Reexamining the dam and geotechnical engineering aspects of the 1889 South Fork Dam breach and Johnstown Flood

By Michael D. Bennett, P.E. – Gannett Fleming TranSystems (Audubon, PA)

Overview

The South Fork Dam breach and Johnstown Flood of May 31st, 1889, remains the USA's deadliest dam disaster. A torrential storm the night before had drenched the area around Lake Conemaugh, a former canal reservoir turned into an upper-class resort in western Pennsylvania. The rain-swollen lake rose ominously throughout the 31st until, that afternoon, it overtopped and breached the dilapidated South Fork Dam that had held it back. The breach sent nearly 4 billion gallons of water thundering through the valley of the Little Conemaugh River, and the wave destroyed railroad tracks, small hamlets, factories, and people. Eventually, the wall of water and wreckage slammed into the bustling steel town of Johnstown, where it killed thousands, injured thousands more, and devastated almost every block. The disaster was quickly named the Johnstown Flood, and its outraged survivors demanded that justice be served to the Pittsburgh tycoons who had owned the lake and dam. However, the moguls and their allies unduly influenced how politicians, courts, and even the American Society of Civil Engineers handled the aftermath of the tragedy. The story serves as a harsh reminder of the duties and responsibilities of civil engineers, especially geotechnical and dam engineers.

Introduction: Traversing the Appalachian Mountains

The events which culminated in the Johnstown Flood began roughly a century earlier following the American Revolution. When the US government evicted Native American tribes from Pennsylvania's Appalachian Mountains, European-Americans began moving west. Settler Joseph Schantz's family was among many that crossed the Allegheny Mountains, the Appalachians' highest and westernmost ridge within Pennsylvania, to seek new opportunities. In the 1790s, Schantz founded a village on the Alleghenies' western slopes where the Little Conemaugh and Stonycreek Rivers converge into the Conemaugh River. The site consists of a small plain surrounded by steep hills about 650 feet high. The Schantz family – also known by its anglicized name, Johns – left about a decade later, but the village took the name Johnstown to honor its first settlers (Coughenour et al. 2022, Hanna 2021).

Settlers kept pushing the US frontier westward during the early 1800s. Wagon roads through the Allegheny Mountains were soon overloaded with traffic, and entrepreneurs, engineers, and politicians began devising alternatives for transportation through or around the range. New York State completed the Erie Canal in 1825, connecting New York City to Buffalo, while Maryland built the Chesapeake and Ohio Canal between Cumberland and Washington, DC. The new canals quickly started raking in toll revenue for their states, and Pennsylvania

Figure 1: Geology of Pennsylvania. The Appalachian Mountains are shown as multicolored lines running through the center of the state. The Allegheny Mountains divide this zone from the Appalachian Plateau, shown in yellow. Source: Miles (2008).

wanted its share. In 1828, the Commonwealth's General Assembly authorized a network of canals and the emerging technology of railroads to link Philadelphia to Pittsburgh. The Keystone State finished the network, christened the Main Line of Public Works, by 1834 (Burgess and Kennedy 1949, Hanna 2021).

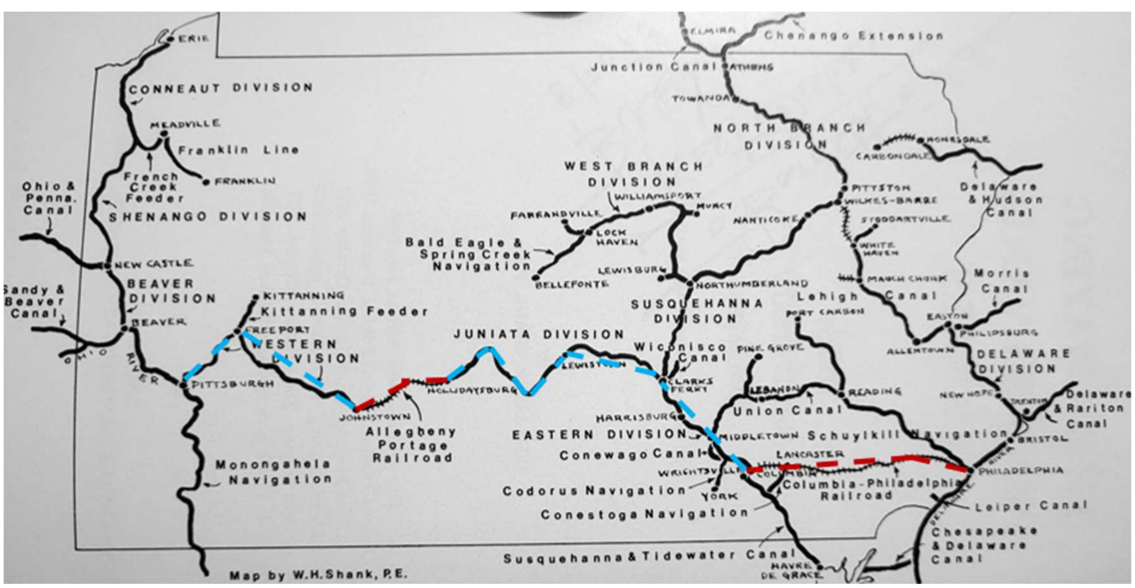


Figure 2: Canals and railroads of Pennsylvania in the early 19th century. The Main Line of Public Works is marked with its railroads in red and canals in blue. Source: ACS (2022); modified by author.

Travelers heading west on the Main Line took a conventional railroad from Philadelphia to Columbia, then were transferred to boats and took canals along the Susquehanna and Juniata Rivers. The canals terminated in Hollidaysburg on the Allegheny Mountains' eastern slopes because the range forms the Eastern Continental Divide within Pennsylvania, separating rivers flowing toward the Eastern Seaboard and the Gulf of Mexico. Next, the travelers were transferred onto the Allegheny Portage Railroad, which brought them up the Alleghenies using a combination of inclined planes and flatter segments of conventional railroads. The planes consisted of stationary steam engines attached to gargantuan cables which hauled railcars laden with passengers, freight, and even whole canal boats along 7% to 10% grades. Safety features such as emergency stoppers, cogged tracks, and – after many accidents – steel cables protected the travelers until they were transferred back to canals in Johnstown. From there, they journeyed along the Conemaugh, Kiskiminetas, and Allegheny Rivers into Pittsburgh. Overall, the nearly 400-mile trip took about 4 days (Burgess and Kennedy 1949).

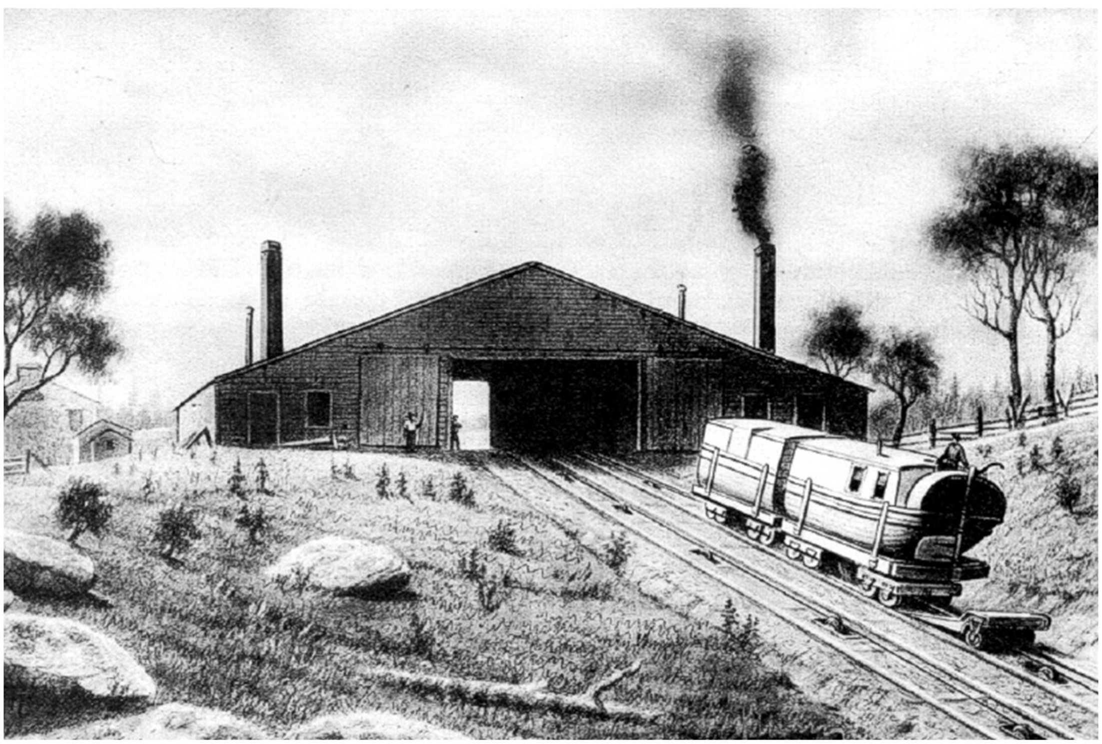


Figure 3: A stationary steam engine hauls a canal boat up an inclined plane on the Allegheny Portage Railroad. Source: PGS (2002).

<u>Improving the Main Line: The Western Reservoir and its dam</u>

Traffic on the Main Line of Public Works needed to stay moving if the Pennsylvania General Assembly were to pay off the construction costs and keep its coffers full. However, both the canals and the adjacent rivers often froze over during chilly Pennsylvania winters and ran low during the state's hot, dry summers. The latter issue was especially pressing near the canal terminals in Hollidaysburg and Johnstown since both towns had relatively small upstream watersheds. The Commonwealth's civil engineers realized that impounding reservoirs on both sides of the Alleghenies could keep the Main Line, and its toll collections, operational. In the mid-1830s, the state sent civil engineer Sylvester Welch to survey potential sites for both reservoirs. For the Conemaugh canals, Welch recommended a site in Cambria County about 14 miles upstream, or roughly 8 miles east-northeast, of Johnstown along the South Fork of the Little Conemaugh River. The elevation difference between the site and Johnstown was about 400 feet, which Welch knew would give the water plenty of head for its long journey to the canal. The state adopted his recommendation (Burgess and Kennedy 1949, Coleman 2019, Francis et al. 1891, Hanna 2021).

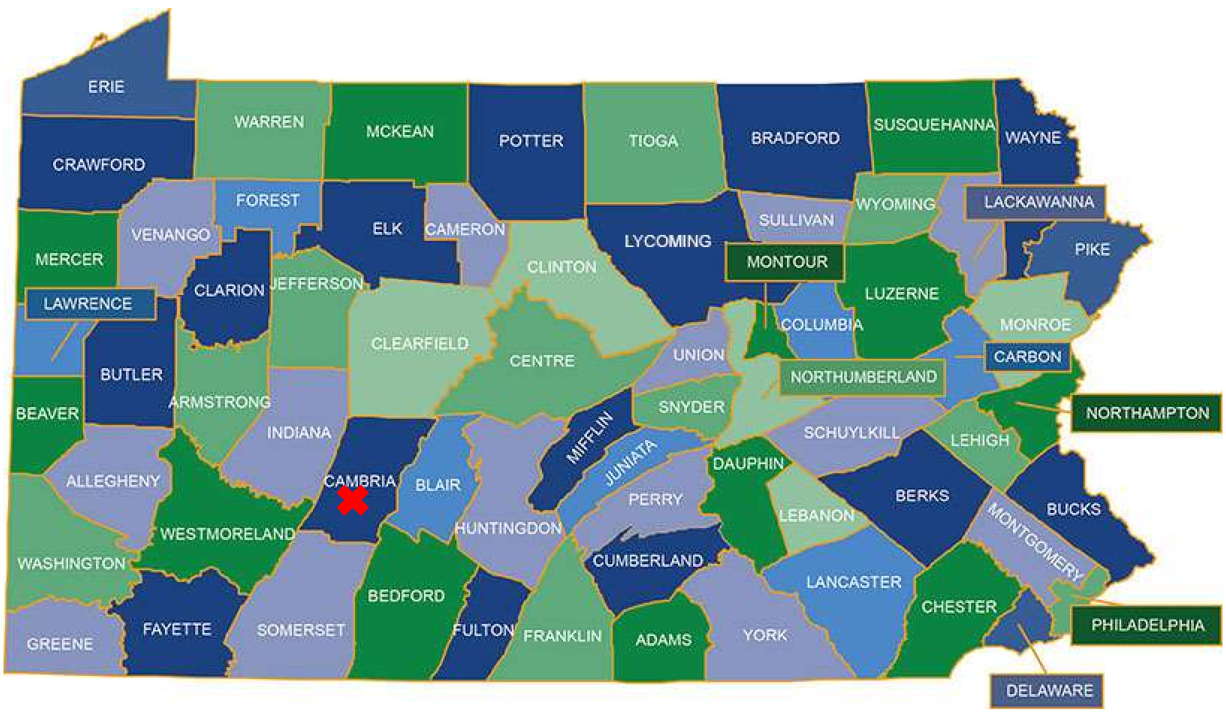


Figure 4: Counties of Pennsylvania, with the Western Reservoir's location marked with a red X. Source: PennDOT (2024); modified by author.

Welch also developed preliminary designs for the dam at the Western Reservoir. He noted that water could not be allowed to overtop an earth dam, now called an embankment dam, if one were built. The note suggests that best practices, aka the standard of care, for designing embankment dams in the mid-1830s included the prevention of overtopping. Welch elaborated that water could be kept from leaking through an embankment dam either by constructing a masonry core wall within it or by building its upstream half using puddled clay. Puddling involves placing wet clay in thin layers and compacting it to make it nearly watertight. Welch estimated that a puddled clay embankment dam would be about two-thirds the cost of a dam with a masonry core wall (Unrau 1980).

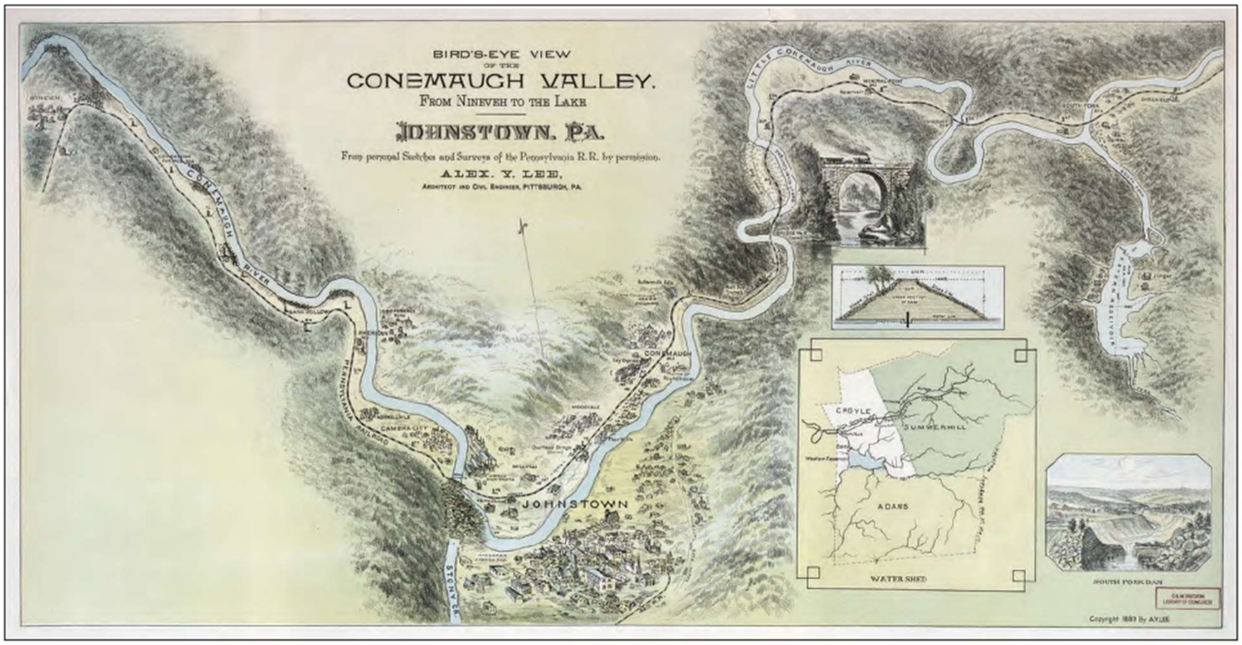


Figure 5: Topography and rivers of southern Cambria County, PA, with locations of Western Reservoir and Johnstown clearly noted. Source: Hanna (2021).

The Commonwealth then tasked civil engineer William Morris with finalizing Welch's dam design for the Western Reservoir. Morris first had laborers dig shafts and tunnels at the proposed dam site to confirm both the presence of bedrock and the availability of good-quality material for the dam. Such a practice might be considered an early version of a modern geotechnical investigation. Their exploration most likely reflected that the dam site lies above the Casselman Formation, which consists of thin, interbedded layers of sedimentary rock such as sandstone, shale, siltstone, and claystone. Morris then used the crew's findings to convert Welch's preliminary dam design into construction plans. He concluded that the floods which sometimes inundated the South Fork of the Little Conemaugh presented "little danger" to the dam if "proper channels [were] constructed for their discharge" (PA DCNR 2023, Unrau 1980).

Morris designed the dam to have spillways totaling 150 feet in width at either or both ends of the dam and called for a drainage outlet at the dam's base. The outlet would allow Main Line canal operators to utilize the full depth of water in the Western Reservoir during dry summer months. Morris's outlet would consist of five cast-iron pipes in the center of the dam, each 24 inches in inner diameter and about 75 feet long, extending from the reservoir into a single brick conduit about 190 feet long. An operator would open and close the pipes as needed from a masonry control tower in the reservoir. Morris also included a trench to be excavated beneath the dam site to bedrock and backfilled with puddled clay to make the dam watertight. This feature, known as a puddle trench, was a forerunner of cutoff trenches beneath current dams. As an added measure, Morris called for a partial masonry core wall to be built within the downstream section of the dam. Per his design, the partial core wall would run the length of the dam and measure 25 feet high (with another 3 feet keyed into the ground surface), 6 feet wide at its base, and 2 feet wide at its crest (Coleman 2019, Francis et al. 1891, Unrau 1980).

For the dam itself, Morris stuck closely to Welch's recommendations. He designed an embankment structure measuring 72 feet high, about 860 feet long, roughly 265 feet wide at its base, and 10 feet wide at its crest. Morris value engineered the dam by going with Welch's idea to build its upstream half of puddled clay. Notably, modern dam engineers recognize that wet, compacted clay is erodible; it thus has limited shear strength and needs a shell of overlying heavy material for protection against an overtopping failure. Engineers of the era had yet to fully understand the mechanics of this process, but Morris appears to have recognized it at least intuitively. He thus called for the structure's downstream half to be built of massive boulders measuring at least 4 cubic feet in volume with soil filling the spaces between them. Morris designed a center section of gravel and weathered rock fragments lying immediately next to the boulders to separate them from the clay. Finally, Morris ordered the dam's upstream face covered with cobble-sized mortared masonry riprap to prevent scour damage to the puddled clay from waves in the reservoir. His design specifications called for a field engineer to inspect construction; the engineer would have the authority to make the contractor redo all poorly done work (Coleman 2019, Francis et al. 1891, Unrau 1980).

<u>Constructing the Western Reservoir and its dam</u>

Crews working for contractors James Morehead and Hezekiah Packer started building the Western Reservoir and embankment dam in the spring of 1840 under the supervision of field engineers reporting to William Morris. Morehead had considerable experience in constructing embankment dams, while Packer was politically well-connected. Their laborers first cleared and grubbed the future reservoir bed and dam site, then dug and backfilled the puddle trench and built the masonry foundation for the outlet pipes. They next began constructing the brick outlet conduit and the embankment itself. As they worked, though, the US entered a recession. Times quickly got tough in Pennsylvania, where the General Assembly was still saddled with unpaid Main Line construction expenses. The Assembly paused construction on the Western Reservoir in 1841 to help the Commonwealth stay solvent (Coleman 2019, Francis et al. 1891, Hanna 2021, Unrau 1980).

The General Assembly intended the construction hiatus at the Western Reservoir to be temporary, but it ended up lasting nearly a decade. The Commonwealth's finances stayed weak throughout the 1840s, and the Assembly used whatever meager funding became available to repair other infrastructure. Damaging floods on the Main Line, political and legal wrangling, and even a cholera epidemic worsened the delay. All the while, freezing winters and dry summers continued bedeviling the Main Line canals and exacerbated the state's budget woes. The reservoir's incomplete dam languished in the elements and sustained several partial breaches. One 1847 washout flooded Johnstown enough to damage the canal, rip several boats from their moorings, and leave parts of town under 4 to 6 feet of water. Such failures almost surely compromised the dam's long-term integrity (Coleman 2019, FWP 1939, Francis et al. 1891, Hanna 2021, Unrau 1980).

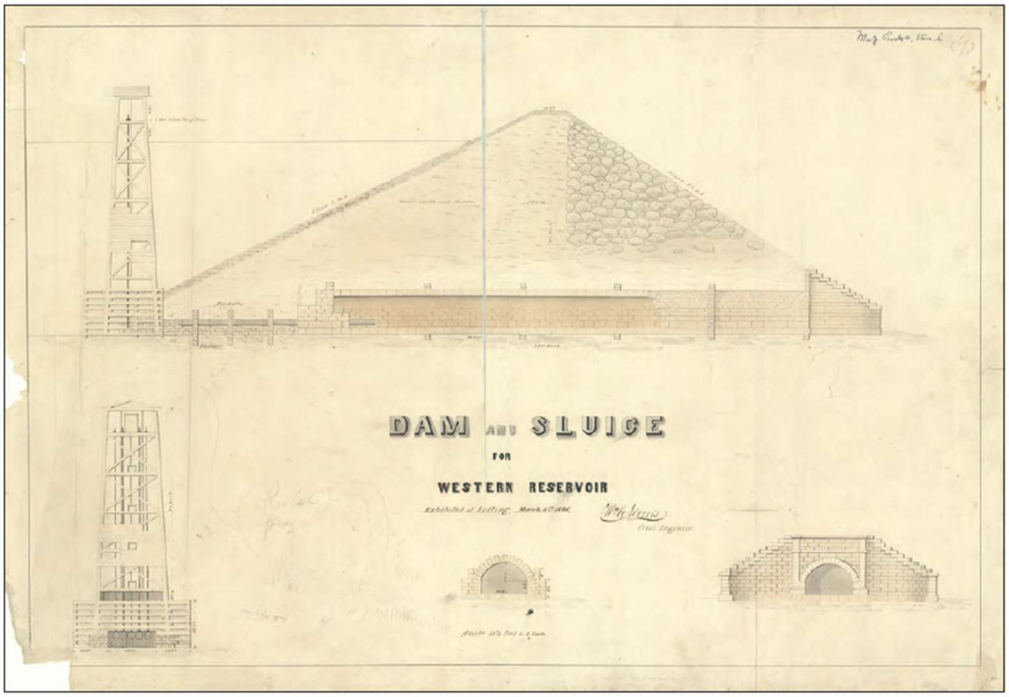


Figure 6: William Morris's final design for the Western Reservoir dam. Source: Hanna (2021).

