

Understanding Dam Failure

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Ground Truth Trekking

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Failed Choices

Faulty decision-making often plays a crucial role in industrial accidents. Two well-understood cases were also world-class dam failures:

Teton Dam, USA, 1976

Teton Dam was the largest structural collapse in U.S. history, exceeding even the World Trade Centers. The day before the breach, with leaks worsening, the project engineer is on record as being unworried.

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Vajont Dam, Italy, 1963

Europe’s tallest dam was almost complete in the Italian Alps, when a giant landslide turned the reservoir into an 800-foot tsunami that crashed over the dam, and destroyed five towns in seven minutes.

Vajont has been called one of the “great failures of science and engineering” - but it was very human choices that pushed the project on past warning signs.

READ ARTICLE (/Issues/OtherIssues/dam-failure-human-factors-cases-Teton-Vajont.html)

Dams are a remarkably useful technology, and their failure - though rare - can be massively destructive.

When dams fail, downstream areas are often inundated by floods, tsunamis, and mudflows. The failures often cause fatalities, destruction of downtream structures, denudation of land, severe pollution, and massive disruption of downstream ecosystems, economies, and communities.

Dam failure is also usually also associated with loss of dam-related functions like irrigation, flood control, electricity generation, and mine operation. Large dams themselves are often huge capital assets, and thus are very expensive to lose.

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Failure Rates

Water dam failures occur at a rate of roughly 1-in-10,000 per year, mostly in smaller dams.

Tailings dams fail much more frequently, at a rate of roughly 1-in-1000 per year (2010 study (http://www.infomine.com/library/publications/docs/Azam2010.pdf)), or 3-4 per year worldwide. Rates of tailings dam failure may be much higher, since extensive under-reporting (http://www.infomine.com/library/publications/docs/Azam2010.pdf) is suspected.

Water Dam Failures

Water dams have failed as long as humans have built them, and many of the principles involved - like the danger of overtopping and the devastating effects of spillway erosion - are something many of us see as children, playing with shovels and streams. Most water dam failures occur in relatively small dams, but large dams have also occassionally failed. The challenge isn't finding examples of dam failure, but choosing among them.

World: The worst dam failure event in history was the Banqiao Dam Disaster (http://en.wikipedia.org/wiki/Banqiao_Dam) in Henan province, China, 1975, in which a series of 62 (http://theenergylibrary.com/node/13072) earthen water dams failed (and were in some cases deliberately breached by air strikes) in a cascading series, during an extremely severe typhoon. The event caused 171,000 deaths, mostly from disease and famine

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which followed the flooding, and is named after the Banqiao Dam, the largest of the dams which failed. Because of the Cold War, the disaster was essentially unknown in the West.



TETON DAM FAILURE — During reservoir filling, water seeped through an abuttment of the Teton embankment dam, and quickly eroded into the dam itself. The dam dam is completely breached, in what may be the largest singe structural failure in U.S. history. — Get Photo (/photos/teton-embankment-dam-failure/)

Europe: Europe's deadliest disaster occurred, remarkably, in an extremely well-engineered, state-of-the-art concrete water dam. In 1963 in the Italian Alps, a landslide displaced the partially filled reservoir of the recently completed Vajont dam, (http://www.vajont.info/gGeoAppl.pdf) creating a wave which overtopped the dam by 500 feet. The wave descended through the steep alpine valley below, destroying five towns and killing 2,000 people in seven minutes.

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United States: The deadliest dam failure in U.S. history was the Johnstown flood (http://en.wikipedia.org/wiki/Johnstown_Flood) of 1889, in which heavy rains overwhelmed an earthen dam holding a recreational lake, destroying the town and killing 2,200 people with a combination of flood and fire burning through the floating debris.

The largest dam failure in U.S. history - the 1976 Teton Dam (http://en.wikipedia.org/wiki/Teton_Dam) breach - was also the largest structural failure of any type in U.S. history, exceeding even the September 11 collapse of the World Trade Center. Teton Dam was built despite strong concerns (/Issues/OtherIssues/dam-failure-human-factors-cases-Teton-Vajont.html) by USGS geologists, and its failure caused 11 deaths and an estimated $2 billion in damages.

Recent: Water dam failures continue to occur periodically throughout the world, mostly in small dams and in countries with less stringent engineering and regulatory regimes.

