THE WILLIAMSBURG RESERVOIR DAM FAILURE OF 1874

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Abstract

The Mill River valley in 1874 reflected the pattern of development during the early industrial era in Massachusetts, with numerous factories powered by Mill River water as it dropped 1100 feet in elevation to the Connecticut River. The villages of Williamsburg, Skinnerville, Haydenville, Leeds, and Florence, had grown around the sixty four mill factories of the valley. These factories produced buttons, silk, wool, cotton, brass fittings, iron tools, and tobacco products. The Mill River provided a primary ingredient needed by these factories – power from the volume and height of fall of the water. Control of the water for consistent and predictable power gave rise to numerous dams along the valley, the most important being the upstream Williamsburg Reservoir Dam, which captured the spring runoff for power during the drier summer months.

The industrialists who built the factories and the dams were a remarkable group – inventive, hard-working, adaptive, political, and compassionate, and they were, by necessity, cooperative in their shared use of the Mill River. However, their human characteristic of Yankee frugality and the physical features of the valley proved to be the major factors in America's first major dam disaster. On Saturday morning, May 16, 1874, the persistent seepage pressure through the Williamsburg Reservoir Dam and foundation finally caused the steep downstream slope of the dam to slide away, releasing the 2000 acre-feet of stored water down the narrow valley, wiping out the valley villages and factories and killing 139 people.

The story of the Mill River flood tragedy paints a fascinating picture of industrial age society, starting with the physical setting and people, the construction of the dam, the remarkable individual actions during the flood, and ending with the post-flood responses. The story also provides a cautionary tale of the potential for poor dam design and construction by industrialists with resources, a story which would be repeated in 15 years, with loss of life consequences 16 times as great, in the Johnstown flood of 1889.

Introduction – A Confession

The story of the Williamsburg Reservoir Dam failure has been well told in extensively-researched detail by Elizabeth Sharpe in her book *In the Shadow of the Dam, The Aftermath of the Mill River Flood of 1874* (Ref. 1). The authors have relied on her work so heavily that this paper could be described properly as a Cliff Notes version of her book for dam engineers (with apologies to Cliff Notes). We highly recommend that you read the original work. Eric Weber of the Williamsburg Historical Society added to our knowledge and resources by orienting us to

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the disaster's setting with his personal tour of the dam site and area, with his wonderful storyboards (Ref. 2), and with many of the historic artifacts and images of the dam (Refs. 3, 4, 5). Other sources of information (Refs. 6-11) merely supplemented the prior efforts of Sharpe, Weber, and the Williamsburg Historical Society.

The Mill River Valley and 1800's Industry

The Industrial Revolution came to New England a bit earlier than the rest of the country, perhaps because farming was difficult and the weather was cold and perhaps because commerce brought new ideas from Europe to the New England ports. However, the one component that New England had in spades to sustain 19th century industry was a ready source of power from the water that flowed down the region's hilly topography. New Englanders had developed regional water power in the late 1800's to such an extent that one third of the hydro power in the United States at the time was located here.

The Mill River in western Massachusetts typified these hydrologic resources, and the valley development by 19th century industry was like that along hundreds of other rivers around New England. The river itself is a tributary of New England's largest river, the Connecticut, intersecting that river from the west at the city of Northampton (Fig. 1). To reach the Connecticut, the Mill River, including its East and West Branches, drops 1100 feet in elevation from the upper reaches of its modest watershed (22 square miles at the upper mills in Williamsburg). This 1100-foot drop occurs over a relatively short distance of 15 miles, resulting in a steep river grade and a narrow valley eroded into the Berkshire hills. Parts of the valley are so narrow that they are described as a gorge and have room for little else other than