By 1850, Pennsylvania at last regained its financial footing. Early in 1851, the General Assembly allotted funding to complete the Western Reservoir. William Morris, still lead designer, further value engineered his plan by substituting a wooden control tower for a masonry one and removing the partial core wall. Modern dam engineers may understandably decry the latter decision as a fateful one, given the wall's intended role as a seepage cutoff. However, civil engineers from three different technical journals independently visited and assessed the dam remnants immediately after the 1889 flood. Two of the journals concluded that the original clay had been puddled well enough to serve adequately as a seepage barrier; the third made no pronouncement on the quality of the original puddling amid its plentiful, detailed critiques of other aspects of the failed dam. Modern civil engineers may also lament that Morris never refined the dam's design during the construction hiatus based on contemporary technical advances in civil engineering. Yet technical progress in the field was sluggish during the 1840s, especially for dam and geotechnical engineering, and best practices for embankment design thus changed little over that span (Coleman 2019, Francis et al. 1891, Frank 1988, Hanna 2021, Unrau 1980, Wellington and Burt 1889 C).

As 1851 continued, Morehead and Packer's crews and the original field engineers resumed work on the Western Reservoir dam. Laborers quickly finished the outlet conduit and tower, then finished building the embankment in layers, or lifts, of clay 24 inches thick. Modern earthwork specifications typically restrict clay lifts to a maximum thickness of 8 to 12 inches, but Morris's stringent specifications in this regard probably met the contemporary standard of care. He required the crews to compact each lift of puddled clay with a 4-inch-diameter rammer before placing another and forbade them from using "light, spongy, alluvial, or vegetable material" within the embankment. Over the next year, the crews made steady progress building the dam, and they successfully placed the downstream riprap boulders – some of which weighed 10 tons – using up to three teams of horses. The crews completed the dam by the summer of 1852. As they wrapped up supporting construction (it would be finished in 1853), the operators began impounding the reservoir. They initially filled it to a depth of 50 feet, well below its maximum safe depth of 60 feet, to allow the field engineers and contractors to address any potential problems with the dam; this practice remains standard for new dams. When no issues arose, the reservoir was filled to a depth of 60 feet. Overall, the dam had cost about $6.8 million in 2024 USD to build (Coleman 2019, Francis et al. 1891, Frank 1988, Hanna 2021, McCullough 1968, McGough 2002, Unrau 1980).

Figure 7: Map of the Western Reservoir upon completion in 1853. Source: Hanna (2021).

Debate persists over how exactly the contractors for the Western Reservoir and its dam constructed the embankment's spillway or spillways. William Morris called in his design for a total width of 150 feet of spillway excavated to bedrock but never specified how many spillways he had in mind. His 1853 as-built plan of the reservoir and dam shows only the discharge outlet and a spillway at the dam's northeast abutment. This spillway had been excavated to a depth of roughly 10 feet through sandstone bedrock and remains clearly visible. Some historians have thus concluded that the dam only ever had one spillway. However, the northeast spillway was only about 70 feet wide at its narrowest point. Field engineers and contractors sometimes engage in give and take, but the strictness of Morris's specifications for the dam make it seem unlikely that he would have accepted Morehead and Packer's handiwork had they built just 70, not 150, feet of spillway width (Coleman 2019, Francis et al. 1891, Kaktins et al. 2013, Unrau 1980).

Civil engineers who surveyed the dam remnants after the 1889 breach noted a swale extending from the reservoir shoreline around the dam's southwest abutment, and it remains visible to a careful observer. As built for the Western Reservoir, the depression was about 3 feet deep and had a consistent width of roughly 70 feet. Whatever Morris's intentions, this would have served as a second spillway during severe floods. Furthermore, Morris could easily have directed Morehead and Packer to fill in the swale had he wanted to increase the Western Reservoir's capacity. It was never excavated to bedrock for reasons unknown, although the project's repeated funding shortfalls during construction likely played a role. Perhaps Morris

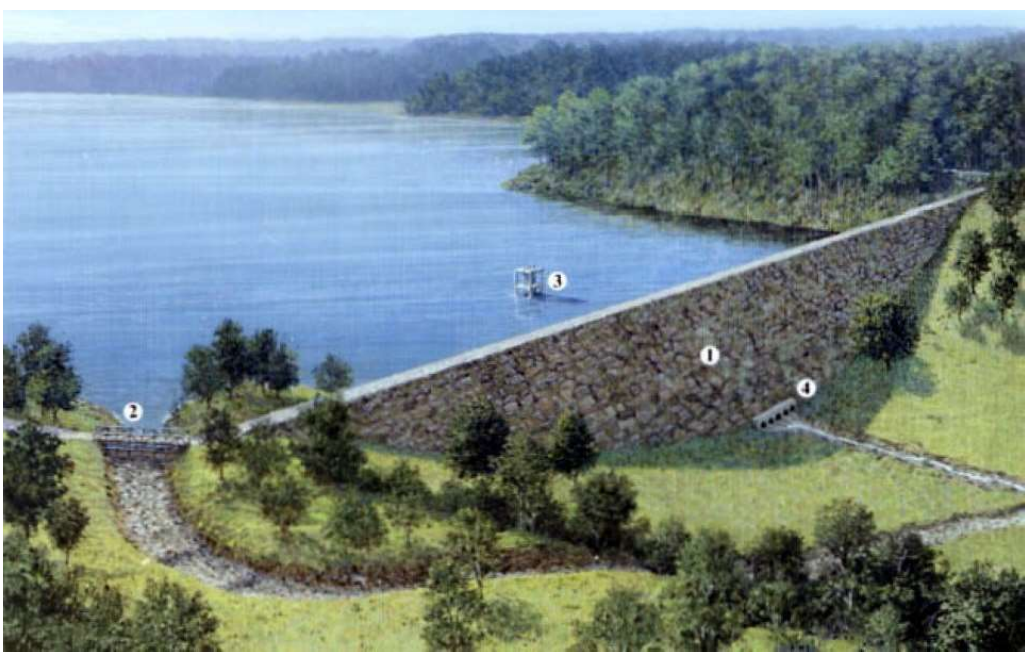


Figure 8: The Western Reservoir dam, 1853-1862. Note its (1) sturdy construction with downstream riprap, (2) northeast spillway, (3) control tower, and (4) discharge culvert. The drawing erroneously omits the southwest spillway and shows the culvert with five openings rather than one. Source: NPS (2023 C).

reasoned that the swale would readily be eroded to bedrock by onrushing waters, and bedrock beneath the swale would, in fact, later be encountered only about 18 inches below grade (Coleman 2019, Francis et al. 1891, Kaktins et al. 2019).

Spillway questions aside, the imposing new Western Reservoir dam failed to meet William Morris's specifications on at least one count. The dressed masonry riprap he envisioned for the dam's upstream slope appears never to have been fully built. Photographs taken after the 1889 breach show riprap on the upstream face, but it appears loose. It remains unknown why the riprap was never dressed, but budget constraints may once again have factored into the decision. Still, neither this shortcoming nor the 1847 breach seem to have hampered the dam's performance. During the reservoir's service life, maintenance workers noted only minor leaks in the dam and readily repaired them. In 1856, the State Engineer personally inspected the dam and reservoir and deemed both to be in "excellent condition" (Coleman 2019, Francis et al. 1891, Kaktins et al. 2019).

Researchers from the University of Pittsburgh at Johnstown (UPJ) performed hydraulic analyses in the 2010s of the Western Reservoir and its dam. For these studies, they took LiDAR scans of, and soil samples from, the former reservoir bed and used them together with modern software to construct a stage-storage curve to estimate the reservoir's capacity. The researchers found that the original reservoir could hold roughly 13,200 acre-feet of water (4.3 billion gallons or 575 million cubic feet) weighing about 17.9 million tons. The researchers also estimated the

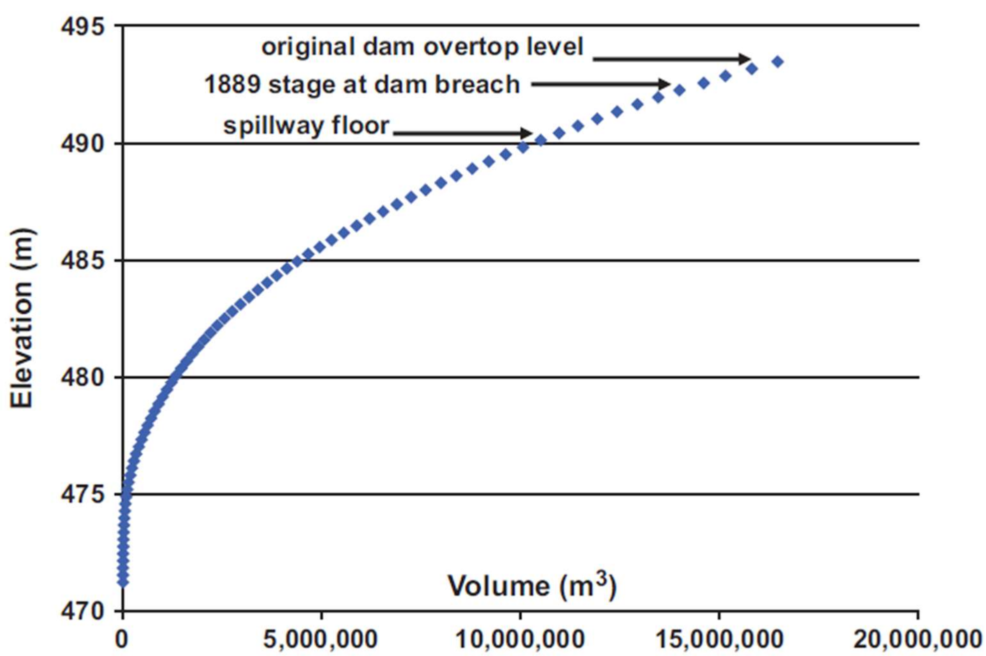


Figure 9: Storage-elevation curve generated by researchers at UPJ for the Western Reservoir and its successor, Lake Conemaugh. Source: Coleman et al. (2016).

discharge capacities in cubic feet per second (cfs) of the three reservoir outlets. They determined that the northeast spillway (5,350 cfs), southwest spillway (900 cfs), and outlet pipes and conduit (700 cfs) gave the dam a discharge capacity of about 6,950 cfs when the reservoir was at its maximum possible depth of 72 feet. These capacities made the reservoir and dam among the largest of their kind in the US in the mid-1850s, and they seemed set for decades of use (Coleman 2019).

Demise of the Western Reservoir: Obsolescence, abandonment, and 1862 breach

Alas, the Western Reservoir and its dam were outdated even before their completion. In the 1830s, US civil engineers began designing improved railroads to replace weather-dependent canals. By the mid-1840s, track gangs were laying rails across both New York and Maryland, and the Pennsylvania General Assembly sought to keep up again. In 1846, the Assembly chartered the Pennsylvania Railroad, which soon became known as the PRR or "Pennsy," to construct a trans-Appalachian route between Philadelphia and Pittsburgh. The PRR initiated surveying, design, and construction in short order and inaugurated continuous cross-state rail service in 1852 (Burgess and Kennedy 1949).

Initially, the Pennsylvania Railroad used the Portage Railroad to cross the Allegheny Mountains. In early 1854, however, the Pennsy opened a permanent line which traversed the ridge using a massive switchback – soon nicknamed the "Horseshoe Curve" – and a pair of tunnels below the ridge's crest. Traffic through the Alleghenies rapidly switched to the PRR's new route, which remains in daily passenger and freight use 170 years later. The Main Line's days were over, and it went from one of Pennsylvania's biggest assets to one of its largest liabilities nearly overnight (Burgess and Kennedy 1949).

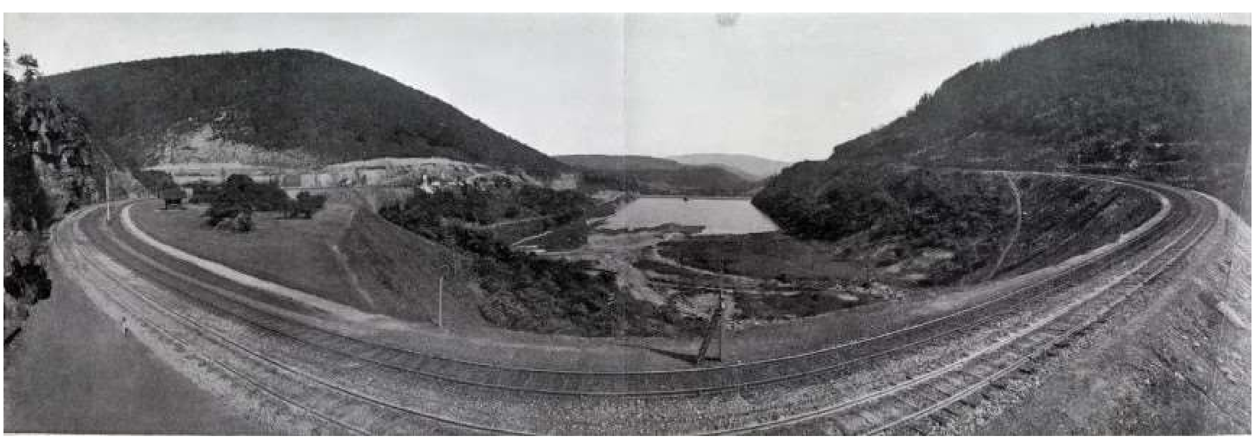


Figure 10: Panoramic view of the Horseshoe Curve near Altoona, PA, in the late 1800s. Its westbound (left to right) ascent is clearly visible. Source: Smolka (2022).

The Pennsy recognized that the Main Line's real estate could serve as rights-of-way for its future tracks and purchased its predecessor from the Commonwealth in 1857 for $270 million in 2024 USD. Almost immediately, the PRR slashed oversight of the Western Reservoir and dam to routine check-ins by local caretakers. Some residents living near the now-unused reservoir used it for fishing and boating. Others stole lead from the seals of the outlet pipes and sold it for scrap (Coleman 2019, McCullough 1968, Shappee 1940, Webster 2024).

Years of neglect and lead theft eventually caused leaks to form in the old embankment dam. In mid-July 1862, the outlet conduit partially collapsed due to the leaks. A week later, local farmer Joseph Leckey was checking the dam on behalf of the Pennsylvania Railroad when he saw muddy water flowing out of the conduit remnants. Current dam and geotechnical engineers know that such turbidity represents ongoing internal erosion, or "piping," within a dam. Leckey did not recognize the ongoing piping but knew the leakage indicated the potential for a major breach. He rowed to the control tower and opened the outlet pipes to lower the abandoned reservoir, then rode to a nearby Pennsy telegraph station, where he and the operator warned Johnstown of the danger. Per Darcy's Law, first quantified in France by its namesake only a few years earlier, the reservoir's relatively low water depth – less than 50 feet –slowed the leaks. However, the piping worsened, and the dam finally failed about 12 hours after Leckey's timely observation (Coleman 2019).

The waters of the old Western Reservoir poured through the breach and down the South Fork of the Little Conemaugh River. They demolished a house, a sawmill, and hundreds of feet of PRR track and left several feet of water in downtown Johnstown. Yet Leckey's warning and the breach's slow formation minimized damage and prevented fatalities, and the depth of flooding in Johnstown was irritating but unremarkable. The media and the public paid little attention to the breach, as the US Civil War was raging. The Union Army spent the summer of 1862 clashing ferociously with Confederate troops in the Peninsula Campaign, the Second Battle of Bull Run, and the Battle of Antietam, among other engagements, and many young men from Cambria County – home of both the reservoir and Johnstown – were serving their country (Coleman 2019, FWP 1939, McCullough 1968).

The Pennsylvania Railroad cared little about the 1862 breach, as it had already planned on abandoning the Main Line canals and reservoirs. The railroad officially did so in 1864 but kept the reservoir property for another decade. The dam's abutments were now separated by a 200-foot-long inverted triangular breach with its point above the ruined outlet conduit, and its remnants were exposed to the elements once more. Locals let their cattle graze on the old reservoir bed and fished in the few deep pools remaining there. In 1875, the Pennsy sold the site to John Reilly, an employee of theirs, at a slight loss. Reilly had just won a US House seat, and the PRR surely valued having favorable representation in Washington, DC. During Reilly's years on Capitol Hill, the wooden control tower burned down (Coleman 2019, Hanna 2021, Unrau 1980).

The South Fork Fishing and Hunting Club and Benjamin Ruff

Congressman Reilly lost his re-election bid in 1878 and began looking to sell the Western Reservoir property. Meanwhile, several rich Pittsburghers had begun planning to establish a country resort for themselves and some fellow Steel City elites. In early 1879, they incorporated the South Fork Fishing and Hunting Club and elected Benjamin Ruff as Club president. Ruff had dabbled in railroad contracting, real estate brokering, and coke sales, and he soon became interested in buying Reilly's property as a site for the Club's resort. Ruff and his peers planned to re-impound the reservoir for recreational use by reconstructing the breached dam, and they planned to rename the reservoir Lake Conemaugh and the embankment the South Fork Dam. Ruff then hired contractor Daniel Kaine to rebuild the dam, and Kaine's crews soon began work. However, Reilly still owned the property and work probably commenced only with his permission (Coleman 2019, Hanna 2021, McCullough 1968).

Figure 11: Benjamin Ruff, 1st president of the South Fork Fishing and Hunting Club. Source: NPS (2021 A).

Qualified civil engineers had been involved throughout the design and construction of the Western Reservoir and its dam embankment. By contrast, the reconstruction of the South Fork Dam and re-impoundment of Lake Conemaugh involved little if any such input. Instead, Benjamin Ruff directed the work himself and appointed former PRR freight agent Edward Pearson to be his foreman. Neither had any civil engineering experience or training. Ruff had experience building railroad embankments and tunnels, and perhaps he believed this experience qualified him to supervise the reconstructing of the dam. He also probably let money influence his decision; cost is always a concern in construction and was likely even more worrisome for the Club, which still mostly existed on paper. However, civil engineers – especially those with field experience – appreciate that they and contractors often have substantially different priorities and types of expertise (Coleman 2019, Hanna 2021, McCullough 1968).

Reconstructing the South Fork Dam: Problems from the start

Benjamin Ruff decided seemingly everything based on finances as Daniel Kaine's 50-man crew began rebuilding the South Fork Dam late in 1879. Since John Reilly still owned the property, it remains unclear whose finances Ruff was considering. What is certain is that no qualified civil engineer at the time would have recommended the changes Kaine's crews began making to the dam at Ruff's behest. First, they removed the outlet pipes, which were sold for scrap. No one seems to have been alarmed that the change made it impossible to control Lake Conemaugh's level if dam repairs were needed or a storm was incoming. Nor was anyone worried when the laborers lowered the dam's crest by about 3 feet, most likely to reuse the material for filling the 1862 breach. This decision reduced the lake's capacity (and the dam's freeboard) by 3 feet, effectively destroyed the southwest spillway, and significantly reduced the discharge capacity of the northeast – and now only – spillway. Moreover, a Christmas storm washed out everything dumped into the breach, presumably including any material salvaged from the crest. Ruff paused work after that not to reconsider his dubious decisions but to avoid further washouts. The crews resumed work in the summer of 1880, by which time the Club had finished purchasing the site from Reilly (Coleman 2019, Hanna 2021, McCullough 1968).

The actions of Kaine's crews upon returning to work reflected Benjamin Ruff's woeful inexperience in dam construction. The laborers resumed work by driving a double layer of hemlock sheet piles to block off the upstream end of the outlet conduit remnants. However, the poorly driven sheet piles were less than 6 inches thick. Contemporary civil engineers would almost surely have recommended thicker sheet piling based on the lateral earth pressure theories of the time. No evidence survives as to whether the crews backfilled the massive void formed by the conduit (Kaktins et al. 2013, Unrau 1980, Wellington and Burt 1889 B).

Next, the laborers began filling the 1862 breach by dumping nearly anything they could find into it, including boulders, cobbles, and shale. Another, more problematic material they likely used was medium to highly plastic clay, which Ruff could readily have procured from local coal mine spoils. Such soil is notoriously weak, tough to compact, and prone to settlement, and 21st-century geotechnical and dam engineering practice would never allow its use in embankment construction. The laborers even resorted to filling parts of the breach with animal manure, which decomposes over time and is also highly plastic. The crews never attempted to properly compact or puddle these materials during placement, thereby failing to meet the contemporary standard of care for embankment construction. Nor, it appears, did they try to bench the material used to fill the old breach into the surviving remnants of the original dam (Kaktins et al. 2013, Unrau 1980, Wellington and Burt 1889 B).

Lake Conemaugh slowly rose behind the South Fork Dam as the laborers haphazardly filled the 1862 breach, but they never diverted the South Fork of the Little Conemaugh River around the breach during their work. Instead, the crews placed a wooden flume over the fill material and covered the refilled breach's upstream face with brush and hay, techniques which probably had little if any impact. Most of the South Fork's waters almost surely kept flowing right through the new fill, saturating it and reducing its shear strength. The crew also installed 18-inch-high fish screens at the bottom of the spillway between the bents of a wooden bridge they had built over it. The screens represented a potential clogging hazard for debris-laden storm outflows and, even without clogs, further compromised the dam's last fail-safe against overtopping by reducing the spillway's discharge capacity even more (Francis et al. 1891, Kaktins et al. 2013, McCullough 1968, NPS 2023 C, Wellington and Burt 1889 B, Unrau 1980).

