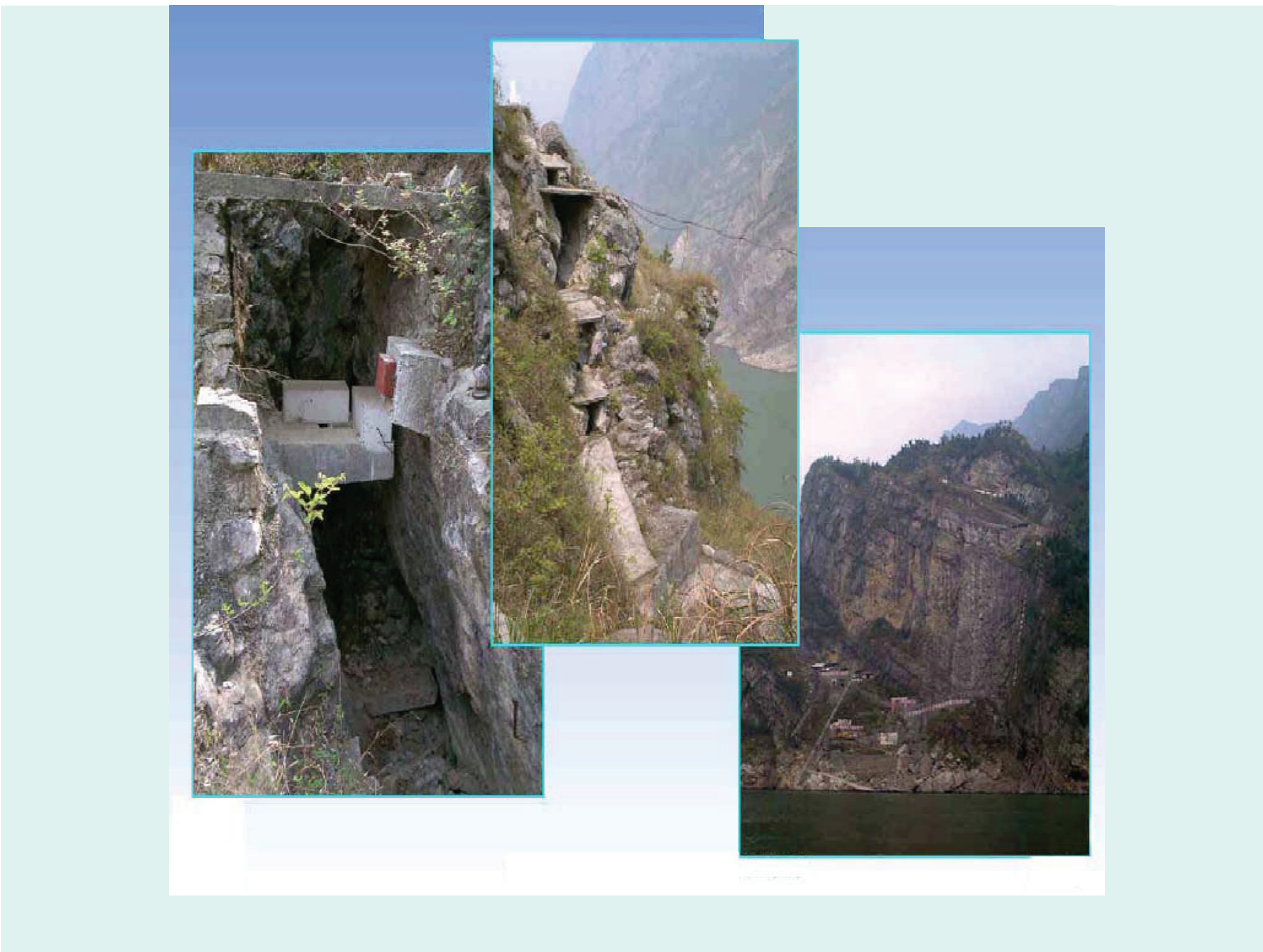
Geographical Overview of the Three Gorges Dam and Reservoir, China—Geologic Hazards and Environmental Impacts



Open-File Report 2008–1241

U.S. Department of the Interior
U.S. Geological Survey

Geographical Overview of the Three Gorges Dam and Reservoir, China—Geologic Hazards and Environmental Impacts

By Lynn M. Highland

Open-File Report 2008–1241

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2008

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

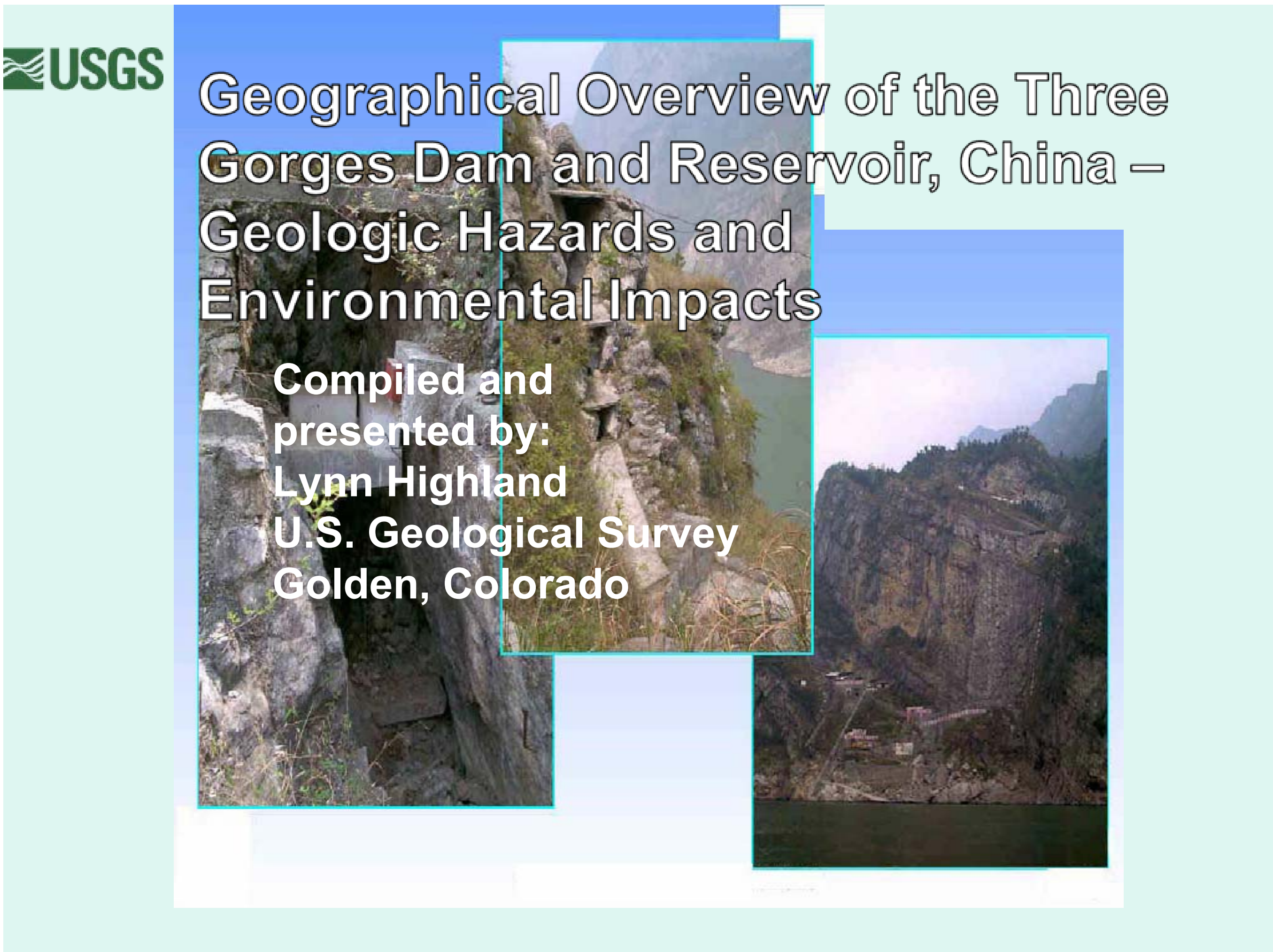
Suggested citation:
Highland, L.M., 2008, Geographical overview of the Three Gorges dam and reservoir, China—Geologic hazards and environmental impacts: U.S. Geological Survey Open-File Report 2008–1241, 79 p.
http://pubs.usgs.gov/of/2008/1241/

Contents

Geographical Overview of the Three Gorges Dam and Reservoir, China—Geologic Hazards and Environmental Impacts

By Lynn M. Highland

Slide 1



Photograph and graphic: modified from GeoForschunpsZeatrim, Potsdam

The Three Gorges dam and reservoir are an ongoing project that will involve a continuous process of construction, maintenance, monitoring, evaluation, and modification. Some of the history, construction characteristics, hydropower statistics, environmental and population impacts, monitoring, and current and potential hazards of the massive dam project are presented in this Microsoft PowerPoint® format (a paper report can also be downloaded from the PowerPoint® version) with references and links to more information (in the notes section of slide 73).

Some information (where noted) came from a field trip the author participated in during the summer of 2006. The author accompanied research scientists from China Three Gorges University, China, and Kyoto University, Japan, who were assessing and monitoring landslide and rockfall hazards in the Three Gorges area.

There is a wealth of information on this project and its ongoing evolution as a source of hydroelectric power and flood control. The world watches with keen interest the progress and challenges of the largest dam project to date (2006) in the world. This presentation is but an overview of the effects of the dam from a geologic hazards point of view and of some of the effects on populations and the environment of this part of the Yangtze River.

Note: Some internet addresses used as references in this report may change with time or become obsolete. If an address does not open, it is suggested that readers try an internet search engine for the same or similar information.

Slide 2

Photograph: source unknown

Much of the English-language background information for this presentation can be found in the official Three Gorges Web site that is maintained by the government of China. The Web site also features an up-to-date news link that presents current news and progress of this ongoing project. (Web sites accessed May 13, 2008.)

Three Gorges official Web site: *http://www.ctgpc.com/*

News link in Web site: *http://www.ctgpc.com/news/news.php*

Dam ownership and operating management: *http://www.ctgpc.com/owner/owner_a.php*

In addition, bibliographic references are provided as appropriate. Much of the information on Three Gorges Dam topics is in Chinese and has not been translated into English.

Slide 3

Dam Experimental Laboratory

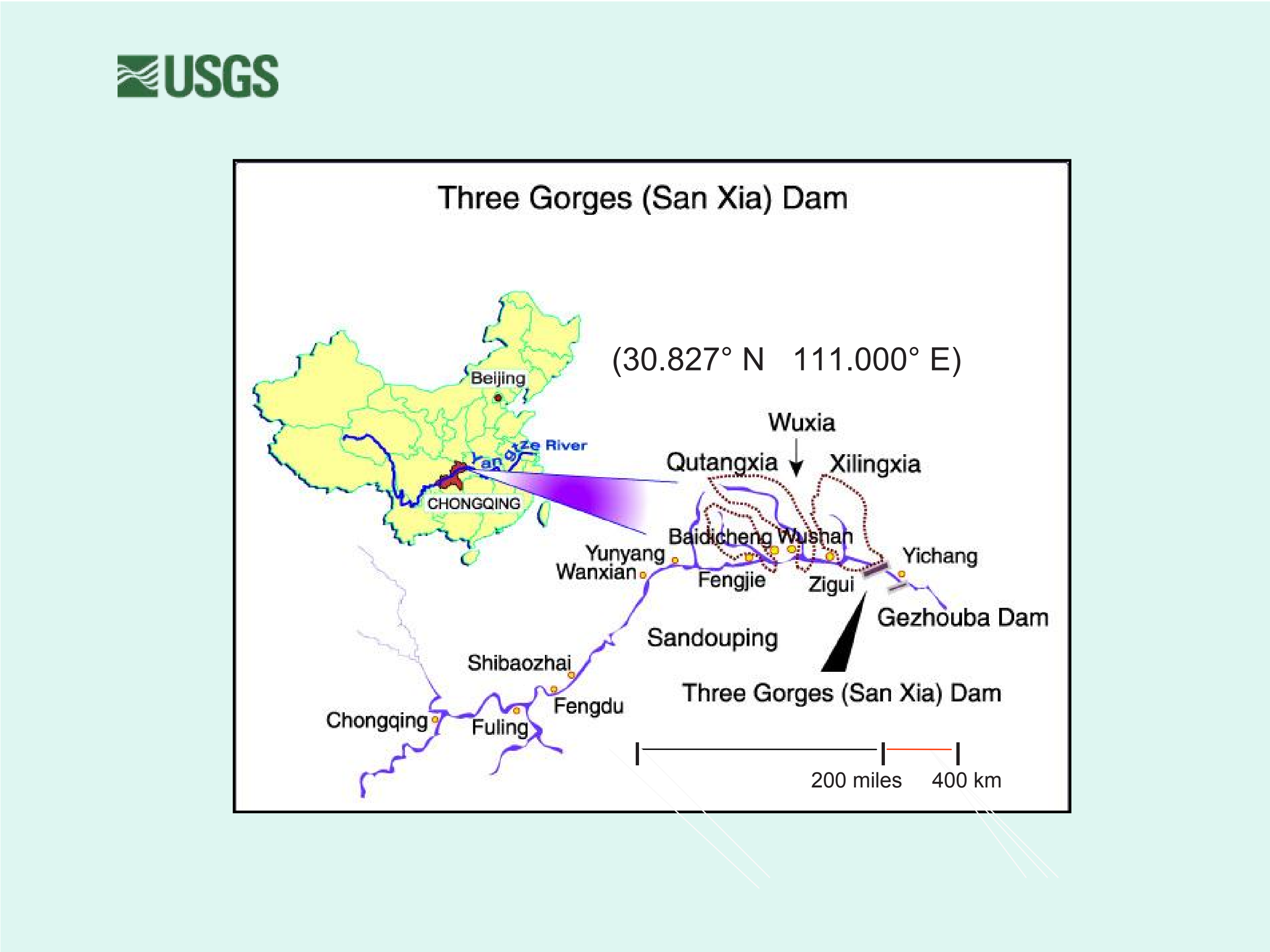
China Three Gorges University (CTGU) was founded in Yichang City, in the year 2000, and is home to the construction of the Three Gorges Project.

CTGU is a comprehensive university, which comprises the former University of Hydraulic & Electric Engineering and Hubei Sanxia University.

Photographs: Lynn Highland, U.S. Geological Survey

Information in this slide was obtained from a field excursion to the university during the field trip to Three Gorges Reservoir, July 2006, and from the China Three Gorges University Web site: *http://www.ctgu.edu.cn/en/*

Slide 4



Graph: source unknown

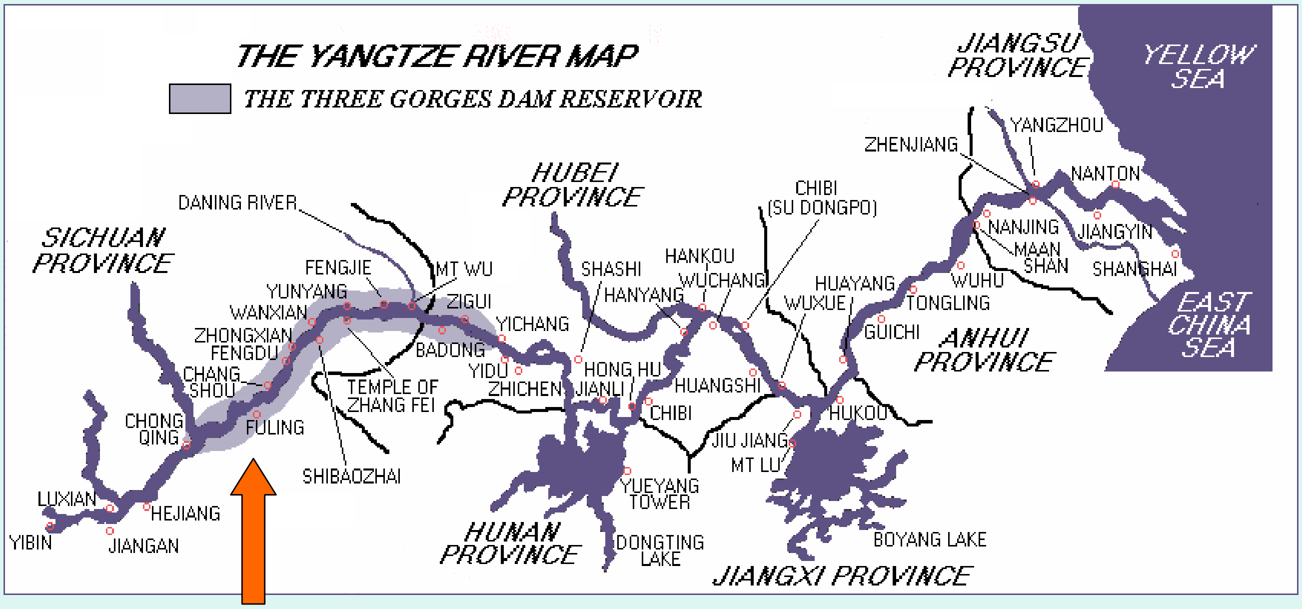
Location of the Three Gorges for which the dam is named—Quatangxia, Wuxia, and Xilingxia. The dam coordinates are 30° 49' 48" N., 111° 0' 36" E.

Slide 5

USGS

Chang Jiang (Yangtze River)

"Long River" in Mandarin



662.4 km- (414 mile-) long reservoir

The Yangtze begins in Tibetan highlands – flows to the East China Sea, and is 6,208 km (3,880 miles) long. It is one of the most sediment-filled rivers on earth.

Graphic: modified from Christine Yun-Yu Sun, *http://www.solidsoftware.com*

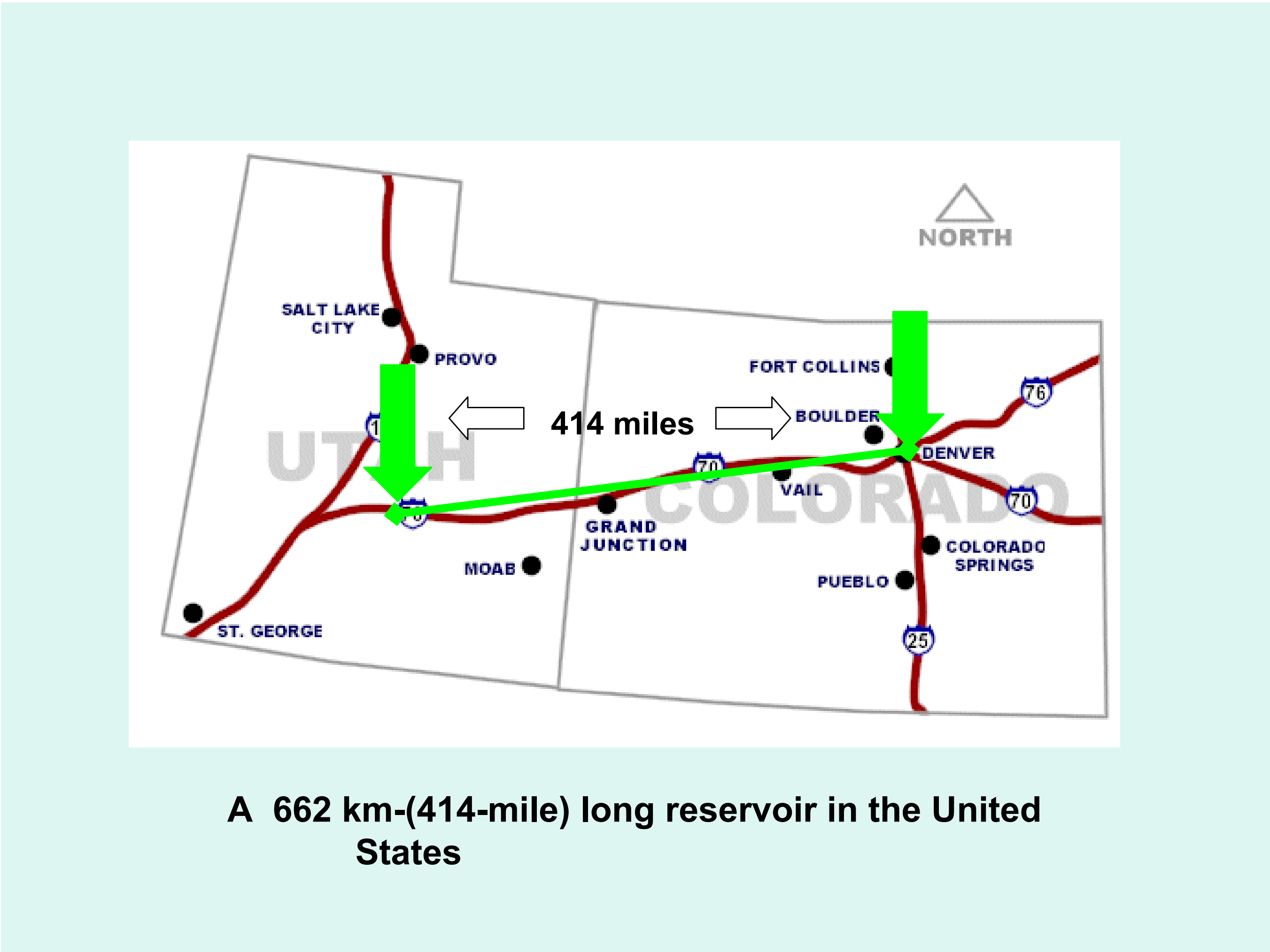
When the reservoir is full, the water level is expected to reach 175 m elevation (525 feet) behind the dam, creating a 632 km[2] reservoir that will flood 2 cities, 11 counties, 116 towns, and the gorges of Qutangxia, Wuxia, and Xilingxia.

Slide 6

Dam Reservoir will be 662 km (414 miles) long after final filling in 2009

Graphic: source unknown

Slide 7



Graphic: Lynn Highland, U.S. Geological Survey

A 662-km (414-mile) distance in the United States.