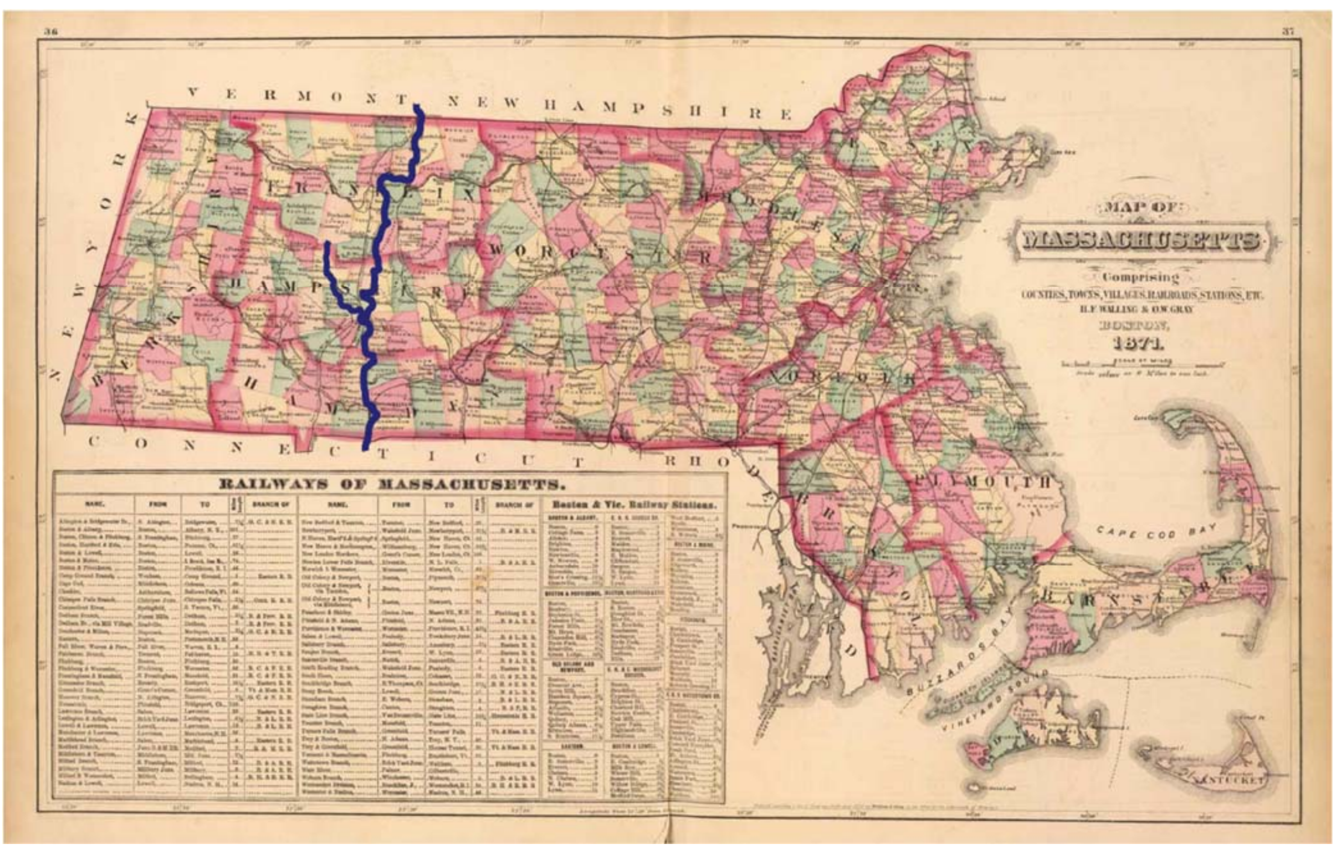


Figure 1. Massachusetts Map, 1871 - Connecticut and Mill River Locations in Blue Overlay

Figure 2. Hayden Brass Works before the Flood.

the river and a road. The valley villages were sited along the river in flatter flood banks which extended only a few hundred feet to the confining valley hills. The river valley broadens greatly when it reaches the upper edges of the Connecticut River valley at Florence Meadows, just above Northampton.

In 1874, the force of gravity pulling water through mill races powered sixty four factories staffed by about 1500 workers in the mill villages of Williamsburg, Skinnerville, Haydenville, Leeds, and Florence clustered on the banks of the river. These factories (Fig. 2) produced brass fittings, iron tools, buttons, silk (Fig. 3), wool, cotton, and tobacco products and supported a populace of about 5000. The valley citizens included the successful mill owners, farmers, and the mill workers and their families, ranging from native Yankees to Irish, German, and French Canadian immigrants. Many young women came to the valley for jobs as factory workers and stayed in local boarding houses. The amount of productivity squeezed out of this 15-mile-long river was impressive and exemplified the Yankee ingenuity cliché.

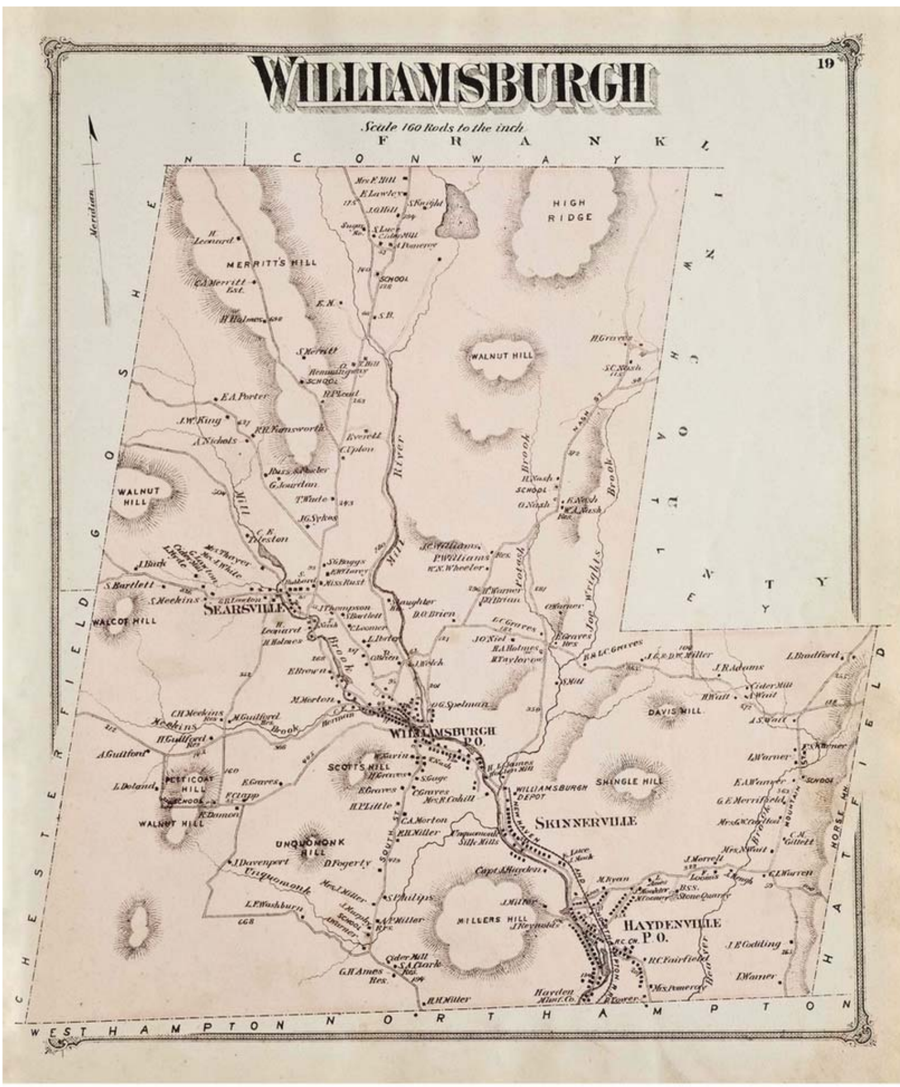
Figure 3. Silk Recovered from the Mill River Valley Flood Debris.