Ruff's crew did cover the new fill's downstream face with riprap, as had William Morris's contractors. However, the new riprap was noticeably smaller than the original dam's colossal boulders. The weak, poorly placed fill thus had less overtopping protection and shear strength than the material surrounding it, which created a dangerous plane of weakness right in the center of the dam. At no time did the laborers remove the trees, brush, and grass that had grown on the dam remnants since the Western Reservoir's completion. The overgrowth had almost certainly tapped into and worsened existing leaks in the dam as it spread its roots. It also made thoroughly inspecting the dam next to impossible (Francis et al. 1891, Kaktins et al. 2013, McCullough 1968, NPS 2023 C, Wellington and Burt 1889 B, Unrau 1980).

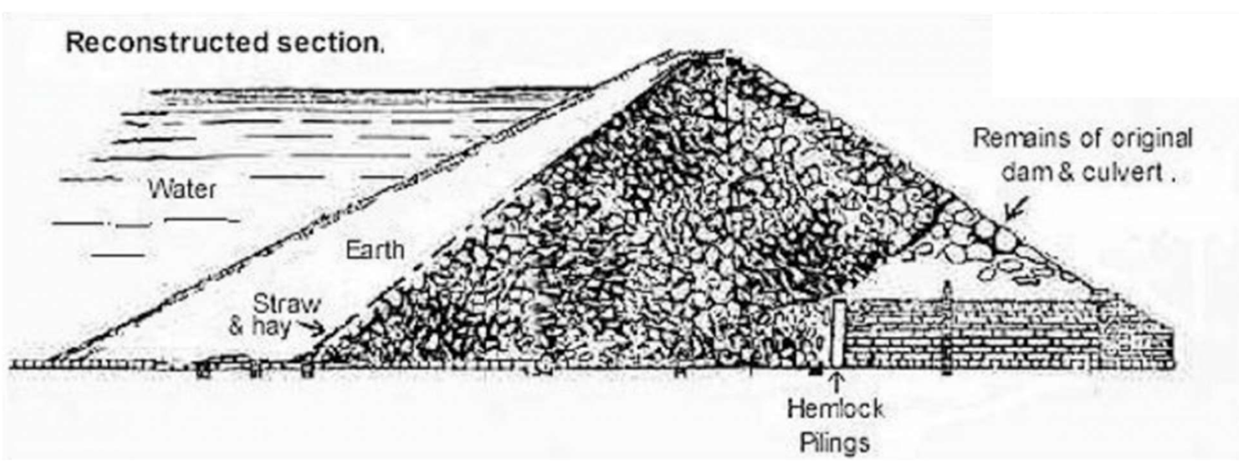


Figure 12: Cross-section of the South Fork Dam as rebuilt. Source: Frank (1988).

Word spread as Kaine's laborers rebuilt the South Fork Dam that their work was shoddy. One civil engineer who visited the construction site noticed leaks near the old outlet conduit, but foreman Pearson dismissed his concerns. Alarm over the sloppy rebuild also reached Daniel Morrell, head of Johnstown's Cambria Iron Company, and his concerns couldn't be ignored so easily. By 1880, Morrell had built his firm into a leader in American steel with about $1.55 billion in 2024 USD invested in and near Johnstown. He also had civic incentives to monitor the dam. Cambria Iron was a paternalistic employer by Gilded Age standards and ran an affordably priced store, a hospital, a night school, and a public library within Johnstown. Lastly, Morrell employed many trained engineers, including his right-hand man John Fulton, and – unlike Ruff – appreciated the value they brought to projects (McCullough 1968, Unrau 1980, Webster 2023).

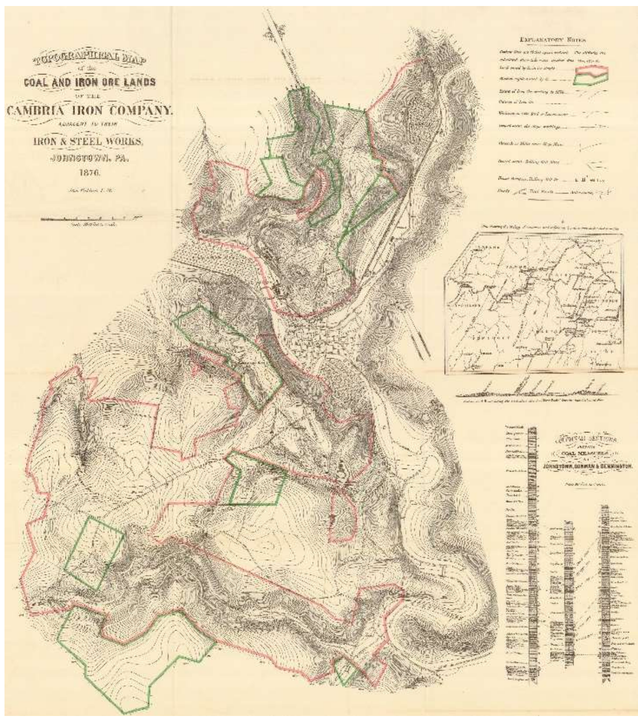
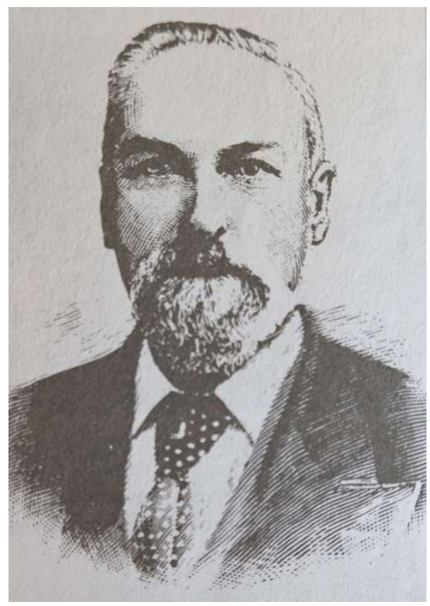


Figure 13: Map by John Fulton of Cambria Iron's land (pink) and mineral (green) holdings in and around Johnstown, mid-1870s. Source: PSU Libraries (2024).

Concerns over the rebuild are rebuffed

Daniel Morrell eventually decided that Cambria Iron should check on the South Fork Dam reconstruction. In November 1880, he dispatched John Fulton to tour the project site with several Club officers, observe everything he could, and summarize his findings in a report. The Club delegation that met Fulton upon his arrival included Club member Col. Elias Unger and civil engineer Nathan McDowell but not Benjamin Ruff. It is unknown how long the Club had retained the Pittsburgh area-based McDowell before the tour or whether he visited the dam on any other occasion (McCullough 1968, McGough 2002, Pittsburg Post 1903, Unrau 1980).

John Fulton overlooked the crews' lowering of the crest of the South Fork Dam during his tour of the project and overestimated the embankment's factor of safety against sliding. However, the former might have escaped the notice of any first-time site visitor, while the latter reflected contemporary civil engineers' incomplete understanding of key geotechnical principles far more than it did any error by Fulton. Indeed, he saw plenty during the tour that worried him based on his engineering expertise, and he included all his concerns in his report to Daniel Morrell. The laborers' haphazard filling of the 1862 breach was not "being done in a careful and substantial manner [as] demanded in a large structure of this kind," Fulton wrote, and had led to "a large leak" flowing through the dam's center. He also noted that the riprap being placed atop the downstream face of the newly placed fill was undersized and that the rebuilt dam lacked an outlet conduit. "When the [lake's] full head … is reached," Fulton grimly concluded from his observations, "it appears to me to be only a question of time until the former [breach] is repeated. Should this break be made during a season of flood, it is evident that considerable damage would ensue along the line of the [Little] Conemaugh" (McCullough 1968, Unrau 1980).



Figures 14A and 14B: The leadership of Cambria Iron in 1880 – general manager Daniel Morrell (L) and chief engineer John Fulton (R). Sources: McCullough (1968), NPS (2022 A).

John Fulton closed his report to Daniel Morrell by recommending that the South Fork Dam be properly rebuilt with a new outlet conduit and large, heavy riprap on its downstream face. Fulton's findings so alarmed Morrell that he immediately forwarded them to Benjamin Ruff, but the Club president's reply several days later was contemptuous. Ruff nitpicked a few minor errors by Fulton (such as misstating the Club's name), denied that the rebuilt dam was leaking, and sneered that Fulton's recommendations were "of no more value than his other assertions." Ruff used an attached report by an unnamed civil engineer retained by the Club, most likely McDowell, to support his assertions. The now-lost report presumably attested to the integrity of the Club's workmanship on the dam. Ruff closed by snapping, "You and your people are in no danger from our enterprise" (McCullough 1968, Unrau 1980).

Daniel Morrell replied a few weeks later, perhaps after giving Ruff – and himself – time to cool down. He acknowledged his deputy's miscues but stood by Fulton, writing, "His conclusions in the main were correct." Morrell also fired back at Ruff and McDowell by pointedly noting, "I think you will find it necessary to provide an outlet pipe or gate before any engineer could pronounce the job a safe one." Furthermore, Morrell – now speaking as head of Cambria Iron – continued, "We must protest against the erection of a dam ... that will be a perpetual menace to the lives and the property of those residing in the upper valley of the [Little] Conemaugh, from its insecure construction." Yet he closed more magnanimously by offering to put his money where his mouth was. If Ruff's contractor rebuilt the dam properly, Morrell wrote, Cambria Iron "would contribute liberally toward making [it] absolutely safe." Morrell almost surely considered Ruff's business sense in presenting his proposal to repair the dam correctly as both safe for the Little Conemaugh valley and economically sound for the Club. Ruff apparently never replied to this second outreach, but John Fulton kept copies of his report and the correspondence between Morrell and Ruff (McCullough 1968, Unrau 1980).

Kaine's crews had nearly finished rebuilding the South Fork Dam by then, but the leaks observed by John Fulton persisted and a winter storm caused another minor breach. The Club then tacitly validated Fulton's concerns and consulted Nathan McDowell on how to patch the leaks. He recommended capping each using hay, manure, brush, and a clay cover per the contemporary standard of care, and this solution worked. The laborers finished their work that spring by installing a V-shaped log boom pointing into Lake Conemaugh in front of the spillway bridge. The boom was meant to keep debris from blocking the fish screens, which suggests that the Club may rightfully have harbored qualms over them. By June 1881 the dam was finished, and the lake opened for recreation. Unlike the Western Reservoir's operators, the Club immediately impounded the lake to its maximum safe depth. It had spent about $520,000 in 2024 USD on the rebuild, less than a tenth the cost of the Western Reservoir. Ironically, as the Club opened the lake, one of its members was Daniel Morrell, who had joined in part to monitor the dam (Coleman 2019, McCullough 1968, Unrau 1980, Webster 2023).

Morrell's concerns were fully warranted, as the rebuilding of the South Fork Dam had clearly failed to meet the standard of care for embankment construction in 1880, or even 1840. Ruff's decisions during the rebuild to lower the dam, remove its outlet pipes and conduit, and lazily repair its 1862 breach had made problems at Lake Conemaugh virtually inevitable. The UPJ stage-storage curve for the Western Reservoir and Lake Conemaugh makes clear just how disastrous his choices were. The 3-foot lowering of the South Fork Dam during its rebuild left Lake Conemaugh with a capacity of about 11,800 acre-feet (3.8 billion gallons or 514 million

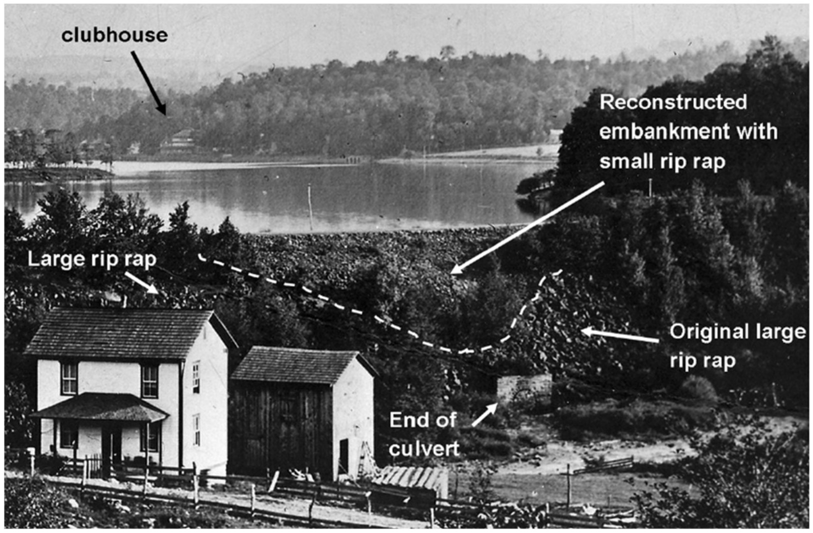


Figure 15: Lake Conemaugh and the South Fork Dam as they looked upon their completion, 1880s. Source: Kaktins et al. (2013).

cubic feet), 11% less than that of the Western Reservoir. Thus, the lake was significantly less well-equipped to attenuate a storm than the reservoir had been. Even more alarming, the lowering of the dam had dramatically reduced its discharge capacity. The removal of the outlet conduit, destruction of the southwest spillway, and downsizing of the northeast spillway had left the rebuilt dam with a discharge capacity of 3,050 cfs, just 44% of its predecessor – provided the fish screens remained unclogged. Nor could the lake, unlike the reservoir, be drawn down before a storm (Coleman 2019, McCullough 1968, Unrau 1980).

Figure 16: The South Fork Dam, 1881-1889. Note its (1,6) poorly rebuilt breach, (2) northeast spillway with fish screens and log boom, (3) lack of a control tower, (4) abandoned discharge culvert, and (5) lowered crest. Source: NPS (2023 C).

Worries about the South Fork Dam

Citizens along the Little Conemaugh River became concerned about the South Fork Dam almost right away. A rainstorm in June 1881, just weeks after the South Fork Fishing and Hunting Club opened, caused extensive flooding in the area and left the citizens of Johnstown terrified that the dam might breach. Cambria Iron sent two of its engineers to Lake Conemaugh to evaluate the situation; while it may have been Daniel Morrell's idea, accounts suggest that he began struggling with dementia at around that time. The Cambria Iron engineers reported back that all was well at the dam, which helped calm the valley residents, but omitted that the storm had left it with just two feet of freeboard (Coleman 2019, McCullough 1968, Unrau 1980).

The crisis at Lake Conemaugh also attracted the attention of Club member and Pennsylvania Railroad executive Robert Pitcairn. He later described Benjamin Ruff as "better than any engineer" but chose in June 1881 to take several Pennsy civil engineers to inspect the South Fork Dam. All were concerned by apparent leaks at the dam's groins, where its abutments segued into the adjacent hillsides. However, Ruff had tagged along and reassured the group that these leaks were actually "springs." Modern geotechnical engineers might find the explanation implausible, given the lake level, but Pitcairn claimed it assuaged his concerns. However, he remained wary enough to ask local businessman Joseph Wilson to alert him if trouble ever arose at the dam (Coleman 2019, McCullough 1968, Unrau 1980).

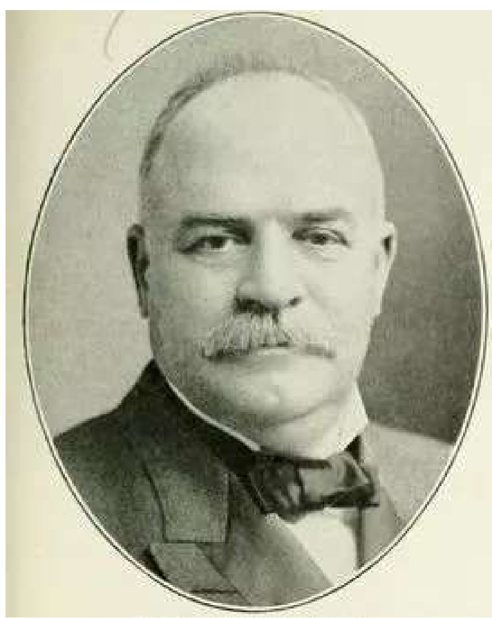


Figure 17: Robert Pitcairn, PRR executive and Club member. Source: NPS (2021 B).

Once the storm and the level of Lake Conemaugh subsided, local fears about the South Fork Dam did as well. Throughout the decade, major storms caused panicking about the dam in the Little Conemaugh River valley yet never amounted to a genuine cause for concern. Locals eventually grew numb to the rumors, and, after 1881, area engineers seem to rarely have visited the dam. By the late 1880s, the prospect of the dam breaching had become somewhat of a running joke among those living along the river. Victor Heiser, then a teenager in Johnstown, summed up their feeling as: "Sometime, that dam will give way, but it won't ever happen to us" (McCullough 1968, Unrau 1980).

<u>Worlds apart: The 1880s at the Club and in Johnstown</u>

Generally, people both at the South Fork Fishing and Hunting Club and along the Little Conemaugh River spent the 1880s focused on things more pleasant, or at least routine, than dam failures. Club members and their guests kicked off summer weekends at Lake Conemaugh by taking Pennsylvania Railroad trains east from Pittsburgh to the hamlet of South Fork at the confluence of the Little Conemaugh's North and South Forks. They then rode carriages two miles upstream along the South Fork to the northeast abutment of the South Fork Dam and crossed its crest, from which they had a fabulous view of the lake. Another mile along the lake shore lay the Clubhouse, the Club's largest building, which had a sizable lakefront porch, bedrooms, and a dining room where vacationers were required to eat their meals. All Club members and guests originally stayed there, but several members later built ornate summer cottages overlooking the lake, 16 of which dotted the shoreline by 1889. They looked northeast across the lake, which was roughly 2.5 miles long and up to a mile wide, at a farmstead which lay across the dam and the wooden bridge over the spillway (McCullough 1968).

Figure 18: Lake Conemaugh as it appeared in the late 1880s. The view is shown from approximately where the Unger farmhouse stood then and still stands. Source: NPS (2023 C).

The Club was rustic by Gilded Age standards but remained high-class. Members included steel baron Andrew Carnegie, banking wizard Andrew Mellon, and coke king Henry Clay Frick, along with Daniel Morrell and Robert Pitcairn. They, their peers, and their families and guests passed the summer weeks sailing, rowing, hunting, fishing, shooting, and riding

Figure 19: Cottages along Lake Conemaugh, 1880s. Source: JAHA (2005).

horseback or in carriages. The spillway was a favorite picnic spot, given the water which always gurgled through it. In the evenings, the men played cards and billiards at the Clubhouse while smoking cigars, and families sat outside and took in the lovely nights of the Allegheny Mountains; from the Clubhouse porch, they could clearly see the ridge's crestline. Benjamin Ruff's death in 1887 had scarcely disrupted the Club's operations. Its biggest problems prior to the spring of 1889 were poachers, unauthorized visitors, and the lack of a sewer system, which

Figure 20: Boys, presumably sons of Club members, sail across Lake Conemaugh as their boat's reflection glistens off the water, 1880s. Source: Historic Pittsburgh (2024).

civil engineers were just starting to build worldwide (Coleman 2019, Hanna 2021, McCullough 1965, McCullough 1968, Unrau 1980).

The Club lay 8 miles east-northeast of Johnstown and 400 feet in elevation above the borough but must have seemed a world away to its residents there. Cambria Iron's round-the-clock operations filled the town and the Little Conemaugh valley with loud clanking, thick smoke, and the red-orange glow of lit furnaces. Steel workers there were lucky to bring home $18,000 annually in 2024 USD from workweeks routinely exceeding 60 hours, and many were injured or even killed on the job, but Cambria Iron was quick to fire any worker who even spoke of striking or organizing. Yet Johnstown, like the USA, seemed set for a bright future and its citizens were generally optimistic. The borough abounded with signs of progress as trolleys clanged down streets brightened by electric lights past homes heated by coal furnaces and bystanders fed by cooking on natural gas stoves. By 1889, Johnstown even boasted 70 telephones. Cambria Iron's business had hardly been impacted by Daniel Morrell's death in 1885 and commerce fueled a population boom along the Little Conemaugh. In 1889, about 30,000 people resided between South Fork and Johnstown. The communities in this 12-mile stretch of valley were tight-knit ones where families had lived for generations, and everybody knew almost everyone else (McCullough 1965, McCullough 1968).

Figure 21: Johnstown, late 1880s. Development encroaches upon its rivers. Source: Hanna (2021).

Lingering problems

During the 1880s, the future appeared bright both at Lake Conemaugh and in Johnstown. Upon closer inspection, though, trouble lurked in both places. At the lake, the South Fork Dam still had problems stemming from Benjamin Ruff's poor reconstruction. Ongoing consolidation of the uncontrolled fill dumped into the 1862 breach had created a sag at least 1 foot deep in the dam's center. The increasingly perceptible sag further reduced the lake's storage capacity and the dam's discharge capacity. Moreover, new leaks kept appearing on the dam's downstream face of the dam, indicating ever-worsening internal stability issues which further compromised its integrity. Several leaks smelled of sulfur, suggesting that some of the uncontrolled fill was indeed comprised of sulfur-rich clays scrounged from local coal mine refuse. Meanwhile, Club picnickers were apparently oblivious as to how the burbling water which gave the spillway its ambience also indicated that the lake was perpetually almost full and could not be proactively lowered (Coleman 2019, Davis Todd 2017, McCullough 1968, Roker 2018).

Figure 22: The South Fork Dam's crest looking southwest, 1880s, with its perceptible central sag. Source: Hanna (2021).

Johnstown had equally serious civil engineering problems. Floods on the Stonycreek and Little Conemaugh Rivers had occurred regularly since Joseph Schantz had settled there but were worsening by the 1880s. Residents had steadily been felling forests throughout the valleys for lumber, and other locals and businesses, most notably Cambria Iron, had been filling in the rivers to create additional land in the mountain-locked borough. Predictably, Johnstown had been inundated more frequently and severely as the ever-smaller river channels were forced to handle ever-more runoff. From 1880 to 1888, the rivers swamped parts of the borough seven times, making the floods a frustrating rite of spring. The unusually wet spring of 1889 suggested more of the same ahead, as multiple heavy snowfalls and rainstorms drenched the region. By late that May, the soil there was nearly saturated (McCullough 1965, McCullough 1968, Shappee 1940).

