left more than a thousand dead, washed away a million homes and, according to initial government estimates, damaged property worth more than £40 million.

But how much did the dam releases contribute to this? In the complex delta river system of West Bengal, it is impossible to be sure. But there are clues. Some of the worst flooding was in Murshidabad, into which the River Mayurakshi, swollen by dam releases, flowed. Also badly hit was Burdwan district. This is in the lower reaches of the River Damodar, below two reservoirs managed by the Damodar Valley Corporation, a body set up 50 years ago to electrify and industrialise the valley using hydroelectricity.

India's first prime minister Jawaharlal Nehru called the corporation's dams "the temples of modern India". Its engineers say that in the past the dams have helped hold back floods. But this time, faced with the risk of over-topping and structural damage at the height of the floods, the corporation's engineers released some 70 000 cubic metres a second from the Maithon dam and 30 000 cubic metres a second from the Panchet dam. The water hurtled down the Damodar and over the Durgapur barrage, flooding towns such as Amta and Khanakul, as it headed towards Calcutta. At the height of the floods, roughly 40 per cent of the 230 000 cubic metres of second of water passing over the Durgapur barrage was a direct result of releases from the two dams.

Suspensions were soon aroused. As news agencies reported that "the floodwaters have drowned much of the Indian-Bangladesh border under three metres of water", Bengali opposition leader and railways minister Mamata Banerjee described the flood as man-made -- a product of the unplanned release of water from the dams. And water officials in Bangladesh said they were flabbergasted by the floods. Parts of the country flooded while most of its main rivers were flowing below danger levels. "We consider this flood unnatural and unprecedented," said the director of the Bangladesh Water Development Board.

Honduras, October 1998

Hurricane Mitch, which ripped through Central America in October 1998, was the most destructive storm in the western hemisphere in 200 years. Its torrential rains brought havoc to Honduras in particular, killing some 10 000 people in floods and landslides. It was a disaster in which the collapse of dams played a small but significant part, particularly for the million inhabitants of the Honduran capital of Tegucigalpa.

Mitch dumped record amounts of rain onto steep hillsides destabilised by tree-cutting and saturated by a month of heavy rain. The resulting landslips were the primary cause of death. But flash floods that turned small mountain streams into torrents were not far behind. And in areas where these streams had been dammed, there was the extra danger of water surges caused by dam collapses.

There is some evidence that this is what happened to Tegucigalpa, when what many people described as a "wall of water" struck the inhabitants of poor low-lying shanty areas shortly before midnight on 30 October 1998, giving nobody time to escape. Investigators from the US Geological Survey, who spent some weeks analysing the disaster, reported that shortly before this time three reservoirs on streams to the south of the city were breached or unleashed exception water flows.

The first to go, at 22.45, was the Los Laureles reservoir. The cascade of water appears to have added significantly to flooding along the banks of the River

Guacerique as far as the southern suburbs of the capital, where 40 homes slid into the river and at least 20 people died that night.

The next to succumb was the Concepcion dam 10 kilometres south of the city on the River Choluteca, which flows through the heart of the capital. Its reservoir was already full before the rains started. According to the operators' log, the dam overflowed at 23.00, causing a "high-flow release" down its spillway that lasted for seven hours. Peak flow towards the capital was 760 cubic metres a second, enough according to the log to rip up the spillway and gouge the downstream channel. What impact it had nearer the city is not recorded.

Finally, came the failure of the Laguna de Pescado. This formed some years ago after a landslide blocked a tributary of the Choluteca, but the authorities never removed it. It was full before Mitch struck. At around 23.00, locals told investigators of the USGS, "a large proportion of the natural dam failed, sending a flood wave" down the channel into the Grande River

Similar stories may explain other "walls of water" that hit other towns that night. Pespire, a town of 30 000 people in southern Honduras suffered 41 dead and lost more than 300 houses when the level of the river that runs beneath it rose by some 15 metres within a matter of minutes. Nobody could remember anything remote like it from the normally placid river. It is just downstream of a large dam that would normally have impounded floodwaters.

In the north of the country, the 220-metre high El Cajon hydroelectric dam, which supplies more than half Honduras's electricity, narrowly survived Hurricane Mitch. At one point water levels were two metres above its design limit and the National Electric Energy Company evacuated people from downstream while they made emergency releases. According to its engineers, on balance the reservoir significantly reduced downstream floods. But the floods brought huge amounts of silt into the reservoir. The resulting reduced capacity told a year later, when engineers again had to make emergency water releases during floods caused by Hurricane Floyd. The Honduran government ordered the evacuation of 50 000 people downstream as fears grew that the dam might be overwhelmed.

