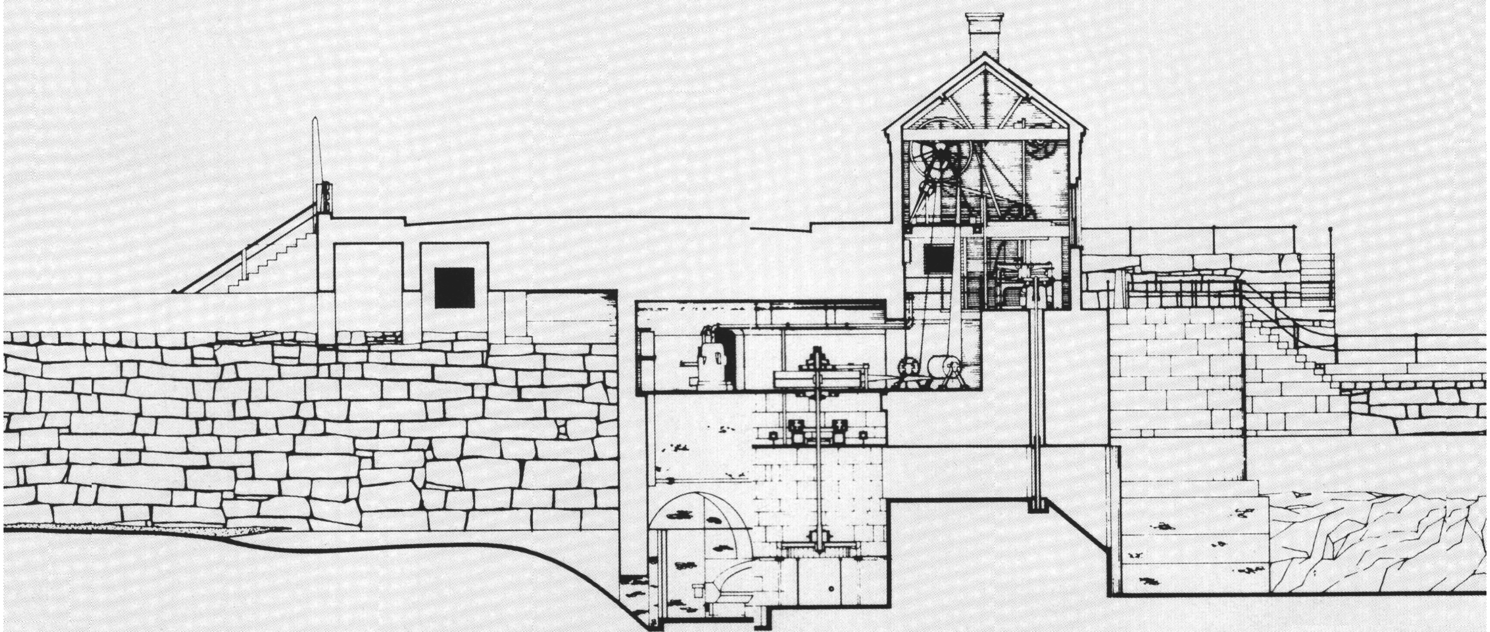
LOWELL



LOWELL WATER POWER SYSTEM

PAWTUCKET GATEHOUSE
HYDRAULIC TURBINE

Designated National
Historic Civil and
Mechanical Engineering
Landmarks by the
American Society of Civil
Engineers and the
American Society of
Mechanical Engineers,
respectively

July 1, 1985
Lowell, Massachusetts

Historical Background

In 1792 shipbuilders and merchants from Newburyport, Massachusetts, incorporated as the Proprietors of Locks and Canals on Merrimack River. This was one of the nation's earliest corporations. It immediately began work on the Pawtucket Canal, which was completed in 1796. This canal by passed Pawtucket Falls and increased the flow of timber and agricultural products from New Hampshire to the sea.