Figure 23: Central Park in Johnstown during a spring flood, 1887. Source: Strayer and London (1964).

Eve of disaster

Thursday, May 30th, 1889, marked the annual holiday of Decoration Day (now Memorial Day). Most Johnstown residents joined throngs of visitors that day to enjoy a grand parade featuring civic groups such as local organizations of Civil War veterans. By contrast, just a few members and officers of the South Fork Fishing and Hunting Club were up at Lake Conemaugh, where the summer tourism season would soon begin. Since April, several dozen laborers had been working at the Club to install a sanitary sewer for the Clubhouse and cottages. The sewer system's cost was around $410,000 in 2024 USD, about 80% of that of the South Fork Dam rebuild. Unlike the dam rebuild, however, the sewer installation was being supervised by a trained civil engineer (McCullough 1968, Shappee 1940, Unrau 1980, Webster 2023).

John Parke, the engineer in charge of the Club's sewer project, was 22 years old. He had studied civil engineering at the University of Pennsylvania for three years, which qualified him to practice in the field per contemporary standards (although he never completed his degree). By 1889, Parke had three years of professional experience and worked for a Pittsburgh engineering firm, Wilkins and Powell. The firm was likely brought aboard the sewer project by Elias Unger, a founding member of the Club and Ruff's successor as its president, who lived on the farmstead across Lake Conemaugh from the Clubhouse. Unger had joined Robert Pitcairn and the Pennsylvania Railroad civil engineers on their June 1881 tour of the South Fork Dam, but his own career was in hotel management, including for the Pennsy. Unger's considerable outlay for the sewer project and his retention of Wilkins and Powell indicate that, perhaps because of his PRR experience, he valued engineering expertise much more than Ruff had (Coleman 2019, McCullough 1968, JAHA 2013, NPS 2023 A).

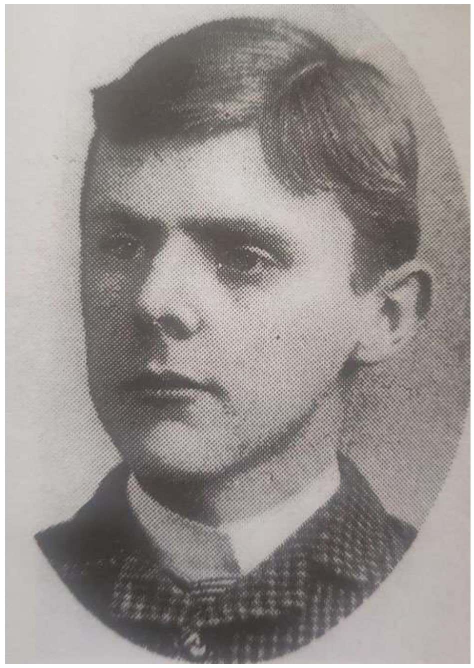


Figure 24: Civil engineer John Parke as a University of Pennsylvania student. Source: McCullough (1968).

The Decoration Day parade dispersed late that afternoon just as light rain began falling along the Little Conemaugh River from Lake Conemaugh to Johnstown. People throughout the valley returned to their homes or hotels, ate dinner, and retired for the night. John Parke went to bed at around 9:30 PM as a stiff wind began blowing at the lake. He had gotten well-acquainted with local weather since the sewer project had started and likely figured the wind preceded a typical, albeit intense, spring rainstorm (Francis et al. 1891, McCullough 1968).

By contrast, the US Army Signal Corps, which monitored the nation's weather in 1889, knew something very uncommon was reaching Cambria County that night. On Sunday, May 26th, the Corps had noticed a major storm system passing eastbound over California and dumping extreme rains as it moved. The system drenched Nebraska and launched lethal tornadoes across Kansas on Tuesday the 28th and soaked the midwestern US the next day. By Thursday the 30th, the storm system was poised to strike southwestern Pennsylvania, and the weather situation there grew even worse when it collided with two other storm systems advancing north. A mild system near the Eastern Seaboard compounded the situation by keeping the cluster of storm systems at a standstill. They became stuck near the crestline of the Allegheny Mountains, where orographic effects likely exacerbated their rains. Lake Conemaugh was thus in the worst possible spot for the incoming storm (Roker 2018).

Figure 25: A spring thunderstorm over Lake Conemaugh, 1880s. Source: Law (1997).

Unlike 21^{st}-century dams, most 19^{th}-century dams, including the South Fork Dam, lacked standard operation and maintenance procedures for inclement weather. Johnstown's telegraph operator had been a civilian Signal Corps weather observer for several years by 1889 and could theoretically have relayed word of the incoming storm to the Club. However, the Club's maintenance crew had not yet connected its summer telephone line, leaving Elias Unger and John Parke without a convenient way to contact her. Moreover, Ruff's decision to remove the outlet pipes and conduit meant that Parke and Unger could have done little to protect the dam anyway aside from building a hastily improvised barrier atop it. A hydrograph constructed for the South Fork of the Little Conemaugh River by UPJ researchers suggests that the storm gathering over Lake Conemaugh that evening was a 2% annual probability (50-year) event, one far less severe than those considered in 2020s dam engineering. Ruff's careless rebuild meant that the dam, which 21^{st}-century engineers would classify as high hazard, had gone in just 35 years from being an American civil engineering marvel to being mortally endangered from a fairly routine storm (Coughenour et al. 2022, Coleman 2019, McCullough 1968, Roker 2018).

The storm strikes

Hard, heavy rain began falling over the Little Conemaugh River valley at around 11 PM on May 30^{th}. In Johnstown, it continued unabated overnight and totaled about 3 to 4 inches. Residents there knew that Friday, May 31^{st} was off to a bad start nearly as soon as they awoke. The Little Conemaugh and Stonycreek Rivers were audibly roaring before daybreak, and by dawn, both rivers were rising – an unprecedented event in Johnstown – at over 1 foot per hour. Local schools and Cambria Iron, neither of which usually acknowledged foul weather, closed mid-morning. At noon, downtown Johnstown was submerged under 2 to 10 feet of water, the worst flood in borough history. Hundreds of wet, flustered citizens tramped to the upper stories of tall downtown buildings or clambered up the high, steep hillsides surrounding the rivers (Coleman 2019, McCullough 1968).

The storm had been even worse near the South Fork Dam, where eyewitnesses reported an overnight rainfall of 6 to 7 inches – an amount supported by 21st-century analyses of the storm. The relentless rain and the region's nearly saturated soil caused excessive runoff in the South Fork of the Little Conemaugh's notoriously flashy watershed. Local creeks and streams were soon running well above their usual levels. One farmer observed a brook typically 2 inches deep swollen to 4 feet in depth. Another found a 3-foot-deep creek flowing through a previously dry field. Every stream in the 53-square mile drainage basin above the dam disgorged its overflowing waters into Lake Conemaugh. As the lake began rising, Elias Unger had only the truncated, screened spillway available to lower it and protect the dam (Coleman 2019, Francis et al. 1891, McCullough 1968).

John Parke awoke at around 6:30 AM and sensed danger almost right away. He saw from the Clubhouse porch that Lake Conemaugh had risen two feet overnight and heard the detritus-laden streams gushing angrily into the lake. Parke rode a horse to the South Fork Dam and found Unger directing the sewer laborers to do what little they could. Several were drawing a plow over the dam's crest to try to augment its dwindling freeboard, while others were using picks and shovels to deepen the swale where the southwest spillway had been. Everyone knew

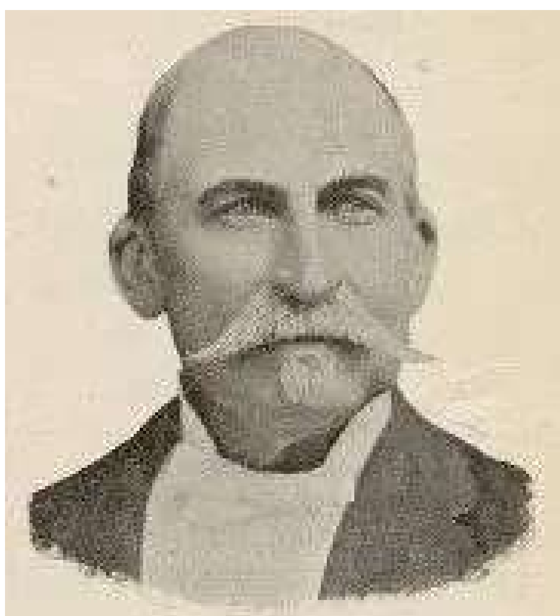


Figure 26: Elias Unger, 2nd and final president of the South Fork Fishing and Hunting Club. Source: NPS (2023 A).

the situation was dire, and Unger vowed to have the dam fully rehabilitated after the storm – assuming it didn't breach, which was no longer assured (Francis et al. 1891, McCullough 1968).

By mid-morning, the rain had largely tapered off. Discharges from local streams hadn't yet peaked, though, and Lake Conemaugh kept rising at around 9 to 10 inches per hour. Unger, Parke, and the laborers toiled valiantly but in vain. Years of carriage traffic had tamped the crest of the South Fork Dam down tightly, albeit not the poorly placed fill deep within it. The plow crew was thus struggling to pile even 1 foot of soil atop the dam, and this loose material would do nothing to halt overtopping. Meanwhile, the laborers in the old southwest spillway had hit bedrock before digging their already overflowing trench even knee-deep. Making matters worse, the timber and debris carried into the lake had overwhelmed the log boom and jammed the fish screens, further lowering the spillway's diminished discharge capacity. Some in the growing

Figure 27: Contemporary illustration of the debris-laden fish screen remnants at Lake Conemaugh's spillway after the South Fork Dam breach. Source: Wellington and Burt (1889 B).

crowd at the spillway urged Unger to remove the screens and bridge. He refused, likely based less on what the situation warranted than on what he believed the Club members would prefer; modern psychologists call such a mindset deferential vulnerability. However, Unger did reassign laborers to clear the screens (Francis et al. 1891, McCullough 1968).

<u>Crisis at the South Fork Dam</u>

The disastrous repercussions of Ruff's stingy, sloppy approach to rebuilding the South Fork Dam and re-impounding Lake Conemaugh now grew excruciatingly clear. As the lake rose, flow through old seeps in and around the dam increased per Darcy's Law, and new leaks began appearing near its base. The spillway's discharge capacity proved pitifully inadequate to counter the rising lake level, even with the emergency trench. The UPJ research team which constructed the stage-storage curve for the lake estimated that its volume was increasing by an acre-foot (43,560 cubic feet; about 325,850 gallons) roughly every 11 seconds at mid-morning on May 31^{st}. At about 11:30 AM, the lake began overtopping the dam and the furrow of loose soil along its crest (Coleman 2019, McCullough 1968).

By then, Elias Unger and John Parke had seen enough. At Unger's request, Parke rode a horse two miles to the closest telegraph office, in South Fork, in about 10 minutes. There, he told a small crowd of the danger at the South Fork Dam and asked two men to have the Pennsylvania Railroad's telegraph operator send a warning message down the Little Conemaugh valley. While Parke left without ensuring that his request was carried out, South Fork operator Emma Ehrenfeld eventually received word of the trouble. She set aside her exasperation that the old rumors about the dam were flying around yet again and tapped out a warning to Frank Deckert, the Pennsy's station agent in Johnstown. In turn, Deckert relayed the telegram to the switchboard operator in Johnstown, although the rising floodwaters starting to ground her lines limited how widely she could spread the alarm. Deckert also sent the message to PRR executive and Club member Robert Pitcairn in Pittsburgh. He was more keenly aware than almost anyone of the consequences if the dam failed, given that he had visited it with Pennsy engineers during the June 1881 scare there. Within an hour of receiving Deckert's message, Pitcairn was aboard the next PRR train bound for Johnstown (Coleman 2019, Francis et al. 1891, McCullough 1968).

Other concerned locals also sent warning telegrams about the South Fork Dam down the Little Conemaugh River valley early that afternoon. Most notably, businessman Joseph Wilson remembered Robert Pitcairn's instructions from years earlier and dictated a telegram to Emma Ehrenfeld which bluntly stated: "*The dam is becoming dangerous and may possibly go.*" She relayed the telegram to Deckert, and it reached Pitcairn aboard his train as it trundled east toward Johnstown. Yet although Pitcairn was notorious for his micromanagement, he never sent his own signed warning message through the valley. An alert from Pitcairn would readily have caught the attention of the valley residents, almost all of whom were familiar with him through his Pennsylvania Railroad role. Instead, few locals heeded John Parke's warning because almost none of them knew or even knew of him (Coleman 2019, McCullough 1968).

Failure of the South Fork Dam

John Parke rode back to Lake Conemaugh as Robert Pitcairn headed east by train and as most locals in the Little Conemaugh valley hunkered down to wait out another seemingly routine spring flood. Back at the lake, Parke found that Elias Unger had reversed course by reassigning laborers to remove the fish screens and log boom. Unfortunately, both had grown too jammed with roaring water and mounting debris to be budged, and the lake now stood roughly 7 feet deeper than its usual level. Even more ominously, the lake had begun overtopping the South Fork Dam's sagging center in a steady flow that was most likely between 5 and 12 inches deep. Parke, likely drawing on his studies at Penn, knew this represented the worst-case scenario for an embankment dam and that a breach was now a strong possibility (Coleman 2019, Francis et al. 1891, McCullough 1968).

The precise mechanisms by which embankments fail in overtopping depend on whether they are built primarily of cohesive soils, which are generally fine-grained, or cohesionless soils, which are usually coarse-grained. Both types of material were used to build and reconstruct the South Fork Dam. However, soils with fine-grained mass fractions of even just 12% will behave like much more cohesive materials. Eyewitness accounts confirm that the stages of the dam's breach most closely matched those of overtopping breaches of cohesive embankments. Such failures typically begin with surface detachment, whereby overflowing water carves rills and gullies in the structure's downstream face. John Parke observed this process at play when he returned from South Fork. The undersized riprap on the rebuilt dam's downstream face had failed in one of its primary roles by not preventing surface detachment (Coleman 2019, Francis et al. 1891, Hanson et al. 2005, McCullough 1968, USACE 2017, Visser 1998).

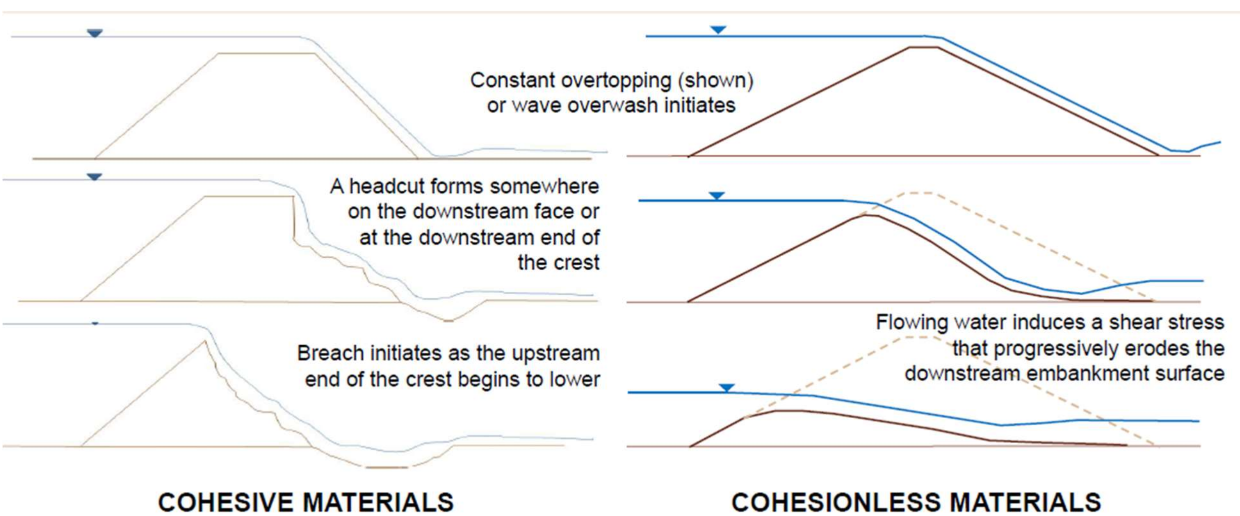


Figure 28: Comparison of overtopping failures in embankments made of cohesive (L) and cohesionless (R) soils. Source: USACE (2017).

Still, Parke saw glimmers of hope in the situation at Lake Conemaugh early that afternoon. The depth of overtopping was holding steady, which indicated that the spillway and emergency trench were functioning relatively well and that the lake was close to cresting. Local eyewitnesses later confirmed that the Little Conemaugh River and its tributaries reached their maximum depths between noon and 1 PM on May 31st, and these accounts match times to peak discharge observed on the river during later storms. The strong possibility that the lake level might begin falling soon led Parke to conclude that his last-ditch plan to save the South Fork Dam by excavating a spillway through the embankment itself was unnecessary. Even had he thought otherwise, the high-risk idea would still have needed approval from Elias Unger, who was clearly susceptible to deferential vulnerability. Parke earnestly believed that the situation was improving and returned to the Clubhouse to eat lunch, no doubt exhausted from his stressful morning (Coleman 2019, Francis et al. 1891, McCullough 1968).

John Parke had done just about everything in his power to protect the South Fork Dam, but his reasonable confidence that it might survive the storm was tragically misplaced. Field studies have since determined that most embankments cannot withstand a sustained overflow 1 foot deep without a high likelihood of an overtopping failure. At the poorly rebuilt dam, even a (likely) shallower depth proved too much. While Parke ate, Lake Conemaugh's overflowing waters etched ever more, ever deeper rills and gullies into the dam's downstream face. Eventually, most of the channels merged into a single step-like gouge in the crest measuring 10 feet wide and 4 feet deep. Such a gouge, now called a headcut, represents the second step in typical overtopping failures of cohesive embankments. When Parke returned from lunch, the unpleasant sight shattered his hopes for the dam's survival. He, Unger, the laborers, and the bystanders watched helplessly as the headcut progressed, or migrated, upstream through the dam (Coleman 2019, Francis et al. 1891, Hanson et al. 2005, McCullough 1968, USACE 2017).

Figure 29: Stages of failure by overtopping of an embankment built of cohesive soil, as seen in a USDA field-scale test. Source: Hanson et al. (2005).

Embankments made of soil compacted near its optimum dry density and moisture content can resist headcut migration during overtopping by several orders of magnitude more than those made of soil compacted less carefully. Thus, Ruff's decision during the South Fork Dam rebuild to let his contractors lackadaisically dump fill material into the 1862 breach almost certainly accelerated the process. Between 2:50 and 2:55 PM, the migrating headcut reached Lake Conemaugh and breached the dam. The embankment failed at that moment, since it could no longer impound the lake. Moments later, though, the dam's myriad issues culminated far more dramatically. Its entire center appeared to give way, and a torrent of water burst forth from the lake. Eyewitnesses remembered this catastrophic final breach much more vividly than the initial, headcut-induced breach (Coleman 2019, Hanson et al. 2005).

The South Fork Dam's final breach: A geotechnical hypothesis

Overtopping caused the South Fork Dam's initial breach, but the geotechnical nature of its final breach appears not to have been discussed at length. No soil or rock from the final breach region remains available for laboratory testing, of course, and doing a full geotechnical forensic analysis of the failure would thus be highly speculative, as well as expensive. However, modern dam and geotechnical engineers can use the current state of practice of civil engineering to interpret surviving evidence from the disaster and reconstruct how the final breach most likely unfolded. Eyewitness accounts suggest that it occurred primarily due to sliding induced by the overtopping which caused the initial breach and uncontrolled seepage.

Cohesive embankments can fail by overtopping in hours, which matches eyewitness accounts from the South Fork Dam. Transverse cracking in such embankments can accelerate their failure, but firsthand accounts from Lake Conemaugh do not mention whether the dam contained such cracks. By contrast, the accounts make it quite clear that the lake's waters surged furiously through the dam remnants after the final breach. One bystander noted that the onrushing wave displaced the air in its path powerfully enough to topple mature trees and send riprap boulders flying, while another recalled that the torrent cut through the dam "like a knife." Others, including Col. Unger and John Parke, commented that the final breach was less an abrupt break in the dam than a pushing away of its center. These first-hand accounts are consistent with a sliding failure of the dam (Coleman 2019, McCullough 1968).

Sliding failures in embankments involve the geotechnical analog of Newton's law of friction, the Mohr-Coulomb equation for a soil's maximum shear strength. An embankment failing by overtopping is gradually eroded by the water flowing over it. The steady decrease in normal stress throughout the structure thus also reduces the maximum shear strength within it. This internal shear strength can decrease even more rapidly in portions of the embankment where uncontrolled seepage has saturated the soil comprising it. Such reductions in shear strength can become even more worrisome in sections of the structure which have always had low shear strength due to improper material placement during construction. All the while, the overflow hardly changes the hydrostatic force of the water retained behind the embankment. Eventually, the shear strength along some surface within the embankment equals the hydrostatic force and the structure's factor of safety against sliding thus equals 1; it then fails by sliding downstream.

The South Fork Dam was riddled with uncontrolled seepage, even if Benjamin Ruff had dismissed these seeps as "springs." It also had a plane of low shear strength in its center where the 1862 breach had occurred and had been carelessly backfilled. (How exactly the crews building the Western Reservoir backfilled the dam's 1847 breach remains unknown, but they labored under the eye of William Morris and his deputy engineers.) Thus, it is unsurprising that eyewitness accounts of the dam's final breach match the basic steps of a sliding failure, especially since the embankment failed in its center (Coleman 2019, McCullough 1968).

Fundamentally, the failure mechanisms of overtopping and sliding are constructs that dam and geotechnical engineers have generated to simplify and quantify the process of designing embankment dams against certain general types of failures. Real-life embankment failures usually involve a complex interplay of mechanisms. Still, the mechanisms remain valuable for geotechnical and dam engineers to use together with experiential judgment to generate strong failure hypotheses. The precise nature of the South Fork Dam's failure cannot be definitively established, but surviving evidence suggests that it was initially breached by overtopping before it underwent a far more catastrophic final breach due to sliding.