Slide 8

Three Gorges Dam Facts

Dam type: Concrete Gravity

Dam height: 199m (652 feet)

Dam length: 2.24 km (1.4 miles)

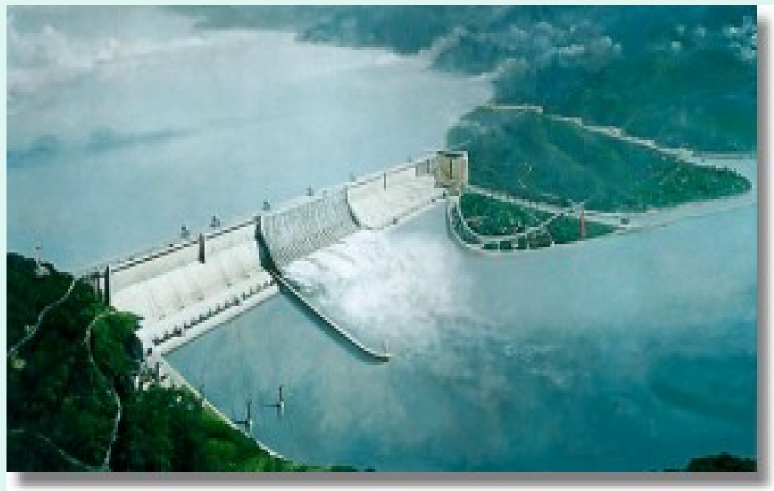
Expected investment:
203.9 billion yuan
(U.S. $24.6 billion)

Construction period:
1993-2009

People to be displaced:
1.3 to 1.9 million

Area to be submerged:
1,000 sq km (400 square miles)
Dam Reservoir length:
662 km (14 miles)

Storage: 39.3 billion cubic meters of water (51.4 billion cubic yards).



The Three Gorges Dam will produce 50 percent more power than South America's Itaipu Dam, which used to be the largest dam in the world.

Photograph: International Hydropower Association, United Kingdom, *http://www.hydropower.org/index.asp*

The Three Gorges Dam Project in Comparison

Three Gorges Dam, China—	**18,200 megawatts**
Itaipu, Brazil and Paraguay—	12,600 megawatts
Guri, Venezuela—	10,000 megawatts
Grand Coulee, United States—	6,494 megawatts
Sayano-Shushensk, Russia—	6,400 megawatts
Krasnoyarsk, Russia—	6,000 megawatts
Churchill Falls, Canada—	5,428 megawatts
La Grande, Canada—	5,328 megawatts

Reference:

International Hydropower Association, United Kingdom. *http://www.hydropower.org/index.asp*

Slide 9

Photograph: source unknown

Reference:

Three Gorges official Web site, *http://www.ctgpc.com/*

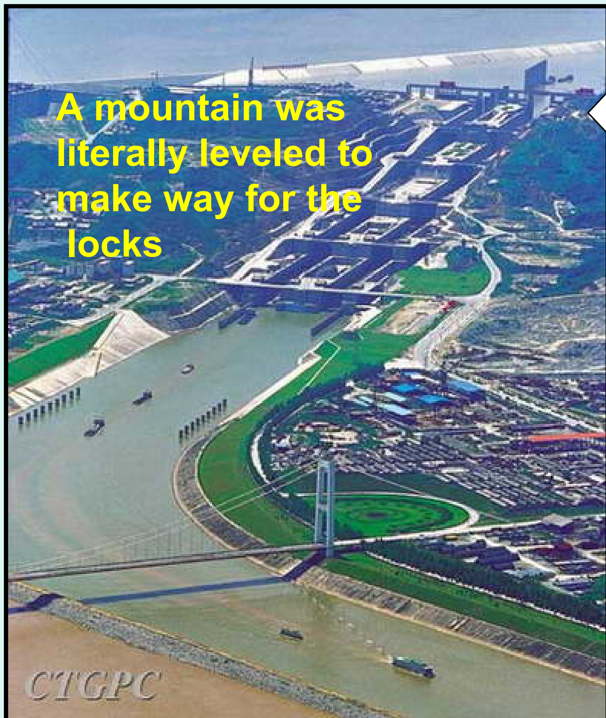
Slide 10

Photograph: source unknown

Reference:

Three Gorges official Web site, *http://www.ctgpc.com/*

Slide 11



Ship Locks for ship navigation through the dam.

Currently takes a ship 4 hours to go through the 5 locks. Eventually, a yet- to-be-built hydraulic lift will lift the ships through much faster

Photos from official Three Gorges Dam website: http://www.ctgpc.com/

USGS

Photographs: source unknown

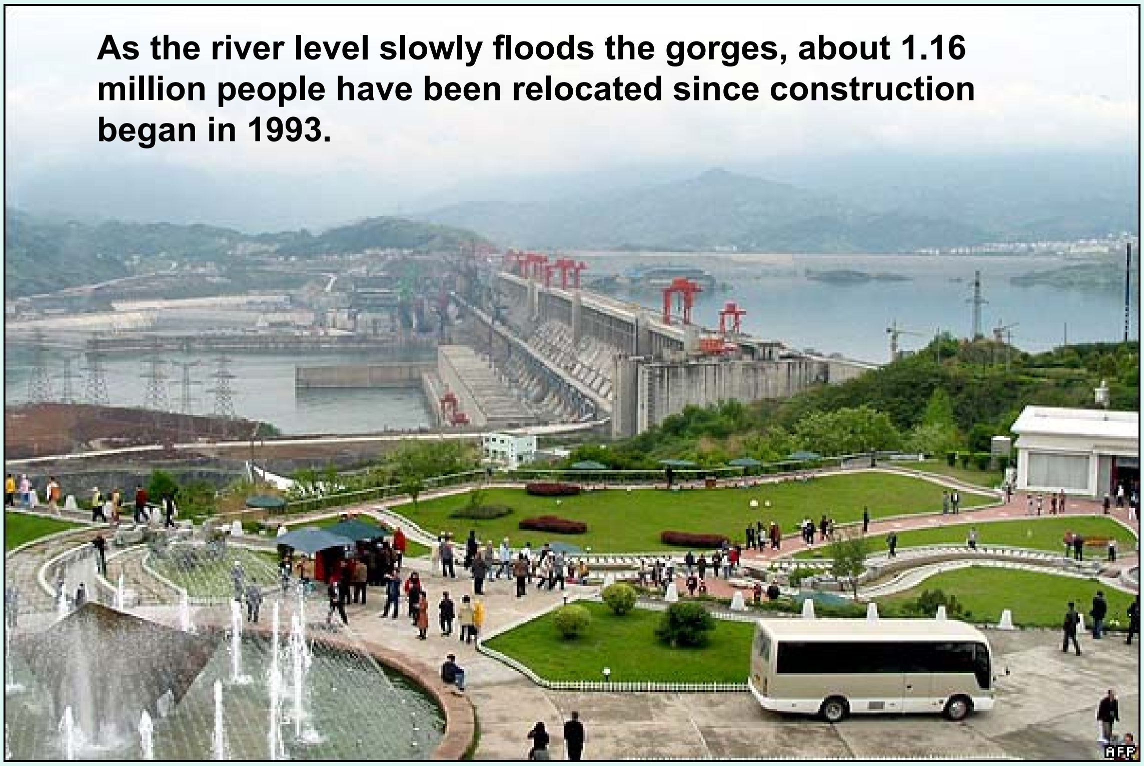
The ongoing dam and reservoir project at the Three Gorges Site is a continuous process of siting, construction, maintenance, and monitoring of functions and effects. The hydropower that is generated is classified as a "renewable" energy source.

References:

Three Gorges official Web site, *http://www.ctgpc.com*

Three Gorges official Web site, *http://www.ctgpc.com/news/news.php*

Slide 12



Some people have been moved to higher elevations above the river, others to other parts of China

Photograph: source unknown

A major concern is the trouble zone created by the future operation of the Three Gorges dam. After the project is completed in 2009, the water level in the reservoir is to be kept at 175 m (525 feet) above sea level during the dry winter months and lowered to 145 m (435 feet) for the summer flood season. The 30-m-high (90-foot-high) strip of land between those two levels will be covered with water in winter and exposed in summer. This wide ring around the Three Gorges reservoir and along the banks of upstream tributaries could become geologically unstable, seriously polluted, and a dangerous source of epidemic disease.

References—Resettlement

Jackson, Sukhan, and Sleigh, Adrian, 2000, Resettlement for China's Three Gorges Dam: Socio-economic impact and institutional tensions: Communist and Post-Communist Studies, v. 33, no. 2 (June), p. 223–241.

Kuhn, Anthony, 2008, Relocated Three Gorges residents face challenges: National Public Radio, series, "China's Three Gorges: Assessing the Impact." January 3, 2008.

http://www.npr.org/templates/story/story.php?storyId=17784497

References—Epidemic disease

http://www.probeinternational.org/catalog/content_fullstory.php?contentId=2781&cat_id=24

Oriental Outlook Magazine (Liaowang dongfang zhouka, a division of China Xinhua News), Shanghai, March 16, 2005.

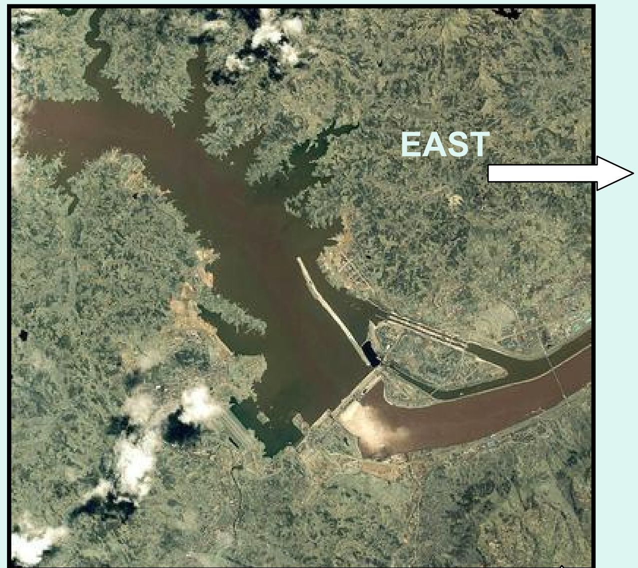
Chongqing, China Morning Post (Chongqing chenbao), March 7, 2005.

Slide 13

Photograph: Lynn Highland, U.S. Geological Survey

Slide 14

Satellite Images of the Three Gorges Dam

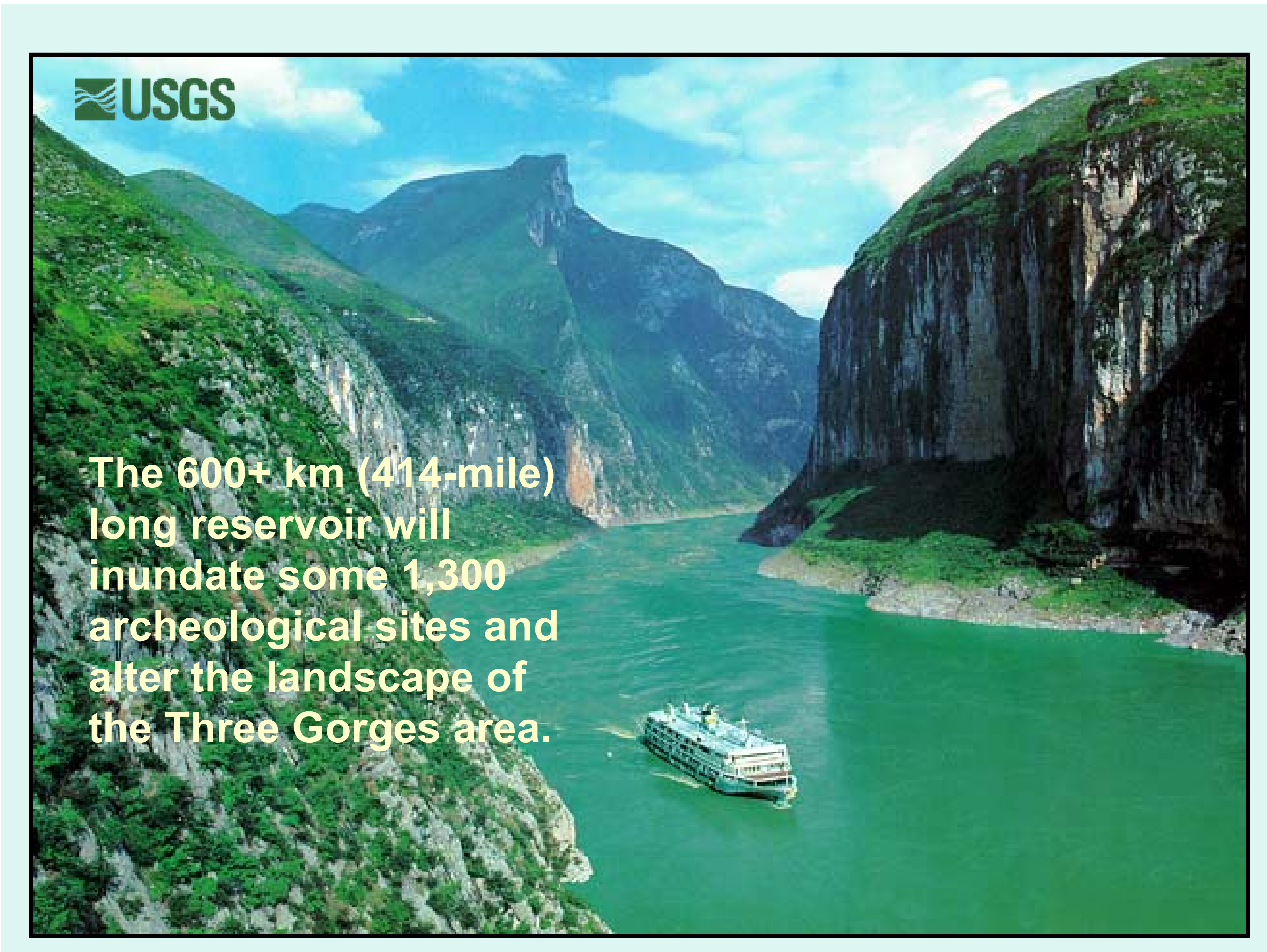


Aerial photo above, shows reservoir at 135 m (443 feet) high in 2006-- it will be 175 m (574 feet) in 2009.

USGS

Photographs: source unknown

Slide 15



Photograph: source unknown

Slide 16

USGS

A Short HISTORY

1. In 1918, Sun Yat-Sen suggested, in his book *Strategy for State, Part II: Industrial Plans*, a scheme to "improve the upstream from here", that is, "a dam should be set here to let ships go downstream and use the water resource as power."

2. In May 1945, Dr. John Lucian Savage, a famous American expert in dam construction put forward his *Preliminary Report on Development Plans of Three Gorges.*

After many, many state councils, and a preliminary small dam was constructed, it was decided the 3 Gorges Dam Construction should go ahead

3. On 14 Dec 1994, the Three Gorges project was officially started. A series of 5 locks to facilitate ship navigation was also started.

4. On 16 June 2003, the trial navigation of ship locks succeeded. On 18 June 2003, the ship lock started to be open to all sorts of ships.

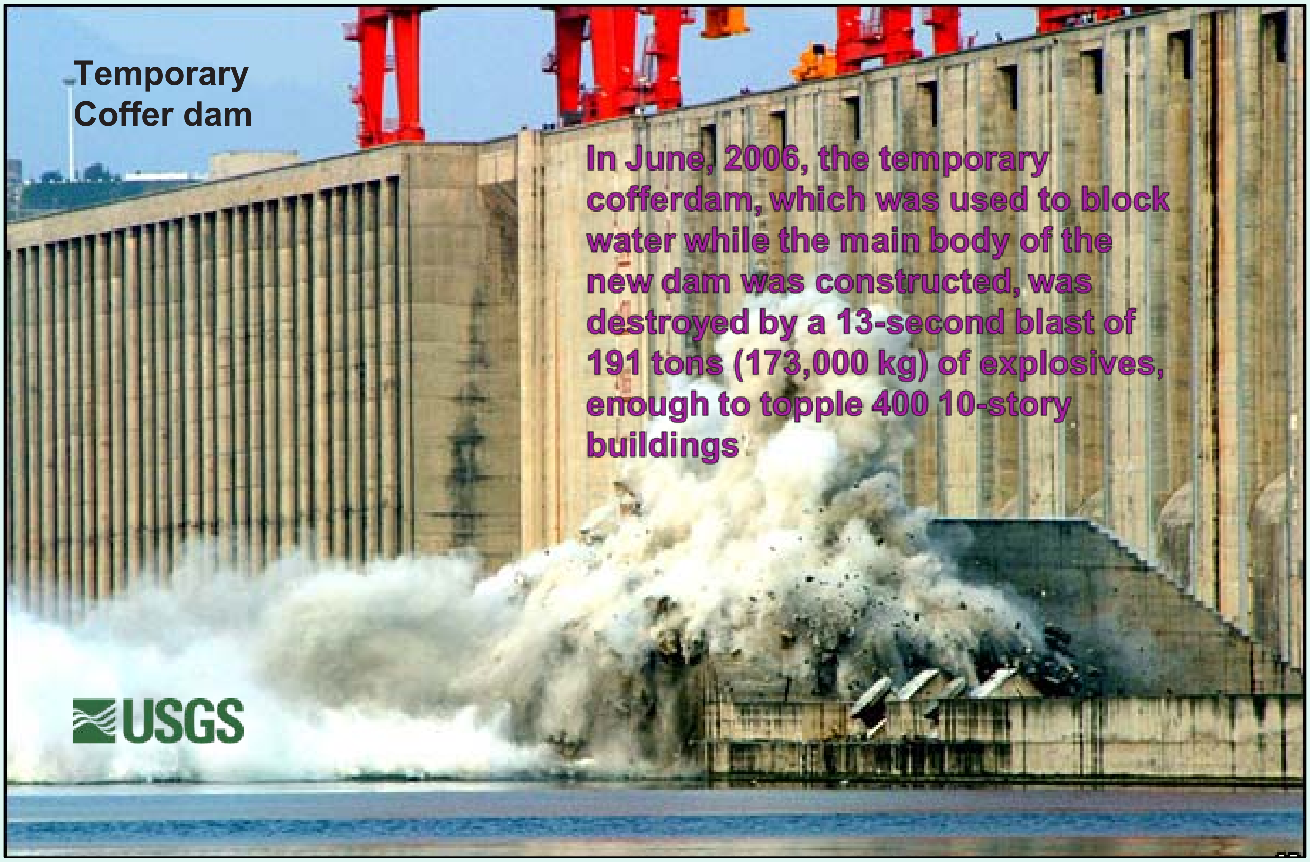
5. On 10 July 2003, the first generator unit began generating and was connected to the power grid.

6. September, 2006 – secondary filling of reservoir begins – to finish late October

Reference:

Three Gorges official Web site, *http://www.ctgpc.com/*

Slide 17

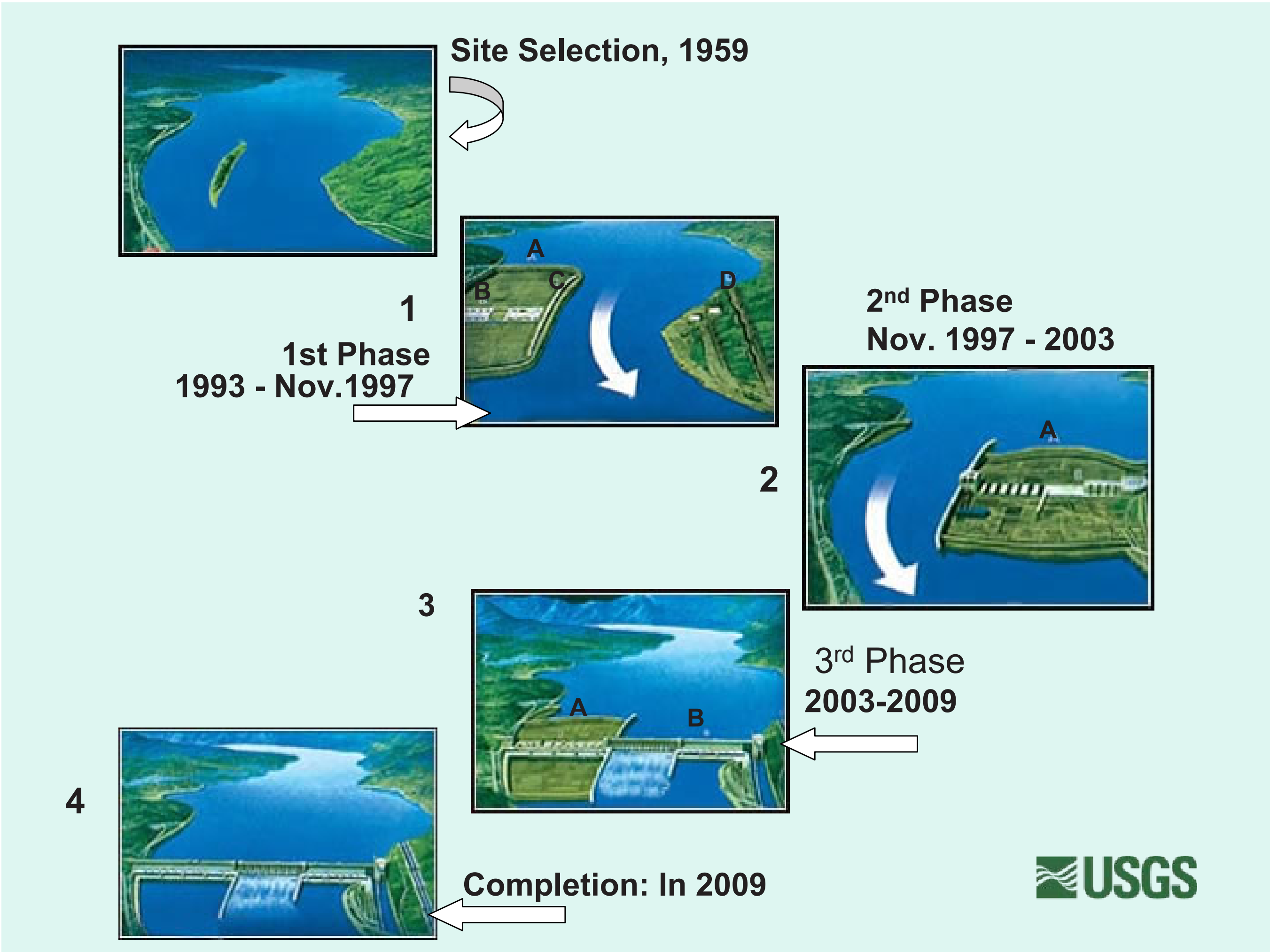


Photograph: source unknown

Reference:

Three Gorges official Web site, *http://www.ctgpc.com/*

Slide 18



Photographs: source unknown

Selection of the site for Three Gorges Dam

The city of Sandouping, 7 km (4.3 miles) from the entrance of Xiling Gorge at the lower reaches of the Yangtze River, was selected as the site of the Three Gorges Dam in 1959. The river here is much wider than it is in other areas. A small island named Zhongbaodao lies in the middle of this part of the river. During the 1980s, plans for the dam were reviewed and modified, and the project was approved by the *National People's Congress* in 1992.