The canal's early success, however, was short lived because the ship building industry at Newburyport had fallen on hard times. Traffic on the Canal decreased with the dwindling demand for New Hampshire timber. In addition the Middlesex Canal was reaching completion, which linked the upper Merrimack with the Charles River and diverted much of the Canal's trade from Newburyport to the larger market at Boston.

It was 1803 and Thomas Jefferson was president. It was a time when America's economy was predominantly agricultural and Jefferson, like many of his countrymen, felt that America's strength lay in its agricultural heritage. It was felt that industrialization, as evidenced by the squalor of European industrial cities, was morally reprehensible. Nevertheless, Jefferson eventually modified his views and came to the conclusion that a certain amount of industrial development was required to maintain economic independence from Europe.

In addition a recent curtailment of trade with Europe sharply reduced the amount of manufactured goods in America. Recognizing the need for such products Jefferson decided that the objectionable aspects of the European industrial experience could be avoided by the dispersal of manufacturing centers throughout the American countryside.

It was under these conditions that Francis Cabott Lowell, a Boston merchant, travelled to England and Scotland in 1811. He toured British textile factories and was impressed with the advanced state of English technology, though he was also deeply affected by the impoverishment of the working classes. Lowell returned to America hoping to perfect a power loom, for use in a factory system of his own. His plans for the power loom, based on his observation of English looms, were developed in 1813 by mechanic Paul Moody. The power loom proved to be a major innovation in American textile manufacture, since it made possible the transformation of raw cotton into finished cloth within a single factory.

This project required large amounts of capital, but fortunately the need came at a time when American merchants were frustrated by Jefferson's embargo of 1807 and the War of 1812. Businessmen were looking for new areas of investment. Lowell was able to find willing investors in the "Boston Associates," a group of businessmen that later formed the Boston Manufacturing Company and began operation on the Charles River at Waltham, Massachusetts. Enthused by the success at Waltham the Boston Associates looked elsewhere for a site with a greater source of power for their new Textile Manufacturing Community.

In 1821 they acquired four hundred acres between the Pawtucket Canal and the Merrimack and Concord Rivers by purchasing the controlling stock of the Proprietors of Locks and Canals.

In 1822 the Merrimack Manufacturing Company was chartered and a rapid construction of textile mills and new power canals followed.

By 1826, construction of new mills was continuing unabated as the former agricultural village of East Chelmsford grew into a town, renamed Lowell for Francis Lowell, who died in 1817. Ten years later, it became the third city incorporated in Massachusetts. By then it had a population of seventeen thousand and included eight major

Society of Civil Engineers, Merrimack Canal, 1875 University of Lowell.

textile mills employing seventy-five hundred workers.

Early Industrial Lowell

Lowell became America's first great industrial city because of the power of the Pawtucket Falls, and the efforts of the amazing group of engineers, industrialists and workers.

It began with the construction of a complex canal system to harness the power of the Pawtucket Falls and the nearby rivers. The 1796 Pawtucket Canal became the feeder for the system begun in 1822. By 1826, two canals branched from the Pawtucket and four additional canals were already envisioned. Ten years later the planned system was complete. Water drove the machinery of mills on two distinct levels, the trailraces of the upper level mills emptied into canals leading to lower level mills.

In 1837, British born James B. Francis became chief engineer, Proprietors of Locks and Canals, a position he held for forty years. Throughout his tenure of office, Francis was primarily concerned with meeting Lowell's demands for increasing amounts of water power.

The Northern Canal

Since 1826, engineers had been able to increase the flow into the Lowell Canal System by constructing dams at Pawtucket Falls. The first was a crude wooden structure, but by 1830 a masonry dam seated on heavy wooden cribbing was helping to maintain a "pond" behind the falls. Three years later, workmen added two more courses of granite headers and raised wooden flashboards above them. This not only raised the level of the upper river but also stilled its current for over eighteen miles.