Figure 30: The final breach of the South Fork Dam on May 31st, 1889. Source: NPS (2023 C).

The flood devastates the Little Conemaugh valley

First-hand accounts of the South Fork Dam's final breach confirm what an astonishing sight it was. John Parke recalled that "trees growing on the outer face of the dam were carried away like straws." The dam's remnants essentially functioned as a weir for the raging outflow, as a V-shaped notch about 10 feet deep and 150 feet long formed in Lake Conemaugh's surface immediately upstream of the breach. UPJ researchers determined that the final breach had the approximate geometry of a large, inverted trapezoid atop a small, inverted trapezoid lying almost exactly in the dam's center. The large trapezoid measured about 420 feet along its longer base, 290 feet along its shorter base, and 44 feet high. The small trapezoid measured about 56 feet along its longer base, 49 feet along its shorter base, and 26 feet high. Using this geometry, the researchers estimated that the breached lake had a probable peak discharge of between 250,000 and 350,000 cfs. They also estimated that it took at least 65 minutes for the lake to drain 44 feet to the bottom of the large trapezoid after the final breach – an astounding drop in the lake level of about 8 inches per minute for over an hour (Coleman 2019, Francis et al. 1891).

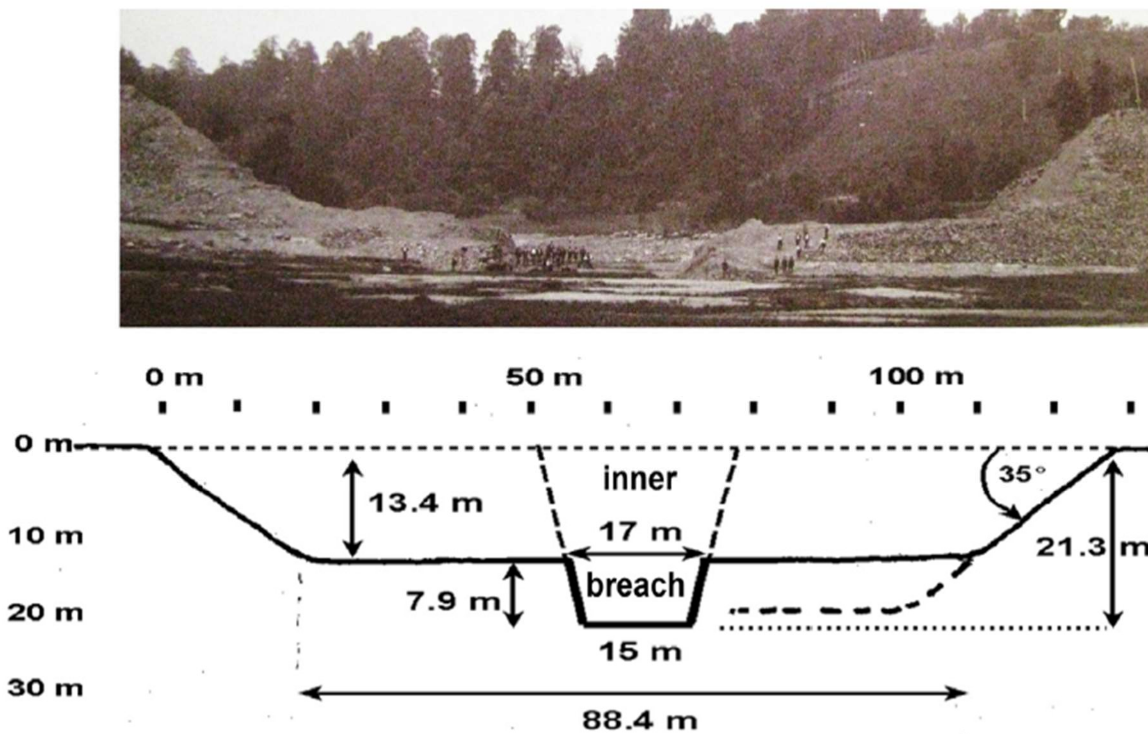


Figure 31: Matching-scale photographic and geometric representations of the South Fork Dam's final breach. Source: Coleman et al. (2016).

The eyewitnesses at the South Fork Dam remnants watched, dazed, as the swollen waters of Lake Conemaugh rushed through the final breach; Elias Unger collapsed from shock. The final breach had grotesquely inverted Sylvester Welch and William Morris's careful calculations and judgments from decades earlier. The engineers had planned that the drop of about 400 feet from the Western Reservoir's surface to Johnstown would make refilling Main Line canals easy during hot summers. Now, however, the altitude difference gave the former waters of Lake Conemaugh an immense elevation head with which to destroy the entire valley below. Soon, citizens along the Little Conemaugh River began learning of the dam failure in the worst way possible (Coleman 2019, McCullough 1968).

The name "Johnstown Flood" fails to convey the horror of what residents of the Little Conemaugh River valley saw that afternoon. The destructive cataract thundering down upon them would have looked like a tsunami, not the gently rising waters of the region's typical spring floods. The technical civil engineering concepts that defined the wave's behavior translated into a terrifying reality for frightened residents of hitherto ordinary towns. Per Bernoulli's Principle, the wave's downhill journey converted its elevation head into pressure and velocity head components, minus energy losses. On the ground, the flood's pressure head appeared to locals as an oncoming wall of water that many, sadly, could not escape and its velocity head appeared as a seething, speeding torrent that swept them up and forced them to frantically struggle to stay afloat. Perhaps worst of all for many citizens, its energy losses equated to the bone-chilling sight of houses or locomotives being hurtled straight at them (Coleman 2019, McCullough 1968).

Figure 32: Contemporary lithograph of the 1889 flood on its deadly rampage. Source: JAHA (2024 B).

The lethally efficient flood wave became a macabre hydraulics problem as it crashed through the Little Conemaugh valley. The waters picked up or demolished nearly everything before them, including trees, railroad cars, boulders, houses, animals, and people. Those trapped atop the wave endured a dizzying, often deadly ride but stood a far better chance than those caught within it. Enormous accumulations of debris and immense obstacles such as a 70-foot-high viaduct temporarily stopped the flood wave at several points during its journey. Each time, though, the overwhelming force of nearly 4 billion gallons of water broke through the jam and the wave continued onward with its deadly energy renewed (Coleman 2019, McCullough 1968).

The flood wave's violent internal mechanics matched its horrific power. As the flood wave descended the Little Conemaugh valley, its bottom portion was slowed as it picked up debris. The wave's comparatively unimpeded top portion then sped over the bottom, smashed downward into the ground, and crushed or buried almost everything in its path. The wave thus flowed in a series of crashing, high-energy loop-de-loops. Collectively, its external and internal hydrodynamics slowed it from an estimated peak speed of 40 miles per hour to an average one of 11 miles per hour (Coleman 2019, McCullough 1968).

The flood wave took about 1 hour and 15 minutes to traverse the valley's 14-mile course from the South Fork Dam remnants to Johnstown. The accounts of those in towns along its path such as South Fork, Mineral Point, East Conemaugh, and Woodvale and of passengers on several weather-delayed Pennsylvania Railroad trains were depressingly, hideously similar. Thousands of ordinary people whose lives had been uneventful minutes earlier now had just moments, if that, to flee the onrushing wave. Many residents and passengers saw or heard the onrushing wave or noticed other improvised warning signals and scrambled to safety just in time. One heroic survivor, PRR engineer John Hess, saved many lives by tying his locomotive's whistle open as he drove away from the wave. However, far too many got no warning at all and found themselves battling to stay afloat atop the wave or, worse, trapped within it. The cacophony of the disaster – buildings crumbling, glass shattering, furnaces and stoves exploding, victims screaming as they faced their end – is too awful to imagine (McCullough 1968).

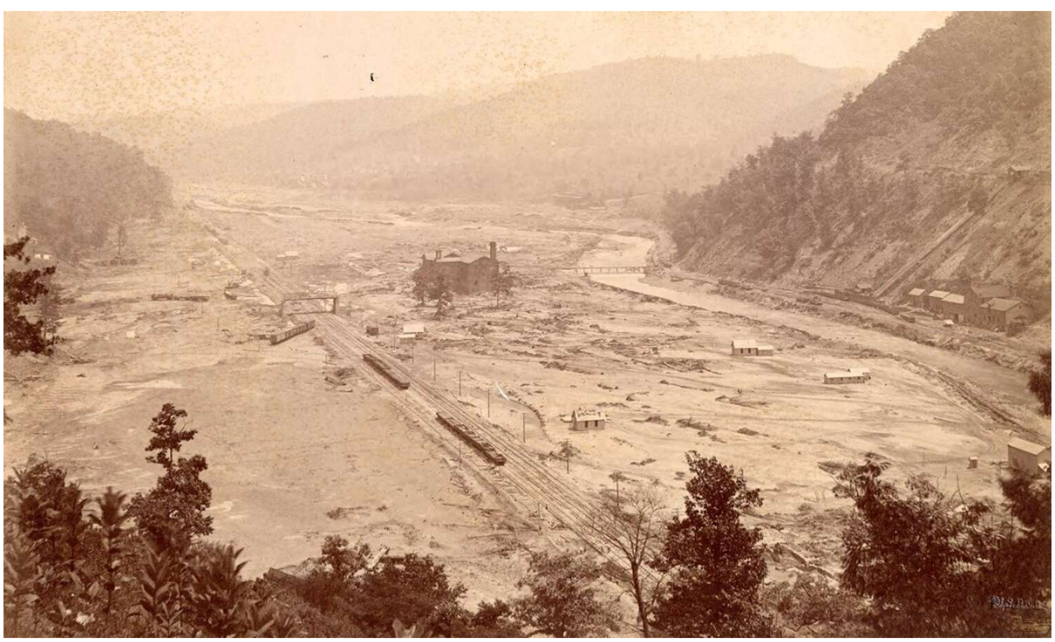


Figure 33: Site of Woodvale, PA following the 1889 flood. Source: May (2023).

The flood reaches Johnstown

The citizens of Johnstown, oblivious to the approaching horrors, were cautiously optimistic about their situation by late afternoon on May 31st, 1889. The sky was getting lighter, the rain was slackening, and the flooded Stonycreek and Little Conemaugh Rivers were slowly retreating; overall, the worst appeared to have passed. However, their world turned upside down at around 4:10 PM when the 20-foot-high flood wave and its debris avalanche smashed into their borough with scarcely any warning. Victor Heiser got about as much notice as anyone else in Johnstown. The teen was untying horses in his family's barn when he heard a low, eerie rumble growing louder and closer. Heiser's father frantically signaled from their home's second-floor window that Victor needed to reach higher ground. No sooner had he clambered onto the barn roof than the wave demolished barn and house alike. Others got even less warning. Rev. H.L. Chapman only learned of the flood when a stranger riding out the flood atop a boxcar desperately leapt through his second-floor window to safety (Davis Todd 2017, Kaktins et al. 2013, McCullough 1968).

Figure 34: Life-size diorama at the Johnstown Flood National Memorial showing Victor Heiser navigating debris during the 1889 flood. Source: Hopey (2022).

The flood wave played a monstrous game of chance with Johnstown's residents as it tore the borough apart. Victor Heiser spent several minutes desperately hopping between floating roofs to dodge trees, beams, and even a freight car. He noticed only midway through the deadly obstacle course that he was riding a torrent of water, not debris. Heiser miraculously survived the disaster, but his parents sadly perished. Schoolgirl Gertrude Quinn's aunt, cousin, and family servant had taken her to the family attic to wait out the storm. Yet the ferocious waters proved too strong for the home, and Gertrude wound up watching in horror as the flood swallowed all three of them. She then rode a mattress for miles downriver until a rescuer swam to her and literally threw her ashore; he also survived (McCullough 1968).

The verifiable stories of the flood's survivors, such as Rev. Chapman, Victor Heiser, and Gertrude Quinn, remain astonishing, heartrending, and powerful. Many, such as Heiser and Quinn, had to ride the wave. Just as many took refuge in their attics, such as Chapman, his wife, the lucky boxcar rider, and several family members and friends. Others watched dumbfounded from the hillsides around town. Johnstown had as much religious variety as any similarly sized American town in 1889, but Chapman probably spoke for many there that day when he wrote of his group that, "None was afraid to meet God, but we all felt willing to put it off." Others were sure Judgment Day had arrived (McCullough 1965, McCullough 1968, Roker 2018).

The human and technical aspects of the flood kept playing out together in a ghastly drama. Eyewitnesses stated that the flood wave split into three smaller but still destructive sub-waves after striking Johnstown. A 2010s geophysical simulation study from UC Santa Cruz successfully created a wave that agreed with these accounts using a computer model based on the "tsunami ball method," which uses energy packets to describe the behavior of tsunamis and landslides. Per both the model and the eyewitnesses, the northernmost sub-wave glanced off a hillside just north of Johnstown and ricocheted back toward downtown. The central sub-wave surged directly over downtown Johnstown before striking a hillside immediately west of town and coursing through downtown again in a raging backwash. The southern sub-wave rampaged

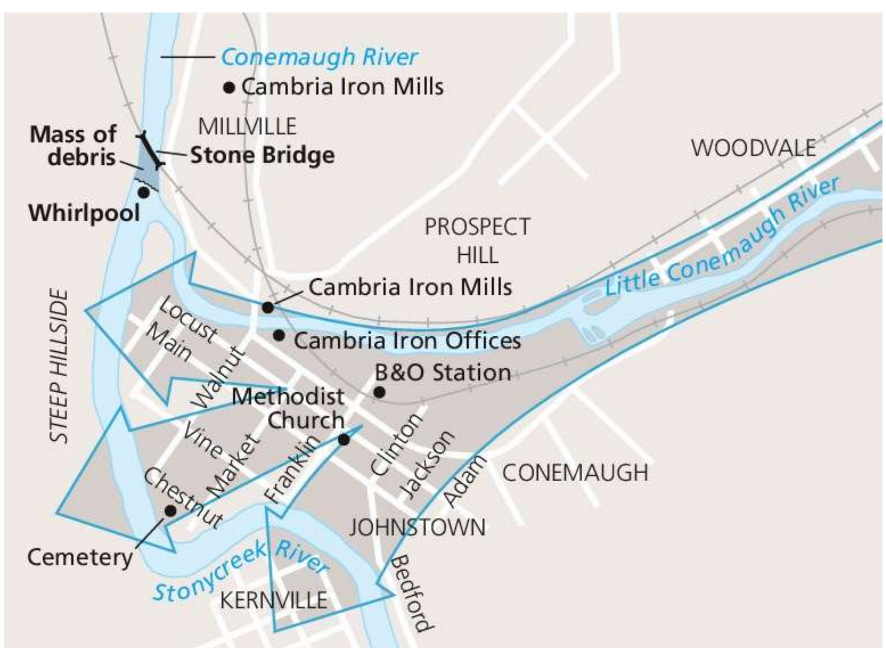


Figure 35: Approximate path of the 1889 flood through Johnstown. Source: NPS (2023 B).

up the Stonycreek River valley and inundated many who had understandably sought refuge there from deluges on the Little Conemaugh. Collectively, the sub-waves destroyed most of Johnstown in about 10 minutes (McCullough 1968, Ward 2011).

The three sub-waves soon poured back down the Little Conemaugh and Stonycreek valleys, reunited, and smashed into the new, seven-arch masonry bridge that carried the Pennsylvania Railroad over the Conemaugh River. The waters had spent enough energy destroying Johnstown that the structure, known as the Stone Bridge, held. However, the weakened wave still had enough strength to crush the flood debris and multitudes of people, some dead but many still alive, in a pile against the bridge. Much of the detritus got tightly wedged within the Stone Bridge's ribbed arches, built to allow the structure to cross the Conemaugh on a skew, and quickly blocked all seven. By 5 PM, the ruins covered over 60 acres, loomed higher than the bridge, and had blocked all seven of its arches. The debris jam

Figure 36: The seven-arched Stone Bridge, Johnstown. The Pennsylvania Railroad later covered its upstream face with concrete during a widening project. Source: Author.

Figure 37: Close-up of one of the Stone Bridge's ribbed arches. Source: Author.

at the Stone Bridge temporarily impounded a debris-laden lake 10 to 30 feet deep over the pulverized ruins of Johnstown, and the grisly new lake only began draining several hours later when the railroad embankment east of the Stone Bridge collapsed due to the mounting water and wreckage (JAHA 2024 A, McCullough 1968, Strayer and London 1964).

The re-released floodwaters badly damaged the towns just downstream of Johnstown, but the temporary dam and the accumulated debris at the Stone Bridge spared them the worst of things. Beyond these hamlets, the flood wave's dissipating powers largely attenuated the damage it could do. Yet things in Johnstown somehow got even worse. The debris mountain at the Stone Bridge included many open-flame furnaces, heaters, stoves, and lamps, along with all kinds of flammable wreckage. By 6 PM, the flames had ignited an inferno. As night fell over what remained of Johnstown, the fire burned scores of flood survivors trapped in the detritus to death and blazed so intensely that one could read by its light. Some US Civil War veterans called the evening the worst sight they could remember, presumably including combat (McCullough 1966, McCullough 1968).

Figure 38: Debris jam at the Stone Bridge after the fire. Source: Lindberg (2024).

Relief and reconstruction efforts

Word of the destruction along the Little Conemaugh River began spreading even before sunset on May 31st. Late that afternoon, Robert Pitcairn's train – hours behind schedule due to the awful weather – stopped several miles downriver of Johnstown because of track damage. The train's crew was figuring out their next steps when they and their passengers were horrified to see survivors riding debris along the Conemaugh River. Pitcairn realized almost immediately that Lake Conemaugh had breached the South Fork Dam and inundated Johnstown. He and others tried desperately to rescue the riders on the swollen Conemaugh but could pull only seven from the water. After several hours, the train returned to the nearest station, where Pitcairn wired Pittsburgh about the valley's devastation and requested immediate, substantial assistance (McCullough 1968).

The news and call for help flashed over telegraph wires to most of the US before midnight, and aid soon began arriving in droves. The Pennsylvania National Guard, the US Army Corps of Engineers, the fledgling American Red Cross, and countless other groups and volunteers flocked to Johnstown to help the town and valley rebuild. Many people across the country and world donated to relief funds which ultimately sent nearly $128 million in 2024 USD to the beleaguered valley. Others sent in-kind contributions ranging from food to clothes to caskets to building materials. The US Military Academy and its superintendent, Col. John Parke, lent the Army Corps a pontoon bridge to help move aid through the Little Conemaugh valley. Col. Parke's nephew and namesake was none other than John Parke, the civil engineer and breach eyewitness (Johnson 1978, NPS 2015, McCullough 1968, Webster 2023).

Figure 39: Soldiers' tents pitched amid the remnants of Johnstown during the rebuilding of the town. Source: Lindberg (2024).

The volunteers and donations proved invaluable as the various organizations, volunteers, and survivors began the difficult work of rebuilding Johnstown and the towns upstream. Work crews needed three days to extinguish the debris fire at the Stone Bridge and dynamite to dislodge the wreckage there. The flood had devastated the Pennsylvania Railroad's main line tracks along the Little Conemaugh valley, and PRR laborers working around the clock required two weeks to restore them to service. Volunteers and survivors had to clear the former towns' streets and – in a distinctly geotechnical precaution – dig the muck and debris out of every flood-buried cellar to ensure the integrity of future structures' foundations. Property damage from the flood came to about $580 million in 2024 USD (McCullough 1968, Webster 2023).

The flood's tens of thousands of survivors had pressing needs. The injured needed time and medical attention to convalesce, and the disaster left many others with cases of the condition now known as post-traumatic stress disorder. Even those who were physically and mentally healthy often had little left except the clothes they were wearing. Volunteers distributed supplies and erected thousands of tents and prefabricated homes to give survivors a decent standard of living during the rebuild. Still, while the temporary housing was much appreciated, its lack of proper sanitation and the hordes of rotting animal corpses soon led to a typhoid outbreak in the Little Conemaugh valley contained only by valiant medical efforts, extensive disinfection, and widespread burning of carcasses and debris (McCullough 1968).

Figure 40: Disease-ridden animal carcasses and perishable debris are incinerated as the rebuilding of Johnstown continues. Source: Lindberg (2024).

Gathering, identifying, counting, and burying the human dead was among the most pressing challenges facing the valley after the disaster. Work crews spent months searching for bodies but could not ensure all the victims' recovery, and human remains were found as far downriver as Cincinnati and as late as 1911. Many corpses were never identified, and the exact number of lives the disaster took remains unknown. A painstaking 1890 study tallied 2,209 victims but double-counted several people and included at least one survivor who, although seriously injured, later recovered fully. In 2023, a new study used 1880s population data and LifeSim, a US Army Corps of Engineers dam and levee risk modeling software, to estimate that 2,262 victims in Johnstown and nearby towns lost their lives directly from the flood. This count excludes some direct deaths elsewhere, such as towns closer to the South Fork Dam and on the weather-delayed PRR trains, and also omits indirect deaths from factors such as flood-caused injuries and illnesses, the Stone Bridge fire, epidemics, and – for at least one troubled soul –

suicide. Collectively, the flood's direct and indirect death toll was most likely about 2,500 victims. The survivors worked closely with volunteers to inter all recovered human remains in a sanitary and dignified manner (Coleman 2019, Mauney 2023, McCullough 1968, NPS 2022 B).

Figure 41: Johnstown during the early weeks of rebuilding, 1889. Source: Hanna (2021).

Engineering journalism and public outrage

The soldiers, medical personnel, volunteers, and survivors in the Little Conemaugh valley were soon joined by throngs of reporters. Most correspondents initially filed stories focused on the flood's devastation and human-interest subjects. As clean-up and relief efforts progressed, many turned their attention to Lake Conemaugh and the South Fork Dam remnants. Journalists who visited the old lakebed included several from engineering publications, such as Arthur Wellington and Frederic Burt of *Engineering News* and H.W. Brinckerhoff of *Engineering and Building Record*. Their publications later merged into *Engineering News-Record*, now *ENR* (Coleman 2019, ENR 2022, McCullough 1968, Unrau 1980).