Citing a recent and staightforward example, Mississippi's well-maintained 14-year-old Big Bay Dam failed (http://www.damsafety.org/media/Documents/PRESS/2014/BigBayDamFailure.pdf) in 2004, as water seepage eroded through the earthen structure, releasing 3.5 billion gallons of water and destroying 100 homes (also see Powerpoint the Big Bay failure (https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0CCUQ&sig2=La0OZQbeciIC9i0lwMwubg&bvm=bv.

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77648437,d.cGU)). In a textbook sequence, ordinary seepage turned to erosive seepage, and erosive seepage burrowed through and breached the dam.

Througout much of 2014, water scoured through Tokwe-Mukorsi Dam (http://www.dailymaverick.co.za/article/2014-04-14-in-photos-the-aftermath-of-zimbabwes-tokwe-mukorsi-dam-disaster/#.VGFPbvnF-ug), during reservoir filling. It temporarily displaced more than 20,000 people.

See this "Lessons Learned from Recent Dam Emergencies" PDF (http://www.mde.state.md.us/programs/Water/DamSafety/TechnicalReferences/Documents/8%20Lessons%20Learned,%20Van%20Aller.pdf) for more examples of contemporary failures and near-misses.

Tailings Dam Failures

While most people are familiar with water dams, tailings & slurry dams are some of largest man-made structures on the planet. While water dams create water reservoirs, generate hydroelectricity, and control floods, tailings dams impound mine tailings (/Issues/MetalsMining/MineTailings.html), coal slurry, and other industrial muds and wastes.

Failed section of Mount Polley tailings dam, BC, Canada

MOUNT POLLEY TAILINGS BREACH — Mount Polley's modified-centerline construction tailings dam failed in August, 2014, released an estimated 25 million cubic meters of water and tailings. Initial reports suggest the tailings may be relatively inert,

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due the presence of carbonate rocks in Mt. Polley's ore body, which buffer the acid-generating properties of the ore. It is hoped that this, combined with settling basins provided by two downstream lakes, will mitigate impact to the watershed, the First Nations immediately downstream, and the Fraser River. The creekbed between the breach and nearest lake was physically destroyed. — Get Photo (/photos/mount-polley-tailings-breach/)

Tailings dams hold thousands to billions of tons of mud-like or semi-solid waste. Because mud flows more slowly than water, discharges and breaches in tailings dams generally lack the massive, instantly destructive force of a catastrophic water dam break. However, they have a very high potential to cause severe environmental, social, and economic harm. In addition to damages caused by physical inundation and loss-of-services, the released material is often toxic or otherwise harmful to people and the environment.

Tailings dams are less numerous than water dams and have only been widely used in the last half-century. Prior to this, mine tailings were generally disposed of in the most convenient way possible. Simultaneously, human production of tailings has accelerated, as global thirst of mined goods has increased, and as we have moved to lower grades of ore. As such, we have less engineering experience with tailings dams than with water dams.

Among the world's estimated 3,500 tailings dams the failure rate is roughly 10 times greater (http://www.infomine.com/library/publications/docs/Azam2010.pdf)than the water dam

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failure rate, with an “average” tailings dam having an estimated failure chance of ~0.1% every year. This statistical population includes all worldwide tailings dams, regardless of their constrution method or quality. Failures tend to concentrate in the less well-built, less well-sited, and less well-maintained dams.

Notable 2014 examples include the Mount Polley breach (described below), and spills at Buenavista del Cobra mine (http://mexiconewsdaily.com/news/profepa-blames-negligence-mine-copper-sulphate-spill/), Mexico (10 million gallon copper sulphate spill) and Duke Energy (http://www.utilitydive.com/news/duke-faces-100m-fine-for-dan-river-coal-ash-spill/365879/), North Carolina (82,000 tons of coal ash and 27 million gallons of water).

Tailings dam failures appear to have been historically significantly under-reported (http://www.infomine.com/library/publications/docs/Azam2010.pdf) around the world, particularly in developing countries, and this is likely still the case. Two of the four following examples are in the United States - likely an artifact of better U.S. records, rather than a worse U.S. record:

Example Tailings Dam Spills:

Church Rock, USA: A 1979 uranium tailings breach (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1963288/) in Church Rock, Navajo Nation, New Mexico, released radioactive tailings into the Puerto Rico river. Immediately after the breach was

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repaired, radiation levels in the river were reportedly measured at 7,000 (http://www.ratical.org/radiation/UraniumInNavLand.html) times the safe drinking water level.

