Excerpted from Chapter 4
of *Silenced Rivers: The Ecology and Politics of Large Dams*
by Patrick McCully

When Things Fall Apart: The Technical Failures of Large Dams

. . . the river . . .
Keeping his seasons and rages, destroyer, reminder
Of what men choose to forget. Unhonoured, unpropitiated
By worshippers of the machine, but waiting, watching and waiting.
T.S. Eliot, from *Four Quartets*, 1941

IRON DAMS AND CORPSES: DAM SAFETY

With the exception of nuclear power plants, no man-made structure has a greater potential for killing a large number of people than a dam.
Joseph Ellam, Pennsylvania State Director of Dam Safety, 1987

By far the world's worst dam disaster occurred in Henan province in central China in August 1975. As many as 230,000 people may have died in the catastrophe, yet for two decades it was successfully airbrushed from history by the Chinese authorities. If the Chinese had not prevented news of the calamity from reaching the outside world, Henan would presumably represent for the public image of the dam industry what Chernobyl and Bhopal represent for the nuclear and chemical industries.[1]

Detailed information on the Henan catastrophe was first published in English by the US-based group Human Rights Watch in February 1995 in a report on human rights violations at the Three Gorges Dam. Their account is based on a small number of articles by top Chinese water resources experts published in limited-circulation books and journals in the relatively open period of the late 1980s, and on an unpublished investigative account written under a pseudonym by a well-known mainland Chinese journalist.

Banqiao and Shimantan dams were built on the basin of the Huai River, a tributary of the lower Yangtze, in the early 1950s. Banqiao, according to Human Rights Watch, was considered 'an "iron dam" that could never collapse.' The dams were built to be capable of

[1] Banqiao Dam was occasionally briefly mentioned in dam industry publications before information on the catastrophe was available in English (see e.g. Lempérière, F. (1995) 'Cost effective improvements in fill dam safety', *Hydropower & Dams*, January; Ding, Z. (1992) 'Forest Cover', *World Water and Environmental Engineer*, October). It is not known if any in the international dam industry knew of the scale of the catastrophe before February 1995 although it is hard to believe that foreign engineers working in China and having contact with Chinese colleagues would not have known that a major calamity had taken place. If any did know they did not publish the information.

withstanding up to a 1-in-1,000-year flood. The freak typhoon which struck Henan between 5 and 7 August, 1975, however, was estimated to be a 1-in-2,000-year event.

On 5 August, Banqiao Reservoir filled to close to maximum capacity. Its sluice gates were opened, but were found to be partly blocked with sediment. The following day the reservoir rose to more than two meters above its designed safe capacity. On the evening of 7 August, Banqiao Dam burst, and 500 million cubic meters of reservoir water surged over the downstream valleys and plains at nearly 50 kilometers per hour. 'Entire villages and small towns', says Human Rights Watch, 'disappeared in an instant.' The smaller Shimantan Dam collapsed shortly afterwards. In total as many as 62 dams are thought to have collapsed during the typhoon.

The floodwaters from the reservoirs and rivers of the Huai Basin combined to form a lake covering thousands of square kilometres, partially or completely submerging countless villages and small towns. Faith in the ability of dams to hold back flooding had meant that for decades, dike maintenance, river dredging and flood diversionary systems within the basin had been neglected, and there were few outlets through which the newly-created lake could drain. A week after the lake formed, several of the surviving dams in Henan — including some built especially for flood control — were dynamited because it was decided that this was the only way to let the water escape.

The vast lake ruptured transport and communications throughout the region, making many areas inaccessible to disaster relief teams and medical workers. The pseudonymous Chinese journalist describes the aftermath of the dam bursts:

> August 13: Two million people across the district are trapped by the water . . . In Runan, 100,000 who were initially submerged but somehow survived are still floating in the water. In Shangcai, another 600,000 are surrounded by the flood; 4,000 members of Liudayu Brigade in Huabo Commune have stripped the trees bare and eaten all the leaves . . .
>
> August 17: There are still 1.1 million people trapped in the water . . . the disease morbidity rate has soared. According to incomplete statistics, 1.13 million people have contracted illnesses . . .
>
> August 18: Altogether 880,000 people are surrounded by water in Shangcai and Xincai. Out of 500,000 people in Runan, 320,000 have now been stricken with disease, including 33,000 cases of dysentery . . .
>
> Some two weeks after the disaster, when the flood waters finally began to retreat in certain areas of Zhumadian Prefecture, mounds of corpses lay everywhere in sight, rotting and decaying under the hot sun.