1st Phase of construction: 1993–Nov. 1997

The planning of the project was started in 1993. The actual building of the dam started on 14 Dec. 1994. Zhongbaodao Island was used to build a dike to dam the river water and to connect the right bank with another dike. In order to build the main part of the dam and the diversion channel afterwards, foundation work B and foundation work C, which is long and thin, were built in the dry riverbed. At the same time, channel construction such as Lock D started.

2nd Phase of construction: Nov. 199–72003

Dike A was built and the left bank was connected to another dike. Later, the flood-relief dam and the main part of the Dam B for the installation of generators were built in the dry riverbed, and then 14 generators were installed. Diversion Channel C was closed to navigation and it was dammed again in Nov. 2002.

3rd Phase of construction: 2003–2009

Diversion channel is dammed. Dike A is being built and the right bank with the other dike will be connected again. Reservoir begins to store water and Generating Set B on the left side will be put into operation. The five stage Ship Lock C will be put into operation. The main part of the Dam D for installation of 12 generators is being built on dry riverbed.

Completion: 2009

The height of the Three Gorges Dam will be 185 m (607 feet). All 26 generators will be put into operation by 2009.

Reference:

Three Gorges official Web site, *http://www.ctgpc.com/*

Slide 19

Photograph: Lynn Highland, U.S. Geological Survey

According to the original plan, the Three Gorges reservoir was to have been filled to 156 m (512 feet) above sea level in 2007 and raised to its final level of 75 m (574 feet) in 2013. But later the timetable was changed dramatically, and the reservoir level rose to 156 m (512 feet) in 2006, one year ahead of schedule, and it is projected to rise to its final level of 175 m (574 feet) in 2009, four years earlier than planned.

Reference:

Three Gorges official Web site, *http://www.ctgpc.com/*

Slide 20

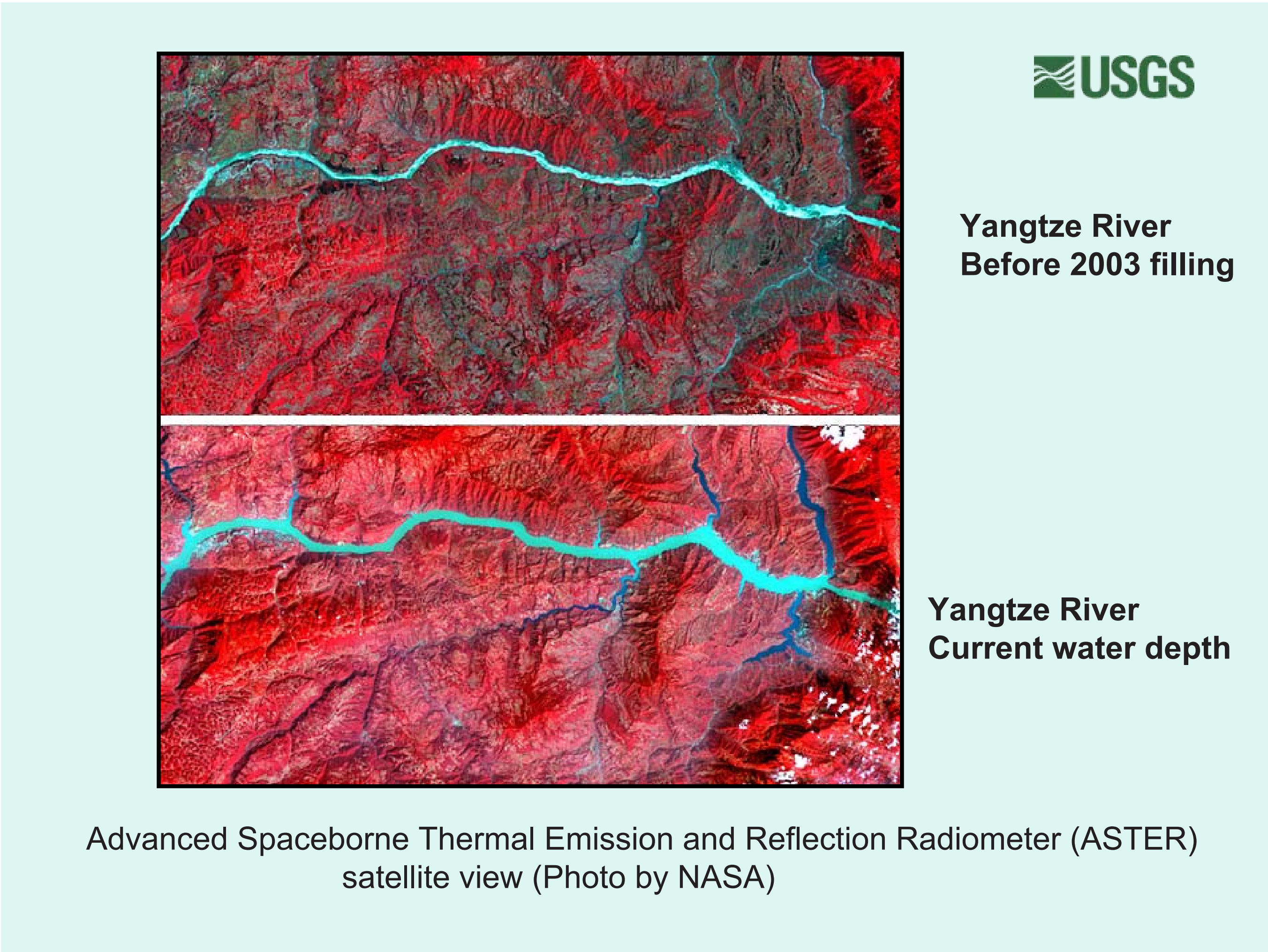


Image: National Aeronautical and Space Administration (NASA) /Jet Propulsion Laboratory

This image was taken by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite. It shows a 60-km stretch of the Yangtze River just west of the Three Gorges Dam. The upper image was acquired on May 20, 2001, before the dam was filled. The bottom image, acquired March 25, 2003, shows the partly filled reservoir.

Reference:

http://www.china-profile.com/data/rs_three-gorges_1.htm

Slide 21

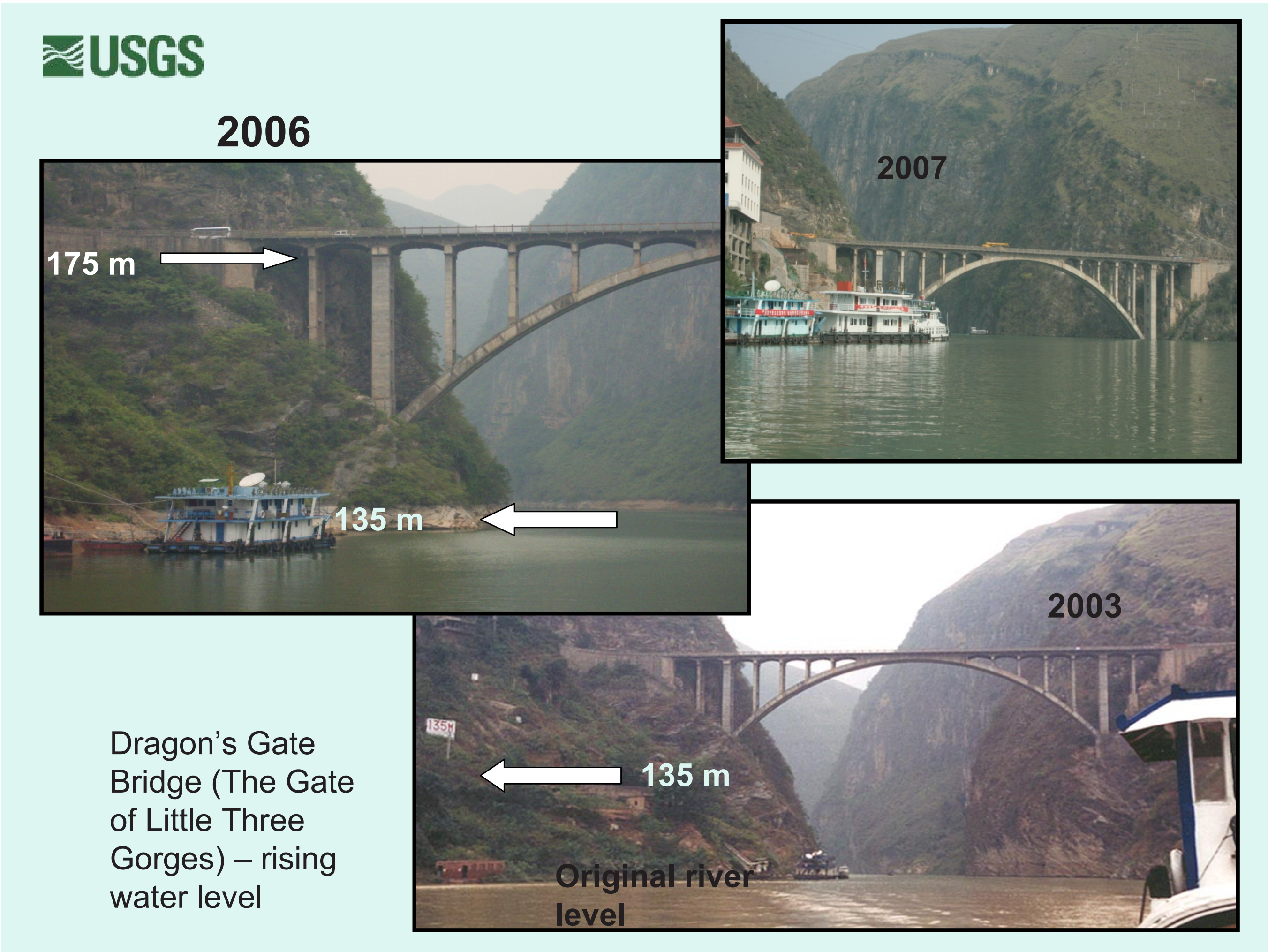
USGS

On the river banks, 175-meter markers are placed at regular intervals along the river

Photograph: Lynn Highland, U.S. Geological Survey

These elevation markers are a constant reminder to people that the reservoir, in its final stages, will inevitably rise to this level.

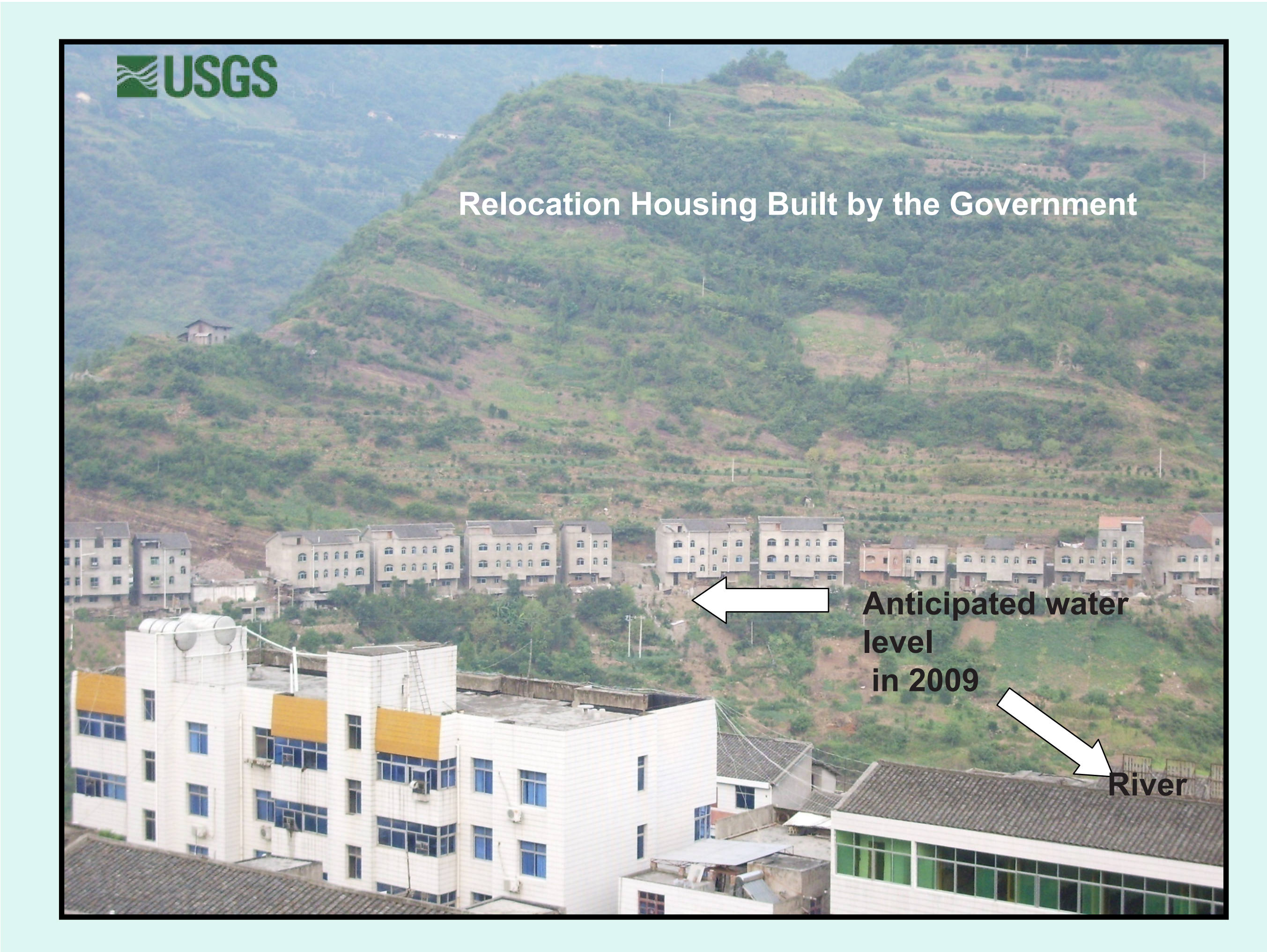
Slide 22



Photographs: 2003—China Travel web site, no longer active; 2006—Lynn Highland, U.S. Geological Survey; 2007—Zhitao Huo

The rising Yangtze river level during four years, and the changing appearance of Dragon's Gate Bridge.

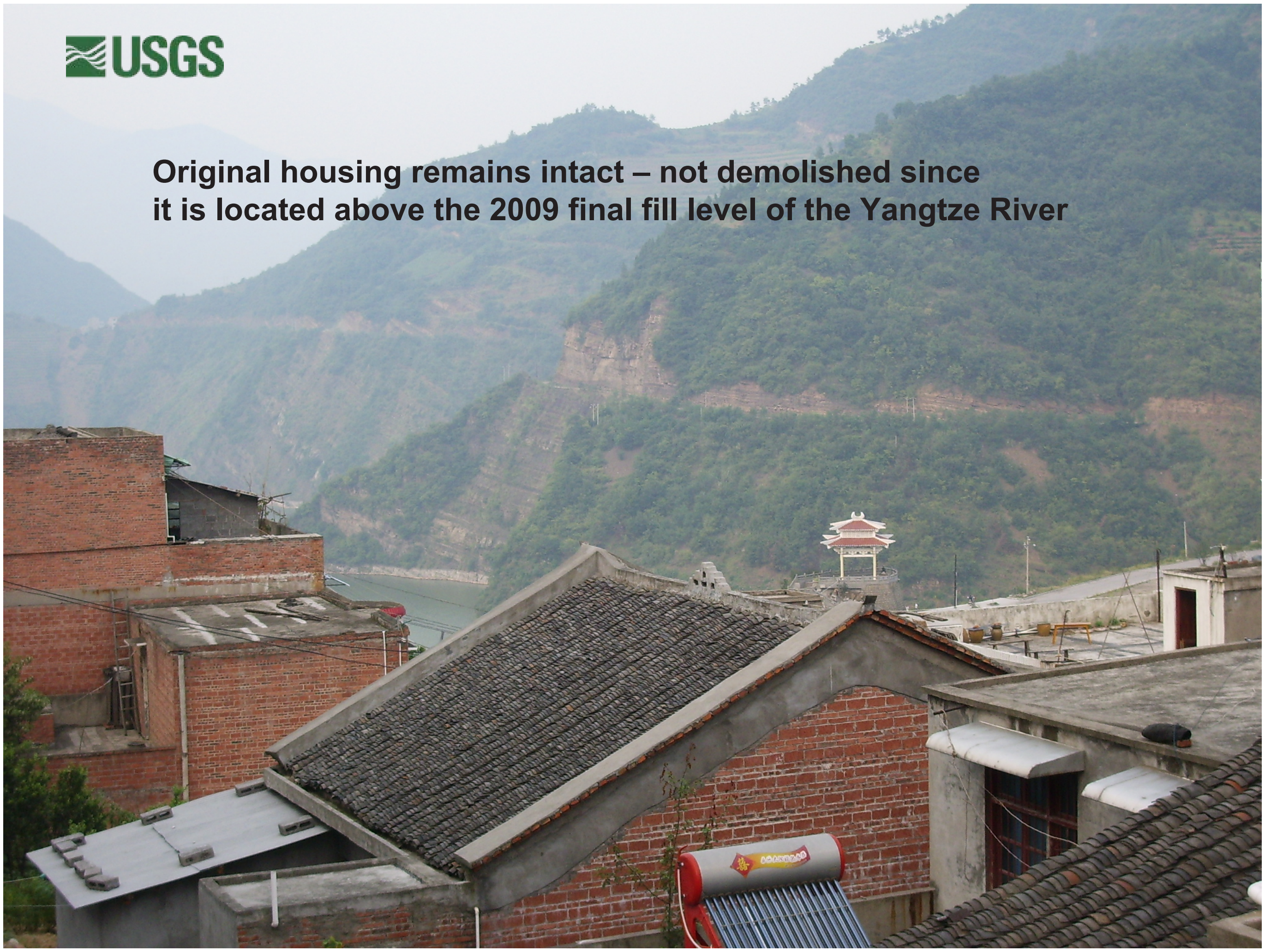
Slide 23



Photograph: Lynn Highland, U.S. Geological Survey

Relocation-type housing near the town of Shazhenxi, which is located near landslides that were viewed on the 2006 field trip.

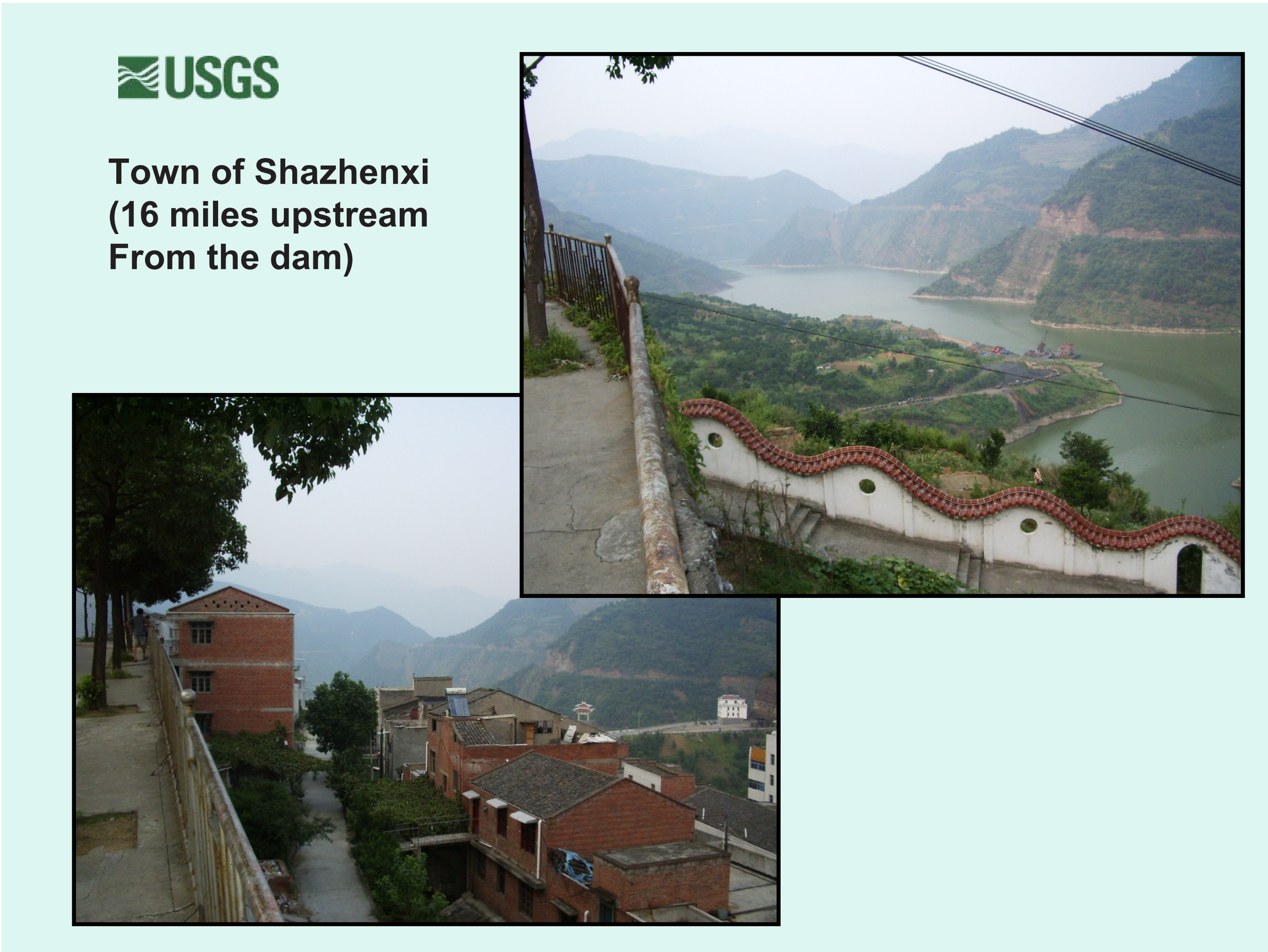
Slide 24



Photograph: Lynn Highland, U.S. Geological Survey

Town of Shazhenxi, China—This town is well above the future fill line of the Yangtze River, and there are no current plans to demolish or relocate this town.