The Williamsburg Reservoir Company and Dam

The Reservoir Company

The industrialists responsible for the Mill River manufacturing cluster exemplified the high-tech entrepreneurs of the mid-19th century who employed ingenuity to harness water power and direct it mechanically to mass produce goods of every sort. These men came from relatively modest means and lived in the Mill River communities where they served as the local leaders and demonstrated a loyalty to the communities and to the well-being of their fellow residents. Joel Hayden, Sr. was the most prominent and successful of the industrialists as the owner of a large brass fixtures factory and smaller iron works, gas plant, and cotton factories in Haydenville. He served as a State Legislator and as Massachusetts Lieutenant Governor. Some of the other factory owners (and their products) included Onslow Spelman (buttons), Lewis Bodman (wool), William Skinner (silk), Lucius Dimock (silk), Alfred Critchlow (buttons), John Williston (cotton), William Clement (hoes, rakes, bayonets, rifle barrels), and William Clark (paper).

These men knew that they benefitted from a shared resource – the river, which required cooperative use as water releases powered each factory in succession down the valley. They also established financial ties by investing in each other's enterprises. Their source of power, while having an abundance of potential energy drops, had its limits because of the size of the watershed and the variability of rainfall. The local New England weather typically resulted in large runoffs from spring rains and snow melts and low flows during the drier summers. The Mill River industrialists knew that storing the higher spring flows for the summer would enhance their factories' productivity. They were not without experience in the practice of building and managing dams in that each mill drew its water from mill ponds impounded by small run-of-the-river dams. In addition, by 1864 they had already built one larger reservoir dam, the Goshen Dam, in the upper watershed on the Mill River's West Branch, to store spring runoff for release during the summer. They knew that more water storage would benefit them all.



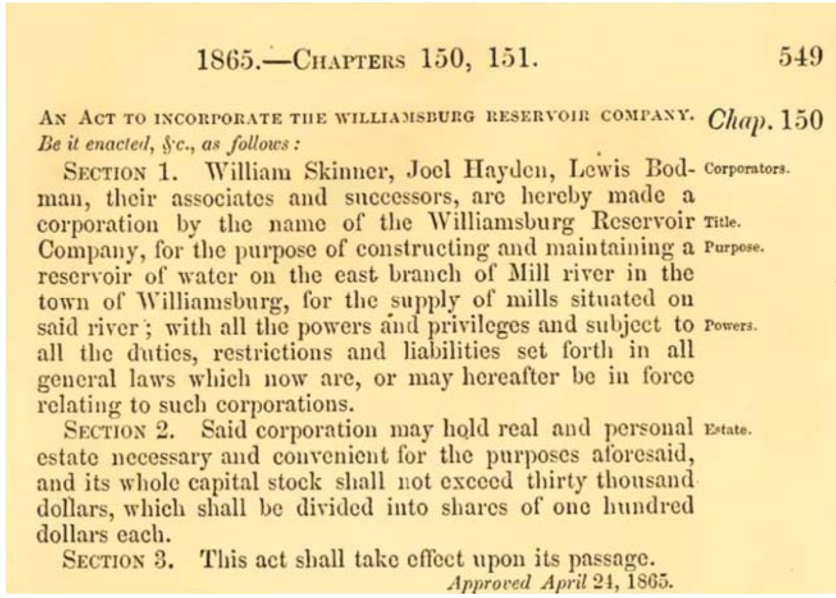
From the Atlas of Hampshire County, Massachusetts 1873 F.W. Beers www.old-maps.com

Figure 4. 1873 Map of Williamsburg Showing the Reservoir Location at Top of Map

In 1864 Joel Hayden Sr. identified a reservoir site on the East Branch of the Mill River above Williamsburg (Fig. 4) and organized the eleven major factory owners to form the Williamsburg Reservoir Company, which was chartered by the Legislature in 1865 by a three sentence act of incorporation (Fig. 5). The dam site would take advantage of a narrow section of the East Branch between hills, which rose more than 50 feet above the river, and which would have a watershed of about 3.2 square miles. With their incorporation, the state empowered the reservoir company to proceed with the plan to build a dam at Hayden's chosen location. No additional regulatory requirements existed for engineering, for construction, for involvement of the local communities, or for follow up inspections.

The Design

Simeon Bartlett, the farmer from whom the reservoir and dam easement was bought, included some interesting conditions in the easement transaction, requiring that the dam have a 16-foot-wide crest road for access and that the dam and reservoir site and height be considered safe by a competent engineer. Bartlett's requirements were more stringent than any of the 1865 Massachusetts laws, which only allowed for review of dam work by county commissioners if they were petitioned. The cost of a county commissioner review would be paid by the petitioner if the dam was deemed by the commissioners to be safe. The reservoir company adhered to Bartlett's contract requirement as they retained a civil engineering company out of Springfield, A.D. Briggs and Company, to survey the site, finalize the dam location, and develop a dam design. The Briggs engineers satisfied farmer Bartlett with their dam location and proposal for a 40-foot-high dam which would cover 108 acres and store about 2000 acre-feet (600 million gallons) of water.