The civil engineering reporters' articles on the South Fork Dam breach reflected where their field stood in 1889. Certain subjects had been somewhat extensively developed, such as surveying and hydraulics, but many remained to be established beyond scattered principles, such as geotechnical engineering. Even with these shortfalls in their technical knowledge, the engineering correspondents found plenty to criticize regarding the dam's reconstruction. They noted the flimsy sheet piles used to barricade the old drainage outlet, the poor workmanship in the refilled breach, and the central sag, of which the dam remnants provided clear evidence. Wellington and Burt noted in indignant italics that Benjamin Ruff and his crew "*were aided by no engineering advice or supervision whatever.*" Ruff's careless handiwork, long forgotten, now came to light again (JAHA 2013, Wellington and Burt 1889 B).

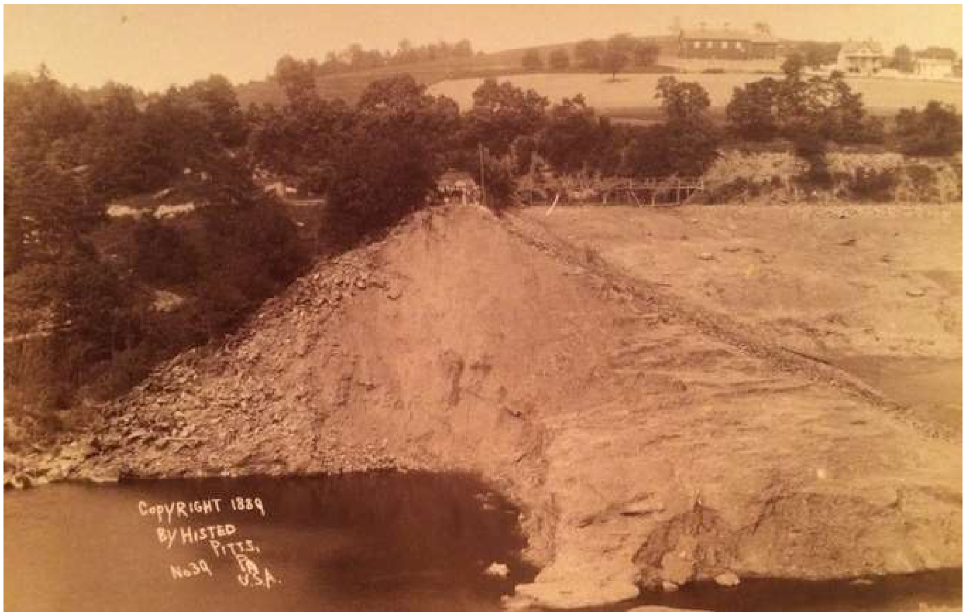


Figure 42: Reporters stand atop and are dwarfed by the former northeast abutment of the South Fork Dam, 1889. Source: Johnstown Flood NPS (2018).

Public anger with the South Fork Fishing and Hunting Club was already simmering when, weeks after the flood, John Fulton publicized both his 1880 report to Daniel Morrell on the lackadaisical rebuilding of the South Fork Dam and Morrell's follow-up exchange with Ruff. The revelations brought outrage with the Club to a boil. "All of the horrors that hell could wish," went one flood elegy; "such was the price that was paid for – fish!" The Johnstown *Daily Tribune* noted more plainly yet just as bitterly, "Our misery is the work of man." Some Club members made sizable individual or corporate contributions to flood relief funds, including Andrew Carnegie, Andrew Mellon, Henry Clay Frick, and Robert Pitcairn; Carnegie also financed the rebuilding of Johnstown's library. Yet about 30 Club members made no contributions, and their stinginess – along with the Club's offer to shelter flood orphans in the Clubhouse – struck many as distasteful (McCullough 1968, Unrau 1980).

The press spent weeks reporting on Ruff's lousy handiwork, and nationwide calls for justice for the flood victims grew ever louder. Locals who had long resented the sumptuous Club and its rich members gladly shared their views with reporters, but coroner's juries in two counties concluded that the Club was to blame for the flood deaths, and even Pennsylvanians more sympathetic to the ruling class agreed. Adjutant General Daniel Hastings of the Pennsylvania National Guard, an attorney, a staunch Republican, and the Commonwealth's future Governor, commented from his headquarters in Johnstown that the South Fork Dam's negligent reconstruction of the dam had obviously caused the tragedy. Many survivors noted the seemingly united public sentiment against the Club and began planning lawsuits against its members for flood damage to their livelihoods, property, and, often, relatives' lives. Others

Figure 43: Former bed of Lake Conemaugh and remnants of the South Fork Dam looking downstream, 1889. Source: Hanna (2021).

preferred not to sue but still wanted the Club to acknowledge its responsibility for the disaster (McCullough 1965, McCullough 1968).

<u>The Club and its allies protect themselves</u>

It remains unclear what the South Fork Fishing and Hunting Club's members had thought about the South Fork Dam before it breached. Daniel Morrell had expressed concerns about the slapdash rebuild while it was ongoing, and Robert Pitcairn's warning to Joseph Wilson suggests he felt similarly uneasy, but most of their peers probably gave the embankment little more thought than did most locals. Many likely shared the valley residents' misplaced faith in Benjamin Ruff's construction judgment and his contractor's handiwork, even if they arguably should have taken more interest in what Morrell and Pitcairn had observed. Thus, the Club members' failure to act on the dam's problems before the breach seems more like oversight than conspiracy. The same cannot be said of their actions after the disaster, when circumstantial evidence suggests that the US Gilded Age aristocracy protected its own. Ultimately, the public could not harness its colossal outrage over the breach either to hold the Club members responsible or to prevent similar future disasters (Coleman 2019, McCullough 1968).

The Club members' political connections certainly helped them after the flood. In Harrisburg, Club-connected business interests such as the PRR dominated the Pennsylvania General Assembly, and the group never turned its attention to dam safety following the disaster. In Washington, DC, Congress was similarly receptive to Club members' interests. GOP kingpin and Pennsylvania Senator Matthew Quay's relief donation was reportedly among the first to reach the Little Conemaugh valley, but he never took legislative action on dam safety either, since US Senators were then elected by their state legislatures. The tragedy moved President Benjamin Harrison to write a relief check and lead a successful meeting to collect more donations. Yet the Presidency was weak relative to Congress during the Gilded Age, making Harrison, in one historian's caustic phrase, "a high-minded figurehead for an alliance of Republican bosses and big businessmen who actually ran the country." One of the bosses was Quay, who had just maneuvered Harrison past a Democratic popular vote win and into the White House. Political cartoonists had been lampooning Senators as millionaires' puppets well before the flood, and they only sharpened their critiques afterward. However, ridicule was essentially the sole consequence the US ruling class faced for its post-flood inaction (McCullough 1968, Miller 1998, Rose 2013).

Figure 44: The US Senate as portrayed by one political cartoonist, 1889. Source: Senate (2022).

Flood victims who challenged Club members in court also emerged empty-handed. Civil liability was fault-based at the time, meaning that plaintiffs had to clearly prove negligence by defendants to win and collect damages. The residents of Johnstown retained the sharpest of the town's attorneys to make their case, but the Club's members included both partners in the prestigious Pittsburgh law firm of Knox and Reed. The partners' legal acumen would have made the Johnstown attorneys' work a tall order before even the most favorable jury, and most prospective jurors then in southwestern Pennsylvania worked in industries such as steel, coke, and railroads over which Club members held immense sway. Therefore, the flood trial jurors likely considered their livelihoods during their deliberations at least as much as the facts of the cases. "It is almost impossible," Victor Heiser recalled decades later, "to imagine how those [Club] people were feared" (Coleman 2019, McCullough 1968, Rose 2013).

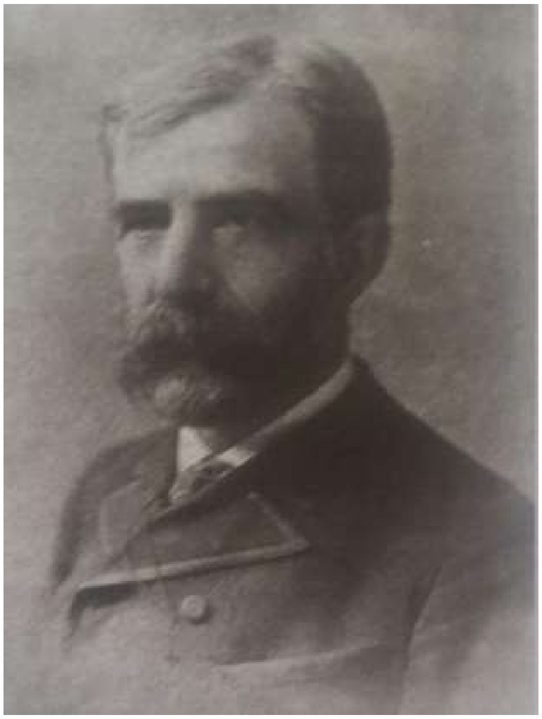
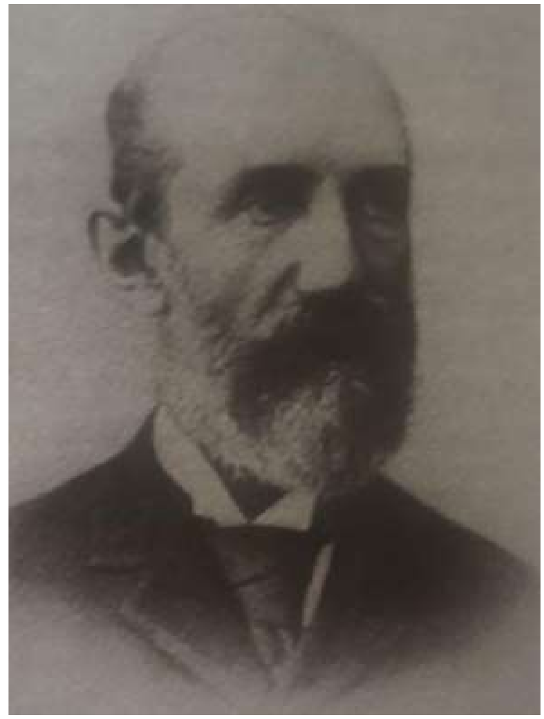
Knox, Reed, and all the Club's attorneys in the flood damage cases argued that the storm, South Fork Dam breach, and flood constituted an "act of God." Ultimately, the jurors agreed with their line of reasoning, and the defendants won all the cases. However, the denial of justice to the flood victims and survivors was widely deplored, and many states adopted the doctrine of strict liability for future such cases. Strict liability holds that a defendant is responsible for property or livelihood damage caused by their assets, such as the failure of a dam they own, regardless of whether they committed negligence, and it remains a mainstay of modern US law (Coleman 2019, McCullough 1968, Rose 2013).

The ASCE report on the disaster: its writing and delayed release

The Club members even influenced the American Society of Civil Engineers' investigation of the flood. In June 1889, ASCE formed a select committee to examine the causes of the disaster. The four committee members had impressive credentials. ASCE President and *de facto* chairman Max Becker was an accomplished railroad engineer, ASCE Vice-President Alphonse Fteley had performed pioneering work on hydraulics, and ASCE Past Presidents James Francis and William Worthen had been involved in the Society's investigation of the fatal Mill River Dam breach of 1874. "A better committee could not be appointed," the *Engineering News* crowed. Over the following months, the members visited the South Fork Dam remnants and took measurements, performed their analyses, and wrote up their conclusions. The committee finished its report in January 1890 (Coleman 2019, Sharpe 2004, Wellington and Burt 1889 A).

In the late 1800s, ASCE select committees usually submitted their completed reports to the Society's Secretary. However, Becker exercised his presidential prerogative and sealed the South Fork Dam report as he finished his term, thereby postponing its release indefinitely. Reporters dutifully repeated Becker's public statement that he delayed the release due to "pending suits against the owners of the dam." Some observers likely noted, though, that only after the report's release could such litigation proceed most effectively. A more plausible, less noble reason for the delay is that Becker's railroad was controlled by the Pennsy, which had substantial connections to the Club through Robert Pitcairn. Clearly, Becker had a conflict of interest when it came to uncovering the truth about the breach. His successor as ASCE president, acclaimed railroad engineer William Shinn, took office in January 1890 with his own conflict of interest related to the select committee; he was a former business partner of Club member Andrew Carnegie (Coleman 2019).

The ASCE Annual Convention in June 1890 suggests how the Society's hierarchy, especially President Shinn, viewed the South Fork Dam report. The convention was held roughly 25 miles northeast of Johnstown in Cresson, Pennsylvania, at the PRR-owned Mountain House Hotel. Pennsy executives were closely involved in planning the event, including the Club's own Robert Pitcairn, who was not an ASCE member. The convention's line-up of papers

Figures 45A and 45B: 1889 and 1890 ASCE Presidents Max Becker (L) and William Shinn (R). Source: Coleman (2018).

excluded the South Fork Dam report in favor of less topical write-ups, such as one on producing salt brine. Nor did the convention's roster of side excursions include one to the former Lake Conemaugh. The 15-mile train and carriage journey there from Cresson was so convenient that multiple attendees visited on their own time, and ASCE chartered a PRR excursion train to take attendees to Johnstown and Cambria Iron's rebuilt plant. Yet the train trip, which passed through South Fork and stopped multiple times to highlight damage from the 1889 flood, did not include the opportunity for its passengers to visit the scene of a historic civil engineering catastrophe a mere two miles from the tracks (Coleman 2019).

Journalists at the 1890 ASCE Convention pressed Max Becker about the South Fork Dam report's delayed release. He dutifully repeated his line about keeping ASCE and its members out of flood lawsuits, but the press was more skeptical this time. The Johnstown *Daily Tribune* noted that Becker's delay was likely "on account of his business associates" in Pittsburgh, such as Robert Pitcairn. The *Tribune* added that several unnamed attendees – perhaps Becker, Pitcairn, and Shinn – held a private meeting at the Mountain House during the convention where they "read and considered" the select committee report "in secret." The press saw that the report was being stonewalled even as Becker downplayed it, and ASCE members were getting fed up. Select committee member James Francis told the *Tribune* he wanted the report released immediately (Coleman 2019).

Figure 46: The Mountain House Hotel in Cresson, PA, site of the 1890 ASCE Convention. Source: Hanna (2021).

The ASCE report: a half-baked effort

Unfortunately, William Shinn kept using his power as ASCE president to forestall the South Fork Dam report's release. Not until May 1891 did the Society's new president, Octave Chanute, finally release the report at ASCE's next convention in Chattanooga, Tennessee; the historical record shows no apparent ties between Chanute and the Club. The distance between Chattanooga and the dam remnants meant attendees could not readily visit the remnants to independently evaluate the report. It could certainly have benefited from such critical reviews. The committee first discussed how quickly the Pennsylvania Railroad reconstructed its tracks through the Little Conemaugh valley after the 1889 flood. This impressive feat of civil engineering was nevertheless irrelevant to the dam breach (Coleman 2019, Francis et al. 1891).

The committee continued its tangent by reviewing in detail the movements of Pennsy trains during the flood. Their descriptions matched statements Robert Pitcairn had made to the PRR's in-house lawyers during pre-trial interviews for flood damage suits. These statements were confidential under attorney-client privilege, which usually only the client can waive during their lifetime. (Pitcairn's interview only became public in the mid-20th century, long after his death, when the Pennsy discarded the transcript and an amateur historian acquired it.) The information's appearance in the ASCE report provides clear evidence that Pitcairn, and thereby the Club, tampered with it (Coleman 2019, Francis et al. 1891).

The committee members next discussed the South Fork Dam's construction, 1862 breach, and reconstruction. They noted that the laborers for Ruff's contractor had neither puddled nor properly compacted the material with which they filled the old breach. However, the committee rationalized this decision by stating that "the hauling by teams over the freshly deposited material, which was kept wet by the rising water, made a fairly compact embankment." The statement ignored how such a half-hearted compaction technique would almost surely have met neither the standard of care in the 1880s for reconstructing dams nor William Morris's strict earthwork specifications for the Western Reservoir. The committee added that "the slopes on both sides of the embankment were covered with a heavy rip-rap" during the rebuild, even though a photograph of the rebuilt dam included in the report directly contradicted this assertion (Coleman 2019, Francis et al. 1891).

The committee then analyzed the South Fork Dam breach and assessed whether the storm of May 30th to 31st, 1889, would also have caused the original dam to breach. They began by calculating the rate of increase of Lake Conemaugh's volume on May 31st. Their calculations assumed the lake had risen until it failed, although John Parke recalled that the lake level was nearly constant just before the breach. Parke made his observation in a letter to the committee which the report included in full, so it is baffling that the committee failed to account for that in its calculations. Nor did the members account for high-water marks seen and documented at the dam remnants by other civil engineers which would have contradicted their calculations. Perhaps most importantly, the committee members never mentioned the southwest spillway in the report. They therefore omitted it from their discharge calculations for the original dam and thus grossly overestimated the rate at which the lake's volume would have increased had the dam's height not been reduced (Coleman 2019, Francis et al. 1891).

The committee members also examined the South Fork Dam's structural integrity. Technical periodicals such as *Engineering News* had reported within weeks of the breach that the Club had barely engaged an engineer while Ruff's contractor rebuilt the dam. However, the committee members omitted this key detail and instead touted the dam remnants' strength and sound construction. Such a blithe assessment reflected survivor bias and poor engineering judgment at best and, at worst, perhaps outright disingenuousness. The committee declared that the dam had not breached due to "any defect in its construction," a statement with which visitors who had observed seepage through it may have disagreed. However, the report never touched on those leaks (Coleman 2019, Francis et al. 1891, Unrau 1980, Wellington and Burt 1889 B).

Finally, the committee members discussed why Lake Conemaugh had overtopped the South Fork Dam. They acknowledged that the Club had lowered the dam during the rebuild and mentioned the northeast spillway's insufficient discharge capacity. (They again omitted the southwest spillway.) Yet the members never connected the dots by discussing how the first had led directly to the second and thus concluded that the storm would also have caused the original dam to breach by overtopping. In fact, the committee praised the Club for having prevented a worse disaster by lowering the dam. "We feel satisfied that [our findings] are not far from the truth," its members concluded with professed sincerity (Coleman 2019, Francis et al. 1891).

Figure 47: Former bed of Lake Conemaugh and remnants of the South Fork Dam, 1889, looking south. Source: Hanna (2021).

Other ASCE members were far less satisfied with the report's findings and made their doubts known when it was released and discussed at the 1891 convention in Chattanooga. The Society's rank-and-file brought up the southwest spillway and that lowering the dam had reduced its discharge capacity. They also noted how Ruff's laborers never compacted the material they dumped into the 1862 breach and how it led to the dam's perceptible central sag. The report's delayed release obviously did little to lessen ASCE members' interest in it. The committee members did not deny their report's shortcomings; for instance, James Francis readily acknowledged the southwest spillway's existence. The disconnect between the report's numerous evident shortcomings and the committee members' eagerness to address them in discussion strongly suggests that the report had been diluted between its completion and its release – most likely by Max Becker and William Shinn (Coleman 2019, Francis et al. 1891).

The ASCE report: Flaws and possible causes

The holes in the ASCE select committee's South Fork Dam report are especially glaring compared to a previous report the Society had authored on a nationally infamous dam failure. In May 1874, the Mill River Dam breach in western Massachusetts killed 139 people, and ASCE formed a select committee to examine the failure almost immediately. The committee included James Francis and William Worthen, both of whom later sat on the South Fork Dam committee. The Mill River Dam committee published its searingly direct report in June 1874. The members concluded the breach had been due to a lack of engineering input, seepage through poorly placed materials, an absence of regular inspections, and "defects of workmanship of the grossest character." Worthen criticized the Mill River Dam's designers and builders even more frankly in ASCE's discussion of the report. During its construction, he stated, "Men were employed who were ignorant of the work to be done, and there was nothing like an inspection, although money and life depended upon it" (Coleman 2019, Francis et al. 1874, Wooten et al. 2014).

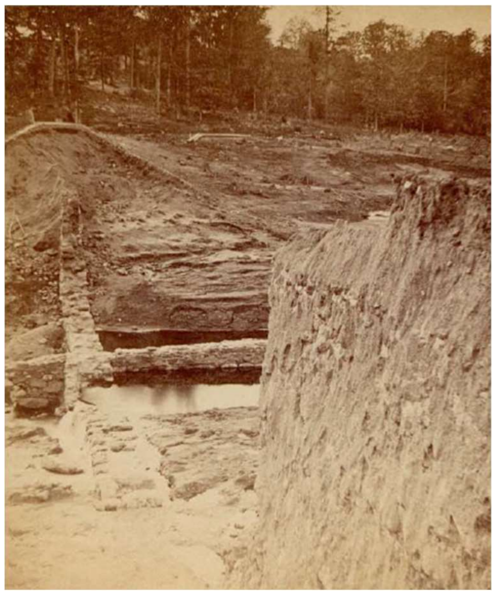


Figure 48: Remnants of the Mill River Dam in Williamsburg, MA after its breach, 1874. Source: Wooten et al. (2014).

The ASCE reports on the Mill River and South Fork dam breaches could hardly have differed more in their publication speed and directness in assigning responsibility, especially since Francis and Worthen sat on both committees. The stark disparity between the reports may relate to who had owned and operated each dam. The Mill River Dam had been owned by manufacturers whose power had largely been local. By contrast, the South Fork Dam's owners in the Club had included some of the USA's richest and most powerful Gilded Age tycoons (Coleman 2019, Sharpe 2004).

The South Fork Fishing and Hunting Club members, unlike the Mill River Dam owners, appear to have influenced the ASCE investigation into their dam's breach in at least two ways. First, Club member and PRR executive Robert Pitcairn seems to have used his business ties to ASCE president and *de facto* South Fork Dam committee chairman Max Becker to pressure Becker into restraining the panel's inquiry. Becker appears to have complied by delaying the report's release until after the ASCE convention in Cresson and cluttering it with information straight from Pitcairn on the Pennsy's train movements. Next, Club member Andrew Carnegie seems to have utilized his old friendship with ASCE's next president, William Shinn, to further delay the report's public debut; Shinn could also have further amended the supposedly sealed document. It cannot be confirmed that the Club and its proxies whitewashed ASCE's South Fork Dam report, but it may readily be surmised (Coleman 2019, Francis et al. 1874).