Slide 25



Photographs: Lynn Highland, U.S. Geological Survey

More views from the higher regions of the town of Shazhenxi.

Slide 26

USGS

Some of the Geologic Hazards in the Three Gorges Area:

Landslides and Other Slope Failures

Destructive Waves in the River from Slope Failures

Earthquakes and Reservoir-Induced Earthquakes

Sediment Problems

Slide 27

►The Three Gorges have been formed by severe incision along narrow fault zones, in response to Quaternary uplift, of massive limestone mountains. These mountains are lower Paleozoic and Mesozoic age.

►Steep slopes develop on easily erodible or “soft” materials, which are extensive, and landslides are common in these areas.

►Rainfall - The average winter precipitation, in this part of China, is 100–150 mm (4 - 6 inches) per month, and the spring–summer (March – August) average can be as high as 200–300 mm (7 – 11 inches) per month.

Photograph: source unknown

References:

Liao, Y., Li, P. and Tan, K., 1996, Environmental and engineering geology of the Yangtze Gorges area, International Geological Congress (IGC), 30th, Field Trip Guide T369: Beijing, Geology Publishing House, 49 p. ISBN: 11602030 6P 1534.

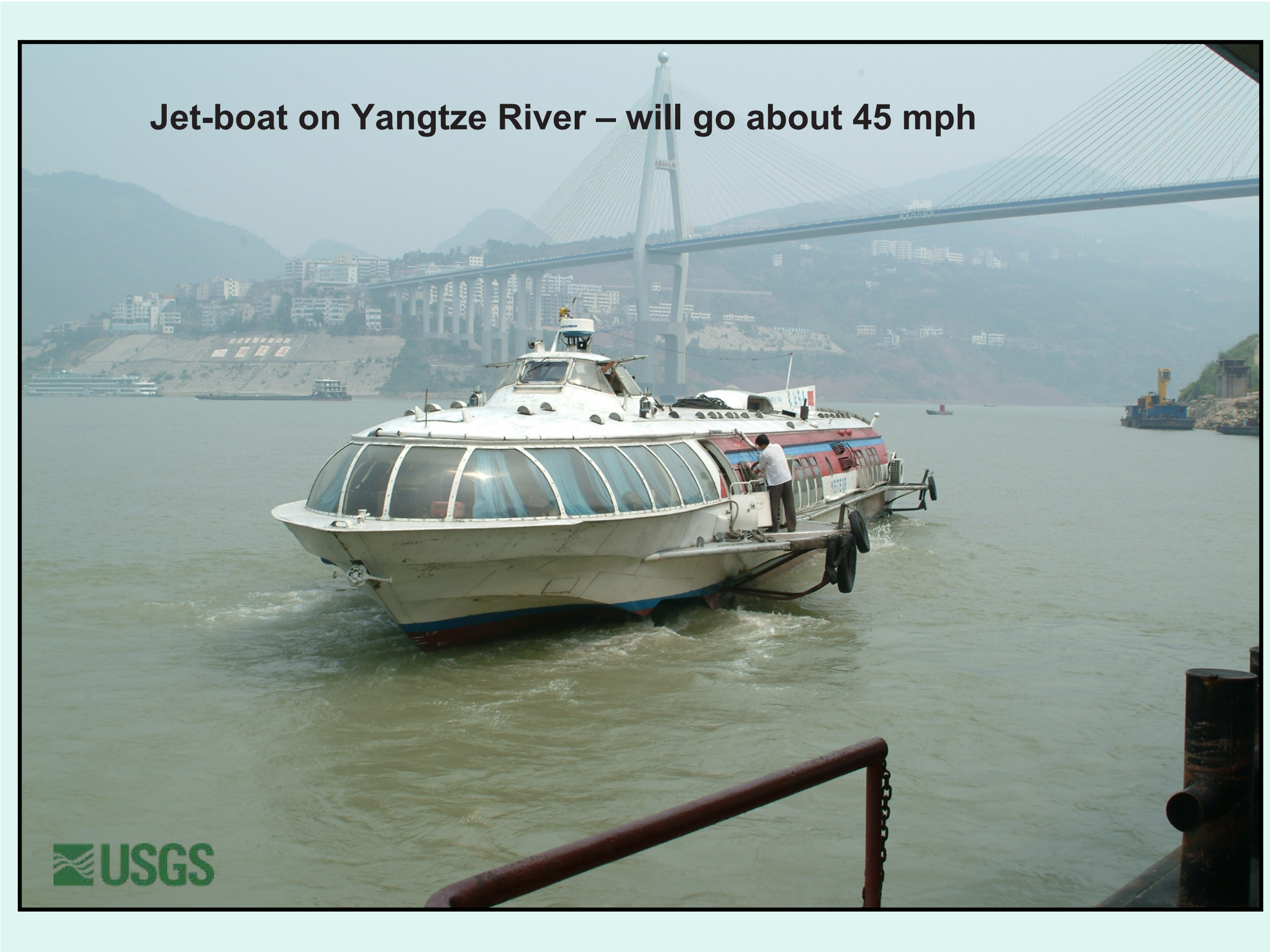
Wu, Shuren; Shi, Ling; Wang, Reijiang; Tan, Chengxuan; Hu, Daogong, Yingtang, Mei; and Xu, Ruichun, 2001, Zonation of the landslide hazards in the fore-reservoir region of the Three Gorges Project on the Yangtze River: Engineering Geology, v. 59, no. 1–2 (January), p. 51–58.

Slide 28

Slope Failures in the Three Gorges Area

1. Rotational slumps in poorly consolidated or unconsolidated materials.
2. Translational rock and debris slides, debris flows and complex slides involving more than one type of failure mechanism and several types of material.
3. Geomorphologic characteristics influencing slope instability in the study area are the attitude of strata with respect to slope angle and aspect. Areas where strata dip towards the slope face tend to experience translational slope failures and slumps, such as rock creeping and landsliding.
4. Massive urban development required for the relocation of major towns to nearby higher positions has triggered several large landslides.
5. Raising and lowering the water level in the Dam reservoir for flood control will saturate older and still-active landslides and subject them to extreme wet-dry cycles – rainfall will intensify the effect.

Slide 29



Photograph: Lynn Highland, U.S. Geological Survey

Jet-boats are used by the communities along the Yangtze to quickly get from place to place. Most of the roads are at the top of the banks and are steeply graded, making road travel much slower than jetting along the river.

Slide 30

Landslides Observed on Three Gorges Field Trip
July/August 2006

Xintan landslide – on a bank of the Yangtze River, 16 miles (26 km) upstream from dam

Lianziya Dangerous Cliff – Crag Mass – on opposite bank from the Xintan landslide

Shuping landslide – on a bank of the Yangtze 49 km upstream from dam

Qianjiangping landslide – On the Quing'ganhe River, a tributary of the Yangtze

At least 14 old landslides are considered likely to be reactivated by the filling of the reservoir.

USGS

Landslides observed on field trip, July and August 2006.

Slide 31

Xintan Landslide June 12, 1985, destroyed Xintan Town in Hubei Province, located 26 km (16 miles) upstream from the Dam--

The landslide body slid into Yangtze River, a third of river width was blocked, and the resultant wave reached 54 m (177 feet) in height and propagated along the river for 42 km (26 miles), 9 people were killed and 77 boats destroyed. People had been evacuated before the slide.

The landslide caused a two-day interruption in shipping on the Yangtze

USGS

Photograph: Yu-Hua Lang, Erosion Control Engineering Laboratory, Tokyo University of Agriculture and Technology

The most recent major landslide in the area occurred at Xintan, in Zigui County, Hubei province, in June 1985. The landslide caused a huge 54-m-high (162-foot-high) wave that claimed 9 lives, destroyed 77 boats, and led to a two-day interruption of shipping on the Yangtze.

References:

Dai, F.C., Deng, J.H., Tham, L.G., Law, K.T., and Lee, C.F., 2004, A large landslide in Zigui County, Three Gorges area: Canadian Geotechnical Journal, v. 41, no. 6, p. 1233–1240.

Liu, Guangrun, 1988, Environmental geologic investigation of Xintan landslide: Environmental Geology, v. 12, no. 1 (August), p. 11–13. See also: *http://www.springerlink.com/content/k42p4534422n7725/*

Slide 32

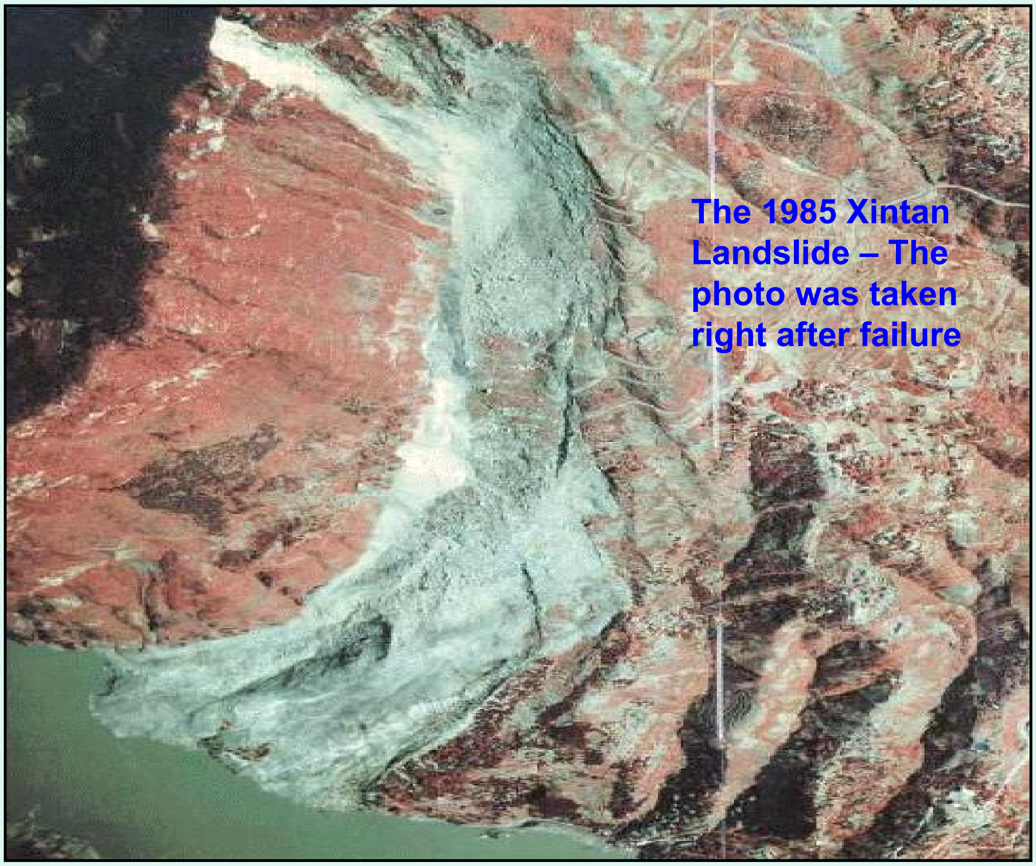
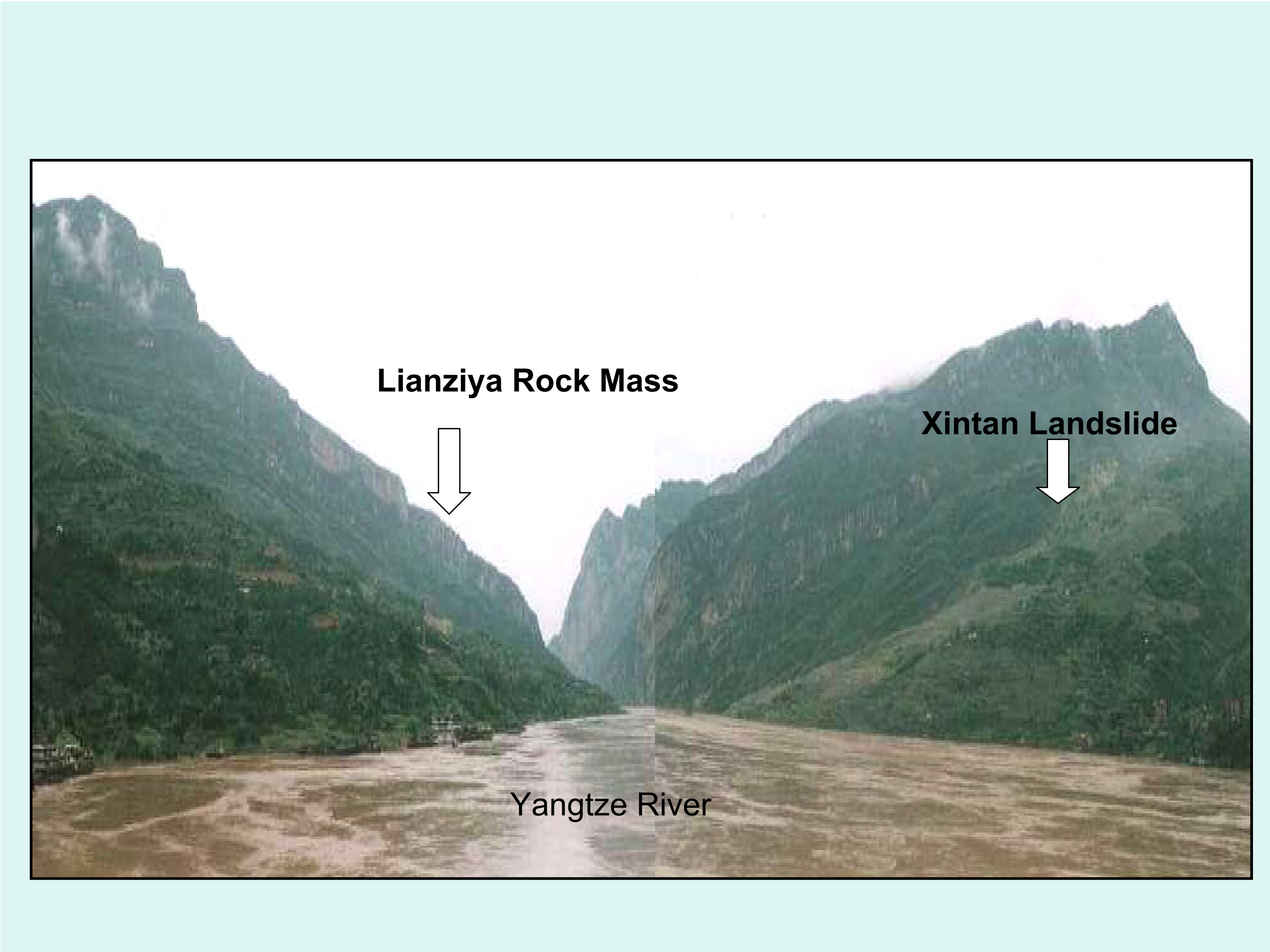


Image: Ministry of Geology and Mineral Resources, Peoples Republic of China

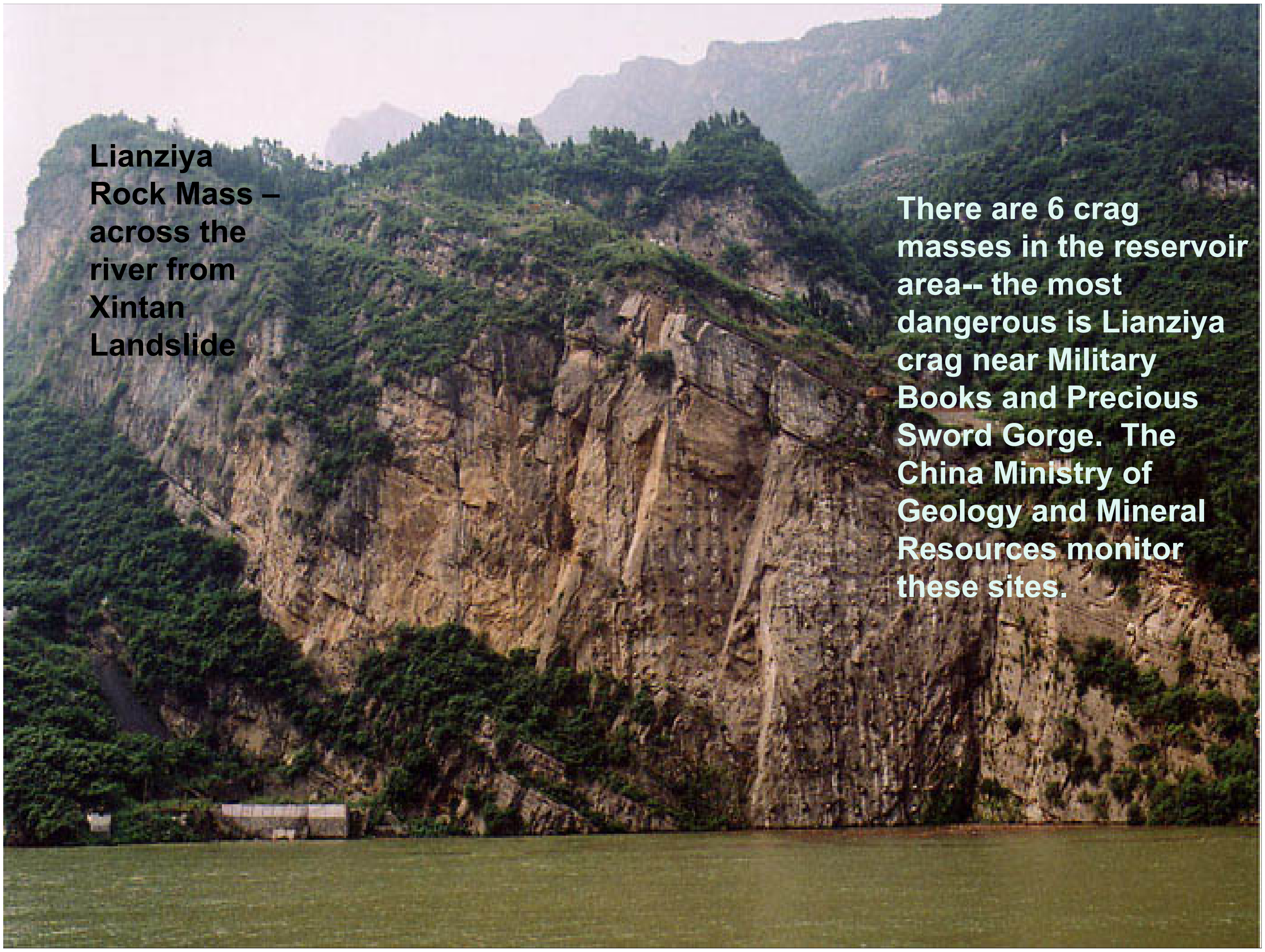
Infrared aerial image of the Xintan landslide area.

Slide 33



Photograph: Yu-Hua Lang, Erosion Control Engineering Laboratory, Tokyo University of Agriculture and Technology

Slide 34



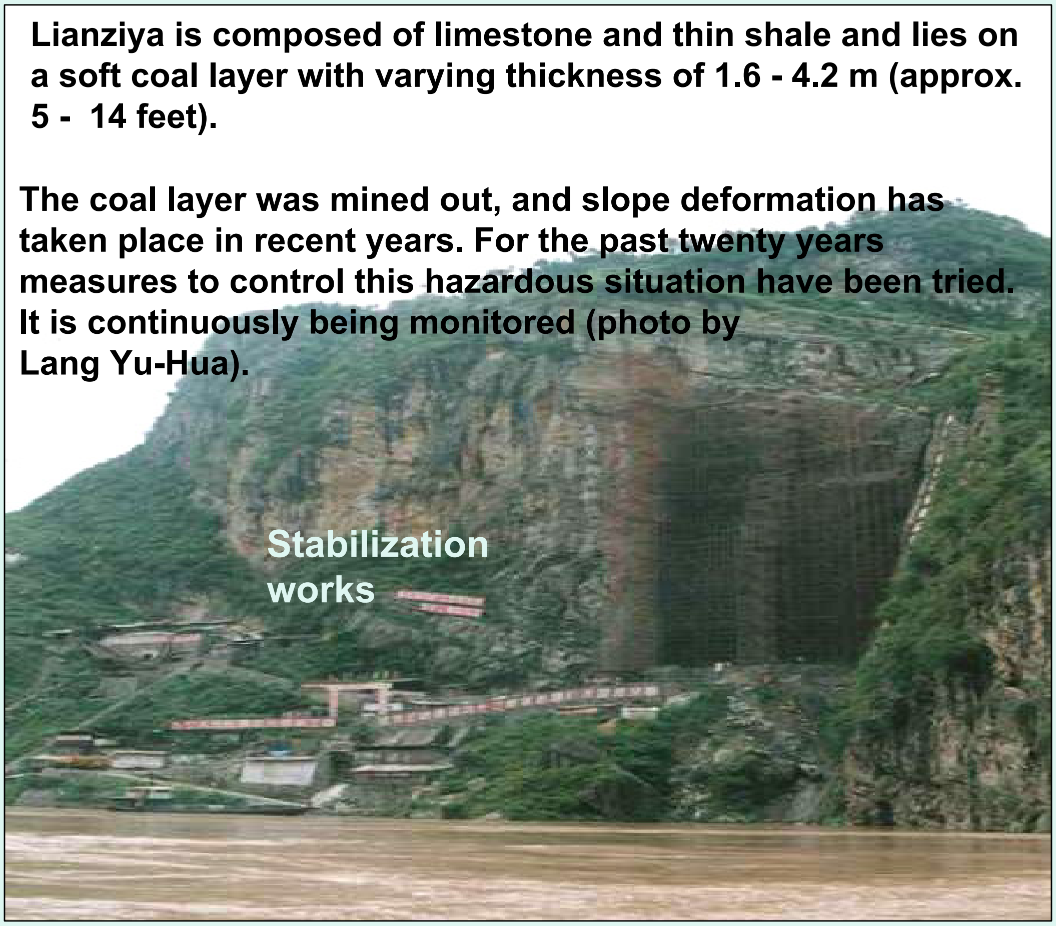
Photograph: Lynn Highland, U.S. Geological Survey

This area has been destabilized by mining coal from underlying seams, thereby weakening the mass.