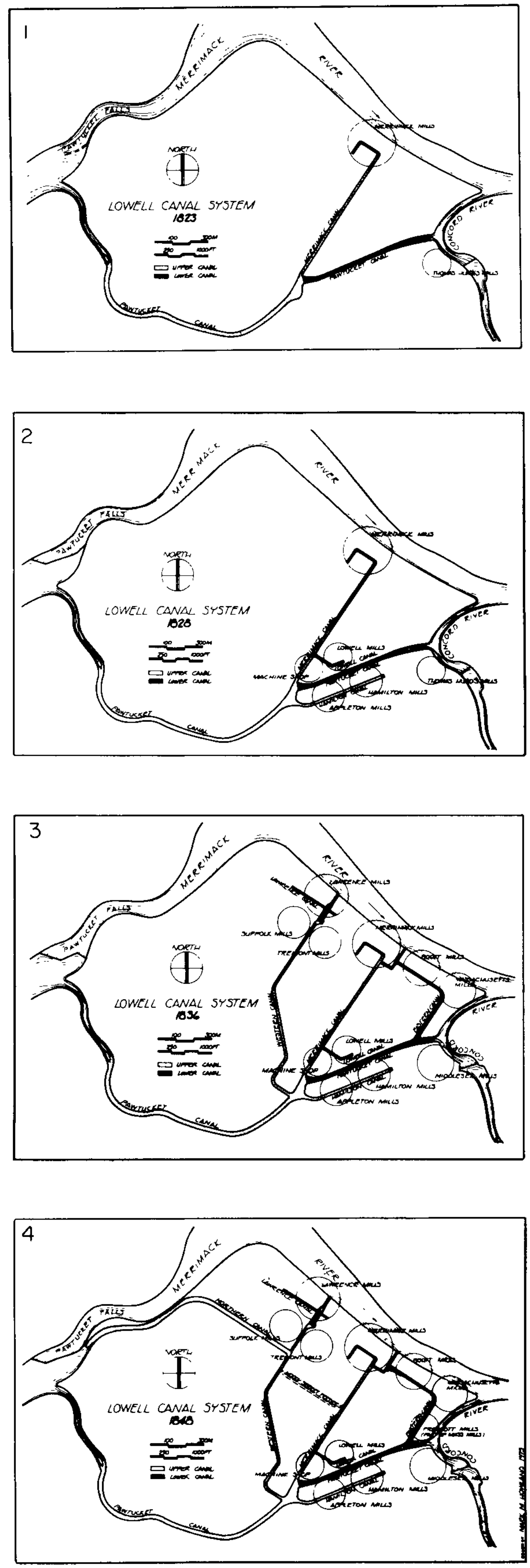
The dam did not, however, satisfy the water needs of the growing industrial city for long. The demand for water power increased each year in Lowell as textile corporations expanded their manufacturing operations. Power was always scarce in the dry summer months, and by the 1840s shortages were common throughout the year. One problem was the severe friction losses in the canals created by greater flow rates. When mills needed more water, the current had to increase to supply this demand.

Increased current produced friction which actually dropped the level of water in the canals, reducing its head, or potential to generate power. Thus, the mills could only get a greater flow of water by giving up some of the head they also needed.

In times of freshet, river water rose into the trailraces of mills impeding their wheels. Such "backwater" conditions placed excessive demands on the canal system, for only a tremendous flow of water could keep wheels turning in flooded wheel pits. Francis proposed the construction of a second feeder canal. This huge waterway would bring additional water into the system and allow a reduction of current in most of the canals.

In order to make such a plan effective, however, two conditions had to be met. First, Locks and Canals would have to prohibit the use of water for manufacturing at night, so that the river's flow could be "ponded" until the morning. Second, the power company would have to control the outlets of the major lakes which fed the Merrimack River.

Using the lakes as reservoirs, Lowell would then have a source of extra water in dry seasons. Economic conditions in the 1840s, a "boom" period of nineteenth-century American textile manufacture, made the attempt at this bold plan both possible and urgent. In combination with the Essex Company of Lawrence, Locks and Canals acquired control of over one hundred square miles of lake surface in New Hampshire, and Francis began work on the greatest engineering challenge



Lowell Canal System. Courtesy of HAER.

of his career, the construction of the Northern Canal.