ASCE viewed professional ethics as its members' private concern during the late 19th century. Therefore, neither Becker nor Shinn violated their obligations as civil engineers through their likely interference with the Society's report on the South Fork Dam breach. However, their actions surrounding the report and likely coordination with former Club members on those actions still smack of irresponsibility – even malfeasance. Their probable decisions to obstruct and dilute the report exposed millions downstream of inadequate dams worldwide to the hazards which had just killed thousands near Lake Conemaugh. The delay may have been fatal in at least one case. In February 1890, the Walnut Grove Dam in western Arizona breached and nearly 100 victims drowned. Investigators found that the failure had involved the absence of trained engineers and an inadequate spillway, just like the South Fork Dam breach. ASCE may well have prevented or lessened the Walnut Grove Dam breach's death toll had it released its South Fork Dam report more swiftly. Clearly, Becker and Shinn – and, most likely, their Club connections – valued their reputations and livelihoods above public safety (Coleman 2019, Gee and Neff 2020, Vesilind 1995).

Engineering advances since 1889

Fortunately for the world, civil engineers and their governmental counterparts have advanced dam safety enormously since the South Fork Dam breach. The decades following the disaster witnessed many technical breakthroughs on topics from embankment permeability to reinforced concrete behavior that directly improved dam engineering. Simultaneously, the political climate shifted in many countries from one of *laissez-faire* economics to one supporting government regulation of health and safety concerns. In the USA, this change played out as the transition from the Gilded Age to the Progressive Era and had clear effects on issues such as dam safety. The US Constitution gives states most powers of professional regulation. Thus, when the Bayless (Austin) Dam in northern Pennsylvania breached in 1911 and killed 80 people, the Commonwealth's General Assembly responded by passing some of the nation's first sweeping laws on dam safety. Meanwhile, in 1914, ASCE heeded the reform-minded *zeitgeist* by adopting its first formal code of ethics (Rose 2013, Vesilind 1995).

The horrors of World War I fostered a widespread global desire for greater international cooperation, leading to the creation of diplomatic institutions such as the League of Nations and global financial agreements such as the Dawes Plan. In the mid-1920s, a group of French engineers began promoting the idea of a similar international group for dam safety. The March

1928 failure of the St. Francis Dam near Los Angeles, which killed roughly 500 people, marked the USA's deadliest dam breach since 1889 and added urgency to the issue. That summer, delegates from six nations founded the International Commission on Large Dams (ICOLD) to help establish uniform, rigorous technical standards for dam design. ICOLD and corresponding domestic dam safety societies in its member nations, such as USCOLD, grew quickly (Ferguson 2019, Hundley and Jackson 2015).

Technical progress also continued during the interwar period. Even before the Armistice, Austro-Hungarian officer and civil engineer Karl Terzaghi had begun performing detailed research on soils' behavior under loading. In 1925, he compiled and published his findings in the book *Erdbaumechanik*, a title loosely translated as *Earthwork Mechanics*. Its debut marked the arrival of geotechnical engineering, the civil engineering discipline that studies the engineering properties and behavior of soils and rocks. Terzaghi and his peers began improving best practices for the design and construction of geotechnical structures such as foundations, retaining walls, and embankments almost immediately – a trend that continues to this day. In the US, the era also witnessed the growth of state laws mandating licensure for civil engineers, a requirement first introduced in Wyoming. Other states soon followed suit, especially after the St. Francis Dam breach (Goodman 1999, NCEES 2020).

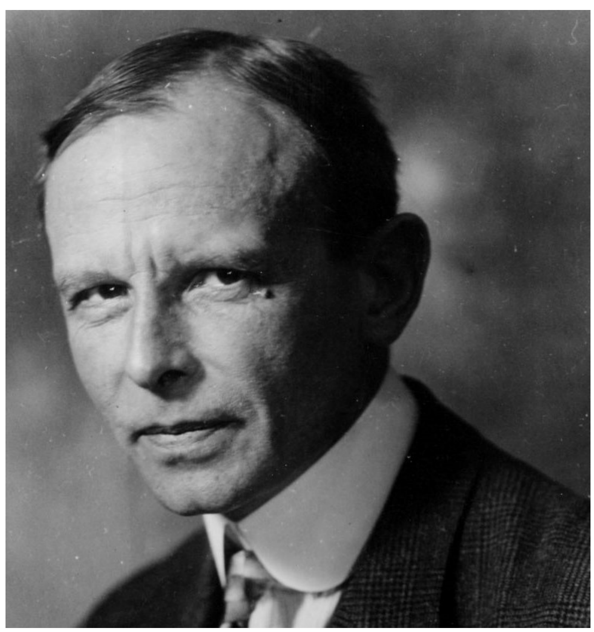


Figure 49: Karl Terzaghi, primary founder of geotechnical engineering, 1926. Source: NGI (2023).

World War II accelerated technical developments in civil engineering both in the US and internationally. Once peace returned, engineers and stakeholders resumed working on the regulation and policy aspects of dam safety. By 1950, every US state had licensure laws for civil engineers on its books, ending the days when freewheelers like Benjamin Ruff could cavalierly build or rebuild dams without competent oversight. Room remained, though, for civil and dam engineering professionals to better ensure public safety. During the 1960s, an in-depth USCOLD review of state dam safety laws and practices found that many laws were ridden with loopholes and varied wildly from state to state – and that many states lacked such laws altogether. A vigorous USCOLD advocacy campaign to change this status quo bore little fruit, and a string of lethal US dam breaches ensued in the 1970s, including – ironically – the 1977 Laurel Run Dam failure near Johnstown. However, the death tolls of these tragedies paled next to that of the August 1975 overtopping-induced failure of China's mammoth Banqiao Dam. The breach killed a total of roughly 230,000 direct and indirect victims, making it the deadliest dam failure ever (Ferguson 2019, Lynch 2023, NCEES 2020).

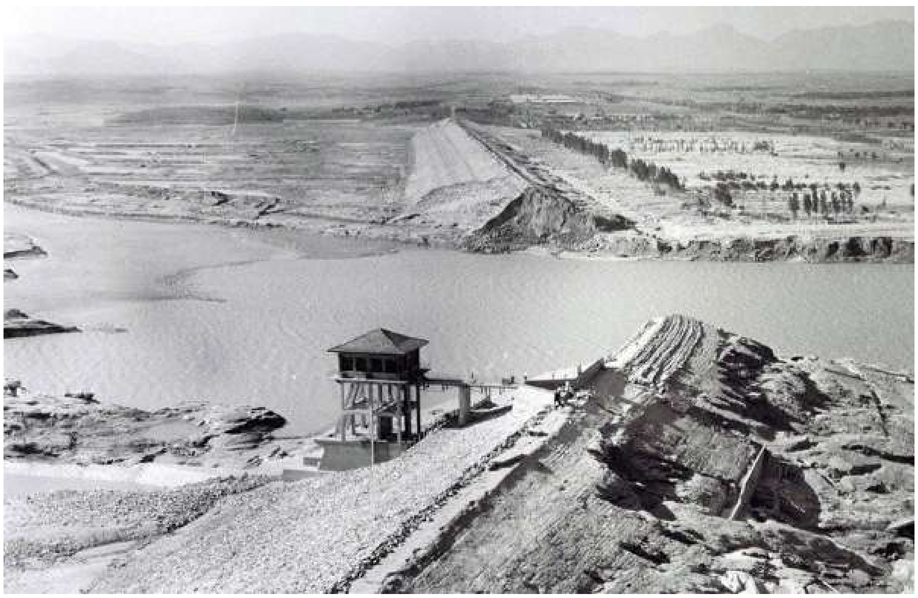


Figure 50: Remnants of the Banqiao Dam in China after its breach, 1975. Source: Lynch (2023).

Other events of the 1970s made clear that existing civil engineering institutions and guidelines needed further reform. In 1973, prosecutors convicted US Vice President Spiro Agnew and forced him to resign over a scandal in which several ASCE members had given him kickbacks in exchange for highway contracts. The corruption underscored how the Society's 1914 code of ethics, still then in effect (albeit with periodic revisions), focused on US civil engineers' individual conduct and duties to their clients and not their broader societal obligations. In response, ASCE adopted a fully revised code of ethics in 1976. The new code clearly required civil engineers to "hold paramount the safety, health and welfare of the public in the performance of their professional duties" (Vesilind 1995).

Meanwhile, the dam failures of the 1970s convinced US dam engineers and regulators that the nation needed a policy-focused group to complement USCOLD's technical work by coordinating state approaches to dam safety. A group of these professionals founded the

Association of State Dam Safety Officials (ASDSO) in 1984 to serve as a forum for states to exchange dam safety information and ideas. ASDSO also acts as a focal point for efforts to improve state-level dam safety policies and practices. One is the group's National Dam Safety Awareness Day, held each May 31st to mark the anniversary of the Johnstown Flood of 1889. Another was ASDSO's long-running effort to have every state implement a dam monitoring and inspection program, which culminated in 2023 when Alabama became the 50th state to adopt one. ICOLD and USCOLD, now rebranded as USSD (US Society on Dams), continue their technical work in parallel with ASDSO's more owner- and policy-oriented efforts (AL ASCE 2023, ASDSO 2022 B, Ferguson 2019, Gardiner 1987).

Today, someone interested in becoming a civil engineer with a PE (Professional Engineer) license starts by earning a bachelor's degree in a civil engineering program credentialed by the non-profit Accreditation Board for Engineering and Technology (ABET). Once the student earns their degree and passes the FE (Fundamentals of Engineering) exam, they apply through their state to earn certification as an EIT (Engineer in Training). The EIT then gains four years of technical work experience under a PE; the EIT can substitute graduate engineering degrees for part of this experience. Finally, the seasoned EIT fills out a detailed record of professional experience and passes the Principles and Practice of Engineering exam to earn their PE license. The non-profit NCEES (National Council of Examiners for Engineering and Surveying) administers both exams nationwide. Civil engineers licensed in one state can gain licensure in others using full or partial reciprocity (NCEES 2020).

ASCE's 1976 code of ethics served the Society, with occasional edits, for over 40 years. Inevitably, though, the world's ever-changing nature made a larger upgrade necessary. In 2020, ASCE once more adopted a wholly rewritten code of ethics. The 2020 Code maintains that a civil engineer's top priority is to "protect the health, safety, and welfare of the public" and reaffirms that civil engineers must practice only within their area of expertise. It also rephrases Society members' obligations in more concise, inclusive, and future-oriented language (ASCE 2020, Vesilind 1995).

The 1889 flood in regional history

ASCE's select committee on the South Fork Dam breach could scarcely have foreseen the many changes to come in civil and dam engineering when it released its report in 1891. What its members likely did recognize was that public outrage over the disaster had largely abated by then. The engineers, the residents of the Little Conemaugh valley, and the former South Fork Fishing and Hunting Club members all wanted to leave the disaster behind them. Johnstown, now reincorporated as a city, finished rebuilding in the mid-1890s, kept growing, and seldom looked back. In the early 1900s, the Maryland Coal Company bought the now-defunct

Club's land and dug mine shafts, built the town of St. Michael on Lake Conemaugh's former bed, and even laid a rail spur to its mines through the dam breach. The Company demolished some of the tycoons' cottages and repurposed others to house its executives, while others bought the clubhouse and converted it into a hotel and restaurant. In 1922, Bethlehem Steel acquired Cambria Iron and continued making steel in Johnstown for decades (Coleman 2019, Farabaugh 2019, Hanna 2021, McCullough 1968).

Figure 51: The Maryland Coal Company mine in St. Michael. Credit: Coal Camp USA (2023).

Johnstown suffered another major flood in 1936 when a St. Patrick's Day storm dumped 5 to 6 inches of rain atop ground covered with 2 feet of snow. It caused far fewer deaths (24) but far more property damage ($925 million in 2024 USD) than the 1889 disaster had. Flood-weary citizens wrote to President Franklin Roosevelt demanding a solution, and he and Congress authorized the Army Corps of Engineers to counteract flooding there and in other high-risk areas across the US. From 1938 to 1943, the Corps constructed 8.7 miles of concrete channels to contain the Little Conemaugh, Stonycreek, and Conemaugh Rivers in and around Johnstown. Upon completing the project, Regional Corps officials boldly declared the city "flood-free" (Coughenour et al. 2022, Davis Todd 2017, Farabaugh 2019, Johnson 1978, Webster 2023).

As the Army Corps finished its work in Johnstown, memories of the 1889 South Fork Dam breach were growing distant. Since then, two world wars, the Great Depression, the Holocaust, and communist and fascist tyranny had each taken and shattered millions of lives. Such a horrible backdrop made Johnstown's suffering in its 1889 flood seem somewhat less apocalyptic. Furthermore, the ranks of eyewitnesses to the flood were steadily dwindling. By the 1950s, most people in the US and even around Johnstown had all but forgotten the tragedy. In 1953, the National Park Service declined to buy the dam remnants, claiming they lacked clear historical value. Instead, in 1960, local preservationists purchased the abutments from the Maryland Coal Company for $1 when it closed its mines in St. Michael (Hanna 2021).

In the spring of 1961, 27-year-old magazine editor David McCullough was visiting the Library of Congress on business when he noticed that staffers had set out a display of photos of Johnstown after the 1889 flood. McCullough, a Pittsburgh native, was stunned by the images and set out to learn more about the tragedy but could not find a reliable history of it. He decided to write one and spent his spare time over the ensuing years combing dusty archives, poring over vintage accounts of the disaster, and interviewing flood survivors in their 80s and 90s. His book, *The Johnstown Flood*, was published in 1968 and represented the first authoritative history of the disaster. The book, which remains in print, became a surprise critical and commercial success and allowed McCullough to become a full-time popular historian. Over the next decade, he followed *The Johnstown Flood* with equally authoritative books on the building of the Brooklyn Bridge and the Panama Canal. In 1981, ASCE recognized McCullough's impressive work on civil engineering history by naming him to its top rank of Honorary – now Distinguished – Member (ASCE 2021 A, Hanna 2021, Marston 2022, McCullough 1968, Sutor 2022).

Figure 52: David McCullough doing historical research in Johnstown, 1966. Source: Sutor (2022).

The 1960s also saw a local resurgence of interest in the 1889 flood. In 1964, Johnstown marked the South Fork Dam breach's 75th anniversary with public ceremonies such as a commemorative banquet; over 250 flood survivors attended and were feted as guests of honor. In 1969, the National Park Service, changing course, opened the Johnstown Flood National Memorial at the site of the dam remnants and Lake Conemaugh. A few years later, volunteers opened the Flood Museum in downtown Johnstown, and regional and national interest in the disaster has stayed strong ever since. *The Johnstown Flood* has also been joined by many other excellent books on the tragedy. The catastrophe's first reliable technical history appeared in 2019 with the publication of *Johnstown's Flood of 1889* by Neil Coleman, PG (Professional Geologist). He added many details to the disaster's story, including its hydrology and hydraulics, several corrections to its timeline, and the glaring flaws in ASCE's 1891 report. Geotechnical and dam engineers have also compiled numerous brief references on the technical aspects of the South Fork Dam breach (ASDSO 2022 A, Coleman 2019, Hanna 2021, JAHA 2022, Strayer and London 1964, VandenBerge et al. 2011).

Figure 53: Neil Coleman, P.G., presenting on the research he led at UPJ on the 1889 flood, 2018. Source: Fisher (2018).

Currently, the Johnstown Flood National Memorial encompasses the South Fork Dam remnants, the Clubhouse, the Unger farmhouse, three of the nine surviving cottages, a Visitors Center, and much of the former bed of Lake Conemaugh. Coal mines remain in operation near St. Michael, and iron-rich acid mine drainage (AMD) long gave the South Fork of the Little Conemaugh River a brilliant orange tint. However, local mine operators built a $15 million AMD treatment plant in the mid-2010s under the watchful eyes of the EPA and Pennsylvania's Department of Environmental Protection. Now, the South Fork is beautifully clear as it runs through the dam remnants and parallel to the double track railroad spur. The National Park Service cleared much of the old lakebed in the early 2020s, and visitors can now easily see the lake's former extent. In July 2024, the Park Service announced the start of a 4-year, $7.9 million dollar program to renovate and restore the Clubhouse. The agency will use additional funding to restore the cottages it owns and the Unger farmhouse (EPA 2015, Hanna 2023).

The 14-mile Path of the Flood Trail, completed in 2023, connects the Johnstown Flood National Memorial to the city of Johnstown. There, the Flood Museum occupies the building which formerly housed the library Andrew Carnegie donated to the city after the 1889 flood. The Museum contains an extensive archive of flood-related documents and features an award-winning short film on the disaster and a display of flood artifacts. One noteworthy relic is a railroad car axle buried by the 1889 flood and unearthed in the early 2010s by crews constructing a bridge over the Little Conemaugh River (Murphy 2023).

Figure 54: Former bed of Lake Conemaugh, Johnstown Flood National Memorial. Source: Author.

Figure 55: Railroad car wheels and axle buried by the 1889 flood on display at the Johnstown Flood Museum. Source: Author.

Challenges of the 21st century: Johnstown, the USA, and the world

Sadly, the past half-century has been tough for Johnstown. In July 1977, a 0.01% annual probability (10,000-year) storm dumped 8 to 10 inches of rain onto the city in 12 hours. During the storm, the Laurel Run Dam north of Johnstown – which hadn't been improved in decades despite repeated warnings from engineers – overtopped and breached, further inundating the city. The flood killed 86 people, caused roughly $1.75 billion in 2024 USD of property damage, and accelerated Johnstown's industrial decline. Bethlehem Steel sold or closed all its operations near the city by 1992, and many residents moved away seeking steady employment (Farabaugh 2019, Havener 2022, Webster 2024).

Johnstown has struggled to find its post-industrial footing, and its estimated 2023 population of 18,000 represented only about 25% of its peak during World War II. In 2019, the city had a median income of about $24,600, less than 40% of Pennsylvania's median, and a poverty rate of about 38%, over triple the statewide rate. However, modern residents share the grit their forebears showed after the 1889 flood, and Johnstown's municipal government is undertaking several initiatives to revitalize the city. Ongoing projects include the remediation of brownfield sites and improvements to infrastructure in the downtown region just south of the Stone Bridge, which remains in daily use (Dubnansky 2022, Faher 2012, US Census 2024).

Figure 56: Present-day Johnstown, looking east. Source: Dubnansky (2022).

Johnstown's antiquated, dilapidated infrastructure reflects a disturbing trend across the US. For decades, civil engineers across the country have often lacked funding to turn advances in design standards into state-of-the-art infrastructure. ASCE's most recent Infrastructure Report Card, released in 2021, reflects this neglect. US infrastructure earned an overall C- on the report card, and the nation's dams got just a D. ASDSO reported in 2023 that upgrading all non-federal US dams to meet current design standards will cost roughly $162 billion in 2024 USD, and the price tag will most likely rise as dam engineering advances further and climate change makes storms more frequent and intense. Alas, the much-touted 2021 Infrastructure Investment and Jobs Act allocated $3 billion to dams – a mere 2% of the estimated need. Headlines reflect the importance of making such investments to guarantee the continued integrity of existing dams and other infrastructure. In September 2023, two dams in eastern Libya failed during an intense storm and killed roughly 11,000 people (ASCE 2021 B, Magdy 2023, Riley 2021, Riley 2023).

Figure 57: Remnants of Derna, Libya, after a double dam breach obliterated the city, 2023. Source: Magdy (2023).

Conclusions: Lessons from the Disaster

The South Fork Dam failure and Johnstown Flood of 1889 still hold many crucial lessons for modern dam and geotechnical engineers, especially licensed PE's. The tragedy underscores how key technical expertise and professional judgment are in the civil engineering profession. It also reemphasizes that civil engineers must primarily handle project challenges based on technical considerations, not business or managerial ones. The stories of Benjamin Ruff's sloppy rebuild of the South Fork Dam and the toothless ASCE report on its failure remind all civil engineers that making technically sound decisions is of paramount importance throughout a project's lifecycle from design to construction to operations and maintenance to even, if need be, failure analysis. The lesson is especially applicable for geotechnical engineers, given the high inherent variability of subsurface materials, and dam engineers, whose discipline incorporates many facets of civil engineering.

The South Fork Dam breach also highlights how essential it is for dam and geotechnical engineers to ensure that their work meets the contemporary standard of care. The flood story reminds everyone in these professions that the current standard memorializes victims of either unforeseen circumstances or violations of previous standards. It also reflects how the technical work of civil engineers ultimately has deeply human impacts and how the consequences of professional successes in the field might only be exceeded by those of professional failures. Other lessons from the breach extend to all lines of work. The flood's history reminds its students of how historical events, like current ones, were never predetermined but instead happened first because of, and then to, people (often, the same people). The catastrophe also illustrates how the truth must always come first for those dealing with matters of public health and safety. Finally, and perhaps most importantly, the tragedy provides a harsh admonition that buttressing the dictates of law with the demands of conscience is the most effective safeguard against the self-interested impulses with which humankind perpetually struggles.

The South Fork Dam remnants at the Johnstown Flood National Memorial powerfully convey the tragedy's lessons. Tourists can see the hulking remnants and the yawning breach between them almost immediately upon arrival. The sight hits home like a gut punch akin to visiting the memorials at Pearl Harbor and the World Trade Center. Visitors walking out on the remnants can easily imagine John Parke desperately riding to South Fork to warn of the pending failure, and flood-swollen Lake Conemaugh pouring through the breached dam, and the terrified citizens of the Little Conemaugh valley screaming as they fled the flood wave, all too often in vain. Visualizing these events solemnly reminds visitors, especially dam and geotechnical engineers, of their professional duties and responsibilities. Some may even be stunned into silence, which seems appropriate given the gravity of the disaster of May 31st, 1889.

Figure 58: Remnants of the South Fork Dam, Johnstown Flood National Memorial. Source: Author.

This work is dedicated to the memory of the victims of the South Fork Dam breach and Johnstown Flood of 1889.