References:

Yin, Yueping, 1997, Anchoring engineering for Lianziya dangerous rock mass controlling at the Three Gorges of the Yangtze River, China, *in* Wang, Sijing, and Marinos, P. eds., International Geological Congress (IGC), 30th, 1997, Beijing, China, Proceedings: Leiden, The Netherlands, Brill Publishing, v. 23, p. 53–58.

Slide 35

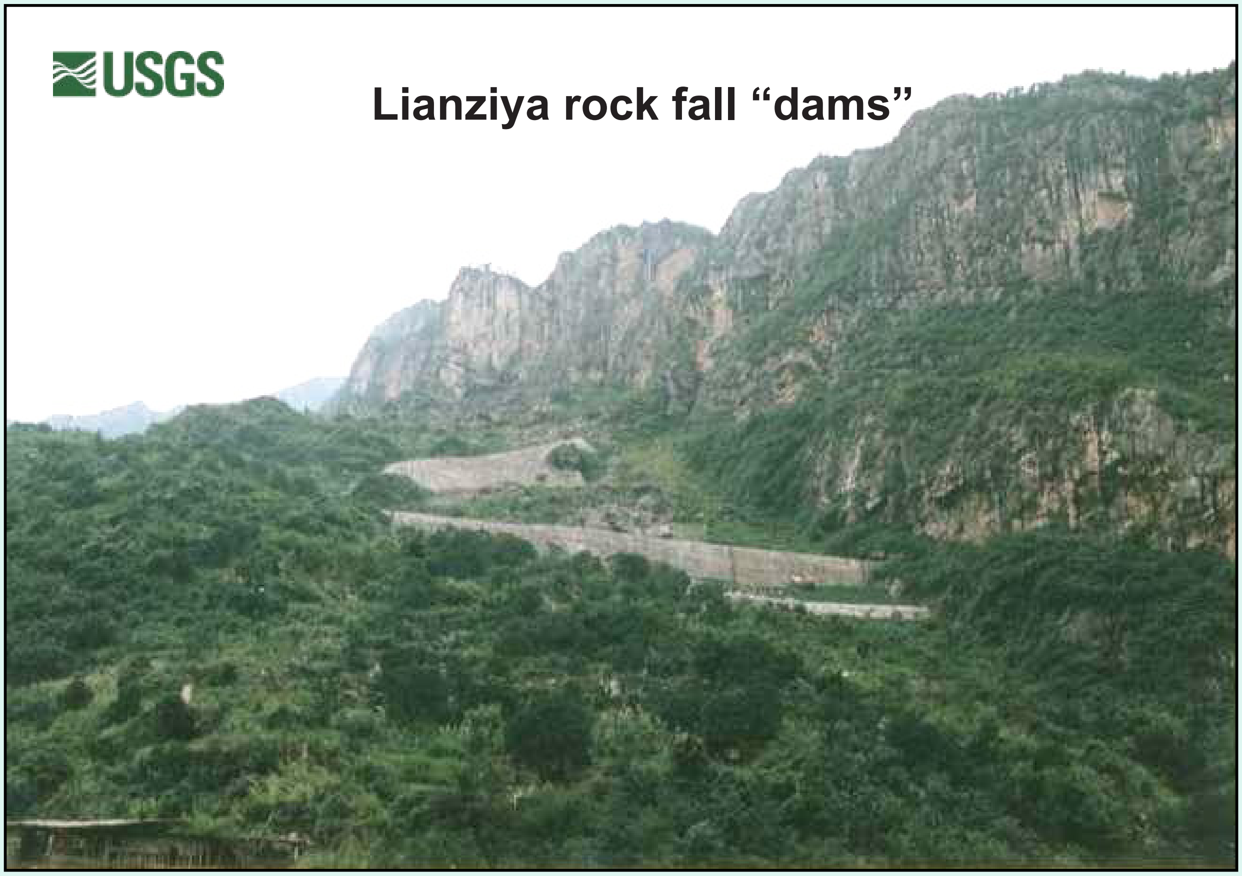


Photograph: Yu-Hua Lang, Erosion Control Engineering Laboratory, Tokyo University of Agriculture and Technology.

Reference:

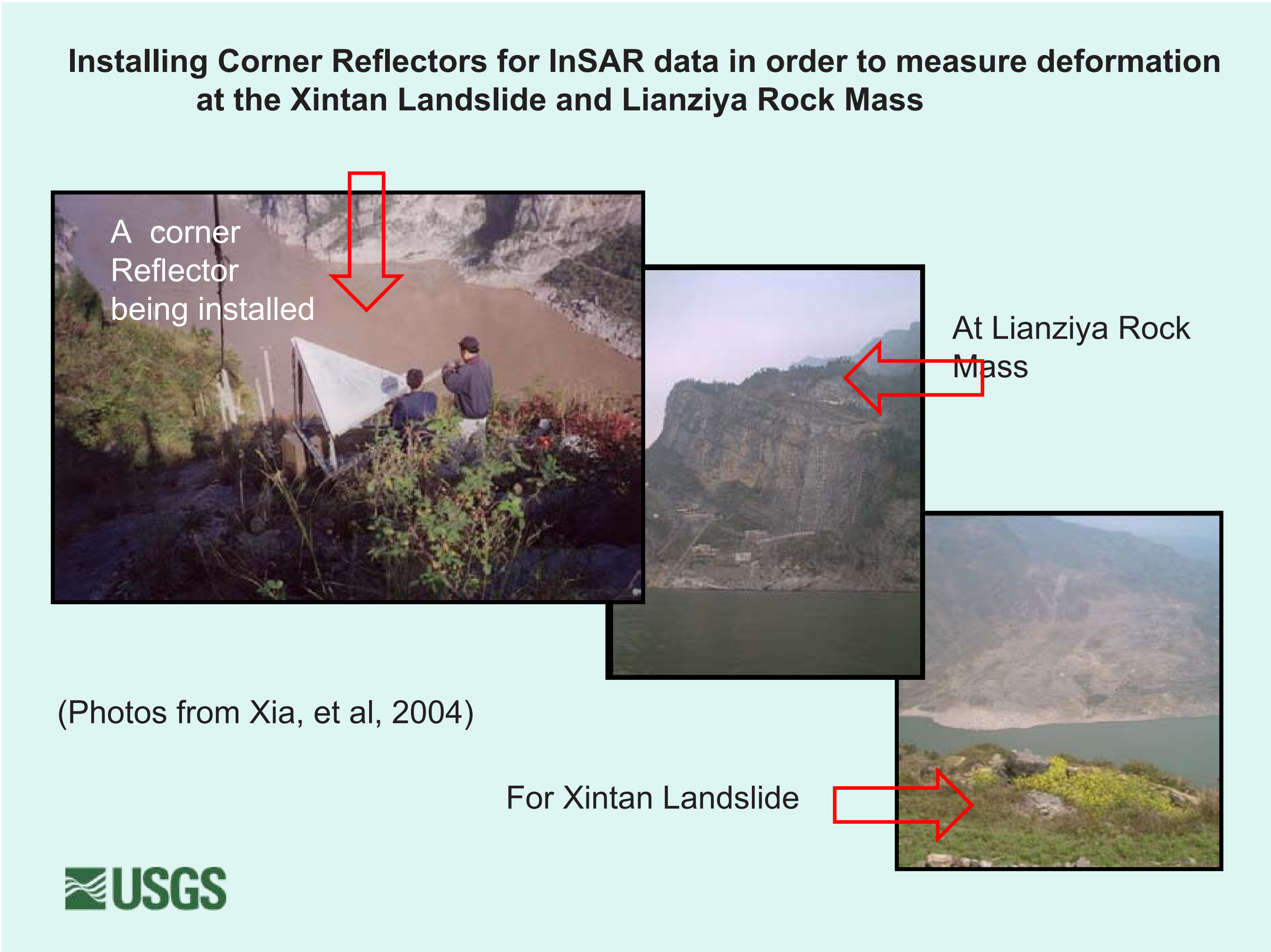
Yin, Yueping, 1997, Anchoring engineering for Lianziya dangerous rock mass controlling at the Three Gorges of the Yangtze River, China, *in* Wang, Sijing, and Marinos, P. eds., International Geological Congress (IGC), 30th, 1997, Beijing, China, Proceedings: Leiden, The Netherlands, Brill Publishing, v. 23, p. 53–58.

Slide 36



Photograph: Yu-Hua Lang, Erosion Control Engineering Laboratory, Tokyo University of Agriculture and Technology

Slide 37



Photographs: source unknown

In order to monitor the instability of Xintan landslide and Lianziya hazardous rock mountain, 4 corner reflectors were installed on the Xintan landslide slope and 6 on the Lianziya hazardous rock mountain.

Reference:

Xia, Ye, Kaufmann, H., and Guo, X. F., 2004, Landslide monitoring in the Three Gorges area using D-InSAR and corner reflectors: Photogrammetric Engineering & Amp—Remote Sensing, v. 70, no. 10, p. 1167–1172.

Abstract: *http://www.cababstractsplus.org/google/abstract.asp?AcNo=20043174598*

Full report: *http://www.gfz-potsdam.de/pb1/pg5/research/methods/insar/web_threegorges.pdf*

What is InSAR?

InSAR is an abbreviation or acronym for interferometric synthetic aperture radar. It thus is a remote-sensing technique that uses radar satellite images. Radar satellites (ERS1, ERS2, JERS, IRS, or Radarsat) constantly shoot beams of radar waves towards the earth and record them after they bounce back off Earth's surface.

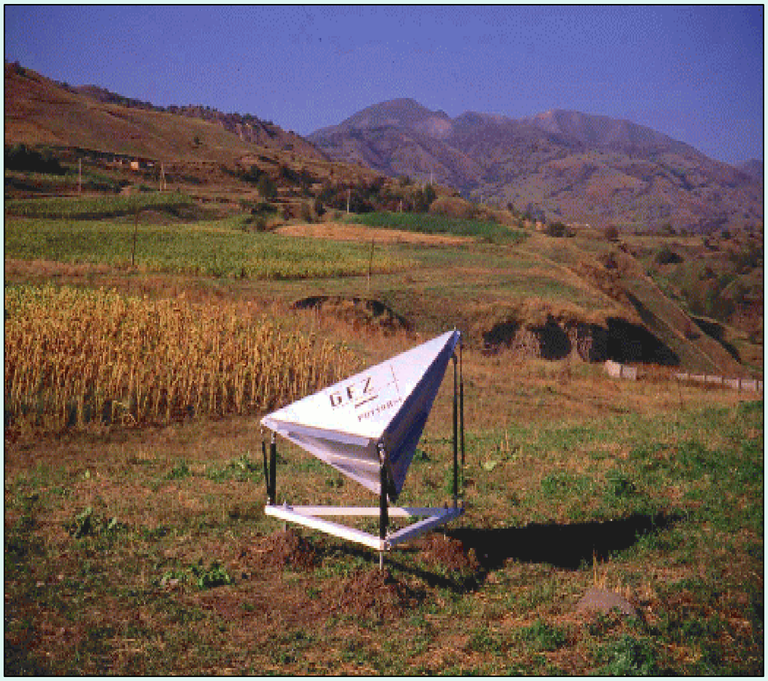
Two kinds of information compose the images. One kind (signal intensity) describes how much of the wave returned to the satellite. That depends on how much of the wave has been absorbed on the way and how much has been reflected in the direction of the satellite.

The second kind of information is the “phase” of the wave. When a wave travels through space, we can think of its phase as a hand on a clock. It starts on 12 when the wave leaves the satellite. The “hand” (phase) keeps running round and round the clock until the wave reaches the ground. When the wave hits the ground, the hand stops indicating a certain “time” or “phase.” When the wave comes back, the satellite detects on what value the “hand” (phase) was stopped.

Reference:

U.S. Geological Survey, *http://quake.usgs.gov/research/deformation/modeling/InSAR/whatisInSAR.html*

Slide 38



Close-up Photo of a Corner reflector

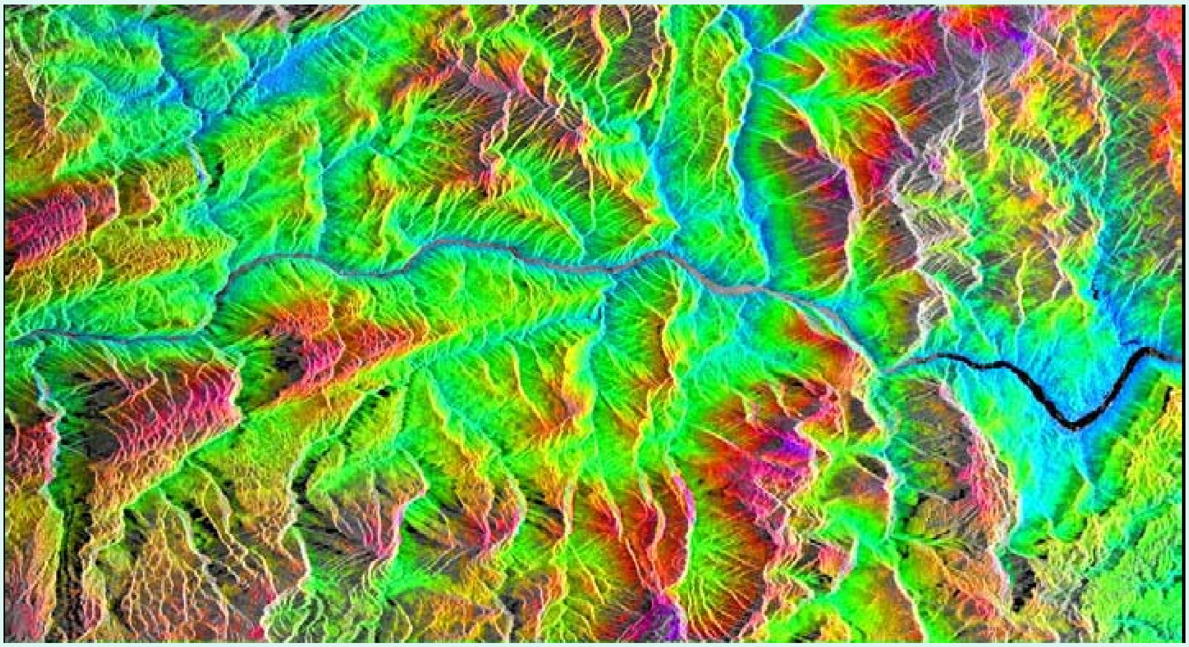
Photograph: Roessner, S., Wetzel, H.-U., Xia, Y., Meleshko, A.V. and Sarnagoev, A.,1999

See previous slide (slide 37) for information on InSAR and corner reflectors.

Reference:

Roessner, S., Wetzel, H.-U., Xia, Y., Meleshko, A.V., and Sarnagoev, A., 1999, Investigation of landslide processes in southern Kyrgyzstan using optical and radar remote sensing in a GIS environment: European Geophysical Society General Assembly 24, The Hague, Geophysical Research Abstracts, v. 1, no. 4, p. 837.

Slide 39



InSAR topography of Yangtze River/Three Gorges Area

Image: source unknown

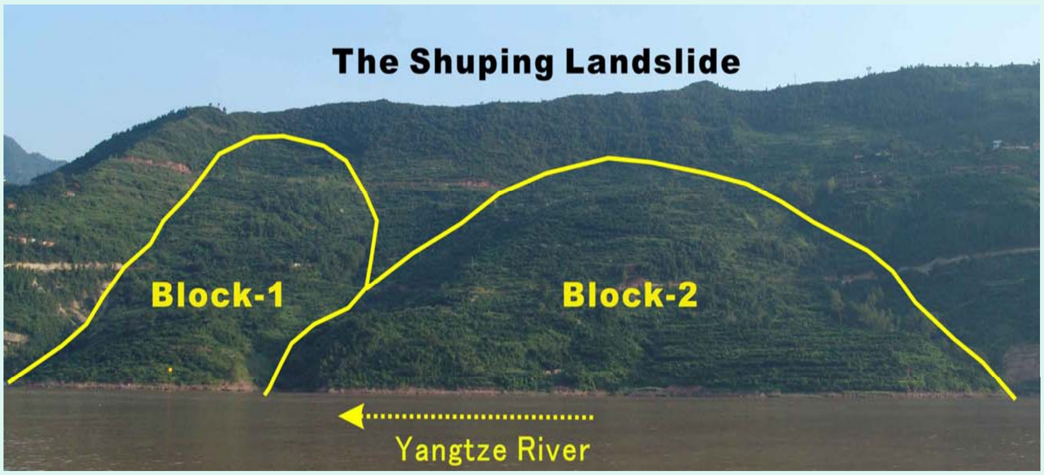
In order to monitor the instability of Xintan landslide and Lianziya hazardous rock mountain, 4 corner reflectors were installed on the Xintan landslide slope and 6 on the Lianziya hazardous rock mountain. Because of a cliff along the western boundary of the Xintan landslide, a descending satellite orbit was chosen, and all the corners were oriented to face the southeast. Each corner was then positioned by means of leveling. See notes for slide 37 for explanation of InSAR.

Reference:

U.S. Geological Survey, *http://quake.usgs.gov/research/deformation/modeling/InSAR/whatisInSAR.html*

Slide 40

One month after the June 2003 filling of the reservoir, the old landslide began deforming, with cracks on the mass growing ever wider. The deformation is still developing today.



Geologists at Kyoto University, Japan, are monitoring this slide and are working to install some type of improved warning system – at present, the basic warning "system" is a flashing yellow strobe light that activates when the landslide moves. In 2004 most inhabitants were permanently moved off the slope (photo by China Geological Survey, Yichang City Branch).

Photograph: China Geological Survey, Yichang City Branch

The Three Gorges area is not only prone to geological disasters such as landslides and earthquakes, but it is also very densely populated. According to official statistics, 2,490 "slip masses" and 90 gullies created by mud-rock flows have been identified along the Yangtze and its tributaries. Moreover, unlike many other large reservoirs around the world, which tend to be located in remote and sparsely populated areas, the Three Gorges reservoir area is so densely populated that finding the space nearby to resettle people displaced by the reservoir has been difficult. Thus, even a moderate geological disaster in the reservoir area can entail enormous human and property losses.

Experts are worried that filling the reservoir could activate big landslide masses upstream of the Three Gorges project. The Shuping landslide, on the right (or south) bank of the Yangtze, 49 km (30 miles) upstream of the dam, has a volume of 23.6 million cubic meters (30.9 cubic yards). One month after the June 2003 filling of the reservoir, the old landslide began deforming as cracks on the mass grew ever wider. The deformation continues today (2006). And so, while travelling on the river from Badong downstream to Maoping (the Zigui county seat), I was told by the captain that all boats going in both directions must sail on the north side as a safety precaution, in accordance with a warning issued by the navigation authority. The Shuping landslide is located about 3 km (1.8 miles) northwest of Shazhenxi Town, Zigui County, Hubei Province. (This town is featured in slides 24 and 25).

References:

Wang, Fawu; Wang, Gonghui; Sassa, Kyoji, Takeuchi, Atsuo; Araiba, Kiminori; Zhang, Yeming; and Peng, Xuanming, 2005, Displacement monitoring and physical exploration on the Shuping landslide reactivated by impoundment of the Three Gorges Reservoir, China, *in* Sassa, Kyoji; Fukuoka, Hiroshi; Wang, Fawu; and Wang, Gonghui, eds., Landslides, International Consortium on Landslides General Assembly, 1st, Proceedings: Springer. p. 313–319. *http://www.springerlink.com/content/j4k7274158p362n1/*

Slide 41

The Qianjiangping landslide occurred in July, 2003. It is located on the Qing'ganhe River (a tributary of the Yangtze River), 3 km (1.8 miles) from the confluence.

Stability of the affected slope was already reduced by a previous landslide at the site, pre-existing bedding-plane shears, quarrying of mudstone from the landslide toe, and heavy rain.

26.5 km (16 miles) from the dam

USGS

Photograph: Fan Xiao, *http://internationalrivers.org/files/FanXiao.pdf*

A landslide resulting from the impoundment of the reservoir took place at the village of Qianjiangping on the Qing'ganhe River, 3 km (1.8 miles) away from its confluence with the Yangtze mainstream. On the morning of July 12, 2003, just one month after the filling of the reservoir, cracks were discovered in the old Qianjiangping landslide. By evening, cracks had also appeared on the walls of a factory building and were growing rapidly. Most factory workers and villagers fled as the dangerous situation developed, although a few remained behind.

Several hours later (00:20 on July 13, 2003), a huge block of the mountain, 24 million cubic meters in volume, slid into the Qing'ganhe River, completely blocking the 100-m-wide river. The landslide's crash into the river also created 20-m-high waves that capsized 22 boats. Within minutes, 4 factories, 300 homes, and more than 1,000 mu (67 hectares) of farmland were destroyed. According to the official count, 14 people were killed and another 10 listed as missing.

Three days after the disaster (July 16, 2003), the Three Gorges Office of Hubei province quickly announced that the reactivation of the Qianjiangping landslide had been caused by days of heavy rainfall and had nothing to do with the filling of the dam's reservoir. However, an investigation conducted by several research institutes and survey teams concluded that the impounding of the reservoir had in fact been one of the main triggers. Their conclusion was that, after the Three Gorges reservoir was filled in June, 2003, to 135 m (443 feet), the water level of the Qing'ganhe River rose by more than 30 m (99 feet). Now immersed in water, the bottom of the slip mass softened, causing instability in the old landslide. Continuous rain from June 21 to July 11 was also a factor, as rainwater had permeated cracks in the landslide mass.

References:

Chinese National Geographic, no. 4, 2006 (translated by Probe International, source of this abridged article).

Wang, Fawu; Zhang, Ye-Ming; Huo, Zhan-Tao; Matsumoto, Tatsunori; and Huang, Bo-Lin, 2004, The July 14, 2003 Qianjiangping landslide, Three Gorges Reservoir, China: Landslides, Springer, v. 1, no. 2, July, p. 157–162. See also: *http://www.springerlink.com/content/g408kx5vae2xgwnr/*

Slide 42

Important Aspects of the Qianjiangping Landslide of July 13, 2003

--Location: the Qianjiangping Landslide is in Hubei Province, on the Quing'ganhe River, a tributary of the Yangtze. The landslide is 24 million cubic meters (31,390,814 million cubic yards) in volume.