Recognized as one of the most impressive achievements in the history of American engineering when completed in 1847, the project set new standards in civil and hydraulic engineering and introduced the famous "Francis" turbine to the world.

The canal system had become a complex affair fed entirely by the Pawtucket Canal, which avoided the high ground downstream of the falls. The route Francis chose for his new feeder canal ran parallel to the river for over 2000 feet, then turned inland to join the Western Canal. He had to cut through part of the difficult, rocky terrain which the Pawtucket Canal missed, and he had to place a major section of his canal in the bed of the river.

To overcome the topographical obstacles required heroic measures, great ingenuity, and much capital. Not only did Francis have to build a "Great River Wall" to hold his canal above the Merrimack rapids, but he also had to rebuild a large part of the Pawtucket Dam, construct sophisticated gate controls, and modify the existing system to integrate it with the new canal.

The Northern Canal brought water into the system with a higher head than had been previously possible, and it reversed the current in the Western Canal from the junction to the Swamp Locks Basin. Water from the Northern supplied the demands of the Tremont, Suffolk, and Lawrence Mills. Once Francis had completed the Moody Street Feeder in 1848, the Northern also fed the Merrimack Canal through three brick-vaulted tunnels. A smaller underground passage, known as the Boott Penstock, transferred some of this flow from the Merrimack Canal to the end of the Eastern Canal, where an adequate water level had always been hard to maintain.

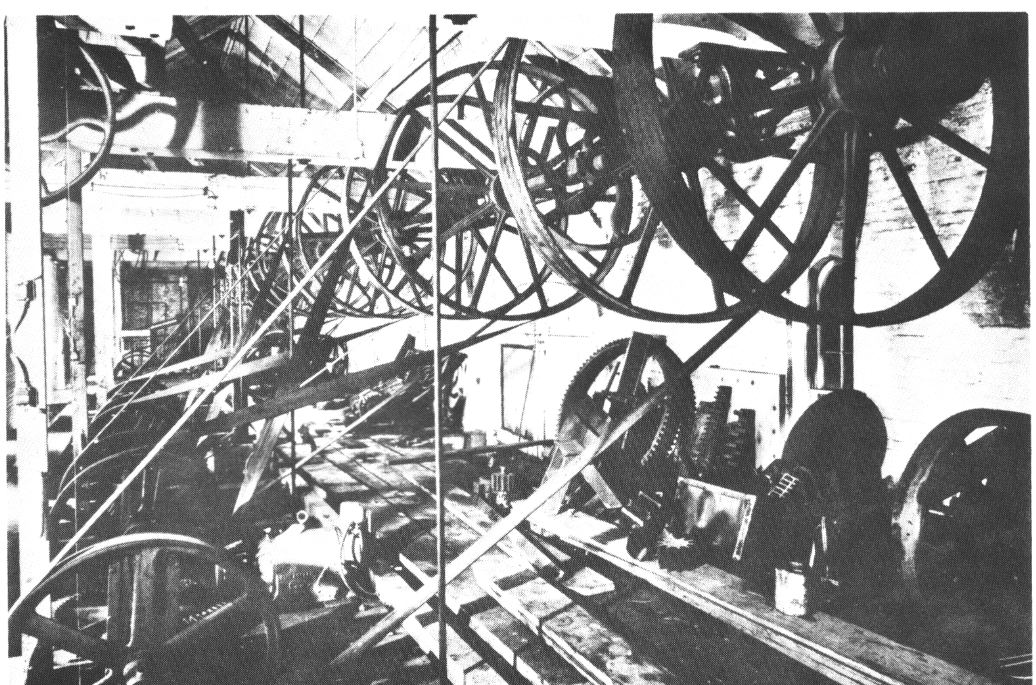
Locks and Canals had spent $551,585 on the Northern Canal and $86,132 on the Moody Street Feeder. The Boott Penstock and the necessary widening of the Western Canal had added another $15,000 of expenses. Yet, the power gained by the various Lowell corporations was easily worth the cost.