Human Rights Watch believes that the most likely interpretation of the few and contradictory statistics available on the death toll from the disaster is that 85,000 were killed by the immediate flood waves from the failed dams, and a further 145,000 died in the epidemics and famine which struck the area in the ensuing weeks.[2]

Statistic Soup

More than 13,500 people have been killed by dam bursts which occurred outside China this century and for which data are available (see Table 7). Statistics on dam failures worldwide, however, are confusing and riddled with inconsistencies. Dam safety expert Robert Jansen, of the Bureau of Reclamation, cites a rough estimate of 2,000 dam failures, including partial collapses, since the 12th century AD and ‘about 200 notable reservoir failures’ between 1900 and 1980. Professor H. Blind of Munich Technical University cites 166 recorded failures of large dams (dams with a height of 15 metres or more). According to Blind’s figures, the rate of failure of small and large dams combined was at its highest in the 1910s and 1920s, with around 30 recorded failures in each decade. Since then the rate has varied between 8 and 25 per decade. Data collected for this book indicate that at least 17 dams failed in the six years between 1990 and 1995.

According to ICOLD data, around 2.2 per cent of all dams built before 1950 have failed and 0.5 per cent of dams built since then. Most of the failures are of small dams — which also make up the great majority of dams. Blind gives an average failure rate between 1900 and 1969 of 2.4 per cent for small dams and 1.7 per cent for large dams. These data explicitly exclude China and are also likely to be incomplete for other countries. Inside China, some 3,200 dams have failed since 1950, four per cent of the 80,000 classified dams in the country. The average worldwide risk of any dam failing in a given year is calculated to be in the order of 1 in 10,000.[3]

A huge number of things can go wrong with a dam. The two main reasons for dam failures are ‘overtopping’ (responsible for around 40 per cent of failures) and foundation problems (around 30 per cent). Embankment dams, which make up about four-fifths of the world’s dams, are most vulnerable to being washed away when water flows over their crest. There is, however, usually a number of interrelated reasons why any particular dam collapses. A dam may be overtopped, for example, because of the inadequate capacity of its spillways to

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[2] 'The Three Gorges Dam in China: Forced Resettlement, Suppression of Dissent and Labor Rights Concerns', *Human Rights Watch/Asia*, Vol. 7, No. 2, 1995.

[3] Jansen, R.B. (1983) *Dams and Public Safety*. US Department of the Interior, Washington, DC; Blind, H. (1983) 'The safety of dams', *Water Power & Dam Construction*, May; 'ICOLD reports on dam failures', *International Water Power & Dam Construction*, May, 1995; Dai, Q. (forthcoming) *Yangtze! Yangtze! Vol. II;* Costa, J.E. (1988) 'Floods from Dam Failures', in Baker, V.R. et al. (eds.) *Flood Geomorphology*. Wiley, New York. Dam failure data usually include tailings (or 'slimes') dams built to contain mining wastes, which are significantly different in design and function than river dams (tailings dams have an abysmal safety record, and often leak toxic heavy metal residues into nearby rivers).

discharge floodwaters, because of a spillway blockage with flood-borne debris, or due to mechanical or electrical problems which prevent the spillway gates being opened in time. The spillway gates may also be opened late because of poor operator judgement or incorrect predictions of the size of flood entering the reservoir. Internal erosion (known as 'piping') caused by leaks through the core of a dam can also cause it to slump and be overtopped.

Table 4.2: Recorded dam failures since 1860 which have killed more than 10 people