--The landslide lasted for about four hours from slight precursors to the final avalanche.

--Four factories were destroyed and 129 families lost their homes. A total of 252 people and 67 households moved out of the affected area of the landslide.

--Because of the local monitoring system and early warning, most people evacuated safely in time. Officially, 14 people were killed, 10 listed as missing.

--Officials in Hubei Province decided heavy rains caused the failure, but subsequent investigation has concluded that it was probably due to several factors—including heavy rainfall, and the raising of the water level in the tributary. This landslide was also a re-activation of an old landslide.

USGS

On July 12, 2003, one month after the filling of the reservoir, cracks were discovered in the old Qianjiangping landslide. By evening, cracks had also appeared on the walls of a factory building and were growing rapidly. Most factory workers and villagers fled as the dangerous situation developed, though a few remained behind.

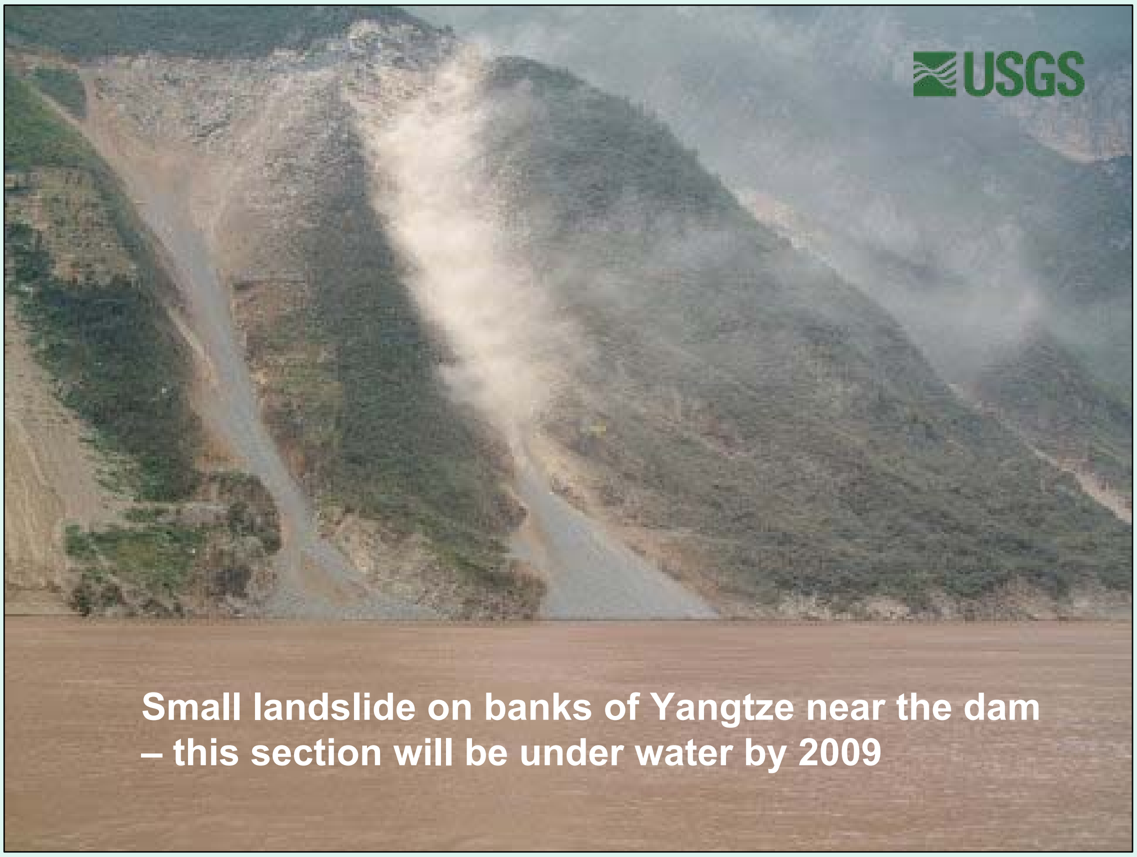
Several hours later (00:20 on July 13, 2003) a huge block of the mountain, 24 million cubic meters in volume, slid into the Qing'ganhe River, completely blocking the 100-meter-wide river. The landslide's crash into the river also created 20-meter-high waves that capsized 22 boats. Within minutes, 4 factories, 300 homes, and more than 67 hectares (165.5 acres) of farmland were destroyed. According to the official count, 14 people were killed and another 10 listed as missing.

Impounding of the reservoir had in fact been one of the main triggers. After the Three Gorges reservoir was filled to 135 m (in June 2003), the water level of the Qing'ganhe River rose by more than 30 m. Now immersed in water, the bottom of the slip mass softened, causing instability in the old landslide. Continuous rain from June 21 to July 11 was also a factor, as rainwater had permeated cracks in the landslide mass.

Reference:

Fan Xiao, Geologist, *http://internationalrivers.org/files/FanXiao.pdf*. (Abridged article from Chinese National Geographic, no. 4, 2006, translated by Probe International)

Slide 43



Photograph: source unknown

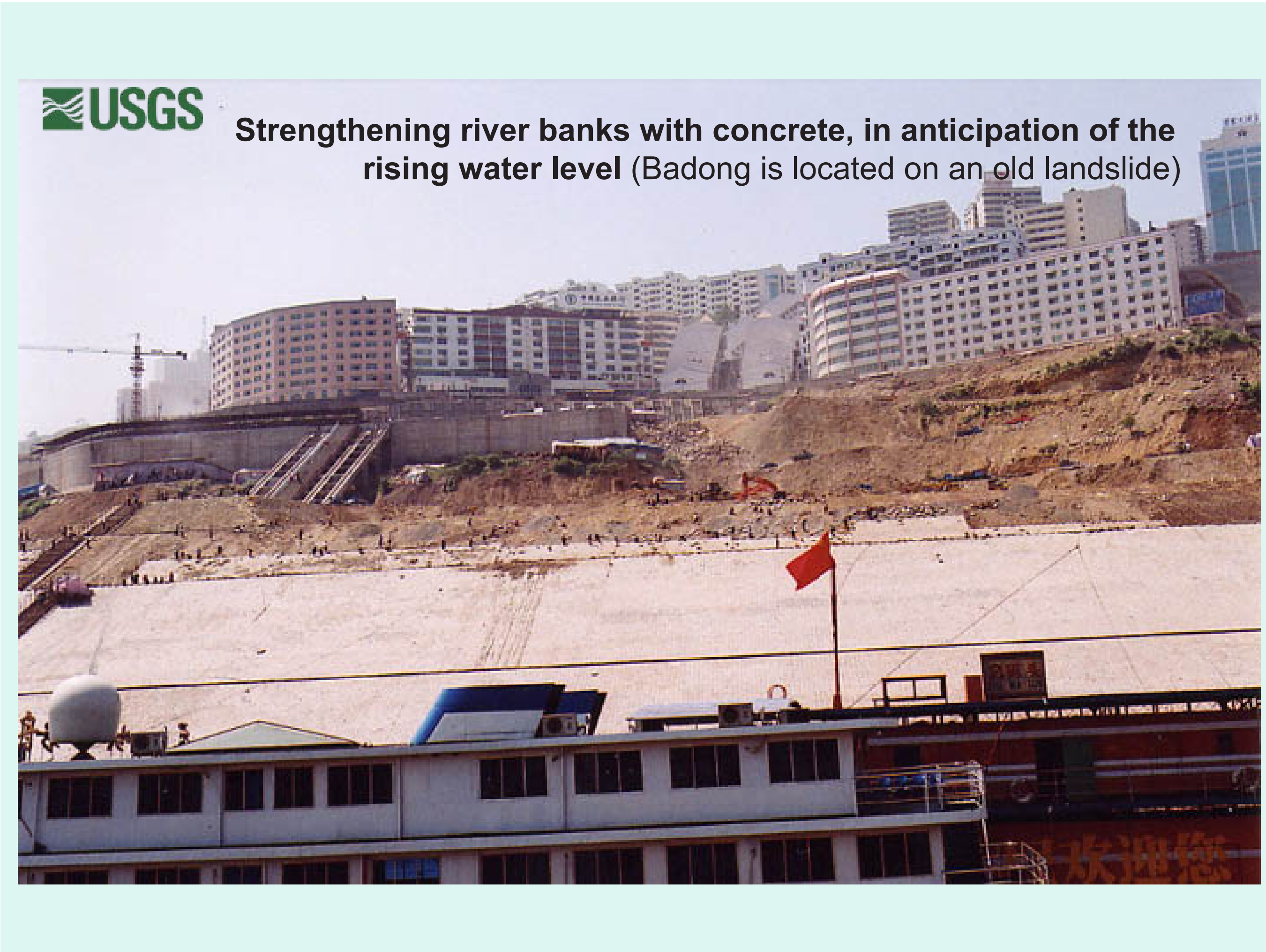
Slide 44

USGS

What else is being done to mitigate the effects of landslides?

Photograph: Chinese Travel Web site, The Three Gorges Dam, no longer active

Slide 45



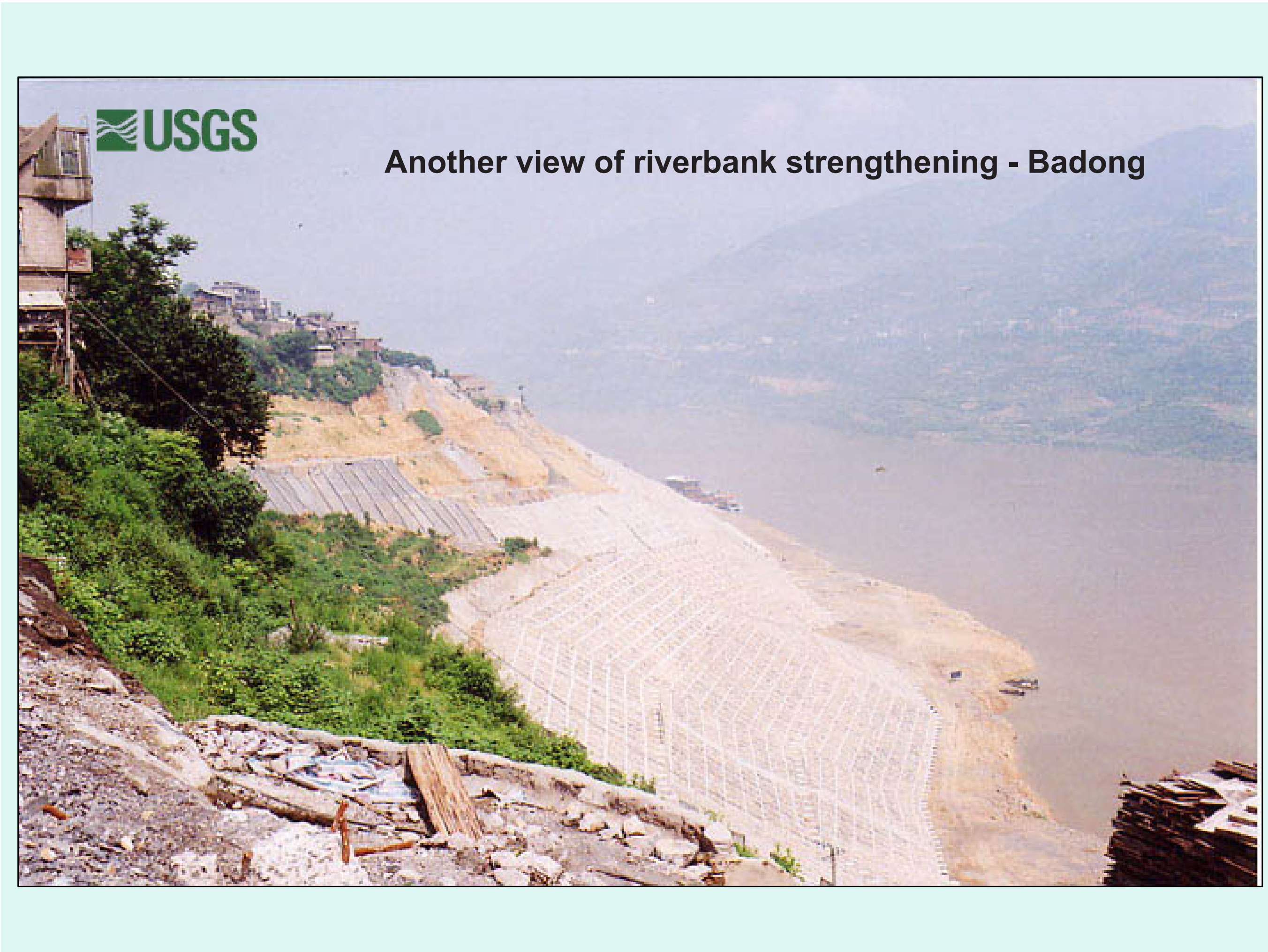
Photograph: Lynn Highland, U.S. Geological Survey

City of Badong, along the Yangtze River.

Reference:

Wu, Faquan, and Luo, Yuanhua 2006, Cutting slope reinforcement in reconstructed migrant cities in the Three Gorges Reservoir area of China, International Association of Engineering Geologists International Congress, 10th, Nottingham, United Kingdom, September 2006, Proceedings: p. 6–10.

Slide 46



Photograph: Lynn Highland, U.S. Geological Survey

City of Badong, along the Yangtze River.

Reference:

Wu, Faquan, and Yuanhua Luo, 2006, Cutting slope reinforcement in reconstructed migrant cities in the Three Gorges Reservoir area of China, International Association of Engineering Geologists International Congress, 10th, Nottingham, United Kingdom, September 2006, Proceedings: p. 6–10.

Slide 47

USGS

What is the Earthquake Hazard to the Three Gorges Dam Area?

Slide 48

1. **The Three Gorges project authority conducted an extensive survey, and found that the dam is situated near six fault lines.**

2. **The Jiuwanxi Fault is located just 17 kilometers (10.5 miles) upstream.**

3. **The Zigui-Badong fault, 80 km (50 miles) upstream from the dam - is considered likely to produce earthquakes that could have an impact on the dam site. The Zigui-Badong fault was responsible for a M = 3. after the reservoir began filling in 2003 (There had had been a M = 6 in the past).**

Three Gorges Dam is built to withstand a M = 7.0 earthquake

After the reservoir was filled to 135 m (443 feet) in 2003, seismic activity increased in several sections of the Three Gorges reservoir. There is good reason to be concerned about two main fault lines: the Jiuwanxi fault and the Zigui-Badong fault. Both are considered likely to produce earthquakes that could have an effect on the dam site, because they are very close to it.

A few minor tremors were recorded along the Jiuwanxi fault, which is located just 17 km (10.5 miles) upstream of the dam. But much more seismic activity occurred along the Zigui-Badong fault, which lies about 80 kilometers upstream of the dam; the biggest tremor since the 2003 reservoir impoundment was recorded at M = 3.4 on the Richter scale. Historically, this fault has produced earthquakes in the M = 5–6 range on the Richter scale.

"During my visit to the Three Gorges area, I met Zeng Xinping, head of the seismological and geological team of the Three Gorges Survey Institute of the Changjiang Water Resources Commission, which is responsible for seismic monitoring in the reservoir area. Mr. Zeng showed us several monitoring stations and told us the network consists of three main components: digital remote sensing, observation of crust deformation, and monitoring of water dynamics. In the reservoir area, a digital remote-sensing network is employed to record minor tremors of less than 4 on the Richter scale, while two special observation stations focus on recording any shocks bigger than that.

In the Three Gorges project feasibility study, experts researched the impact of earthquakes on the dam project. Based on the results of those studies, they predicted that the biggest earthquake in the river section where the Jiuwanxi and the Zigui-Badong faults are located would be around 6 on the Richter scale.

But the question remained: Could the filling of the reservoir to its final height in 2009 trigger earthquakes larger than those ever recorded in the area or anticipated by the experts? Some experts believe that reservoir-induced earthquakes are likely to be as much as 1 or 2 Richter points bigger than the recorded high in a region. Others are worried about the Three Gorges dam for the following reason: In the case of the Tangshan earthquake in 1976 in northeast China, no significant tremors had previously been recorded there until a massive quake measuring M = 7.8 on the Richter scale occurred, killing more than 242,000 people, according to the official toll" (Fan Xiao, 2006).

Reference:

Xiao, Fan, 2006, Three Gorges revisited: Chinese National Geographic, May 3, 2006. *http://internationalrivers.org/files/FanXiao.pdf*

Slide 49

USGS

Earthquakes and Earthquake Monitoring in the Three Gorges area

A network of 21 digital earthquake monitoring stations is to be set up in the Chongqing section of the Three Gorges Reservoir (far western end of the reservoir) area by the end of 2007

Costing 29.6 million yuan (3.7 million U.S. dollars), the stations will monitor seismological activity around the clock and provide an earthquake warning system for the local government

Reference:

Xinhua News Agency, Aug. 31, 2006, China to build earthquake warning system at Three Gorges Reservoir Area," reprinted online by TerraDaily:

http://www.terradaily.com/reports/China_To_Build_Earthquake_Warning_System_At_Three_Gorges_Reservoir_Area_999.html

Slide 50

USGS

Sample of Historical Seismicity in the Three Gorges Area:

From 1407 to 1631, four medium and strong earthquakes were recorded, with the largest believed to have been magnitude 6.5.

From 1855 to the present, six medium and strong earthquakes have been recorded, the biggest having a magnitude of 5.5.

Recurrence Rates: 4 or 5 earthquakes occurred every eight to 10 years in the Three Gorges area.

References:

Tan, Chengxuan; Sun, Ye; Wang, Reijiang; and Daogong, Hu, 1997, Assessment and zonation of regional crustal stability in and around the dam region of the Three Gorges Project on the Yangtze River: Environmental Geology, Springer, v. 32, no. 4, p. 285–295. *http://www.springerlink.com/content/4p7cfy1593h88yta/*

Hu, Daogong; Wu, Shuren; and Tan, Chengxuan, 1999, Grey prediction of seismic activity in the Three Gorges area of the Yangtze River: Journal of Geodynamics, v. 31, no. 5, July 2001, p. 481–498.

Slide 51

Three Gorges Project Feasibility Study:

Various Chinese seismologists have predicted that the biggest earthquake to affect the reservoir and dam would be in the river section where the Jiuwanxi and the Zigui-Badong faults are located:

M = 6 on the Richter scale, most likely epicenter about 17 km (10 miles) from dam.

Reference:

Chen, Deji, 1999, Engineering geological problems in the Three Gorges Project on the Yangtze, China: Engineering Geology, v. 51, no. 3, p. 183–193. *http://www.sciencedirect.com/science*

Slide 52

USGS

Another category of earthquake can be caused by the collapse of limestone (karst) caves and holes left over from mining activities.

In the Wu Gorge, where there are many limestone caves, and in the Xiangxi valley, with its concentration of coal mines, minor tremors were recorded after the filling of the reservoir.

Later on, in 2003, minor tremors of 1.8 and 2.5 on the Richter scale were recorded. Cracks appeared on the walls of 22 houses.

With this kind of quake, the tremors are usually shallow, occurring close to the earth's surface, but the degree of damage to lives and property can be tremendous.

Another category of earthquake can be caused by the collapse of limestone (karst) caves and by underground holes left over from mining activities. For example, in the Wu Gorge, where there are many limestone caves, and in the Xiangxi valley, which has a concentration of coal mines, minor tremors were recorded after the filling of the reservoir. On Dec. 18 and 19, 2003, minor tremors of M = 1.8 and 2.5 on the Richter scale were recorded at Mazongshan, Guandukou township, Badong county, which is 80 km (50 miles) upstream of the dam; and in Peishi township, Wushan county 120 km (75 miles) upstream of the dam. In the case of Mazongshan, cracks appeared on the walls of 22 houses. With this kind of earthquake, the tremors are usually shallow and close to the Earth's surface, but the degree of damage to lives and property can be tremendous.

Reference:

Chen, Deji, 1999, Engineering geological problems in the Three Gorges Project on the Yangtze, China: Engineering Geology, v. 51, no. 3, p. 183–193. *http://www.sciencedirect.com/science*

Slide 53

RESERVOIR-INDUCED SEISMICITY

The weight of the dam and reservoir can theoretically induce seismicity.

Some experts believe that reservoir-induced earthquakes are likely to be as much as 1 or 2 Richter points bigger than the recorded high in a region.

Others are worried about the Three Gorges Dam for the following reason: In the case of the Tangshan Earthquake in northeast China, no significant tremors had previously been recorded there until a massive quake measuring M = 7.8 on the Richter scale occurred in 1976, killing more than 242,000 people, according to the official toll.

References:

Chen, Deji, 1999, Engineering geological problems in the Three Gorges Project on the Yangtze, China, Engineering Geology, v. 51, no. 3, p. 183–193 *http://www.sciencedirect.com/science*

Chen, L., and P. Talwani, 1998, Reservoir-induced seismicity in China: Journal of Applied Geophysics, v. 153, no. 1, p. 133–149. *http://www.springerlink.com/content/vu4u79euw6w01unx/*

Mason, R., 1999, The Three Gorges Dam of the Yangtze River, China—Engineering geology in China: Geology Today, v. 15, no. 1, p. 30–33.

Slide 54

China has experienced earthquakes triggered by reservoir-filling before.

--In 1962, an earthquake measuring 6.1 on the Richter scale shook a reservoir in Guangdong province.

--The epicenter of the tremor was 100 meters (330 feet) beneath the dam, and the structure sustained severe damage:

--A powerhouse was destroyed

--82-meter-long (269 foot) crack developed on the upper part of the dam.

--6 deaths, 80 injuries

--Damaged 1,800 houses.

USGS

One of the most serious such tremors occurred near the Xinfengjiang reservoir on the Dong River in Guangdong province. Low-level seismic activity was detected just a month after the reservoir was filled in 1959. On May 7, 1962, a powerful earthquake registering M = 6.1 on the Richter scale shook the area; the epicenter was only 1.1 km (0.7 miles) upstream of the dam. The earthquake killed six people, destroyed 1,800 houses and caused an 82-m-long (90-yard-long) crack to open in the structure of the dam, rendering it unworkable. The incident was ranked as one of the world's six most powerful earthquakes above 6 on the Richter scale that have been triggered by reservoirs impounded by man-made dams.