After testing the results of his physical improvements to the system, Francis arranged for redistribution of power and an increase in the number of "mill powers" leased to each company.

Because of the limitations of the old Pawtucket Canal as the sole feeder, only ninety-one mill powers had been leased up to that time. The Northern Canal enabled the chief engineer to lease 139 mill powers, a gain of more than 50 percent. These "permanent mill powers" were to be supplied in all seasons; for most of the year, the corporations could also purchase "surplus" mill powers at an inexpensive rate.

The mill complexes were assured of almost twelve thousand gross horsepower, even in summer. Francis, acting as "The Chief of Police of Water," tried to prevent waste in the system and developed techniques to monitor the water used by individual corporations. When river flow was low, he even closed the gates of the Northern Canal during the noon break.

His 1846 tests of Uriah Boyden's outward-flow turbines in the Appleton Mills convinced him that the corporations should switch from breast wheels to more efficient hydraulic turbines. In this way, they could produce more net horsepower from each "mill power" delivered to their sites. Also, turbines, which ran well under water, could generate during the "back-water" conditions that ruined the efficiency of breast wheels.



Line shaft for gate-hoisting mechanisms in the Pawtucket Gatehouse. Courtesy of HAER.

The widespread conversion to turbines in Lowell took place during and immediately following the construction of the Northern Canal.

The Pawtucket Gatehouse

Some of Francis' most famous studies of turbine operation and of the flow of water over weirs took place in the Pawtucket Gatehouse. The great engineer actually designed the gatehouse with special testing chambers and other features associated with scientific experimentation. Thus it deserves special attention as one of our nation's first industrial research laboratories. The results of Francis' research won international acclaim with the publication of his *Lowell Hydraulic Experiments* in 1855. The turbine in the Pawtucket Gatehouse was the first that Francis built for practical use. It is almost nine feet in diameter and is installed in a vertical setting within a granite ashlar wheel pit of cylindrical form. It is an inward-flow type, an improvement on the wheel patented by Samuel Howd in 1838.

Francis used his experiments on his 1847 turbine to design a much improved model with curved guides and buckets for the Boott Mills in 1849. The development of the modern, mixed-flow reaction turbine was a lengthy process involving many inventors, but Francis was a pioneer in this field. Most turbines in use today for hydroelectric generation are called "Francis" types in his honor.

Environment

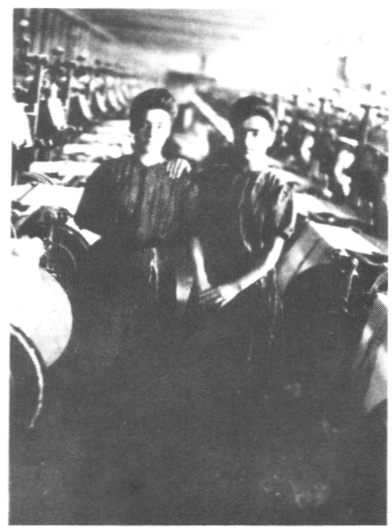
From the very beginning of industrial development in Lowell, the corporations were concerned about their public image and about the aesthetic and recreational aspects of the built environment which they were creating. Whenever industrial necessity permitted, the corporations tried to beautify their structures and the landscape around them.

Francis, who studied botany as well as engineering, took personal charge of landscaping along the Northern Canal. Records of his plantings remain in the papers of the Proprietors of Locks and Canals, and these might be a basis for determining what of the present vegetation of the island area is due to his selection.

Lowell's Female "Operatives"

In their search for model workers and a reliable labor source, the Boston Associates recruited the daughters of Yankee farmers. Lowell's mills provided young New England farm women a respectable way to earn money and an opportunity to improve their lives. Hired by company agents, women came to earn dowries for future husbands, to send a brother to college, to help support their family's farm or to become self-sufficient.