Dam	Country	Type	Height (m)	Year Completed	Year Failed	Cause of Failure	People Killed	Cost of Damage
Dale Dyke (Bradfield)	England	E	29	1858	1864	SF	250[1]	£0.5m
Iruhaike	Japan	E	28	1633	1868	OT	>1,000[2]	
Mill River	MA, USA	E	13	1865	1874	SF	143	>$1m
El Habra†	Algeria	R	36		1881	OT	209	
Valparaíso	Chile	E	17		1888	SF	>100	
South Fork (Johnstown)	PA, USA	E	22	1853	1889	OT	2,209	
Walnut Grove	AZ, USA	R	34	1888	1890	OT	150	
Bouzey	France	G	15	1881	1895	SF	150[1]	
Austin	PA, USA	G	15	1909	1911	SF	80	
Lower Otay	CA, USA	R	40	1897	1916	OT	30	
Bila Desna	Czecho-slovakia	E	17	1915	1916	SF	65	
Tigra	India	G	24	1917	1917	OT	>1,000[2]	
Gleno	Italy	M/G	44	1923	1923	SF	600	
Eigiau Coedty§	Wales	G E	11	1908 1924	1925	PI OT	16	
St Francis	CA, USA	A	62	1926	1928	SF	450	
Alla Sella Zerbino	Italy	G	12	1923	1935	OT	>100	
Vega de Terra (Ribadelago)	Spain	B	34	1957	1959	SF	145	
Malpasset (Fréjus)	France	A	61	1954	1959	F	421	
Orós	Brazil	E	54	const	1960	OT	c.1,000	
Babii Yar	Ukraine	E			1961	OT	145	
Panshet Khadakwasla§	India	E R	54 42	const 1879	1961	SF/OT OT	>1,000[2]	
Hyokiri	S. Korea				1961		250	
Kuala Lumpur	Malaysia				1961		600	
Vaiont	Italy	A	261	1960	1963	OT	2,600	

Quebrada la Chapa	Colombia				1963		250	
Swift	MT, USA				1964		19[3]	
Zgorigrad (Vratza)	Bulgaria	Ta	12		1966	OT	>96	
Nanaksagar	India	E	16	1962	1967	SF/OT	c.100	
Sempor	Indonesia	R	54	const	1967	SF/OT	c.200	
Frías	Argentina	R	15	1940	1970	OT	>42	
Buffalo Creek	WV, USA	Ta	32	const	1972	OT	125	$30-50m[a]
Canyon Lake	SD, USA	E	6	1938	1972	OT	237*	$60m
Banqiao Shimantan 60 others	China	E		late 1950s	1975	OT	≤230,000[4]	
Teton	ID, USA	E	90	1976	1976	SF	11-14	$400m-$1bn
Laurel Run	PA, USA				1977		39[3]	$20-45m[a]
Kelly Barnes (Toccoa Falls)	GA, USA	E	13	1899	1977	SF	39[3]	
Machhu II	India	E	26	1972	1979	OT	>2000	$15m crops
Gopinatham	India			1980	1981	OT	47[5]	
Tous	Spain	R	77	1980	1982	OT	>20[6]	
Stava	Italy	Ta		1960s	1985		269[7]	
Kantalai	Sri Lanka	R	15	1952	1986	PI	≤82[8]	
Sargazon	Tadjik-istan		23	1980	1987		>19[9]	
Belci	Romania	E	18	1962	1991	OT	c.48[10]	
Gouhou	China	R	71	1987	1993	PI	342[11]	$18m
Tirlyan	Russia	E	10	<1917	1994	OT	19-37[12]	Rbls40bn
Virginia No. 15	S. Africa	Ta	47		1994		39[13]	$15m
Lake Blackshear Project Flint River Dam	GA, USA	E E	<15 <15		1994	OT OT	15[14]	
N/A	Philli-pines	N/A	N/A	N/A	1995	N/A	c.30[15]	

Dam Types: E = earthfill R = rockfill G = gravity M = multi-arch B = buttress
A = arch Ta = tailings dam

Cause of Failure: OT = overtopping PI = piping SF = structural failure
F = geological/foundation weakness

* = unable to distinguish dam break fatalities with those caused by 'natural' flood

† El Habra first failed in 1872 without loss of life. It was then rebuilt, failed again in 1881, rebuilt again, then failed again in 1927 (without fatalities) and was then abandoned.

§ The flood from the collapse of the first dam breached the second dam downstream.

Sources:

1. Smith, N. (1971) *A History of Dams*. Peter Davies, London.
2. Lempérière, F. (1993) 'Dams that have failed by flooding: an anlysis of 70 failures', *Water Power and Dam Construction*, October.
3. Costa, J.E. (1988) 'Floods from Dam Failures', in Baker, V.R. et al. (eds.) *Flood Geomorphology.* Wiley, New York.
4. Human Rights Watch/Asia (1995) *The Three Gorges Dam in China: Forced Resettlement, Suppression of Dissent and Labor Rights Concerns*. New York, February.
5. Centre for Science and Environment (1982) *The State of India's Environment --1982: A Citizen's Report*. CSE, New Delhi.
6. 'Overtopped Spanish dam collapses as spillway gates stay shut', *World Water*, November, 1982.
7. 'South African dam breach followed warnings', *Construction Today*, March, 1994.
8. 'Kantalai failure leaves 18,000 homeless', *Water Power and Dam Construction*, May, 1986.
9. 'Burst raises doubts about Soviet hydroelectricity dam', *Nature*, March 26, 1987.
10. 'Flooding and landslides cause three major failures in Romania', *Water Power and Dam Construction*, October, 1991.
11. 'China Disciplines 15 for Dam Break', *Tibetan Environment & Development News*, Issue 16, 1994.
12. 'The Tirlyan breakthrough', *Moscow News*, August 19, 1944.
13. 'When the bough breaks . . . ', *Higher Values* (Minewatch Bulletin), April, 1994.
14. 'Georgia flood deaths', *International Water Power and Dam Construction*, August, 1994.
15. Tangbawan, R. (1995) 'Angela's toll in Philippines nearing 500', *San Francisco Chronicle*, November 5.
16. Ellingwood, B. et al. (1993) 'Assessing Costs of Dam Failure', *Journal of Water Resources Planning and Management*, Vol. 119, No. 1, January/February.
All others: Jansen, R.B. (1980) *Dams and Public Safety.* US Department of the Interior, Washington, DC.

Building a totally safe dam is simply not possible. Robert Jansen says that dams 'require defensive engineering, which means listing every imaginable force that might be imposed, examination of every possible set of circumstances, and incorporation of protective elements to cope with each and every condition.' This is clearly an unattainable target. In the real world, the degree of 'defensive engineering' applied to the design of a dam will be decided by economics. The safer a dam — the greater the capacity of its spillways to cope with floods, the better the quality of its construction materials, the more extensive the exploration of the local geology — the more it will cost. ICOLD itself recognizes the conflict, stating in its 1987 guidelines on dam safety that: 'For every dam project, a balance has to be found between dam safety and economy.'[4]

There will always therefore be pressure for dam builders to cut corners on safety, just as they cut corners on hydrological or sedimentation studies. A confidential 1991 World Bank report notes that because of 'financial factors and local pressure to take shortcuts or ignore poor quality work', construction quality in India is 'deficient for a number of dams, posing serious potential risk to downstream populations'. The report explains how during construction 'large illicit profits can be made by using substandard materials.'[5]

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[4] Jansen (1983), op. cit., 91; 'Dam Safety Recommendations', ICOLD Bulletin 59, 1987, Paris, 17.
[5] World Bank (1991) 'India: Irrigation Sector Review. Volume 1 - Main Report', India Department, 38.

Although several large dams have been seriously damaged by earthquakes, none are yet known to have collapsed because of seismic shaking. At least part of the reason for the apparent resilience of large dams to earthquake damage is, as the US Committee on Large Dams notes, that most have been built very recently in seismic terms, and few 'have been shaken by earthquakes of local duration and intensity sufficient to jeopardize their structural integrity'. USCOLD also points out that 'a few dams have experienced significant damage under shaking less demanding than what had or should have been considered in their design.' The good luck that not many dams have yet been seriously tested in a severe earthquake is compounded with at least one incident where only luck prevented earthquake damage to a dam being translated into a catastrophe.

The Upper and Lower Van Norman Dams in the San Fernando Valley in southern California, completed between 1918 and 1921, were two of the most important dams in the Los Angeles water supply system. On 9 February, 1971, a magnitude 6.5 quake struck the San Fernando Valley, with its epicentre about 11 kilometres from the dams. The upstream face of the 43-metre-high Lower Van Norman Dam slumped and collapsed into its reservoir. Due to a preceding dry winter the reservoir was only half full, its surface nearly 11 metres beneath the crest of the earthfill dam. After the tremor struck, only 1.5 metres separated the reservoir surface from the ragged top of the surviving embankment.[6]

The smaller upper dam also slumped during the quake, though less severely than its downstream neighbour. Had this upper dam failed, the ensuing spill would undoubtedly have overtopped and washed away the remaining part of the lower dam. Fears that aftershocks could have caused either or both dams to be breached led to the evacuation of 70,000 valley residents until the lower dam could be safely drained. 'There is no question that, if conditions had been just fractionally more adverse,' says BuRec's Robert Jansen, 'this event would have been recorded as one of the worst disasters in history.'[7]