Reference:

Chen, Deji, 1999, Engineering geological problems in the Three Gorges Project on the Yangtze, China: Engineering Geology, v. 51, no. 3, January, p. 183–193.

Slide 55

Sedimentation

Excessive sedimentation can block the sluice gates which can cause dam failure under some conditions.

Sedimentation was a contributing cause of the Banqiao Dam, China failure in 1975—The Banqiao Dam failure precipitated the failure of 61 other dams and resulted in over 26,000 deaths; 5,960,000 buildings collapsed, and 11 million residents were affected. (Banqiao dam is located on the Ru River north of the Yangtze).

Photographs: source unknown

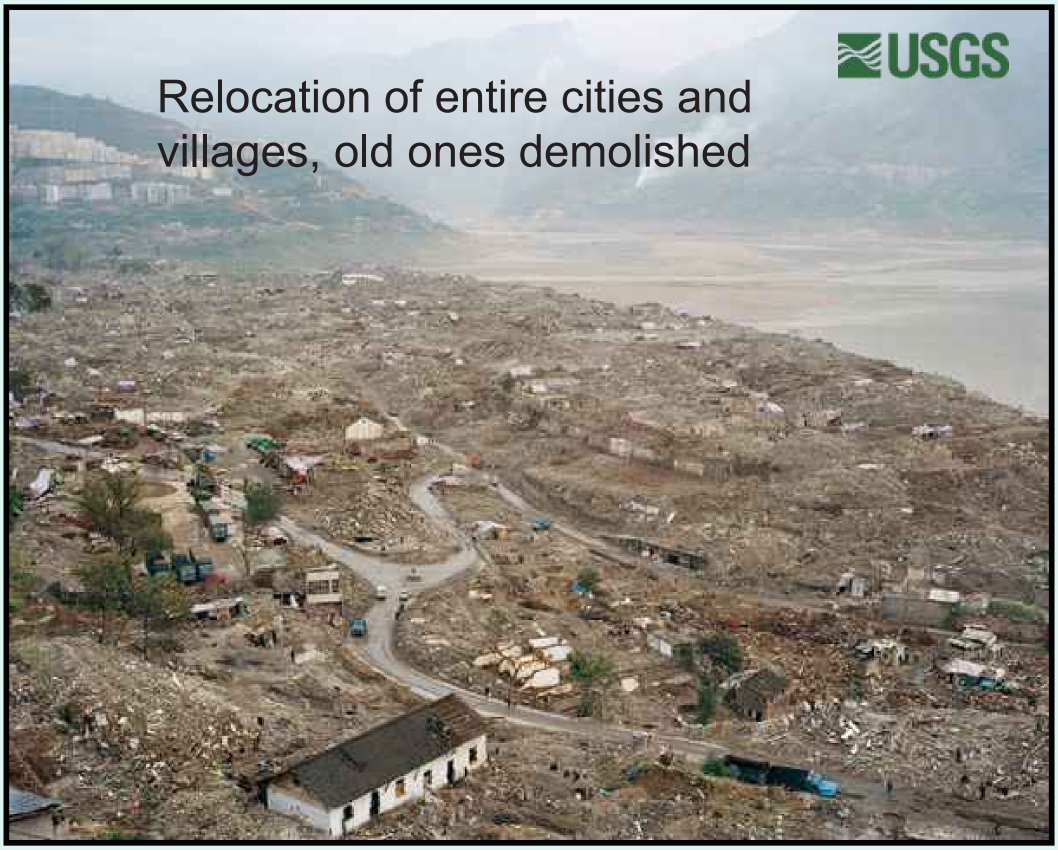
Reference:

Yi, Si, 1998, The world's most catastrophic dam failures—The August 1975 collapse of the Banqiao and Shimantan dams, in Qing, Dai, ed., The River Dragon has come!—The fate of China's Yangtze River and its people: New York, M.E. Sharpe, p. 25–38 (translated by Yi Ming).

Slide 56

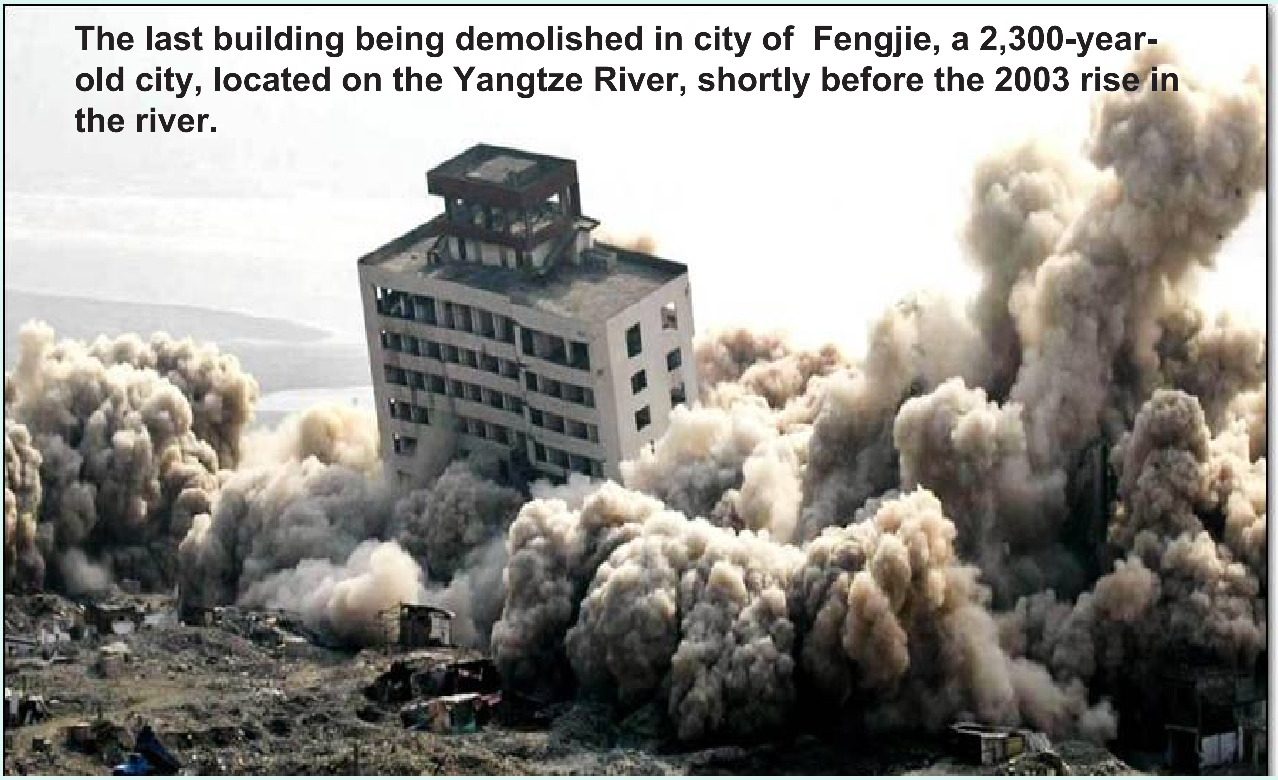
Effects of the massive relocation of cities and people resulting from the construction of the dam and filling of the reservoir

Slide 57



Photograph: source unknown

Slide 58



USGS

Photograph: source unknown

Reference:

China Education and Research Network. *http://www.edu.cn/20020122/3018405.shtml*

Slide 59

Photograph: source unknown

Reference:

Documentary film about the Fengjie relocation, May 18, 2004: *http://www.chinadaily.com.cn/english/doc/2004-05/18/content_331598.htm*

Slide 60

A few examples of the rising level of the river's impact on historical artifacts.

Chinese Poetry carved in rock that will be lost below the river level

Carvings preserved at Baiheliang Underwater Museum

USGS

Photographs: source unknown

Note: Some artifacts are being preserved:

"Located at the mainstream of the Yangtze River to the north of Fuling District of Chongqing Municipality, Baiheliang (White Crane Ridge in Chinese) is a 1.6 km-long (1 mile-long) and 16 km-wide (10 mile-long) reef. Ancient people carved many carp-shaped marks on the massive reef to record the low water and floods of the River. However, this massive reef will be inundated by the on-going Three Gorges Reservoir Project. It will be about 40 m below the water surface when the entire project is completed by 2009. To ensure that those precious cultural relics receive the appropriate protection, the Chinese government has started research into ways to protect Baiheliang. Experts once raised several proposals.

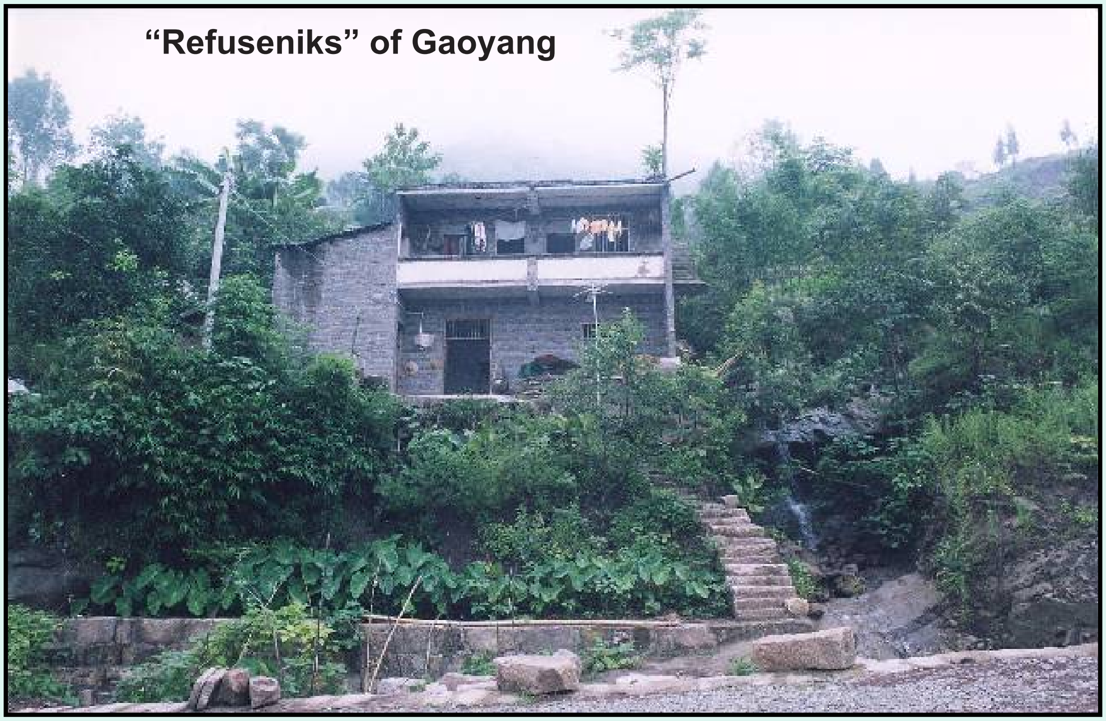
The solution raised by Prof. Ge Xiurun, an expert on rock mechanics from the CAS Wuhan Institute of Rock and Soil Mechanics and a member of the Chinese Academy of Engineering, was accepted. He suggested the covering of the Baiheliang reef by a water pressure-free container with an arch shape. Fresh water will be instilled in the container, making its inside and outside water pressure balanced. Two underwater channels will be built from the river bank, so visitors can see the stone inscriptions on Baiheliang by walking through the underwater channel. More than 10,000 underwater LED lights will be installed so visitors can view the inscriptions via the glass protection windows.

The main body of Baiheliang underwater museum has been completed. Started in 2002, the construction will cost about 140 million yuan (about US$17 million)."

Reference:

Newsletter of the Chinese Embassy in Romania, May 10, 2006. *http://www.chinaembassy.org.ro/rom/kjwh/t251366.htm*

Slide 61



Returned migrants rent a house near where their old home used to stand.
They will have to move when the river is raised in 2009.

Photograph: Three Gorges Probe news

Reference:

http://www.threegorgesprobe.org/tgp/Refuseniks_Gallery/index.html

Slide 62

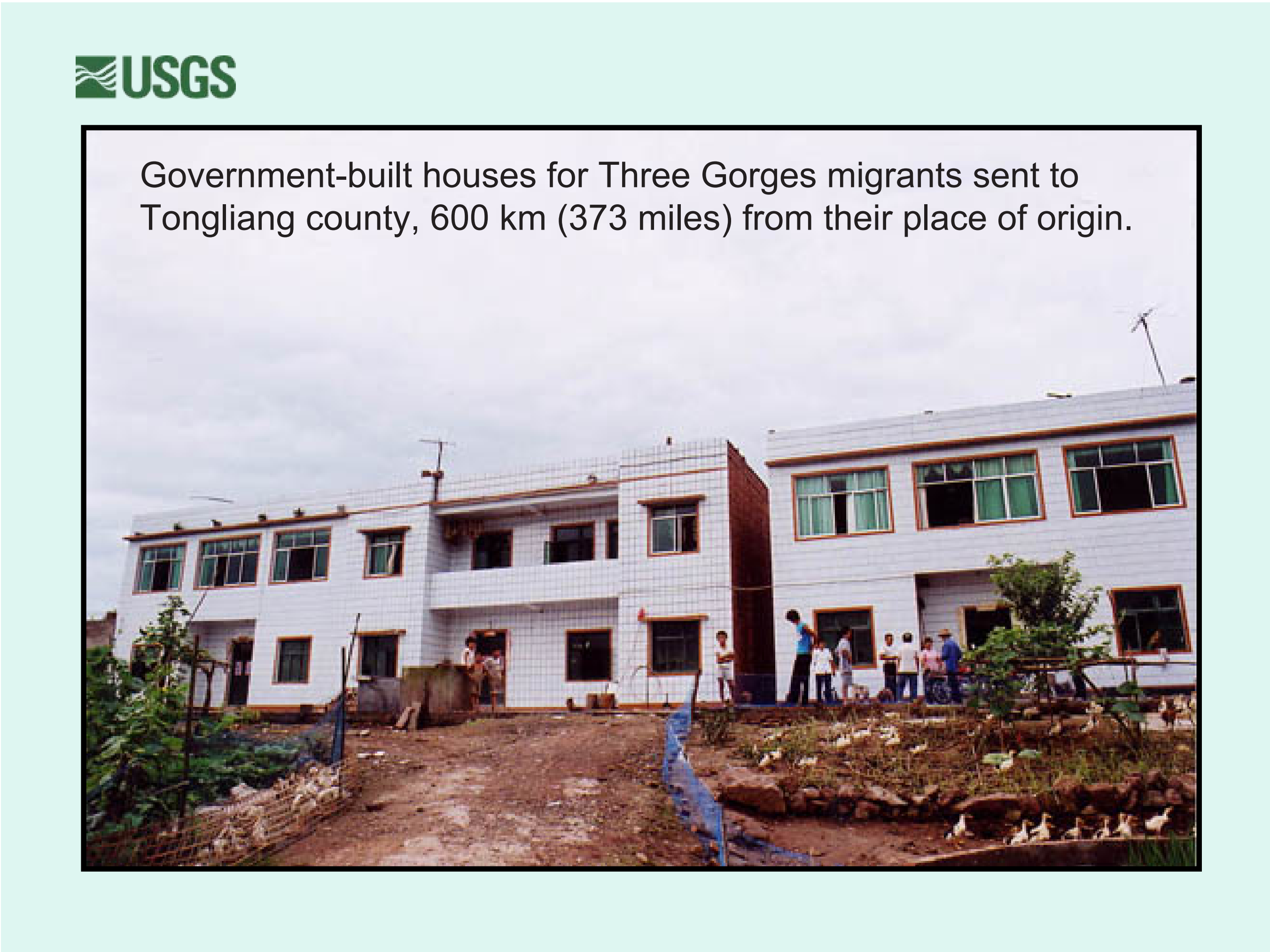
Returning migrants live close to where their homes were demolished
- most grow vegetables, work as janitors, laborers.

Photograph: Three Gorges Probe news

Reference:

http://www.threegorgesprobe.org/tgp/Refuseniks_Gallery/index.html

Slide 63

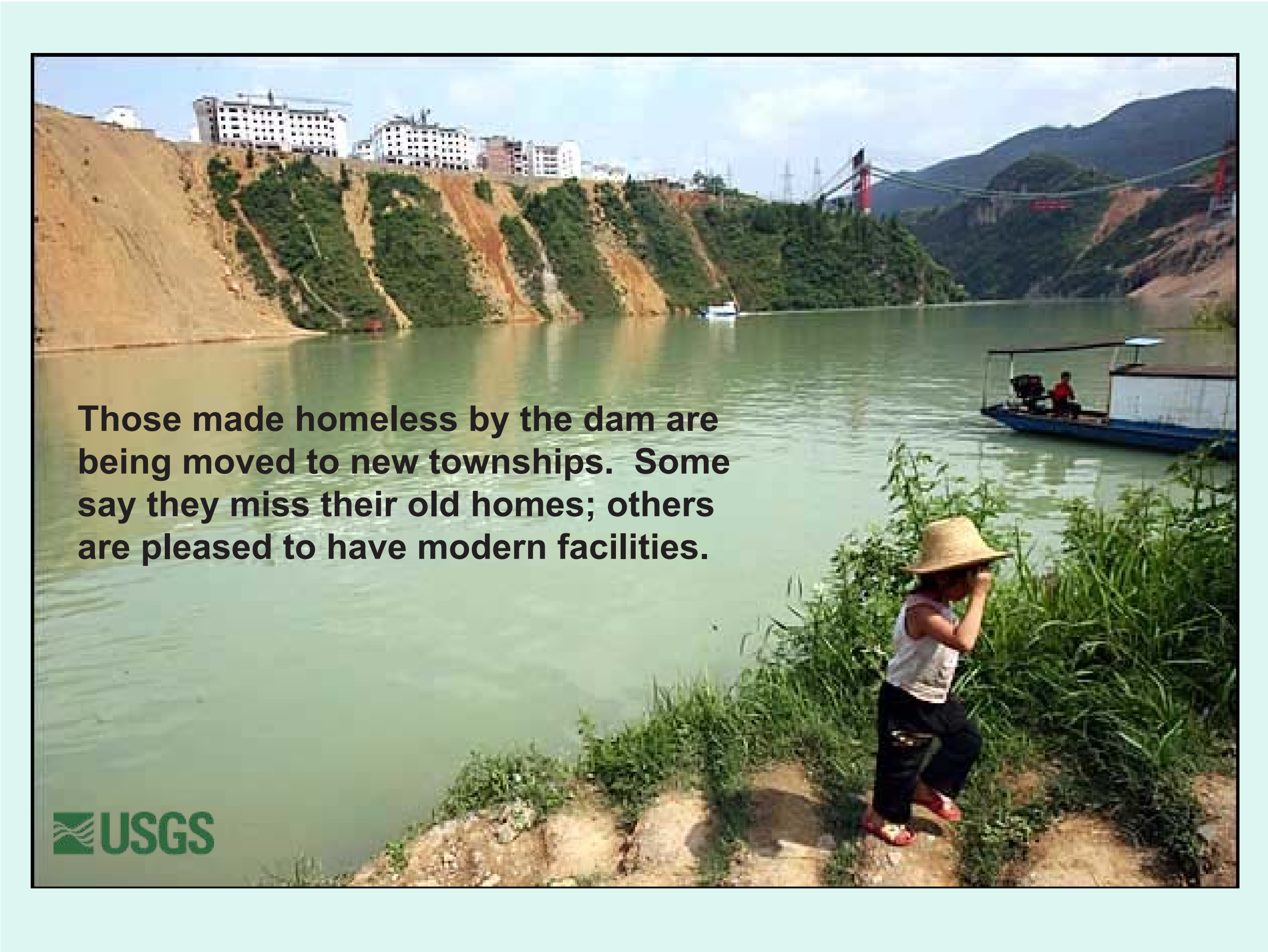


Photograph and information: Three Gorges Probe news

Reference:

http://www.threegorgesprobe.org/tgp/Refuseniks_Gallery/index.html

Slide 64



Photograph: source unknown

Slide 65

Lost Archaeological Sites:

An estimated 1,300 excavated sites and 8,000 unexcavated sites will be inundated by the rising water.

Slide 66

Photograph: source unknown

Slide 67

Potential Hazards from rising and falling of river level due to flood control

After the project is completed in 2009, the water level in the reservoir is to be kept at 175 meters above sea level during the dry winter months, and lowered to 145 meters for the summer flood season.

The 30-meter-high (98 foot-high) strip of land between those two levels will be covered with water in winter and exposed in summer. This wide ring around the Three Gorges reservoir and along the banks of upstream tributaries could become geologically unstable, seriously polluted and a dangerous source of epidemic disease.

--This zone presents a dilemma for local people. It would provide good farmland when the water recedes and exposes fertile soil.

--When the water rises again in winter, the chemical fertilizer and pesticides used on the fields would go into the river water, posing a serious pollution problem.

--Experts have argued that no farming should be allowed in this zone, in order to protect the environment in the reservoir area.

USGS

Reference—Yangtze River Basin

Chen, Xiquing; Zong, Yongqiang; Zhang, Erfeng; Xu, Jiangang; and Li, Shijie, 2001, Human impacts on the Changjiang (Yangtze) River Basin, China, with special reference to the impacts on the dry season water discharge into the sea: Geomorphology, v. 41, p. 111–123.