1865.—CHAPTERS 150, 151. 549

AN ACT TO INCORPORATE THE WILLIAMSBURG RESERVOIR COMPANY. *Chap.* 150

Be it enacted, &c., as follows:

SECTION 1. William Skinner, Joel Hayden, Lewis Bodman, their associates and successors, are hereby made a corporation by the name of the Williamsburg Reservoir Company, for the purpose of constructing and maintaining a reservoir of water on the east branch of Mill river in the town of Williamsburg, for the supply of mills situated on said river; with all the powers and privileges and subject to all the duties, restrictions and liabilities set forth in all general laws which now are, or may hereafter be in force relating to such corporations. Corporators. Title. Purpose. Powers.

SECTION 2. Said corporation may hold real and personal estate necessary and convenient for the purposes aforesaid, and its whole capital stock shall not exceed thirty thousand dollars, which shall be divided into shares of one hundred dollars each. Estate.

SECTION 3. This act shall take effect upon its passage.

Approved April 24, 1865.

Figure 5. The Williamsburg Reservoir Company Incorporation Act.

Briggs would continue their work with a first-draft design plan for an embankment dam with a core of either double rubble masonry walls with tongue-and-grove wood planks set between the walls or a dry-laid fitted-stone masonry wall. The embankment slopes would be 3 horizontal to 1 vertical (3H:1V). However, because the estimated cost of the design, about $100,000, exceeded their budget by $70,000, the reservoir company started looking for cheaper designs. Another design was prepared by an engineer for the Holyoke Water Power Company, Stewart Chase, who proposed an embankment design with a brick core wall. The reservoir company did not use this proposed design either, but for reasons which remain unknown.

The reservoir company eventually asked Lucius Fenn to prepare the dam specifications without drawings. Fenn had no experience designing dams but was known to the owners because of his work surveying the local railroad. His initial design proposal was for an embankment with 2H:1V slopes and a masonry core wall set into a 5-foot-deep cutoff trench which could be shallower if hardpan was reached. Hardpan in New England was and is a loosely defined term for hard-to-dig dense glacial till which may range from a rocklike cemented silt-clay-sand-gravel mix to a silty sandy gravel. The hard-to-dig criterion may provide a good indicator for a subgrade bearing and wearing capacity but does not correlate to the most significant quality of a good dam foundation – low permeability.

However, the mill owners wanted more economy, believing that they could fix problems with remedial measures later, a practice that may have been common with their small mill pond dams. Fenn eventually provided specifications for a dam, which were included as part of an eleven-paragraph-long contract for the construction. Those specifications called for an embankment with 1.5H:1V slopes and a rubble (uncut) stone masonry core wall founded in a 3-foot-deep trench with a tapered width (1H:12V sides) from 2 feet at the top to about 6 feet at its lowest level. Within 5 feet of the core wall, the embankment was to be placed in thin lifts, which were to be “wet and tamped or beaten with a maul.” Outside of these zones, the embankment would consist of earth, free from organic material, placed in compacted 5-foot-thick lifts. An 18-inch-diameter cast iron pipe set on a masonry wall would be the main outlet and would be controlled with a valve on its downstream end. The crest width was set at 16 feet and the dam height at 43 feet, 3 feet higher than agreed upon with farmer Bartlett.

The Construction

A construction company owned by two partners, Emory Wells and Joel Bassett, responded to an ad by the reservoir company, using these specifications and information from their site reconnaissance, including borings, to propose a price of $22,000. Wells and Bassett had constructed two mill dams, neither of which was of the scale proposed for the Williamsburg Reservoir. The reservoir company accepted the proposal and construction started on July 15, 1865. Construction would entail up to seventy workers and would take only six months.

Foundation preparation consisted of plowing the subgrade and scraping the loosened material beyond the dam footprint. Fenn, the dam’s specification writer, staked out the core trench alignment, which was excavated down to a gravelly layer of material below the loose surface layers on the east side of the dam. On the west side, the contractors dug 10 feet without reaching hardpan. To avoid additional expense, the reservoir company decided to dig no further and to found the wall on the sand and gravel layer which was encountered. The contractor advised them that the dam would leak through this layer but that the leaks could be fixed. He also expressed concerns to a coworker about the owners’ decision to not dig deeper.

Stone for the core wall came from both a quarry and from the surrounding area. Workers built the core wall by stacking rubble stones of all sizes in 3- to 5-foot-high lifts and grouting that height of the wall with a grout mix of sand, hydraulic lime (the mortar of the period), and water to fill voids. The mortar used for binding and sealing the top 10 to 15 feet of the wall consisted of a mix of 75% hydraulic lime and 25% cheaper quick lime. The contractor excavated soil for the embankment from nearby borrow areas and placed the soil in 2-foot-thick puddled lifts near the wall and 5-foot-thick lifts elsewhere. Coverage by the construction horse and wagon traffic compacted the embankment soil.