Despite the massive risk to human life and property posed by large dams, few countries have comprehensive safety legislation covering such areas as the safety criteria that new dams should have to meet; the regular inspection and repair of old dams; and the preparation of emergency evacuation plans for people living downstream. Many older dams were not built with sufficient spillway capacity to pass what hydrologists would now consider the largest flood likely in their basin (conventionally classified as the 'Probable Maximum Flood' or PMF), or sufficient strength to withstand the most powerful earthquake the dam might have to survive (conventionally classified as the 'Maximum Credible Earthquake' or MCE). Yet in most countries there is no requirement for dam owners to upgrade their structures, little data

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6 'Had the reservoir been at its normal (and five-foot higher) water level at the time of the earthquake the 70,000 people that lived immediately downstream . . . would not have been evacuated in time' (US Committee on Large Dams (1992), op. cit., 62).

7 Jansen, R.B. (1980) *Dams and Public Safety*. US Department of the Interior, Washington, DC.

with which to calculate the PMF and MCE, and rarely even agreement among different dam building agencies over whether or not the PMF and MCE are suitable safety criteria.[8]

Studies in the US have shown that where early warning systems and evacuation plans are in place, the fatalities caused by dam bursts are on average reduced by a factor of more than one hundred. However such plans have been made for only a handful of the world's dams, mostly in the US, Canada and Australia. The first step in an emergency plan should be to draw up and make public a detailed 'inundation map' of areas at risk if a dam should burst. Yet according to David Ingle Smith of the Australian National University in Canberra, of the few countries that have produced adequate inundation maps some regard them as so confidential that they do not allow even the emergency services to see them. This obsessive secrecy is sometimes due to concerns over the maps being used by the enemy in times of war: in other cases, says Smith, the authorities simply do not want to admit that all dams are potential threats to people living below them.[9]

Disasters Waiting to Happen

When a big project has troubles, they may well be big troubles.

John Lowe III and Wilson V. Binger, Partners of New York consulting engineers TAMS, discussing their involvement in Tarbela Dam, 1982

Advances in hydrology and dam building technology, especially in the understanding of the behaviour of rock, earth and water under pressure, means that, in general, new dams are progressively becoming less likely to collapse. However the risk of another serious dam disaster occurring is continually rising as more dams are built; as their average height increases; as the best locations are used up, forcing dam builders onto increasingly difficult sites; and as the world's largest dams, almost all of which have been built since the 1950s, steadily age and deteriorate. Of the world's nearly 300 'major' dams, as defined by the industry, only Vaiont has caused a major disaster, but a couple of known near misses indicate that these dams, some of which have the potential to kill hundreds of thousands, even millions, of people, are no more unbreakable than the Titanic was unsinkable.

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8 Dams are built to safely pass their 'design flood', which most regulatory agencies define as the Probable Maximum Flood or as a flood which is statistically likely to occur once in a certain number of years (normally between 1,000 and 10,000) (see e.g. Cassidy, J.J. (1994) 'Choice and computation of design floods and the influence on dam safety', *Hydropower & Dams*, January). The statistical methods used by hydrologists to calculate floods of low exceedence such as those over 1:1000 years are subject to many controversial assumptions.

9 Smith, D.I. (1989) 'A dam disaster waiting to break', *New Scientist*, November 11; Nielson, N.M. (1993) 'BC Hydro's approach to dam safety', *Water Power & Dam Construction*, March). In Britain people living below dams are never alerted to the fact that they could be at risk, no inundation maps exist, no emergency plans have been drawn up in case of a dam failure, and there is no agreement over who should be responsible for warning or evacuating people if a break does occur (Connolly, J. (1985) 'Fears over Britain's dams', *Sunday Times*, London, July 28; 'The case of one hundred disappearing reservoirs', *New Scientist*, July 31, 1993).