Southern Africa, March 2000

The floods across southern Africa in March 2000 were among the worst ever experience in a region known more for its droughts than downpours. Rivers such as the Limpopo and Zambezi became choked with water, and broke banks, flooding farmland over a wide area before moving on down to the coastal floodplains of Mozambique, where the world watched in horror as huge areas of the country went under water.

Nobody would claim that dams were responsible for all, or even most, of the flooding. In much of the region five times more rain than usual fell in the first three months of the year. And it is widely recognised that the effects of this heavy rain were accentuated by changes in land use in recent decades. This included deforestation, the draining of wetlands, soil erosion and the replacement of bush with bare soil. But dams, and particularly the way in which they were managed, did play a significant role in many places, say hydrologists. And there were real fears at the time that they could trigger a yet-worse disaster.

Mark Jury, a climate modeller at the University of Zululand in South Africa, produced some remarkably accurate forecasts of the likely extent of the heavy rains in the months beforehand. He says now that if dam managers had taken more notice of his warnings, the flooding could have been reduced. "Dam managers try to hang on to their water at all costs," he says. They were keeping the

reservoirs 80-per-cent full at the start of the wet season which even in a normal year produces 85 per cent of the year's rain. When it became clear that they had a major flood on their hands, the operators began to empty the reservoirs quickly. But it was too late to do this without adding to the already severe flooding problems downstream. "They should have started to empty them much earlier," Jury says. But, he argues, after more than 20 years of low rainfall and droughts, people had forgotten the devastation that floods can cause

The abrupt releases of water certainly worsened local flooding across the interior of the region. And many dams simply failed. Dam breaks were reported in South Africa and on the catchment of the River Save in Zimbabwe, where they helping spread floodwaters across the southeast of the country. In Botswana, the Nywane, Shashe, Letsibogo, Gaborone and Bokaa dams were all reported to have been overtopped.

There is less certainty about the role of dams in the events in southern Mozambique. The country suffered very heavy local rains downstream of any dams. And it is quite clear that dams on rivers draining into the country, including the Limpopo, had nowhere near enough capacity to hold back the floodwaters reaching Mozambique from the interior. According to South African water officials, enough water flowed down the Limpopo in just eight days at the height of the floods to fill all its 24 dams in the catchment five times. But if Jury's warnings of very heavy rains had been heeded and the reservoirs emptied prior to the floods, the capture of even two days of floodwaters could have made all the difference in some places.

Events were equally fraught further north on the Zambezi river, the largest in southern Africa. This river, which forms the border between Zambia and Zimbabwe, is interrupted by two massive hydroelectric dams, the British-built Kariba and the Cahora Bassa in Mozambique, which was built during the Portuguese colonial era and is still 80-per-cent owned by the Portuguese government.

The Kariba reservoir is more than 280 kilometres long. Through the early months of 2000 it filled rapidly, until by 26 February engineers were forced to begin emergency releases of water. Three of the dam's five floodgates were opened, discharging 4500 cubic metres a second downstream. People rushed from miles around to see the unique spectacle. But some 12 000 people living along the river bank downstream in Chiawa district saw the water surge through their fields, grain stores, schools and villages. The Mozambique town of Zumbo, just over the border, was also flooded.

The Zambezi River Authority said it had to act because water levels behind the dam were at the highest level seen since the reservoir filled in 1963. Its chief executive has argued that the discharge was lower than flows into the reservoir at the height of the storms. "If Kariba dam had not been there, the areas downstream would have been subjected to worse floods," he said.

But critics argue that dams advertised for their ability to protect communities against floods encourage people to build on the floodplain -- something that before the dam's construction they would not have dared to do. Moreover, as the BBC reported at the time, "there seems to be no contingency plan in place to help people or businesses... a year's supply of food for thousands of people who farm along the banks of the Zambezi was wiped out in just nine hours."

In the midst of the crisis on the Zambezi, Bryan Davies from the University of Cape Town wrote to the South African government warning of even worse to come. He feared that the water flooding from Kariba could cause a disaster downstream at the 160-metre Cahora Bassa dam that might lead to "tens of thousands" of deaths. Portuguese engineers in charge of the Cahora Bassa dam had dropped their past practice of partially emptying its reservoir before the start of the

rainy season, he said. And technical flaws in the dam meant that emergency discharges could result in "catastrophe".

His fear arose from events during heavy rains in February 1997. Then, operators opening sluice gates to release water set off vibrations in the walls of the dam. This "extraordinarily dangerous state of affairs", said Davies, could have weakened the rock in which the dam was embedded and might have triggered a failure of the entire structure when the gates were next operated. The dam survived -- though at the expense of widespread flooding downstream that rendering homeless tens of thousands of people.