The dam’s water conveyance structures consisted of the low-level outlet pipe and an earth-lined spillway. The specifications called for the outlet pipe to be supported on a rubble masonry wall and for the upstream 30 feet and downstream 20 feet of that wall to be grouted. The spillway was dug and channeled into the west abutment and had a relatively level grade for a few hundred feet before dropping steeply well downstream of the embankment. The reservoir company decided during construction to reduce the outlet size from 18 to 16 inches as another cost-saving measure.

Eugene Gardner, a local architect and surveyor, was hired by the mill owners to provide part-time inspection of the construction. His visits were described as infrequent because of his own illness (typhoid fever) and because of illness and death in his family. Lucius Fenn, the specification writer / designer, had little involvement with construction beyond laying out the core alignment.

Initial Operations – The First Seven Years

The contractor received $23,600 on January 11, 1866 at the completion of their work. Initial filling of the reservoir commenced with that spring's runoff. As the reservoir filled, the downstream slope became saturated and appeared likely to slump. Flow through the spillway threatened to erode that unlined channel. The owners responded by placing soil on the embankment to decrease the slopes to 2H:1V, by placing brush, stone, and timbers on the wet areas to hold them in place, by digging trenches to hardpan along the embankment-abutment contacts which were backfilled with puddled soil, and by channeling seepage flow from wet areas back to the river. They also fenced off wet areas to protect local cattle.

After one year of service, a 40-foot-wide by 8-foot-deep section of the dam extending about two-thirds of the dam height slipped from the slope. The reservoir company subsequently funded repairs and a salaried dam tender and built a house for the dam tender on the bank of the spillway. To calm local concerns, the mill owners asked the county commissioners to examine the dam in 1867. After inspection, the commissioners refused to accept the dam because of the leakage. The reservoir company contracted additional fixes, which included excavating down to a bed of coarse gravel and placing puddled soil in the excavation. The location of the puddled trenches is not known. On their return inspection in 1867, the commissioners accepted the dam. We do not know the reservoir level at the time of inspection.

Joel Hayden, the former Lieutenant Governor, acted as the supervisor of the reservoir for the reservoir company for the first seven years and kept the reservoir level low, especially in the spring. He frequently visited the dam during rainy nights to ease his own concerns. The usual leaks at the dam ran along the downstream toe with the largest, on the east side, being described as having a diameter equal to the size of a man's arm. Cheney, the dam tender, had advised one of the mill owners, Lucius Dimock, about the leak in 1873, but, based on their joint inspection at the time, they decided that the leak was not a problem because the flow was clear.

In November of 1873, at the age of 75, Hayden died and the supervision of the dam was passed to Onslow Spelman, the mill owner who lived in the upstream village of Williamsburg, closest to the dam. April of 1874 brought several large snows to western Massachusetts. At Spelman's direction, George Cheney fully closed the outlet in May to capture the runoff from these snows. The reservoir filled quickly, and on May 15th, Spelman and Cheney inspected the dam and decided that its condition was normal; that is, no new leaks were noted.

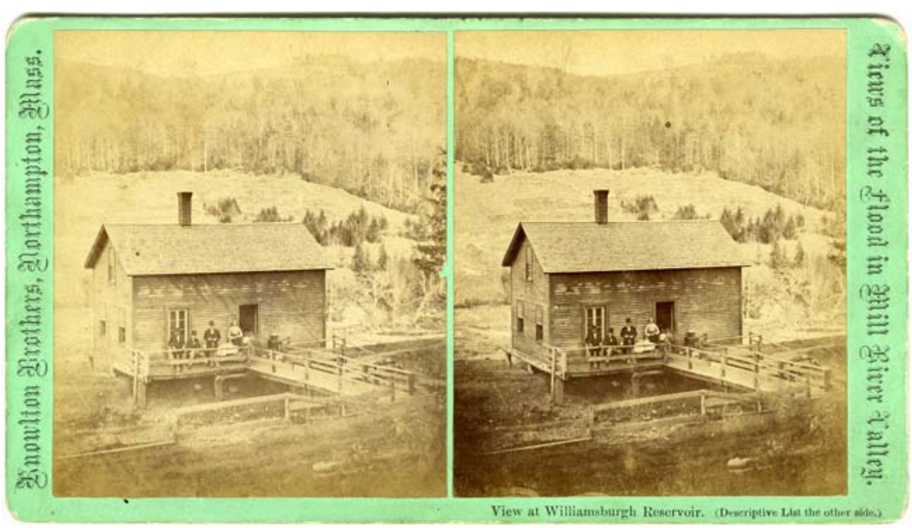


Figure 6. Caretaker's Cabin and the Cheney family.

Saturday, May 16, 1874

Saturday, May 16, 1874, like all Saturdays, was a workday. Workers reported to the mills up and down the Mill River valley. The Williamsburg Reservoir had filled to a level that caused flow to start in the spillway. George Cheney inspected the dam's usual leaks at the start of the day on Saturday, and decided that things were as expected with the full reservoir. Leak flow was heavier but not unusual.

Cheney returned for breakfast to the caretaker's cabin (Fig. 6) overlooking the downstream slope. The small cabin housed Cheney, his wife, their five children, and his parents. Cheney's father, upon getting up from their meal, called out to his son "For God's sake, George, look there," as the east side of the dam sloughed. A section of the embankment slope, about 40 feet wide by 25 feet high, moved downstream off of the dam. George Cheney raced to the downstream gatehouse to open the valve. Seepage from the east slope exposed by the slide accelerated, and Cheney feared that dam would not hold. He left the gatehouse, bridled his horse (Fig. 7), a cheap mare, and rode bareback the three miles down the valley to Williamsburg to contact Spelman. His father ran to warn the downstream farmer of the peril to his cows.