Tarbela, in Pakistan, a massive embankment of earth and rock nearly three kilometres long and at its highest point rising 143 metres above its foundations, is perhaps the world's most problem-stricken major dam. Only a highly expensive programme of emergency repairs and continual monitoring and maintenance have prevented its reservoir from bursting through the embankment and devastating the densely populated Vale of Peshawar below. The full story of how close the mammoth dam came to being breached has never been fully revealed. The following description is mainly taken from a leaked report written for the World Bank by their consultants on the project, UK engineering firm, Sir Alexander Gibb & Partners.[10]

The catalogue of mishaps at Tarbela began with the first reservoir impoundment during the 1974 flood season when two out of four tunnels being used to control the rate of filling had to be closed due to serious damage to their linings and outlets. A week after their closure, one of the tunnels still in operation collapsed, bringing down nearly half a million cubic metres of the dam structure and nearby bedrock with it. This threat to the dam required an 'immediate emergency drawdown' of the reservoir through the sole remaining undamaged tunnel as well as through the least-damaged gates of the two tunnels which had earlier been shut.

After the emergency drawdown, engineers found that the blanket of silt and gravel laid on the reservoir bed near the dam to prevent seepage under the embankment had cracked and subsided at around 70 'sinkholes' up to a metre deep and five metres across. The following year several hundred more sinkholes appeared in the blanket, and in 1976 large depressions appeared in the upstream face of the main embankment and one of two smaller auxiliary embankments. Between 1975 and 1978 the sinkholes were covered by dumping thousands of barge loads of earth into the reservoir. A large sinkhole which appeared in the main embankment in 1984 was in 1991 still causing concern that it could at some time affect the permeability of the dam.[11]

The designers of Tarbela's spillways knew that the force of flood water plunging off the concrete chutes and into the river below would erode away the fractured, soft rock at the spillway bases, but it was wrongly presumed that this would happen gradually and safely. The main spillway began full operation in the 1976 flood season. Within three weeks, the spilled water had gouged out a hole in the 'plunge pool' at its bottom in places 50 metres deep and 300 metres wide, causing the original sides of the pool to collapse. The following flood season the rocks at the base of the spillway began to be eaten away, threatening the safety of the huge concrete spillway, which at one point actually began to move.[12]

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[10] Sir Alexander Gibb & Partners (1980) *The Tarbela Experience. A Report to the World Bank*. Reading, England, June, 26-27.

[11] 'Report of the 17th ICOLD Congress: Q65: Ageing of dams and remedial measures', *Water Power & Dam Construction*, October 1991.

[12] la Villa, G. and Golser, J. (1982) 'Slopes of the Tarbela Dam Project', *Rock Mechanics*, Suppl. 12; Lowe III, J., Chao, P.C. and Luecker, A.R. (1979) 'Tarbela service spillway plunge pool development', *Water Power & Dam Construction*, November.

Tarbela's auxiliary spillway, originally designed only to be used in the event of the most extreme floods, had to be operated regularly from 1975 onwards to relieve some of the pressure on the main spillway. In 1979 it was found that the erosion in the auxiliary plunge pool had also been much more serious than expected, endangering the two auxiliary embankments holding back the reservoir in the spillway section of the dam. A massively expensive operation to stabilize the rock around the plunge pools took three years to complete.

The stop-gap programme to prevent disaster at Tarbela almost doubled the cost of the project. Estimated to cost $800 million in 1968, Pakistan had spent around $1.5 billion on Tarbela by 1986 (estimates in constant 1989 prices).[13]

Another notable near miss occurred at the 216-metre Glen Canyon Dam on the Colorado during heavy floods in June 1983. One of the dam's two spillways (which are tunnels through rock at the side of the dam rather than uncovered chutes as at Tarbela) partially caved in. The threat this posed to the stability of the dam abutments meant that both spillways had to be shut. Powell Reservoir, however, kept rising, and would have overtopped the gates of the endangered spillways had not plywood boards obtained from a local lumberyard been fastened to the top of the gates, holding back the reservoir for a few more nerve-wracking days.

BuRec engineers, according to an internal memo, thought there would be an 'uncontrolled release' if the reservoir reached 3,708.40 feet above sea level. The reservoir finally peaked at 3,708.34 feet. Less than an inch — around two centimetres — saved the lower Colorado from probably the most massive flood in human history.[14] Banqiao and Shimantan combined released 600 million cubic meters of water: Powell Reservoir in June 1983 held more than 33 *billion* cubic metres.

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[13] Dixon, J.A., et al. (1989) *Dams and the Environment: Considerations in World Bank Projects*. World Bank Technical Paper 110, 35.

[14] See Martin, R. (1989) *A Story that Stands Like a Dam*. Henry Holt, New York, 315-317; Fradkin, P.L. (1995) 'The Year the Dam (Almost) Broke', *Los Angeles Times*, 29 October.