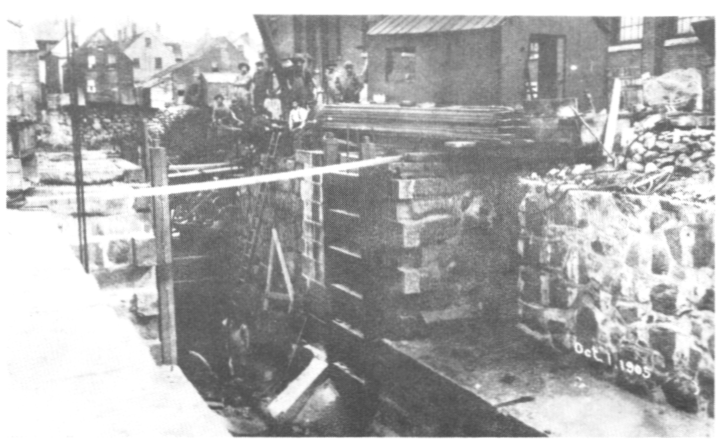
Living in company boarding houses, their lifestyle was controlled by strict company codes. A twelve-hour day and a six-day work week were normal. Every waking hour was regulated by a bell. Wages for female operatives were set at a rate of $2.25 to $4.25 per week with $1.25 deducted for room and board.



Della Braga, spinner, Appleton Mills, 1910
Lowell Historical Society.

Eva and Alvana Desroches, weavers, Boott Mill, 1903
Lowell Museum.

Lower Locks, Pawtucket Canal, 1905
University of Lowell.



Birth of a Park

Rise and Fall of Lowell

By the middle of the 19th century industrial structures dominated the urban landscape of Lowell. Many manufacturers had come to supply the needs of the great textile corporations for belts, shuttles, card clothing, rollers, and hundreds of other items. Companies with products unrelated to textiles located in the city because of its pool of skilled workers, its excellent transportation links to wide-spread markets, or its reputation as a clean or orderly industrial community with an unlimited future. The population had soared from 2500 in 1826 to 33,000 in 1850.

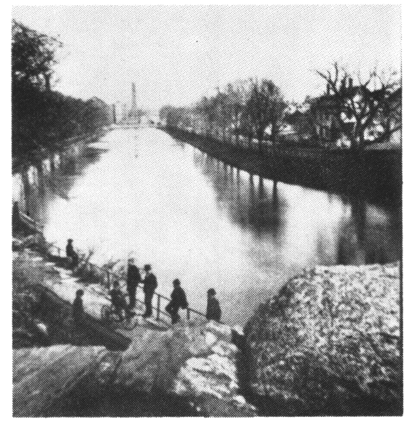
Lowell's continuing growth was impressive, but the city was losing ground to other rising industrial centers. By 1875 it was no longer the largest cotton textile producer in Massachusetts; Fall River was. By 1880 Lowell had begun to slip from the limelight in engineering as well as in textile manufacture.

Francis was still a giant in his profession, but, after working on the dam and on several systems of gate control in the 1870s, he faced no further significant challenges on the network of canals.

As Lowell struggled with its declining economy in the middle of the twentieth century, "modernization" and urban renewal threatened to destroy the city's historic districts. Late in the 1960s a community based federal program, Model Cities, proposed to revitalize the city through the rediscovery of its heritage. The Lowell City Council adopted a resolution in response to this proposal in 1972 which designated a "historical park concept" as a focal point of future urban development.