References

ACS (American Canal Society). 2022. "Pennsylvania: Canal history." *The American Canal Society.* Accessed Jun. 12, 2024. https://americancanalsociety.org/pennsylvania-canals/

AL ASCE (Alabama Section of American Society of Civil Engineers). 2023. "Alabama establishes first state dam safety program." *Alabama Section of ASCE.* Accessed Jun. 2, 2024. https://www.alabama-asce.org/alabama-establishes-first-state-dam-safety-program/

ASCE (American Society of Civil Engineers). 2020. "Code of ethics." *ASCE.* Accessed Jun. 15, 2024. https://www.asce.org/career-growth/ethics/code-of-ethics

ASCE. 2021. "Distinguished Members." *ASCE.* Accessed Jun. 15, 2024. https://www.asce.org/-/media/asce-images-and-files/career-and-growth/awards--and-honors/documents/asce-distinguished-members-historical-list.pdf

ASCE. 2021. "2021 report card for America's infrastructure." *ASCE: Infrastructure report card.* Accessed Jun. 15, 2024. https://infrastructurereportcard.org/

ASDSO (Association of State Dam Safety Officials). 2022. "Case study: South Fork Dam (Pennsylvania, 1889) – Photos." *Lessons learned from dam incidents and failures.* Accessed Jun. 15, 2024. https://damfailures.org/case-study/south-fork-dam-pennsylvania-1889/

ASDSO. 2022. "Take action and be prepared: May 31st is National Dam Safety Awareness Day." *ASDSO: Association of State Dam Safety Officials.* Accessed Jun. 15, 2024. https://damsafety.org/NDSAD

Burgess, G.H., and M.C. Kennedy. 1949. *Centennial history of the Pennsylvania Railroad Company: 1846-1946.* Philadelphia, PA, USA: The Pennsylvania Railroad Company.

Coal Camp USA. 2023. "St. Michael, PA." Coal Camp USA. Accessed Jun. 15, 2024. https://www.coalcampusa.com/westpa/windber/stmichael/stmichael.htm

Coleman, N.M. 2019. *Johnstown's flood of 1889: Power over truth and the science behind the disaster.* Cham, Switzerland: Springer.

Coleman, N.M., U. Kaktins, and S. Wojno. 2016. "Dam-breach hydrology of the Johnstown Flood of 1889 – Challenging the findings of the 1891 investigation report." *Heliyon*, 2 (6), e00120.

Coughenour, C.L., N.M. Coleman, and A.L. Taylor. 2022. "In the shadow of the dam – hydrology of the Little Conemaugh River and its South Fork, with insights about past and future flooding." *Heliyon*, 8 (9), e10679.

Davis Todd, C.E. 2017. "New insights and lessons learned from the Johnstown, Pennsylvania, flood of 1889." *Geol. Soc. Am.*, Field Guide 46.

Dubnansky, J. 2022. "City of Johnstown Request for Proposals: Environmental and historic property planning services for the City of Johnstown, Pennsylvania." Johnstown, PA, USA; City of Johnstown, Office of Community and Economic Development.

ENR (Engineering News-Record). 2022. "ENR: About us". *ENR: Engineering News-Record.* Accessed Jun. 15, 2024. https://www.enr.com/aboutus

EPA (US Environmental Protection Agency). 2015. "Actions eliminate long-time, major acid mine discharge – St. Michael, PA." *Environmental Protection Agency*, Sept. 3. Accessed Jun. 15, 2024. https://www.epa.gov/pa/actions-eliminate-long-time-major-acid-mine-discharge

Faher, M. 2012. "Census release offers insight into 1940s." *Johnstown Tribune-Democrat*, Apr. 7. Accessed Jun. 15, 2024. https://www.tribdem.com/news/local_news/census-release-offers-insight-into-1940s/article_91b594d0-5cc0-5d3b-abbe-96f18ca5cc11.html

Farabaugh, P. 2019. "Water and steel: The 1977 Johnstown Flood and the Bethlehem Steel Corporation." *Penn. Hist.*, 86 (3), 383-410.

FWP (Federal Writers' Project). 1939. *The floods of Johnstown.* Johnstown, PA, USA: Mayor's Committee of the City of Johnstown. Accessed May 26, 2024. https://johnstownhistory.blogspot.com/search/label/1889%20Flood

Ferguson, K. 2019. "USSD – a review of key historical milestones." *United States Society on Dams (USSD)*. Accessed Jun. 1, 2024. https://www.ussdams.org/about/history/

Fisher, R. 2018. "In new book, Pitt-Johnstown geologist looks at 1889 flood with fresh eyes." *Johnstown Tribune-Democrat*, Nov. 30. Accessed Jun. 15, 2024. https://www.tribdem.com/news/in-new-book-pitt-johnstown-geologist-looks-at-1889-flood-with-fresh-eyes/article_c932cefc-f454-11e8-907c-fb0274383391.html

Francis, J.B., T.G. Ellis, and W.E. Worthen. 1874. "The failure of the dam on Mill River." *Trans. Am. Soc. Civ. Eng.*, 3 (90), 118-122.

Francis, J.B., W.E. Worthen, M.J. Becker, and A. Fteley. 1891. "Report of the Committee on the cause of the failure of the South Fork Dam, with discussion." *Trans. Am. Soc. Civ. Eng.*, 24 (477), 431-469.

Frank, W.S. 1988. "The cause of the Johnstown Flood: a new look at the historic Johnstown Flood of 1889." *Civ. Eng.*, 58 (5), 63-66.

Gardner, C.H. 1987. "Origins of the Association of State Dam Safety Officials." *Association of State Dam Safety Officials (ASDSO)*. Accessed Jun. 1, 2024. https://damsafety.org/history

Gee, N., and K. Neff. 2020. "The Walnut Grove Dam 1890 failure: the worst and most forgotten disaster in Arizona history." In *Proc., ASDSO Ann. Conf.* Virtual event: Association of State Dam Safety Officials.

Goodman, R.E. 1999. *Karl Terzaghi: The engineer as artist.* Reston, VA, USA: ASCE Press.

Hanna, J.G. 2021. *Cultural landscape report for Johnstown Flood National Memorial*. Boston, MA, USA: Olmsted Center for Landscape Preservation/National Park Service.

Hanson, G.J., K.R. Cook, and S.L. Hunt. 2005. "Physical modeling of overtopping erosion and breach formation of cohesive embankments." *Trans. Am. Soc. Agric. Eng.*, 48 (5), 1783-1794.

Havener, C. 2022. "On 45th anniversary of 1977 Johnstown Flood, risk of future disaster is growing." *WJAC TV*, Jul. 20. Accessed Jun. 15, 2024. https://wjactv.com/news/local/on-45th-anniversary-of-1977-johnstown-flood-risk-of-future-disaster-is-growing

Historic Pittsburgh. 2024. "Louis Semple Clark Collection." *University of Pittsburgh Library System.* Accessed May 26, 2024. https://historicpittsburgh.org/collection/louis-semple-clarke-collection

Hopey, D. 2022. "Johnstown Flood National Memorial: An amazing tale of survival." *Pittsburgh Post-Gazette.* Accessed Jun. 15, 2024. https://newsinteractive.post-gazette.com/usparks/victor-heiser-survived-the-flood/

Hundley, N., and D.C. Jackson. 2015. *Heavy ground: William Mulholland and the St. Francis Dam disaster.* Oakland, CA, USA: University of California Press.

Hurst, D. 2024. "$8 million Clubhouse restoration planned at South Fork Fishing and Hunting Club." *Johnstown Tribune-Democrat*, Jul. 24. Accessed Aug. 3, 2024. https://www.tribdem.com/news/city_of_johnstown/8-million-clubhouse-restoration-planned-at-south-fork-fishing-and-hunting-club/article_31717e20-4957-11ef-a4e7-1b8ec9a29fff.html

JAHA (Johnstown Area Heritage Association). 2005. "South Fork Hunting and Fishing Club [Photo gallery]." *Johnstown Area Heritage Association.* Accessed May 26, 2024. https://www.jaha.org/edusecret/flood/why/img/club_gallery/

JAHA. 2013. "*Engineering and Building Record*: Special report on the Johnstown Flood, June 1889." *Johnstown Area Heritage Association.* Accessed Jun. 15, 2024. https://www.jaha.org/education-materials/flood-museum-materials/engineering-and-building-record-special-report-on-the-johnstown-flood-june-1889/

JAHA. 2022. "JAHA timeline: History and future." *Johnstown Area Heritage Association.* Accessed Dec. 19, 2022. https://www.jaha.org/about-jaha/about/history-timeline/

JAHA. 2024. "The Stone Bridge: Bridge history." *Johnstown Area Heritage Association*. Accessed Jul. 4, 2024. https://www.jaha.org/attractions/the-stone-bridge/about-the-bridge/bridge-history/

JAHA. 2024. "Telling the story." *Johnstown Area Heritage Association.* Accessed May 26, 2024. https://www.jaha.org/education/flood-museum/telling-the-story/

Johnson, L.R. 1978. *The Headwaters District: A history of the Pittsburgh District, U.S. Army Corps of Engineers*. Washington, DC, USA; Department of Defense.

Johnstown Flood NPS (@JohnstownFldNPS). 2018. "Tweet, 2:37 PM, 5/10/18." *X.* Accessed Jun. 15, 2024. https://twitter.com/johnstownfldnps/status/994647737701367810

Kaktins, U., C. Davis Todd, S. Wojno, and N. Coleman. 2013. "Revisiting the timing and events leading to and causing the Johnstown Flood of 1889." *Penn. Hist.*, 80 (3), 335-363.

Law, A.S. 1997. *The great flood: Johnstown, Pennsylvania, 1889.* Johnstown, PA, USA: Johnstown Area Heritage Association.

Lindberg, M. 2024. "Johnstown Flood: Documenting a disaster." *Library of Congress Blogs*, May 31. Accessed Jun. 15, 2024. https://blogs.loc.gov/picturethis/2024/05/johnstown-flood-documenting-a-disaster/

Lynch, A. 2023. "Case study: Banqiao Dam (China, 1975) – Description and background." *Lessons learned from dam incidents and failures.* Accessed Jun. 15, 2024. https://damfailures.org/case-study/banqiao-dam-china-1975/

Magdy, S. 2023. "Libya was mired in chaos and corruption. For years, warnings the Derna dams may burst went unheeded." *Associated Press*, Sept. 18. Accessed Jun. 15, 2024. https://www.nytimes.com/2023/09/21/world/middleeast/libya-floods-derna-crackdown.html

Marston, J. 2022. "David McCullough, a Distinguished Member for acclaimed histories of civil engineering achievements, dies at 89." *ASCE: Obituaries*, Aug. 9. Accessed Jun. 16, 2024. https://www.asce.org/publications-and-news/civil-engineering-source/article/2022/08/09/david-mccullough-a-distinguished-member-for-acclaimed-histories-of-civil-engineering-achievements-dies-at-89

Mauney, L. 2023. "DLS-203: Validation case studies – Teton and Johnstown Flood." *US Army Corps of Engineers: Dam and Levee Safety Program*, May 23. Accessed Sept. 25, 2024. https://www.youtube.com/watch?v=Df3XzCqahGo

May, W. 2023. "Johnstown Flood." *Butler Eagle*, May 9. Accessed Jun. 15, 2024. https://www.butlereagle.com/20230509/johnstown-flood/

McCullough, D. 1965. "Victor Heiser, M.D. [Taped interview]." Audio recording.

McCullough, D. 1966. "Run for your lives!" *Am. Heritage*, 17 (4).

McCullough, D. 1968. *The Johnstown Flood.* New York, NY, USA: Simon and Schuster.

McGough, M.R. 2002. *The 1889 Flood in Johnstown, Pennsylvania.* Gettysburg, PA, USA: Thomas Publications.

Miles, C.E. 2008. "Geologic shaded-relief map of Pennsylvania." *Pennsylvania Department of Conservation and Natural Resources*, Map 67. Accessed Jun. 15, 2024. https://www.dcnr.pa.gov/Education/GeologyEducation/Pages/default.aspx

Miller, N. 1998. *Star-spangled men: America's ten worst Presidents.* New York, NY, USA: Scribner.

Murphy, C. 2023. "Cambria County's Path of the Flood Trail officially completed." *WTAJ*, May 23. Accessed Jun. 15, 2024. https://www.wtaj.com/news/local-news/cambria-countys-path-of-the-flood-trail-officially-completed/

NCEES (National Council of Examiners for Engineering and Surveying). 2020. *The history of the National Council of Examiners for Engineering and Surveying, 1920-2020.* Greenville, SC, USA: NCEES.

NGI (Norwegian Geotechnical Institute). 2023. "Terzaghi Library." *NGI*, Feb. 8. Accessed Jun. 15, 2024. https://inte.ngi.no/en/about-ngi/ngis-historical-libraries/terzaghi/

NPS (National Park Service). 2015. "John G. Parke." *Petersburg National Battlefield*, Jun. 17. Accessed Jun. 15, 2024. https://www.nps.gov/people/john-g-parke.htm

NPS. 2021. "Benjamin Franklin Ruff (1829-1887)." *Johnstown Flood National Memorial*, Feb. 20. Accessed Jun. 15, 2024. https://www.nps.gov/jofl/learn/historyculture/benjamin-franklin-ruff.htm

NPS. 2021. "Robert Pitcairn (1836-1909)." *Johnstown Flood National Memorial*, Feb. 20. Accessed Jun. 15, 2024. https://www.nps.gov/jofl/learn/historyculture/robert-pitcairn.htm

NPS. 2022. "Daniel Johnson Morrell (1821-1885)." *Johnstown Flood National Memorial*, Feb. 6. Accessed Aug. 3, 2024. https://www.nps.gov/jofl/learn/historyculture/daniel-johnson-morrell.htm

NPS. 2022. "Frequently asked questions." *Johnstown Flood National Memorial*, Mar. 12. Accessed Jun. 15, 2024. https://www.nps.gov/jofl/faqs.htm

NPS. 2023. "Colonel Elias J. Unger (1830-1896)." *Johnstown Flood National Memorial*, Apr. 15. Accessed Jun. 15, 2024. https://www.nps.gov/jofl/learn/historyculture/colonel-elias-j-unger.htm

NPS. 2023. "Maps." *Johnstown Flood National Memorial*, Jan. 11. Accessed Jun. 15, 2024. https://www.nps.gov/jofl/planyourvisit/maps.htm

NPS. 2023. "The South Fork Dam." *Johnstown Flood National Memorial*, Mar. 21. Accessed Jul. 4, 2024. https://www.nps.gov/jofl/learn/historyculture/the-south-fork-dam.htm

PADCNR (Pennsylvania Department of Conservation and Natural Resources). 2023. "PAGEODE – Pennsylvania Geologic Data Exploration." *Pennsylvania Department of*

Conservation and Natural Resources. Accessed Jun. 15, 2024. https://www.gis.dcnr.state.pa.us/pageode/

PennDOT (Pennsylvania Department of Transportation). 2024. "County Type 10 maps." *Pennsylvania Department of Transportation.* Accessed Jun. 12, 2024. https://www.penndot.pa.gov/ProjectAndPrograms/Planning/Maps/pages/county-type-10.aspx

PGS (Pittsburgh Geological Society). 2002. *The history and geology of the Allegheny Portage Railroad, Blair and Cambria Counties, Pennsylvania.* Pittsburgh, PA, USA: Pittsburgh Geological Society.

Pittsburg *Post*. 1903. "Nathan M. McDowell [Obituary]." *Pittsburg Post.* Accessed May 25, 2024. https://www.newspapers.com/article/the-pittsburgh-post/14278414/

PSU Libraries (Penn State University Libraries.) 2024. "Topographical map of the coal and iron ore lands of the Cambria Iron Company adjacent to their iron and steel works, Johnstown, PA. H2." *Collections: Pennsylvania Geology.* Accessed Aug. 3, 2024. https://digital.libraries.psu.edu/digital/collection/pageol/id/52414/rec/218

Riley, K. 2021. "Infrastructure bill includes significant funding for dam safety programs." *Association of State Dam Safety Officials*, Nov. 18. Accessed Aug. 3, 2024. https://damsafety.org/article/legislative/infrastructure-bill-includes-significant%C2%A0funding-dam-safety-programs

Riley, K. 2023. "$157.5 billion needed to rehabilitate the nation's non-federal dams." *Association of State Dam Safety Officials*, Apr. 14. Accessed Aug. 3, 2024. https://damsafety.org/RehabEstimate

Roker, A. 2018. *Ruthless tide: The heroes and villains of the Johnstown Flood, America's astonishing Gilded Age disaster.* New York, NY, USA: HarperCollins.

Rose, A.T. 2013. "The influence of dam failures on dam safety laws in Pennsylvania." In *Proc., ASDSO Ann. Conf.* Providence, RI, USA: Association of State Dam Safety Officials.

Senate (US Senate). 2022. "The bosses of the Senate." *United States Senate.* Accessed Jun. 15, 2024. https://www.senate.gov/art-artifacts/historical-images/political-cartoons-caricatures/38_00392.htm

Shappee, N.D. 1940. "A history of Johnstown and the Great Flood of 1889: A study of disaster and rehabilitation." Ph.D. dissertation. Pittsburgh, PA, USA: University of Pittsburgh.

Sharpe, E.M. 2004. *In the shadow of the dam: The aftermath of the Mill River Flood of 1874.* New York, NY, USA: Free Press.

Smolka, M. 2022. "Destination PA: A trip to the world-famous Horseshoe Curve." *ABC News WHTM 27 (Harrisburg).* Accessed Jun. 13, 2024. https://www.abc27.com/news/destination-pa-a-trip-to-the-world-famous-horseshoe-curve/

Strayer, H.H., and I.L. London. 1964. *A photographic story of the 1889 Johnstown Flood.* Johnstown, PA, USA: The Camera Shop.

Sutor, D. 2022. "'America's best narrative historian': David McCullough, author of 'The Johnstown Flood', remembered fondly in city where his career took off." *Johnstown Tribune-Democrat*, Aug. 9. Accessed Jun. 15, 2024. https://www.tribdem.com/news/america-s-best-narrative-historian-david-mccullough-author-of-the-johnstown-flood-remembered-fondly-in/article_934864de-175d-11ed-a2d6-2fff16e02db9.html

USACE (US Army Corps of Engineers). 2017. "Overtopping failure." PowerPoint Presentation. Washington, DC, USA: USACE.

US Census (US Census Bureau). 2022. "QuickFacts: Johnstown City, Pennsylvania." *United States Census Bureau.* Accessed Jun. 15, 2024. https://www.census.gov/quickfacts/fact/table/johnstowncitypennsylvania/PST045222

Unrau, H.D. 1980. *Historic Structure Report: The South Fork Dam – Historical data, Johnstown Flood National Memorial, Pennsylvania*. Denver, CO, USA: National Park Service.

VandenBerge, D.R., J.M. Duncan, and T. Brandon. 2011. *CGPR Report No. 62: Lessons learned from dam failures.* Blacksburg, VA, USA: Virginia Tech.

Vesilind, P.A. 1995. "Evolution of the American Society of Civil Engineers Code of Ethics." *J. Prof. Issues Eng. Educ. Pract.* 121 (1), 4-10.

Visser, P.J. 1998. *Breach growth in sand-dikes.* Delft, Netherlands: Technische Universiteit Delft.

Ward, S.N. 2011. "The 1889 Johnstown, Pennsylvania flood – a physics-based simulation." In *The Tsunami Threat: Research and Technology*, N.-A. Morner, ed. London, UK: IntechOpen, 447-466.

Webster, I. 2024. "CPI inflation calculator." *Inflation Calculator.* Accessed May 26, 2024. https://www.in2013dollars.com/us/inflation

Wellington, A.M., and F.P. Burt. 1889. "A Committee to investigate the Johnstown disaster." *Eng. News Am. Rail. J.*, XXI (24), 539.

Wellington, A.M., and F.P. Burt. 1889. "The South Fork Dam and Johnstown disaster." *Eng. News Am. Rail. J.*, XXI (24), 540-545.

Wellington, A.M., and F.P. Burt. 1889. "The South Forks [*sic*] Dam." *Eng. News Am. Rail. J.*, XXI (24), 551-553.

Wooten, R.L., P.L. Spangenberg, W.C. Salomaa, and M. Misslin. 2014. "The Williamsburg Reservoir Dam Failure of 1874." In *Proc., ASDSO Ann. Conf.* San Diego, CA: Association of State Dam Safety Officials.

Acknowledgments

Editors

American Geotechnical and Environmental Services (Canonsburg, PA): Katherine Brust; Sebastian Lobo-Guerrero, Ph.D., P.E., BC.GE.; Neil Styler, Ph.D., P.E.; Brian Tittmann, P.E., P.G.

Baldwin Wallace University (Berea, OH): Carrie Davis Todd, Ph.D.

Gannett Fleming (Camp Hill, PA): Robert Kline, P.E.

Geopier (Davidson, NC): Thomas Kennedy

University of Pittsburgh at Johnstown (PA): Christopher Coughenour, Ph.D.; Andrew Rose, Ph.D., P.E.

Historical Contributors

Johnstown Area Heritage Association (PA): David Casker

M.R. McGough, LLC (Abbottstown, PA): Michael McGough, Ed.D.

University of Pittsburgh at Johnstown (PA): Neil Coleman, P.G.

Legal Contributors

Ellucian (Malvern, PA): James Bennett, Esq. (*Disclosure: Mr. Bennett is the author's father.*)

Perez Morris (Philadelphia, PA): Frank Baer, Esq.

Technical Contributors

Engineering Analytics (Ft. Collins, CO): L. Clinton Brown, P.E.

Gannett Fleming: William Bingham, P.E. (Camp Hill, PA); Brian Greene, Ph.D., P.G. (Pittsburgh, PA); Dina Hunt, P.E. (Roseville, CA); Gregory Richards, P.E. (Bountiful, UT)

HDR (Denver, CO): Keith Ferguson, P.E., BC.GE; Lee Mauney, P.E.

JWF Consulting (Denver, CO): John France, P.E., BC.GE, BC.WRE

University of Illinois at Urbana-Champaign: Travis Shoemaker, P.E.; Timothy Stark, Ph.D., P.E., BC.GE. *Mr. Shoemaker is also affiliated with Schnabel Engineering (Chadds Ford, PA).*

Previous versions of this write-up appeared on an independent website in June 2022 (co-written by the author and Thomas Kennedy) and on the ASCE Geo-Institute website from January to April 2023 (authored solo).