Buffalo Creek, USA: In 1972 at Buffalo Creek, West Virginia (http://en.wikipedia.org/wiki/Ajka_alumina_plant_accident) a dam failure killed 125 people and destroyed 500 homes. The psychological trauma observed in survivors helped lead to the recognition Post Traumatic Stress Disorder in the field of psychology.

Ajka Alumina, Hungary: The 2010 Ajka alumina plant "red mud" dam failure (http://en.wikipedia.org/wiki/Ajka_alumina_plant_accident) in Hungary is notable for its obvious chemical consequence: the mud released was relatively non-toxic, but was highly caustic. The mud flooded a town and village, causing severe chemical burns to residents, killing 10 and injuring 150. The red mud makes inundation and material spread vividly visible: see news article slideshow (http://www.nbcnews.com/id/39602254/ns/world_news-europe/t/second-wave-sludge-expected-hungary/#.VGD6APnF-ug).

Mount Polley, Canada: In August 2014, the tailings dam at British Columbia's Mount Polley Mine catastrophically failed (http://en.wikipedia.org/wiki/Mount_Polley_mine_disaster). This breach may have released 25 million cubic meters (http://www.wise-uranium.org/mdaf.html) of water and mud. An official report (https://www.mountpolleyreviewpanel.ca/) blames Mount Polley's failure on the placement of the dams over weak glacial sediment deposits, followed by oversteepending of the dams

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and allowing too much water to accumulate over the tailings. Fortunately, two lakes immediately below the facility acted as settling ponds, and minimized impact further downstream (in contrast to the Bento Rodriguez failure, below).

Bento Rodrigues, Brazil: In November 2015, a large tailings dam failed (https://en.wikipedia.org/wiki/Bento_Rodrigues_dam_disaster) at the Samarco iron mine in Brazil, killing at least 17 people. (http://www.bbc.com/news/business-35158646) An estimated 60 million (http://www.aljazeera.com/news/2015/11/brazil-dam-bursts-toxic-sludge-151122125732943.html) cubic meters of mud was released, creating a large mudflow, and sending muddy water plume down the local river system and into coastal Atlantic waters, causing a large die-off of aquatic life. The event has been called (http://tvuol.uol.com.br/video/boechat-mariana-e-a-maior-tragedia-ambiental-do-brasil-04024C9B3162DCB15326) the worst environmental disaster in Brazilian history. The Samarco mine is expected to be closed for several years (http://www.smh.com.au/business/mining-and-resources/bhp-billitons-burst-brazilian-dam-likely-to-stay-shut-for-years-20151109-gkucid.html) The financial impact on the mine's two owners - global mining giants Vale (http://www.mining.com/vale-several-years-to-recover-from-brazil-mine-disaster/) and BHP Billiton (http://www.wsj.com/articles/dam-burst-costs-could-break-1-billion-analyst-says-1447043902) - has been substantial.

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The Good & Bad of Dams

Dams are arguably humanity's greatest feats of both monumental and humanitarian engineering. They have changed the course of human civilization, benefited billions of people, and protected natural environments. Dams may rank among our greatest discoveries, along with metalworking, the wheel, the lever, the shovel, and the use of fire - and they may outlast all other human constructions.

Like most powerful technologies, dams also have downsides. Misapplications of dams appear to have caused gross social, economic, and environmental losses. Some dams have heavily benefited special interests, at the expense of other groups or society as a whole.

This article isn't a critique of dams. Whether we build dams or demolish them, dam failure is an important industrial issue.

Two Kinds of Dams: Embankment and Concrete

In addition to the two main functions of dams, there are two main types of dam design: Concrete dams ("walls of concrete") and embankment dams ("broad piles of earth and rubble"). These different types have different vulnerabilities, and often fail differently.

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Embankment Dams , made mostly of earth or rock fill, dominate the world's population of dams both in number (73% of all dams, in 2001) and in sheer size. They are much less expensive per unit volume to build than concrete dams, making them an attractive option where geography and conditions allow. The world's largest dams are all embankment dams, topped by the Mildred Lake Settling Basin's Syncrude Tailings Dam (http://en.wikipedia.org/wiki/Syncrude_Tailings_Dam) in the oil sands of Canada and the Tarbela water dam (http://en.wikipedia.org/wiki/Tarbela_Dam) in Pakistan.