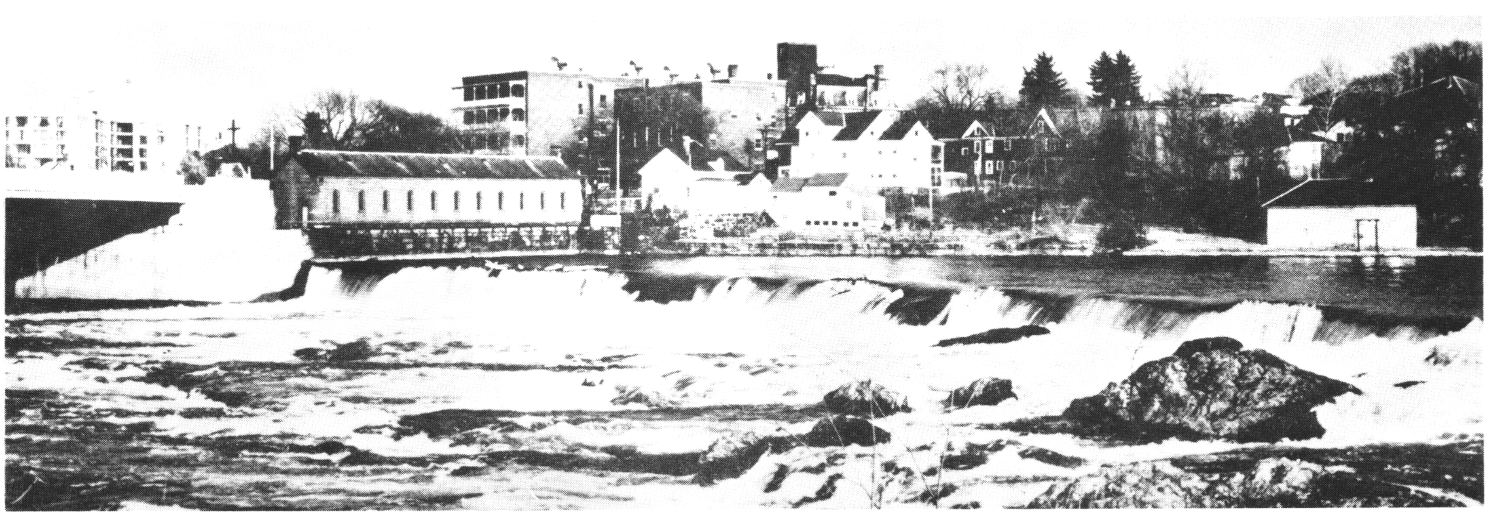
Subsequent to Congressional approval, President Carter signed the law establishing Lowell National Historical Park and the Lowell Historic Preservation District on June 5, 1978. The National Park Service administers the Park in cooperation with the Commonwealth of Massachusetts, the City of Lowell, and other local and private organizations, under the direction of the Secretary of the Interior.

The historic engineering and industrial structures in Lowell today reflect the technical skill which created them. Lowell's engineers, technicians, and workers have left a lasting heritage in the man-made environment of their City. Lowell was not only a leader in textile production but also a showpiece of engineering expertise.



Northern Canal Walkway, date unknown Lowell Historical Society.

Pawtucket Dam and Pawtucket Gatehouse. Courtesy of HAER.



Present Conditions

The Northern Canal

From its entrance to the point where it intersects with the Western Canal, the Northern Canal is 4,373 feet in length. It averages 100 feet in width and is 15 to 21 feet deep. The cross section is basically a shallow rectangle, although there is often a slight slope to the masonry walls and cut ledge forming the sides of the channel.

The canal has one bend, a curve which does not seriously affect the smooth flow of water. Francis designed the canal to deliver water with very little friction head loss, and it still performs that function very well.

The "wall" between the canal and the river varies in form but has three distinct sections.

The first 130 feet downstream from the School Street Bridge consists of a concrete spilling wall encased by a battered, dry-laid, squared rubble wall.

The next section, approximately 1000 feet long, was built on an island formed by the excavation of the canal parallel to the river. It contains a spilling wall of random coursed rubble laid in cement, encased in a backfill of puddle clay, and further backfilled with earth which is retained by two battered, dry-laid, squared rubble walls.

The third section is the famous Great River Wall, which can be reached by a walkway from the School Street Bridge and along the island.

Pawtucket Gatehouse

The guard sluice gates, the brick gatehouse, and a navigation lock were all constructed as a part of the 1846-47 Northern Canal project. The gatehouse shelters and supports the gate hoisting machinery.

Its attenuated plan dimensions of 22 feet by 122 feet relate to the rank of ten sluice gates and the single Penstock gate for the turbine chamber. Each longitudinal elevation contains eleven fenestration openings (now filled with brick on the north elevation), indicating the eleven gates inside.

