WATER POWER IN LOWELL, MASSACHUSETTS

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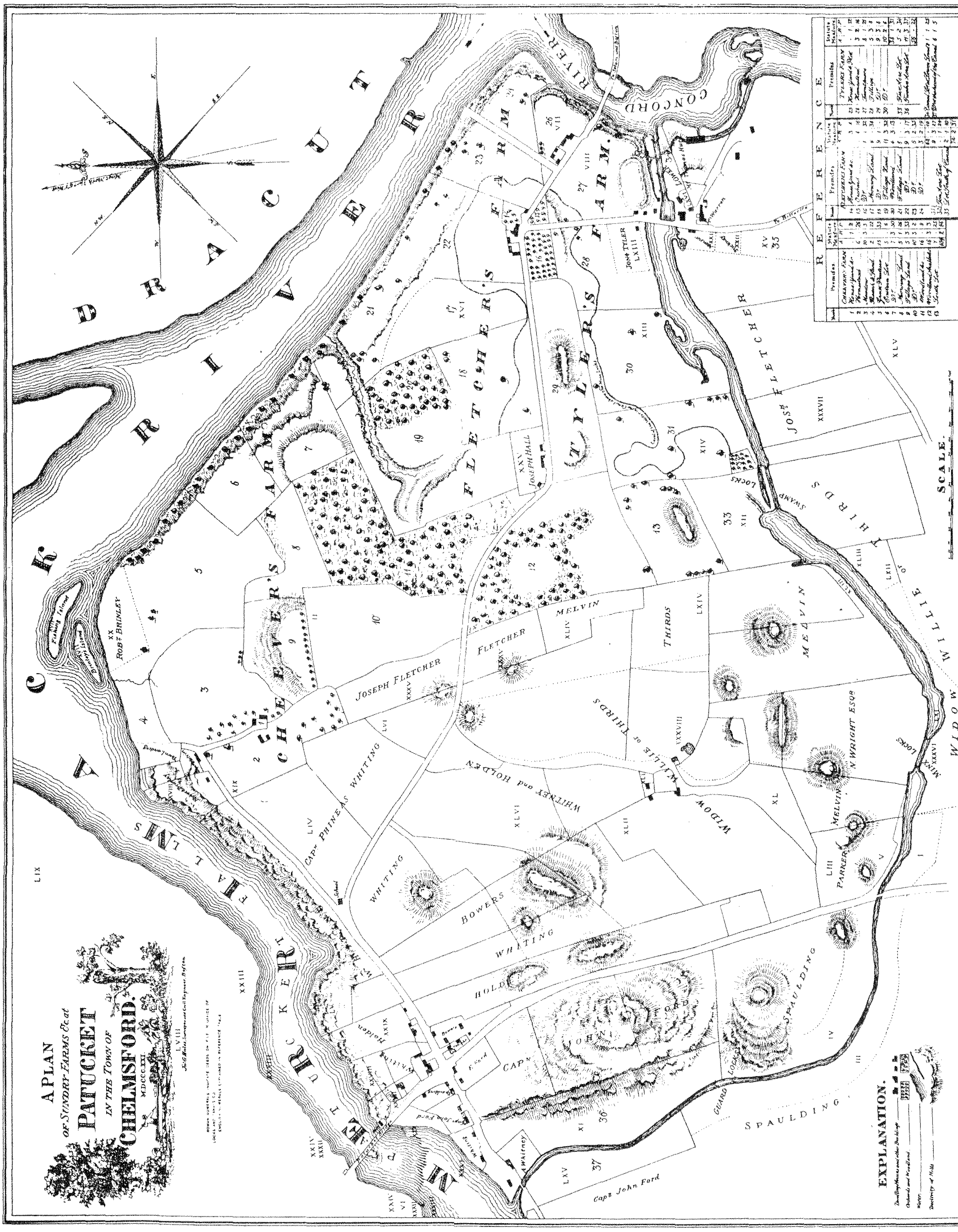
Lowell, Massachusetts became America's first great industrial city because of the power of the Merrimack River. The textile mills which brought prosperity to early Lowell depended on water power delivered by a complex system of canals. These man-made waterways were, and still are, an engineering marvel. They greatly affected the patterns of urban development in Lowell and earned the city its reputation as the "Venice of America."

An 1821 map of "Pawtucket in the town of Chelmsford" shows the rural area which would soon become the city of Lowell. Here the Concord River joins the Merrimack below the Pawtucket Falls. Lowell historian Henry Miles described the falls as "a descent of thirty-two feet--not perpendicular, but over several rapids, in circuitous channels, with a violent current amidst sharp-pointed rocks."[1] In earlier times the Indians had fished at the falls, but by the late eighteenth century the rapids seriously interrupted the flow of goods, principally lumber, that came down the Merrimack to Newburyport on the coast. In 1792 a corporation known as the Proprietors of Locks and Canals on the Merrimack River was established with a plan to by-pass this natural obstacle.

The Proprietors built a transportation canal which ran from just above the falls to the Concord River. Once in the Concord, boats or rafts drifted 1000 feet downstream to rejoin the Merrimack. The Pawtucket Canal was completed in 1796 at a cost of $50,000.[2] Its total length was 9,188 feet[3], but it was not a rigidly constrained waterway. The first half of the canal followed the curving bed of an old stream; the second half meandered a great deal, swelling to fill lowlands along the route. The descent from the river level above the falls to that below the rapids was achieved through the use of four sets of locks.