"It is a myth that dams protect against floods," says Davies. "When the big beggar comes they exacerbate floods by emergency releases."

THE CASE OF THE MEKONG

As the pace of large-dam construction has accelerated on rivers round the world over the past half century, the Mekong has to date been an exception. Though the catchment contains nine sizeable dams, they are still a small element in the river's hydrology. It is one of the last of the "living rivers". Partly for this reason, its natural fecundity -- measured in fish catches and the natural fertility of soils along its banks -- is almost unrivalled.

The Mekong has been spared the tyranny of dams by a half-century of political and military conflict, and more recently by the Asian economic crisis. But today, a new era of stability and economic growth in the region suggests that this may change. In 1995, the four nations of the lower Mekong signed an agreement for cooperation in the sustainable development of the Mekong, establishing a Mekong River Commission. Should that development include large dams?

While international aid agencies are today much more circumspect about funding dam projects unless the benefits clearly outweigh the disbenefits, many governments particularly in Asia remain keen on their development. A further 12 dams are under construction or in the planning stage along the Mekong, and many more have been suggested, including 18 in Laos alone. The Mekong River presents an important test case for whether governments can make rational decisions about the management of an international river.

The stakes are high. The Mekong contains 1300 species of freshwater fish -- more than any other river bar the Amazon. And there are undoubtedly more. Three new species of fish, each more than a metre long, were discovered in the river in the late 1990s. This diversity is a huge economic resource. The fish are a prime source of protein for the 60 million people living in the river's lower basin. But it is perilously dependent on the river's hydrological cycles -- cycles that face disruptions if dams are built.

The path of the Mekong through Cambodia and Vietnam to its delta is a maze of seasonally flooded pastures, woodlands and natural flood reservoirs known as bongs. These bongs cover 20 000 square kilometres in all. They act like a natural flood regulator, absorbing part of the monsoon flood and, equally important, increasing dry-season flows in the river. Half of their capacity is found in one extraordinary feature, the Tonle Sap or Great Lake in the heart of Cambodia. It is a large shallow expanse of water, linked to the Mekong by the River Tonle Sap. This river is almost unique in the world because it can flow in either direction. For most of the year it drains south into the Mekong but at the height of the monsoon floods it reverses, bursting back into the Great Lake and spilling into the forests around. These flooded forests act as a giant feeding and nursery ground for fish. When the monsoon abates the fish-laden river reverses again and the lake partially drains.

The Tonle Sap, the flooded forests around it, and the other wetlands along the Mekong are believed to be the spawning grounds for 90 per cent of the river's fish. But large-scale dam construction could threaten everything from the ubiquitous hilsa fish to the giant local catfish, which grows up to two metres long and weighs as much as a man.

The fear is that this fecundity could be damaged by dam schemes upstream. More electricity for Laos and Thailand could mean fewer fish for Cambodia and less rice in Vietnam . Engineers would like to use dams to hold back monsoon floods and release more water down the river during the winter dry season. That could maximise hydroelectric power generation. But it would dry up the bungs and have a profound effect on the Tonle Sap's unique hydrology -- and perhaps also the fish that it nurtures.

And, as we have seen, large dams holding back monsoon floods are a recipe for a flooding disaster.

The issue of course is not about dams alone. The entire Mekong catchment has to be developed to maximise the benefit that the river and its attendant wetlands, watersheds and floodplain can offer to the people of the region. Already there are worrying signs of how this process can go wrong. The floods in the Mekong basin in September and October 2000 caused hundreds of deaths and forced more than a million from their homes. The UN Economic and Social Commission for Asia concluded that much of the flooding had been caused by the effects of rampant deforestation, which has seen forest cover reduced from 70% in 1945 to 25% today. Deforestation reduces the ability of soils to soak up heavy rains, triggers flash floods.

The fear is that an acceleration of the convention methods of economic development will worsen such disasters. And dams could play a major factor in that process.

Sustainable development need not require the total cessation of dam building. But it will require detailed assessment of the environmental and social impacts in advance, and in particular a clear understanding of the benefits of freshwater ecosystems, including wetlands and groundwaters, and their dependence on hydrological flows. Where dams are built, their management too will have to be sustainable, with water releases and impoundments attuned to the requirements of the natural river system and downstream human beneficiaries of the river ecosystem, such as fishing communities, floodplain farmers and the users of wetlands. Above all, it will have to be designed on the precautionary principle so that disasters such as those seen around the world from structurally suspect and incompetently managed dams can never be repeated.