In Williamsburg, after a few minutes of discussion, Cheney convinced Spelman that the dam was failing. Spelman instructed Cheney to warn Haydenville. While getting a fresh horse, Cheney warned others of the peril, including Collins Graves, a local farmer making his morning milk deliveries. Graves decided immediately to unbridle his horse and ride down the valley to give the warning and told Cheney to alarm the local community. It was estimated that the initiation of the warning in Williamsburg was 25 minutes after Cheney left the dam and that most of that time was spent convincing Spelman and the livery stable owner of the peril.

Figure 7. George Cheney and His Horse.

Back at the dam, Cheney's wife, Elizabeth watched. About 20 minutes after George's departure, she saw the eastern side of the dam finally fail as the eastern slope, in Elizabeth's words, "seemed to burst all at once, from the bottom, where the earth seemed to be lifted up." The failure, again in Elizabeth's words "made an awful noise, like an earthquake." The sound of the breach was heard by many in the surrounding area as "louder than the biggest clap of thunder."

Elizabeth's description of the failure as a burst from the bottom suggests that the increased seepage after the initial slide failure allowed internal erosion or piping of the dam or the foundation material. This mechanism manifested itself as the "burst" or pressurized upheaval from the dam toe when the eroded pathway through the lower part of the dam or the foundation opened enough to provide an unimpeded pipe between the reservoir and dam toe. Elizabeth's description did not differentiate between the uplift of the toe and breaching of the dam but rather indicated that these mechanisms happened together.

The breach widened to about 250 feet, half of the span of the dam, releasing the 2000 acre-feet of storage from the reservoir into the valley over a period of about one hour. Much of

Figure 8. Mill River Gorge below Haydenville, 2014.

the flow would have occurred during the early part of that hour, when the head difference between the reservoir and the downstream valley was greatest. One observer who tried to run ahead of the flood estimated that it took about 20 minutes for the wave to cover the 3 miles and the 300 foot elevation drop from the dam to Williamsburg, a speed of about 9 miles per hour.

George Cheney was able to warn others in Williamsburg but was cut off from riding downstream by floodwaters. Collins Graves, because he was set to go and did so without hesitation, rode through Williamsburg, Skinnerville, and Haydenville, shouting as he went to any along the way and making sure to warn each of the mill factories in those communities. However, because he had not seen or heard the flood himself, the skepticism of the brass factory's superintendent caused Graves to turn around in Haydenville until he encountered another rider, Jerome Hillman, who confirmed the flood and helped with the warnings. Hillman and Graves stopped in Haydenville when the flood prevented further travel.

Myron Day, a farmer and delivery man, upon hearing the initial warnings from Hillman in Haydenville and seeing the first evidence of a floodwave, headed downriver to Leeds. Myron Day's initiative may have been the most courageous of the various messengers because a mile-long steep and narrow gorge (Fig. 8) separated Leeds from Haydenville. Escape from the

Figure 9. Newspaper Interpretive Sketch of the Flood

gorge, other than by outrunning the flood, would have been difficult if not impossible. Day, or rather Day's horse, did outrun the floodwave and reached Leeds in time to warn those he saw and one of the factories before the flood stopped him also.

The floodwave ripped through Williamsburg, Skinnerville, Haydenville, and Leeds and was described as "a great wall about 40 feet high," probably an exaggeration. Photos of scarred trees suggest a height of 10 to 20 feet for the floodwave. The current, aided by the steepness of the river grade and confined by the narrow valley hills wrecked the river-hugging villages (Fig. 9). The warnings of Cheney, Graves, Hillman, and Day saved hundreds of lives, but not all. The flood killed those who did not hear the warnings, those who could not flee fast enough, those who lingered or tried to save either friends or family in the face of the floodwave, and those unlucky enough to pick the wrong escape route. The stories told by survivors were fascinating and are recounted by Sharpe with clarity and detail.

Below Leeds, the floodwave fell over a steep and short drop to the broad area of Florence meadows which spread the flood energy over several hundred acres of flat, fertile farmland. Here, the flood dropped a layer of material described by Sharpe as a 2- to 3-foot-thick layer of mud gravel covered by 6 feet of debris. A telegraph to Florence and Northampton prepared those communities for the flood. They escaped with no deaths and only damage to bridges and mills near the river. The buffering of the flood energy by the Florence Meadows flatland spared the downstream communities from catastrophic losses. However, the farmland of the meadows was rendered useless, another major blow to the valley.

Figure 10. Newspaper Sketch (Artist's Concept) of the Valley after the Flood.

The Aftermath

The Mill River valley citizens immediately started looking for survivors and the dead in the flood's wake. Bodies in the upper valley villages were found where they were trapped, in buildings or trees. Many of the dead had to be exhumed from the mass of debris in Florence Meadows. Over the next few days, bodies were brought to several temporary morgues up and down the valley. In total, the failure of the Williamsburg Reservoir Dam took 139 lives, an immense tragedy and the worst fatality toll in this country for a dam failure until the Johnstown flood. The flood deaths were spread throughout the valley with 57 victims in Williamsburg, 4 in

Skinnerville, 27 in Haydenville, and 51 in Leeds. Forty-three of the dead were children under the age of ten.