Embankment dams are nominally more vulnerable than massive concrete dams, as water infiltration can penetrate and erode or liquefy their loose cores, making it relatively easy for a flood of water or sediment to cut a large channel through dam. Surprisingly, however, a 2001 ICOLD study (http://www.unep.fr/shared/publications/pdf/2891-TailingsDams.PDF) found that embankment dams are not appreciably more likely to fail than concrete dams.

Massive Concrete Dams are the large, wall-like dams most people think of at the word "dam": solid monumental massifs of steel and concrete. Famous examples include Three Gorges (http://en.wikipedia.org/wiki/Three_Gorges_Dam), Hoover (http://www.usbr.gov/lc/hooverdam/faqs/damfaqs.html), Grand Coulee (http://www.usbr.gov/pn/grandcoulee/about/index.html), Kariba (http://en.wikipedia.org/wiki/Kariba_Dam), and Vajont (http://en.wikipedia.org/wiki/Vajont_Dam#Reconstruction).

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Massive concrete dams often retain their structural integrity even during failure. For example Vajont is estimated to have withstood eight times its design stress when its reservoir was displaced violently by rock and earth, which piled against the backside of the dam, and caused a reservoir tsunami to overtop it by hundreds of feet.

However, concrete dams still break apart in some cases - such as when Austin Dam was pushed off its foundations, and when St. Francis dam ruptured for reasons still not conclusively proven (but most likely due to foundation failure).

Common Factors in Dam Failure

Reservoir Filling, High Water, and Overtopping

Water dams mostly fail during or immediately after reservoir filling. (http://ofmpub.epa.gov/eims/eimscomm.getfile?p_download_id=513583) In this article, this is relevant to the failures of Vajont, Tokwe-Mukorsi, Teton, and Three Gorges dams.

When dam failures occur in well-established water dams, they are usually associated with overfilled reservoirs (ex: Glen Canyon 1983, Johnstown 1889, Taum Sauk 2005, Gibson 1964), although conspicuous failures have also occurred under normal conditions (ex: Big Bay 2004, St. Francis 1920). ICOLD (http://www.icold-cigb.org/) has found that the most common cause of failure is overtopping, and that most failures occur in smaller dams - which are also far more numerous than large dams.

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Water overtopping accounts for about 30% (http://www.usbr.gov/ssle/damsafety/Risk/BestPractices/16-FloodOvertoppingPP20121126.pdf) of U.S. dam failures in the last 75 years.

Tailings dams, in contrast, are more-or-less equally likely to fail at any time in their lives, since they are continuously raised over time. As the quantity of tailings they impound grows larger, the dams are built higher. This means the dam is being built and the reservoir is being filled for the entire operating life of the mine or industrial plant they are associated with. After the mine or plant concludes operations, the tailings dams are frequently left in place perpetually, to contain the wastes. At this point, the dam may be at less risk of failure since it is no longer being raised, but may be at greater risk if monitoring & maintenance degrade.

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SEQUENCE OF AN EMBANKMENT DAM FAILURE — In a controlled event, water overtops an earthen embankment dam and rapidly incises through it. This sequence is taken from a 2012 Bureau of Reclamation & Army Corp of Engineers presentation. — Get Photo (/photos/Embankment-earth-dam-failure-time-series/)

Embankment dams in particular are very vulnerable if overtopped, as flowing water rapidly cuts through them. Some concrete dams can better survive overtopping, temporarily becoming man-made waterfalls. This occurred at Gibson Dam (http://www.usbr.gov/ssle/damsafety/TechDev/DSOTechDev/DSO-98-05.pdf). (See prior link (http://www.usbr.gov/ssle/damsafety/Risk/BestPractices/16-

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FloodOvertoppingPP20121126.pdf) for photographs of Gibson, embankment overtoppings, and a time-series demonstrating an overtopping-caused embankment breach.)

Taum Sauk Pumped Storage Project's upper reservoir failed (http://www.nxtbook.com/nxtbooks/naylor/CDAQ0411/index.php?startid=16#/16) in 2005 as a result of overtopping, and it provides an example of the various "signals" and problems (http://web.mst.edu/~rogersda/dams/taum-sauk/watkins-taum-sauk-gsa_branson-compressed.pdf) which operators of a dam must interpret and resolve, some of which do not end up foretelling failure. At Taum Sauk, operators observed extensive settling of the embankment, leakage problems which were largely solved by the addition of a membrane reservoir liner, and others signals - none of which appear to have foretold the breach.