Vaguely Romanesque revival in style, the building is constructed of red pressed brick on a granite ashlar foundation and is covered by a gable roof of slate.

Distinctive decorative features are the corbeled brick raking cornices and the quarter rounded southwest corner with its corbeled transition into the right-angled cornice. This rounded corner was intended to facilitate the passage of flood water and flotsam without damage to the brick.

The ten sluice gates which control the flow of water into the Nothern Canal were first operated by a complex mechanical system. Most of the power equipment, including belt, pulley, line shafting to the hoisting machinery, and the 1847 turbine and twin hoisting screws for each gate, remain intact. Among other notable features is Lowell's last surviving main belt drive for a mechanical power transmission system.

Experimentation with electric motor drive at the gatehouse began in 1891, but the turbine was apparently not retired from operation until 1923. One of the early motors survives, but the line shaft has stood idle since small, modern motors were installed on each set of hoisting machinery.

Great River Wall

Great River Wall was built in the natural bed of the river, and rises as much as thirty-six feet above the rapids. At times over a thousand men were employed at once in its construction. This thousand-foot retaining wall is founded on ledge and is made primarily of granite blocks, roughly squared in the interior and quarry-faced, coursed ashlar on the exterior.

Both sides of the wall are battered, and the wetted area of the inside surface is made impermeable by a lining of small-sized rubble set in cement. A pedestrian walkway crowns the massive stone wall.

Pawtucket Dam

The Pawtucket Dam was built and rebuilt piecemeal over the previous half century. The present masonry dam was built in two sections, the first in 1847 and the second in 1875. This dam replaced an earlier masonry dam built between 1830 and 1833. As the date suggests, the 1847 section was constructed as part of the Northern Canal project. It represents roughly one-third of the present dam stretching from the Northern Gatehouse.

The dam as a whole is 1,093.5 feet long, following the irregular outline of the natural ledge of the falls. Its foundation consists of granite blocks laid in a trench. The face of the dam is constructed of quarry-faced granite blocks, and the interior is granite rubble set in hydraulic cement. The dam has no spill way.

Atop the granite dam is a row of flashboards running the entire length of the structure and held in place by iron pins set in the capstones. These boards raise the level of the pond significantly with a minimum of capital investment.

The fishway at the northern end of the Pawtucket Dam was installed in 1921 and will be replaced during construction of a new power station, without adverse effect to any historic feature of the dam.

Navigation Lock

Francis added a navigation lock to the entrance of the Northern Canal when he built the Pawtucket Gatehouse. The lock has not been used since 1871, and is now blocked by a concrete wall built in 1939. The National Park Service plans to reopen the lock in the near future.

Waste Gatehouse and Waste Weir

The most sensitive historic feature of the Northern Canal is the Waste Gatehouse, or High Bridge Gatehouse, immediately upstream from the bend of the canal. Here Francis installed four manually operated waste gates to draw the canal and two scouring holes to remove silt from it.

Francis also built a waste weir with multiple bays at the top of the wall and next to the scouring holes.

Major modifications took place in 1872, when one of the scouring holes was converted into a wheel pit for a turbine. Francis installed a small, scroll-cased turbine with a mixed-flow runner and no guides. This turbine and almost all of the mechanical drive system are still intact.

Acknowledgments

The American Societies of Civil and Mechanical Engineers wish to acknowledge the efforts of all who cooperated on the Landmark designation of the Lowell Canal System and Pawtucket Gatehouse Hydraulic Turbine, particularly Lowell's National Park Service Staff; Dr. Patrick M. Malone of the Slater Mills, whose material was used to prepare this brochure, and Ensign John H. Gale, III, of the ASME Student Section at Lowell Institute of Technology, for his early research and preparation of material for the Landmark nomination.

Photo credits: The Historic American Engineering Record, Lowell Historical Society, and Lowell University.

For further information on the ASCE and/or ASME History and Heritage programs, please contact either Society at 345 East 47th St., N.Y., NY 10017

The American Society of Civil Engineers

The American Society of Mechanical Engineers