Word of the disaster spread rapidly across the country and brought large numbers of reporters and sightseers to the valley, along with an outpouring of charity and aid. Newspapers, the primary source of information for the country, fed the public curiosity about

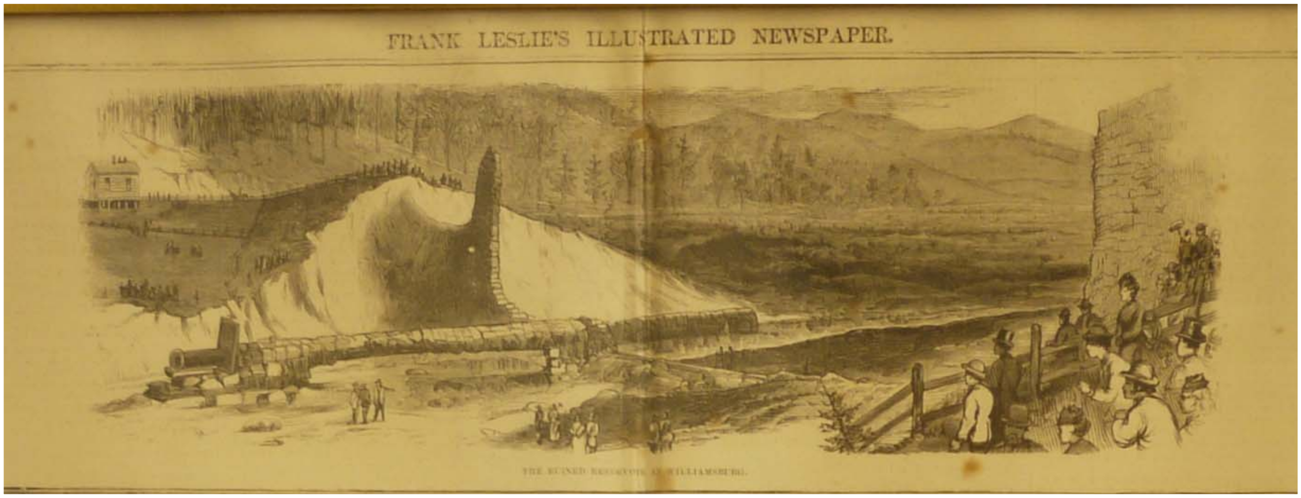


Figure 11. Newspaper Sketch of the Dam Ruins.

the flood with extensive coverage. Much of the history of the flood came from the stories in newspapers like the *Springfield Daily Republican,* the *New York Times,* and the *Harper's Weekly*. The images that exist of the post flood conditions were either sketched by artists from the newspapers (Figs. 9, 10, and 11) or taken by photographers who profited from the sale of the stereographic images (Figs. 2, 6, 7, 12, 13, 14, 15, and 16), a favored 19th century indulgence. Sidney Dickinson from nearby Amherst wrote a twenty-five stanza poem, "The Ride of Collins Graves," to honor the effort of Graves and Cheney.

Figure 12. The Hayden Brass Works, Post-Flood.

Industry and infrastructure in the valley were ruined with losses estimated to exceed $1,000,000 at a time when a mill worker might earn $200 in a year. The loss of rail access, roads, and bridges hindered relief efforts, but perhaps to a lesser degree than today because of the capacity of horses to travel off road. The population of the valley performed most of the recovery work with funds from outside charity organizations and nearby communities like

Figure 13. Silk Mill Ruins, Skinnerville.

Northampton. Relief help by neighboring towns in times of distress was commonly provided with the expectation that such help would be reciprocated if roles were ever reversed. The Legislature did provide significant funds, $120,000, for repair of the roads. Federal help at the time did not exist.

Relief funds were given to those who lost their homes or housing. Homeless families received $300 to reestablish themselves; homeless men received $50, and homeless women received $100 and a trunk with the expectation that they would move elsewhere.

Many of the mill owners rebuilt their factories and had limited success. Joel Hayden, Jr., paid his mill workers to help recover the brass works assets, especially brass fitting patterns, and to rebuild the brass works in Haydenville. In the process, the company incurred debt from which it never recovered. William Skinner was lured away from the valley by the city of Holyoke which offered the assets of the Connecticut River for power to drive his silk

Figure 14. The Dam from the West Abutment, 1874.

factories. The Skinner Silk Mills prospered and stayed in business until 1961. The valley made do, but never returned to its pre-flood prosperity.

The Coroner's Inquest and the ASCE Investigation

The investigation into the flood was prompt, starting on the fifth day after the flood, when the Hampshire County Coroner convened a jury of six men. The counties in Massachusetts in 1874 used the coroner's inquest to investigate causes of violent deaths. The county selected one victim, John Atkinson, as the proxy for all of the flood fatalities. Atkinson died while trying to warn his family of the flood. He had not known that his wife and daughter had fled earlier to safety.

The jurors first examined the remains of the dam and subsequently heard testimony from forty two witnesses. That testimony required only five days to be heard but required over one thousand pages to record. Witnesses included Cheney and his family, the other men who warned the valley - Graves and Day, the reservoir company owners involved with the dam construction and management, the engineers - specification writer Lucius Fenn and architect/surveyor/construction monitor Eugene Gardner, the contractors – Joel Bassett and Emory Wells, subcontractors, and the county commissioners who inspected the dam.

The jury visited the dam a second time after hearing some of the testimony to evaluate what they saw with what they had heard, and they deliberated and composed their eight-page verdict. That verdict found fault with all parties – with the Massachusetts legislature for not adequately regulating dams, with the reservoir company owners for reducing costs at the expense of public safety, with the engineers for yielding to the owners' directions to reduce costs and for not providing thorough inspection of the construction, with the contractors for not meeting the specification requirements for the foundation, wall, and grout, and with the county commissioners for lack of thoroughness in their inspection. However, in a manner consistent with that era, no one was indicted and no civil suits were filed.