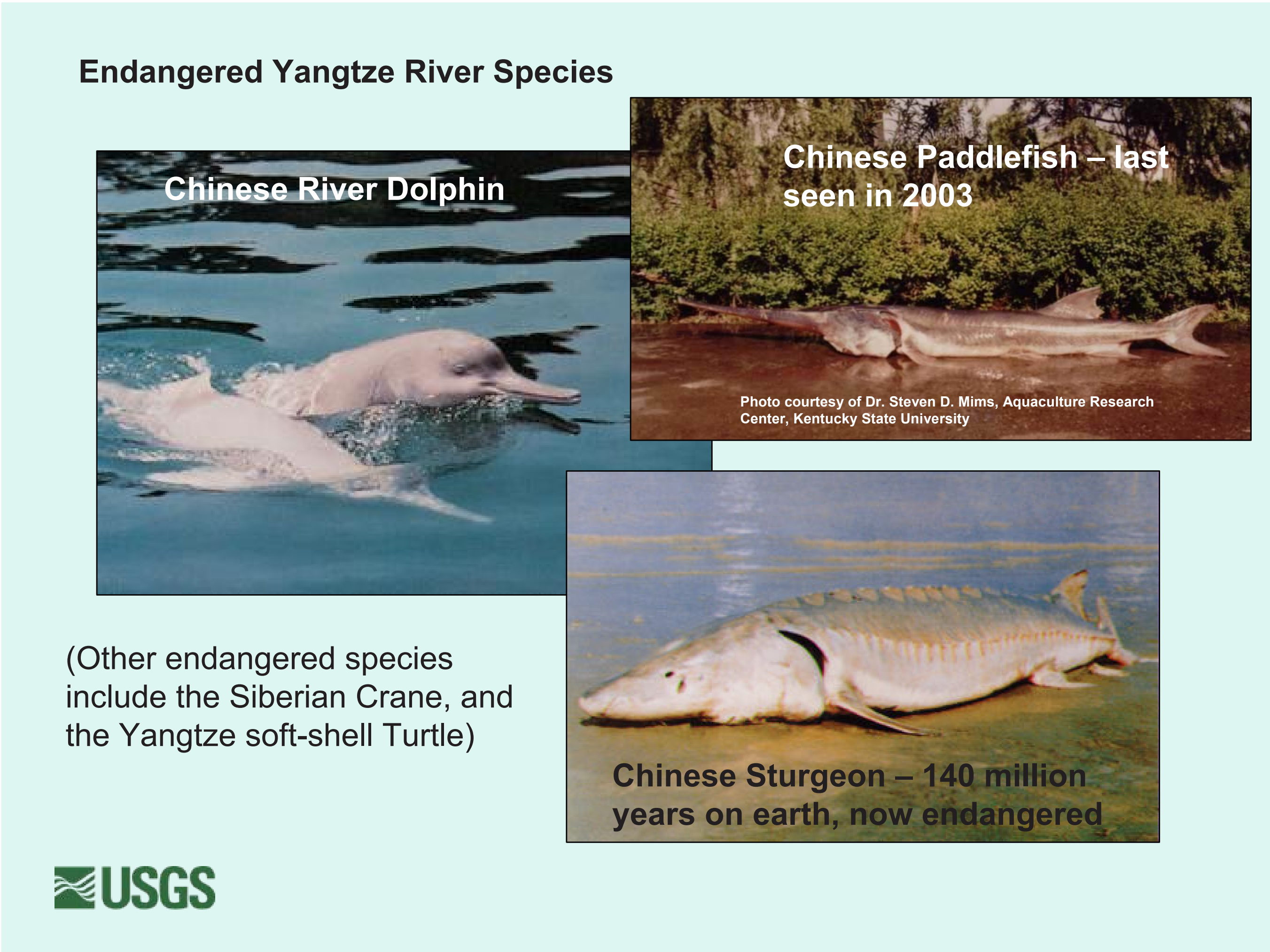
References—Epidemic disease

http://www.probeinternational.org/catalog/content_fullstory.php?contentId=2781&cat_id=24

Oriental Outlook Magazine ((Liaowang dongfang zhouka, a division of China Xinhua News), Shanghai, March 16, 2005.

Chongqing, China Morning Post (*Chongqing chenbao), March 7, 2005.*

Slide 68



As of summer 2007, no one has seen any Chinese river dolphins, and they are now thought to be extinct. As of December 2007, there are only two Yangtze soft-shell turtles left in captivity (New York Times, December, 2007). Sturgeon are being raised domestically.

References:

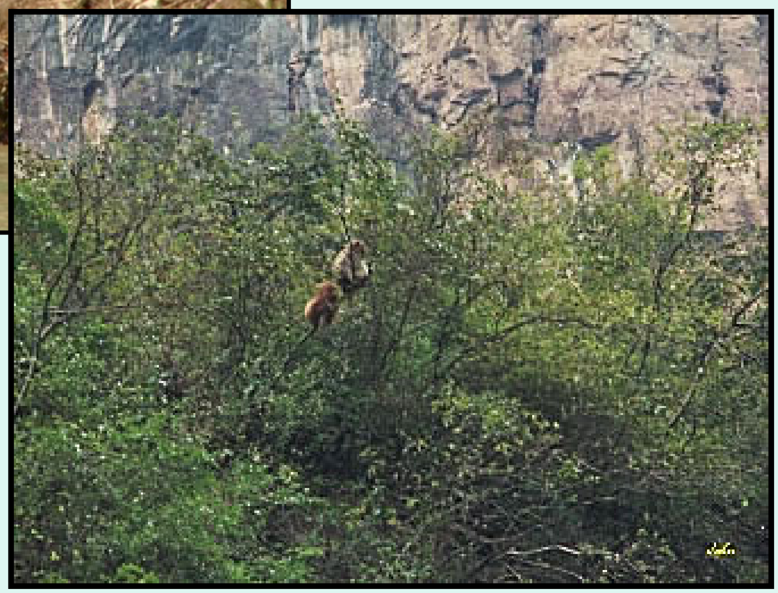
Smith, B.D., Zhou, K., Wang, D., Reeves, R.R., Barlow, J., Taylor, B., and Pitman, R., 2007, Lipotes vexillifer, International Union of Nature and Natural Resources (IUCN) Red List of Threatened Species. *http://www.iucnredlist.org*

Xie, Ping; Wu, Jianguo; Huang, Jianghui; and Han, Xingguo, 2003, Three Gorges Dam—Risk to ancient fish: Science, v. 302, no. 5648, p. 1149–1151. *http://www.sciencemag.org/cgi/content/citation/302/5648/1149b*

Slide 69

Yangtze River
Rhesus Monkeys

(Populations of Macaque Monkeys have recently been re-introduced into the area).



No one knows the effect of the raising of the river level on monkey and wild goat populations along the river.

Photographs: source unknown

Reference:

http://news.xinhuanet.com/english/2007-1/22/content_7128212.htm

Slide 70

Update as of May, 2007 – Three Gorges Landslide Hazards

Reactivation of Yemaomian (Wild Cat Face) Landslide – 17 kilometers (11 miles) upstream from the dam.

99 villagers from the village of Miaohe, Hubei Province, were evacuated in April, due to extensive new cracking in an old landslide bordering the Yangtze

The village is 17 km (10.6 miles) upstream from the dam, and the crack runs east-west, 200 meters(656 feet) in length, right under the village.

The ground began cracking in October, 2006 after flood season, when the Reservoir was being filled back up to 156 meters (512 feet).

USGS

Reference:

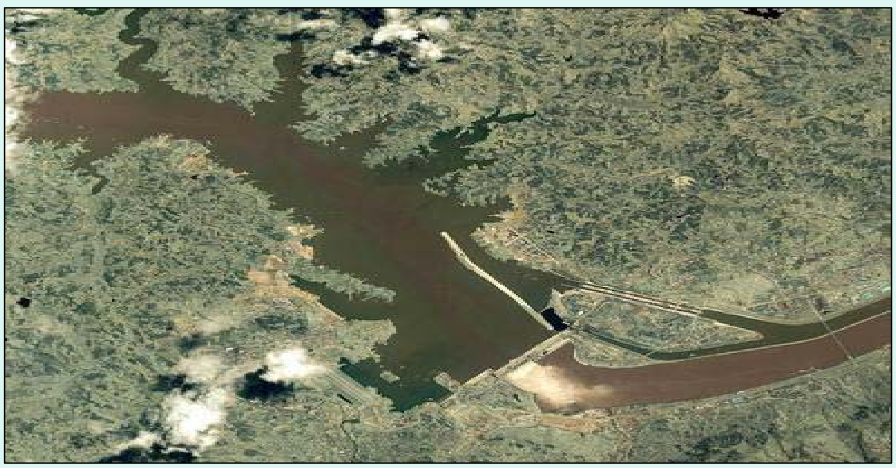
May 15, 2007. *http://www.geoprac.net/project-related/three-gorges-landslide-threat-forces-villagers-to-flee-2.html*

Slide 71

--Newest controversy is whether to build more hydroelectric dams in tributary channels, upstream from the Three Gorges Dam.

--Critics say it will decimate fish populations, as the dams will be in designated fish conservation zones.

--Also, below the dam, the Yangtze is now carrying less silt, and as a result the river is flowing faster, and scouring the banks at an accelerated rate impacting structures and levees.



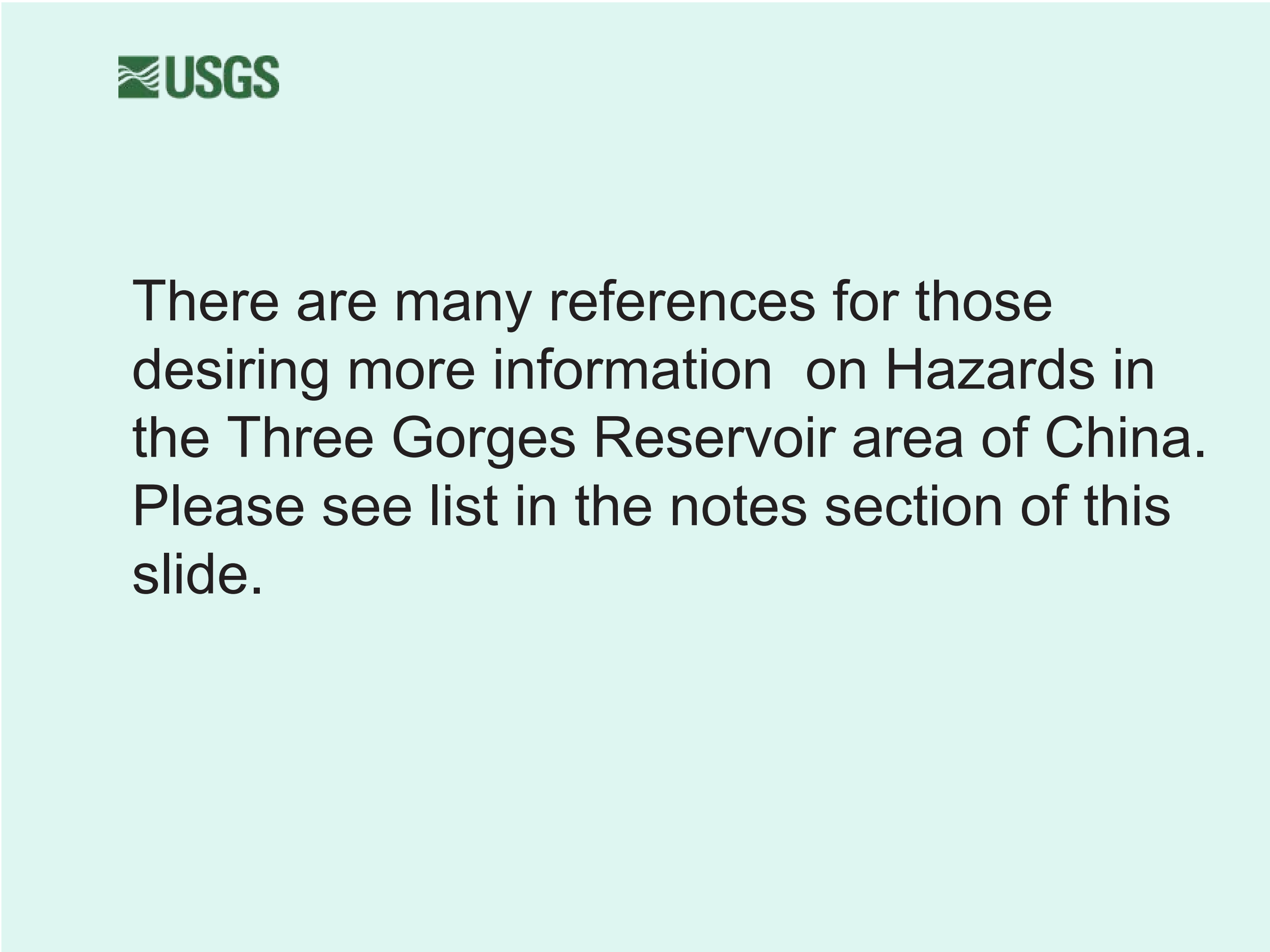
Photograph: source unknown

References:

Wang, Fawu; Wang, Gonghui; Sassa, Kyoji; Takeuchi, Atsuo; Araiba, Kiminori; Zhang, Yeming; and Peng, Xuanming, 2005, Displacement monitoring and physical exploration on the Shuping landslide reactivated by impoundment of the Three Gorges Reservoir, China, *in* Sassa, Kyoji; Fukuoka, Hiroshi; Wang, Fawu; and Wang, Gonghui, eds., Landslides, General Assembly of the International Consortium on Landslides, 1st, Proceedings: Berlin, Springer, p. 313–319. *http://www.springerlink.com/content/j4k7274158p362n1/*

Yeng, S.L., 2003, Delta response to decline in sediment supply from the Yangtze River—Evidence of the recent four decades and expectation for the next half century: Estuarine, Coastal, and Shelf Science, v. 57, p. 689–699.

Slide 72



References and further reading:

Canadian International Project Managers (CIPM) Yangtze Joint Venture (CYJV), Three Gorges Water Control Project Feasibility Study, August 1988.

Chen, Deji, 1999, Engineering geological problems in the Three Gorges project on the Yangtze, China: Engineering Geology, v. 51, no. 3, p. 183–193.

Chen, L., and Talwani, P., 1998, Reservoir-induced Seismicity in China: Journal of Applied Geophysics, Birkhäuser Basel, v. 153, no. 1, p. 133–149. *http://www.springerlink.com/content/vu4u79euw6w01unx/*

Chen, Xiquing; Zong, Yongqiang; Zhang, Erfeng; Xu, Jiangang; and Li, Shijie, 2001, Human impacts on the Changjiang (Yangtze) River Basin, China, with special reference to the impacts on the dry season water discharge into the sea: Geomorphology, v. 41, p. 111–123.

China Three Gorges University, Yichang City, China. *http://www.ctgu.edu.cn/en/*

Dai, F.C., Deng, J.H., Tham, L.G., Law, K.T., and Lee, C.F. 2004, A large landslide in Zigui County, Three Gorges area: Canadian Geotechnical Journal, v. 41, no. 6, p. 1233–1240.

Deng, Q.L., 2000, Mass rock creep and landsliding on the Huangtupo slope in the reservoir area of the Three Gorges project, Yangtze River, China: Engineering Geology, v. 58, p. 67–83.

Guo, X., 1991, Geological hazards in China and their prevention and control: Beijing, Geological Publishing House, p. 48–81 (in Chinese).

Han, Z.S., 1988, Landslides and rockfalls of the Yangtze River Gorges: Beijing, Geological Press, p. 5–80 (in Chinese).

Hu, Daogong; Wu, Shuren; and Tan, Chengxuan, 1999, Grey prediction of seismic activity in the Three Gorges area of the Yangtze River: Journal of Geodynamics, v. 31, no. 5, July 2001, p. 481-498.

Kuhn, Anthony, 2008, Relocated Three Gorges residents face challenges: National Public Radio series, "China's Three Gorges: Assessing the Impact," *http://www.npr.org/templates/story/story.php?storyId=17784497*

Li, Y.S., and Zhang, Y., 1993, Large-scale landslides and rockfalls in the reservoir of the Three Gorges project of the Yangtze River: Guangzhou, Guangzhou Tour Press, p. 1–6 (in Chinese and English).

Liao, Y., Li, P., and Tan, K.,1996, Environmental and engineering geology of the Yangtze Gorges area, International Geological Congress (IGC), 30th, Field Trip Guide T369: Beijing, Geology Publishing House, 49 p.

Liu, Guangrun, 1988, Environmental geologic investigation of Xintan landslide: Environmental Geology, August, v. 12, no. 1, p. 11–13. *http://www.springerlink.com/content/k42p4534422n7725/*

Mason, R., 1999, The Three Gorges Dam of the Yangtze River, China—Engineering geology in China: Geology Today, v. 15, no. 1, p. 30–33.

Roessner, S., Wetzel, H.U., Xia, Y., Meleshko, A.V., and Sarnagoev, A., 1999, Investigation of landslide processes in southern Kyrgyzstan using optical and radar remote sensing in a GIS environment, EGS General Assembly, 24th, The Hague, Geophysical Research Abstracts, v. 1, no. 4, p. 837.

Sassa, Kyoji; Fukuoka, Hiroshi; Wang, Fawu; and Wang, Gonghui, eds., Landslides, General Assembly of the International Consortium on Landslides, 1st, Proceedings: Springer, p. 313–319. *http://www.springerlink.com/content/j4k7274158p362n1/*

Smith, B.D., Zhou, K., Wang, D., Reeves, R.R., Barlow, J., Taylor, B., and Pitman, R., 2007, Lipotes vexillifer, International Union of Nature and Natural Resources (IUCN) Red List of Threatened Species: *http://www.iucnredlist.org/*

Sukhan, Jackson, and Sleigh, Adrian, 2000, Resettlement for China's Three Gorges Dam— Socioeconomic impact and institutional tensions: Communist and Post-Communist Studies, v. 33, no. 2, June, p. 223–241.

Tan, Chengxuan; Sun, Ye; Wang, Reijiang; and Daogong, Hu, 1997, Assessment and zonation of regional crustal stability in and around three dam region of the Three Gorges Project on the Yangtze River: Environmental Geology, v. 32, no. 4, p. 51–58. *http://www.springerlink.com/content/4p7cfy1593h88yta/*

Three Gorges Probe News. *http://www.probeinternational.org*

Wang, Fawu; Wang, Gonghui; Sassa, Kyoji; Takeuchi, Atsuo; Araiba, Kiminori; Zhang, Yeming; and Peng, Xuanming, 2005, Displacement monitoring and physical Exploration on the Shuping landslide reactivated by impoundment of the Three Gorges Reservoir, China, *in* Sassa, Kyoji; Fukuoka, Hiroshi; Wang, Fawu; and Wang, Gonghui, eds., Landslides, General Assembly of the International Consortium on Landslides, 1st, Proceedings: Springer, p. 313–319. *http://www.springerlink.com/content/j4k7274158p362n1/*

Wang, Fawu; Zhang, Ye-Ming; Huo, Zhi-Tao; Matsumoto, Tatsunori; and Huang, Bo-Lin, 2004, The July 14, 2003, Qianjiangping landslide, Three Gorges Reservoir, China: Landslides, v. 1, no. 2, July, p. 157–162. *http://www.springerlink.com/content/g408kx5vae2xgwnr/*

Wang, J., Li, S., Yan, L., and Dong, D., 2002, Preliminary analysis on the May 1, 2001, landslide at Wulong of Chongqing City: Engineering Science, v. 4, p. 22–28 (in Chinese).

Wu, Faquan, and Luo, Yuanhua, 2006, Cutting slope reinforcement in reconstructed migrant cities in the Three Gorges Reservoir area of China, International Association for Engineering Geology, International Congress, 10th, Nottingham, United Kingdom, September, p. 6–10.

Wu, S., Shi, L., Tan, C., Hu, D., Mei, Y., and Xu, R., 2000, Fractal analyses of the Huanglashi and Huangtupo landslides in the Three Gorges, Yangtze River, China: Earth Science, v. 25, p. 61–65 (in Chinese).

Wu, Shuren; Shi, Ling; Wang, Reijiang; Tan, Chengxuan; Hu, Daogong; Mei, Yingtang; and Xu, Ruichun, 2001, Zonation of the landslide hazards in the fore-reservoir region of the Three Gorges Project on the Yangtze River: Engineering Geology, v. 59, no. 1 and 2, January, p. 51–58.

Wu, S., Shi, L., Wang, R., Tan, C., and D. Hu, 2001, Zonation of the landslides hazards in the reservoir region of the Three Gorges project on the Yangtze River: Engineering Geology, v. 59, p. 51–58.

Wu, S., Zhang, Y., and Shi, J., 2002, The investigations of geological hazards in the Fengdu County of the reservoir region of the Three Gorges Project on the Yangtze River—Research Report, Institute of Geomechanics: Chinese Academy of Geological Sciences, Beijing, China, p. 17–111 (in Chinese).

Xia, Ye, Kaufmann, H., and Guo, X.F., 2004, Landslide monitoring in the Three Gorges area using D-InSAR and corner reflectors: Photogrammetric Engineering & Amp—Remote Sensing, v. 70, no. 10, p. 1167–1172.

Xiao, Fan, 2006, Three Gorges revisited: Chinese National Geographic, May 3, 2006. *http://internationalrivers.org/files/FanXiao.pdf*

Xie, Ping, Wu, Jianguo, Huang, Jianghui, and Han, Xingguo, 2003, Three Gorges Dam—Risk to ancient fish: Science, v. 302, no. 5648, p. 1149–1151. *http://www.sciencemag.org/cgi/content/citation/302/5648/1149b*

Yeng, S.L., 2003, Delta response to decline in sediment supply from the Yangtze River—Evidence of the recent four decades and expectation for the next half century: Estuarine, Coastal, and Shelf Science, v. 57, p. 689–99.

Yi, Si, 1998, The World's most catastrophic dam failures—The August 1975 collapse of the China's Yangtze River and its people: New York, M.E. Sharpe, p. 25–38 (translated by Yi Ming). *http://www.chinadaily.com.cn/english/doc/2004-05/18/content_331598.htm* (a documentary film)

Yin, Y., Kang, H., and Chen, B., 2000, Landslide control and utilization of measurement in immigrant settlement region of Three Gorges project on the Yangtze River: Journal of Geological Hazards and Environmental Preservation, v. 11, no. 2, p. 135–140 (in Chinese).

Yin, Yueping, 1997, Anchoring engineering for Lianziya dangerous rock mass controlling at the Three Gorges of the Yangtze River, China, in Wang, Sijing, and Marinos, P. eds., International Geological Congress (IGC), 30th, 1997, Beijing, China, Proceedings: Leiden, The Netherlands, Brill Publishing, v. 23, p. 53–58.

Zhou, P., and Ou, Z., 1997, Stability estimation of the different types of gentle slope in the reservoir area of the Three Gorges project on the Yangtze River: Chinese Journal Geologic Hazard Control, v. 8, no. 2, p. 24–32 (in Chinese).

USGS

Highland—**Three Gorges Dam and Resevoir, China—Geologic Hazards**—Open-File Report 2008–1241