Sensor problems at Taum Sauk, instead, led to a catastrophic overtopping event. This was not entirely unforeseen: a plant operator issued a dire warning that the facility was in danger, but it was ignored by higher authorities. In this way Taum Sauk is an excellent example of human factors (/Issues/OtherIssues/dam-failure-human-factors-cases-Teton-Vajont.html) obstructing a fixable engineering problem, and leading to dam failure.

Even where high water is not the primary cause of dam failure, it is very frequently a contributing cause.

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Location & Geology



VAJONT DAM AFTER THE LANDSLIDE — Vajont's reservoir was mostly displaced by a massive landslide, creating a wave that crested 500 feet over the dam's rim. The dam still stands, but the event permanently removed it from service. — Get Photo (/photos/vajont-dam-disaster-landslide-aftermath/)

Poor dam siting (ex: Teton 1976) and poor engineering (ex: Banqiao 1975 (http://www.sjsu.edu/faculty/watkins/aug1975.htm)) can be key contributing factors in failures. Geological events like landslides (ex: Vajont 1963) and

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earthquakes (ex: Fujinuma 2011 (http://www.groupdelta.com/Papers/Failure-of-Fujinuma-Dam-During-the-2011-Tohoku-Earthquake.pdf)) are in rare instances associated with dam failure, but the historic record is dominated dams successfully weathering earthquakes, landslides, and reservoir tsunamis. Indeed, dams were in fact the first structures to be systematically engineered against earthquakes.

Reservoir tsunmis, as a special sidenote, are not well-documented in the scientific literature. A literature review by the author revealed no examples of dams structurally failing due reservoir tsunamis. Vajont Dam clearly remained intact but functionally "failed" when it was overtopped by a tsunami and permanently removed from useful service. In contrast, Three Gorges Dam suffered no damages when a reservoir filling-induced landslide generated a tsunami (http://link.springer.com/article/10.1007/s10346-004-0020-6) in 2003, but the tsunami nontheless killed 11 fishermen. In 2009, a 30-foot tsunami in Grand Coulee Dam's reservoir caused only natural and property damages.

Foundation Failure

The foundations of any dam can be compromised, and this is one of the most feared and dangerous types of dam failure.

Concrete arches have in some cases ruptured suddenly. Notably, Malpasset arch dam in France suddenly broke from its foundations in 1959 during a heavy rainstorm, killing 421 people. St. Francis arch dam (http://www.smithsonianmag.com/

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history/occasions-i-envy-dead-st-francis-dam-disaster-180954543/?no-ist) in California ruptured catastrophically in 1920, but under normal weather and load conditions, killing an estimated 470. St. Francis dam, among other failings, was built on a weak sedimentary rock and directly across a known fault. Foundation failure is believed to have caused the dam to collapse, but no witnesses survived the event.

Concrete gravity dams, which hold water back by their sheer mass (as do embankment dams) have in some cases slid as units (http://www.usbr.gov/ssle/damsafety/TechDev/DSOTechDev/DSO-98-05.pdf) off their foundations, under the force of the water contained. In one striking case, the Austin Dam in Texas slid three separate times during the first part of the 20th century.

Foundation failure is currently an immanent concern (http://www.irinnews.org/report/99904/kariba-dam-collapse-fears-and-disaster-preparedness-in-zimbabwe) at Africa's massive concrete arch Kariba dam. Erosion in the plunge pool below the dam now threatens the foundations, endangering 3.5 million people downstream. Kariba is in danger of suffering a catastrophic structural failure if repairs are not conducted, and emergency international funding has been secured to repair it.

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In Iraq, Mosul embankment dam faces another foundation threat. It is built on karst (http://en.wikipedia.org/wiki/Karst) gypsum, which is soluble in water. The foundation rock contains voids and has been continuing to dissolve over time, making the foundation weaker and weaker over time.

Mount Polley tailings dam, in British Columbia, failed due to multiple factors, but central within them was foundation failure: ice-age sediments below a ~30 meter tall section of the dam moved under the weight of the dam and tailings, causing the dam to collapse.

Piping & Internal Erosion

When water penetrates through a dam, it is known as “piping.” Piping water can scour the inside of a dam, eroding it out from the inside. Piping is a frequent mode of failure, was noted at Teton, Big Bay, and Tokwe-Morse. Embankment dams are particularly vulnerable to piping, but even concrete dams can suffer internal erosion.