Figure 15. East Side of the Dam from Downstream, 1874

The relatively new American Society of Civil Engineers (ASCE) independently sent a group of prominent engineers to investigate the dam failure. They reported that:

- Lucius Fenn wrote the specifications under the directions of the reservoir company directors, acting, “only as the attorney for the company.” They stated that “it is obvious that this cannot be called an engineering work. No engineer, or person calling himself such, can be held responsible for either its design or execution.”
- The bottom of the dam rested on 2 feet of coarse gravel and a few inches of soil over impervious hard-pan.
- The core wall trench was dug to meet the specification requirement for a “firm, hard and secure bottom…which will not allow the masonry to settle” (from the specifications), “ignoring the vital function of the cement wall, by not adopting means to prevent the passage of the water under it” (from the report).
- In general, the hardpan was not washed out at the breach except for a several-foot-deep gully near the low-level outlet pipe.
- The embankment material was gravelly with no cohesion, would not puddle, and would not provide significant seepage impedance due to its higher permeability.
- “There was no sufficient inspection.”
- “The remains of the dam indicate defects of workmanship of the grossest character.”
- The grout quality and workmanship of the core wall was poor such that cavities were not completely filled and the mortar was “some of it, very bad.”
- The specified embankment slopes were too steep.
- The top of the core wall should have been below 5 feet for frost protection.

Figure 16. View from East along Core Wall, 1874.

They noted that the exact cause was uncertain but proposed that foundation underseepage on the east side, 100 feet from the outlet, saturated the downstream slope, causing it to slide, leaving the core wall with inadequate support to resist the water load. Their findings were consistent with period photos which showed that the base of the core wall was not washed out by foundation erosion (Figs. 15 and 16). They proposed "a gradual working out of the gravel under and near the wall, and loose places or cavities formed," that is internal erosion / piping, as the mechanism for the deterioration of the seepage condition and stability.

A more basic conclusion was voiced by one of the ASCE engineers, William Worthen, who said: "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. I do not believe, however much we are an evolved species, that we are derived from beavers; a man cannot make a dam by instinct or intuition."

A 21st Century Perspective

As engineers and dam safety regulators, we have a natural curiosity about the physical and social causes and about lessons from the disaster. Remnants of the core wall (Fig. 17), the outlet pipe foundation, the embankments, and the spillway remain but have melded back into a New England wood. Our best sources of information are the historical accounts and investigations of 1874.

Seepage was the obvious destabilizing factor in the failure. The poor design and construction give us many choices for the pathway of the seepage to the downstream slope. The pervious foundation, a poorly grouted core wall, the unmortared central section of the low-level outlet foundation wall, and the loose, poorly-compacted, coarse embankment material could each have provided a part of the seepage flow path to the downstream slope. The high seepage pressures from a reservoir, which was allowed to fill to normal pool after Hayden's death, counteracted the stabilizing soil friction forces on the downstream embankment, causing the initial failure witnessed by the Cheney family at breakfast. Elizabeth Cheney's description of the subsequent breach of the dam, which "seemed to burst all at once, from the bottom, where the earth seemed to be lifted up," suggests the sudden release of an open flow path which could have been

Figure 17. East Abutment and East Side Breach Area, 2014.

formed by internal erosion under or through the dam. However, the preservation of the base of the core wall across the valley indicates that the flow path may have occurred through a section of the wall in the lower part of the dam, but above the wall base.

The Williamsburg Reservoir Dam failure has been overshadowed by the immensity of the Johnstown flood, which occurred 15 years later in 1889 and took the lives of 2209 people when the South Fork Dam failed. Failures of dams in the 1800s were unfortunately common. Four dam failures occurred within 100 miles of the valley during the 35 years before the Mill River flood. The failure of another dam in the Berkshires, Mud Pond Dam, in 1889 devastated the small village of East Lee, Massachusetts, killing seven people. These disasters were the results of several factors – no regulation or standards, little publicly available guidance about design and construction of dams, less developed design and construction principles particularly regarding seepage, filters, and hydrology, and the willingness of industrialists to take chances with dam design and construction for the sake of economy.

Many of the dams from the 19th century are still with us, especially in New England. In fact, the Commonwealth of Massachusetts owns the two dams on the West Branch of the Mill River that these same industrialists built before and after the Williamsburg Reservoir Dam construction. The surviving 19th century dams tend to be those built with some degree of conservatism for the 1800's relative to seepage and flood passage. We continue to deal with the challenges of evaluating and maintaining these dams.

A major difference between the floods on the Mill River and in Johnstown was the warning that reached the Mill River villages before the flood. The decision by the mill owners to support a full time dam tender, the good fortune to have the failure occur when the dam tender could see the preceding slope slide, and the quick actions of George Cheney, Collins Graves, Jerome Hillman, and Myron Day saved hundreds of lives.

Few of our dams now have full time dam tenders. We can hope that current emergency action plans (EAPs) with increased monitoring during flood periods and modern communications will provide better warnings than the Mill River valley had. However, without early detection of a pending or in-progress dam failure, our modern EAPs will be much less effective than 19th century men on horseback. We should consider increased and widespread use of remote monitoring on our high hazard dams for failure indices such as downstream flow and pressures and for visual confirmation using video monitors. Our cell phones can beat George Cheney's mare only if we know about an impending disaster.

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Authors

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