A slightly different, striking form of internal erosion began to occur at Glen Canyon dam in 1983. Violent cavitation (http://www.popsci.com/scitech/article/2003-03/water-vapor-almost-busts-dam) in the spillway tunnels excavated thousands of tons of concrete and steel from the structure. Had the event continued or the water excavated in a different direction, the dam might have catastrophically failed. Notably, this problem did not arise from classic construction flaws, human error, or too much water _per se. _Hydraulic cavitation was a technically

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known phenomenon, but was unexpected in the dam. It manifested only during powerful water flow through Glen Canyon's massive spillways. After the event, the spillways were modified to prevent future cavitation damage.

ICOLD: A Credible Source

"ICOLD" is the ** International Commission on Large Dams (http://www.icold-cigb.org/)** , an international organization with more than 90 member countries.

ICOLD is dedicated to the exchange of engineering knowledge on large dams. ICOLD sets standards and guidelines, and publishes studies, and is a very credible source for dam-related information.

Maintenance & Monitoring

Finally, maintenance plays a crucial factor in dam survival. Dams appear monolithic, but require ongoing maintenance. Concrete cracks and must be grouted with fresh concrete, earthen slopes naturally erode and must be maintained, spillways must be kept clear and functioning, and so forth. Many modern dams have the potential to last indefinitely if well maintained, but all dams are vulnerable to inadequate maintenance. Although the world's largest embankment and concrete dams would likely outlast all other human constructions if we vanished tomorrow, they will not do so in good working order.

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The ability and willingness of dam operators to maintain the dam is therefore an important consideration in dam safety. Societies and dam owners are strongly motivated to maintain most water dams, which provide ongoing values like electricity generation, flood control, and irrigation water. Many of these dams also exist in areas where a failure could cause large-scale loss of life and property downstream.

Tailings dams, in contrast, are built to contain wastes, and are cost-prevention devices and unwanted burdens, rather than being value-generating assets. This creates a risk dynamic which
ICOLD specifically highlights as problematic in a study of tailings dam risks. (http://www.unep.fr/shared/publications/pdf/2891-TailingsDams.PDF) Tailings dams must often be maintained long after the related profit-producing mines and plants close, and after the responsible companies move on or dissolve - meaning that dam maintenance becomes a totally unwanted cost. As a result, economic and pyschological forces can conspire against proper long-term maintenance for tailings dams.

Risk of Failure to the Susitna-Watana Hydroelectric Project

Within Alaska, a massive concrete dam has been proposed (/Issues/RenewableEnergy/Susitna-Hydro-Dam.html) several times on the Susitna river. Such a dam would potentially provide inexpensive hydroelectricity to the Railbelt power grid,

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and help Alaska reach renewable energy goals. It would also alter the flow of the Susitna river, possibly having a major adverse effect on downstream salmon runs.

A catastrophic or major structural failure of the proposed Susitna-Watana hydroelectric project would very unlikely. No massive concrete dam of similar scale to the Susitna-Watana proposal has ever failed in the United States, and the engineering of such structures is taken extremely seriously. The collapse of Teton Dam (an earthen embankment dam) remains a strong reminder of the potential costs of complacency. Consideration of failure scenarios and damages is part of the current permitting process.

Susitna-Watana would need to account for a variety of stability threats, including seismic (earthquake) activity in Alaska. Earthquakes can affect dams with shaking, landslides, foundation shifting, and reservoir tsunamis. The Federal Energy Regulatory Commission requires review of seismic and other risks by independent consultants.

gtt prepared comments on the Susitna seismic risk assessment process during summer 2014 (not yet posted), and earlier a fact sheet (/Issues/Renewable-Energy-in-Alaska/susitna-watana-hydropower-seismic-earthquake-hazards.html) on the general seismic seismic situation as it pertains to the dam proposal.

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Further Reading

> Wikipedia (http://en.wikipedia.org/wiki/Dam_failure)

> WISE Uranium Project (http://www.wise-uranium.org/mdaf.html)

> Association of State Dam Safety Officials (http://www.damsafety.org/news/?p=412f29c8-3fd8-4529-b5c9-8d47364c1f3e)

> Dam safety & failure has been the subject of intense engineering study, and broad literature of deeper technical material is available. Incomplete online lists of specific dam failures include: (None)

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