I. Patucket Farms - 1821 - by J. G. Hales

Collection of the Lowell Historical Society

Figure 1

The Pawtucket Canal soon proved to be a bad investment. In 1793, one year following the establishment of the Locks and Canals Company, a rival canal company was formed--the Proprietors of the Middlesex Canal. This company had a grander scheme for improving New England trade routes: a 27-mile-long canal running from the Merrimack above the Pawtucket Canal to the Charles River near Boston.[4] The Middlesex Canal, begun in 1795, was completed in 1803. For obvious reasons this canal drew traffic from the Pawtucket; it was preferable to trade in Boston rather than in Newburyport's much smaller market. Hence in the early 1820's the Pawtucket was little used for transportation, and shareholders in the Proprietors of Locks and Canals were only too happy to unload their stock to representatives of the Merrimack Manufacturing Company, a new company quietly but actively in search of "a suitable water power" for the manufacturing and printing of cotton cloth.

The Merrimack Manufacturing Company was incorporated in 1822 by men seeking sufficient land and water power for a major industrial undertaking. Two of the founders, Patrick Tracy Jackson and Nathan Appleton, had been partners of Francis Cabot Lowell in his highly successful "Waltham experiment." At Waltham, Massachusetts, Lowell for the first time processed cotton into cloth within a single mill.[5] His system of boarding houses and strict social regulations brought New England girls into his mills and improved the reputation of factory labor. Expansion at the Waltham site was impossible, however, for the sluggish Charles River could not power a major mill complex or a print works for decorated cloth. After Lowell's death in 1817, his associates began to look for a better location; they found one in 1821 by the Pawtucket Falls.

Nathan Appleton writes of his inspection of the site:

> Our first visit to the spot was in the month of November, 1821, and a slight

> snow covered the ground. The party consisted of Patrick T. Jackson, Kirk Boott, Warren Dutton, Paul Moody, John W. Boott and myself. We perambulated the grounds, and scanned the possibilites of the place, and the remark was made that some of us might live to see the place contain twenty thousand inhabitants. At that time there were, I think, less than a dozen houses on what now constitutes the city of Lowell, or rather the thickly settled parts of it...[6]

Representatives of the Merrimack Manufacturing Company not only bought the holdings of the Proprietors of Locks and Canals at a bargain price, but by hiding their intentions to build a manufacturing city, also purchased without great expense much of the farmland lying between the Pawtucket Canal and the Merrimack River. A few small mills in the area already produced gunpowder, sawn timber, flour and woolens;[7] but none of the two hundred local residents could imagine the great industrial development that would take place in Lowell.

Even the founders of Lowell underestimated the full potential of the Pawtucket Falls as a source of water power. Although Appleton, Jackson, and their chief executive, Kirk Boott, realized that ownership of the 1792 charter of the Proprietors of Locks and Canals gave their Merrimack Company rights to all the water going over the falls,[8] they did not foresee the complete system of canals that would eventually run ten large mill complexes and a great machine shop. In 1822, they thought first of putting a single Merrimack Company mill in operation. After that they would work on the problem of supplying additional mill sites with water power. They estimated that enough water could be channeled into the Pawtucket Canal to generate fifty mill powers, or the power to drive fifty mills the size of the second mill at Waltham, a mill of 3,584 spindles.[9] (The Merrimack Company, of course, did not plan to construct fifty small mills in Lowell; the Lowell mill complexes, much larger than the Waltham mills, would operate off multiple mill powers.) In terms of water flow, fifty mill powers were equivalent to a flow rate of 1,250 cubic feet of water per second over a thirty-foot fall. In 1853, five years after the completion of the last canal built in Lowell by the Proprietors of Locks and Canals, the system, operating on two levels, provided almost three times the power estimated in 1822--and water flowed through Lowell mills at a rate of 6,574 cubic feet per second.[10]

The simplest way to supply a series of mills with water power is to use a single power canal running parallel to a straight river with a falls. If the canal leaves the river above the falls and reenters at some distance downstream then the land between the canal and the river becomes an island on which mills can be placed to advantage. By keeping the level of water in the canal approximately equal to that in the river above the falls, there will be a difference in water level between the canal and the river at every point below the falls. Water from the canal can be let into the mills on the island to drop through power-producing machinery, such as water wheels, and into the lower level of the river. In this way the harnessed energy of falling water can power manufacturing processes in each mill.

Unfortunately for the planners of Lowell, the Merrimack River makes a sharp bend just below the falls. Also, the Pawtucket Canal was already in place, forming a wide arc around the bend in the river. The topography of the site and the route of the existing canal forced officials of the Merrimack Company to consider the construction of additional power canals which would be fed by a reconstructed Pawtucket Canal. The future canal system would obviously be a complex one, creating far more engineering problems than a single canal in the ideal situation discussed above. Adding to the complexity would be the necessity of retaining the original function of the Pawtucket

Canal as a transportation waterway. Construction supplies, raw materials, and mill products would have to travel through the canal for many years to come.

The initial projects of the Merrimack Manufacturing Company were "to erect the dam across the Merrimack at the Pawtucket Falls, widen and deepen the Pawtucket Canal, renew the locks, and open a lateral canal from the main canal to the river, on the margin of which their mills were to stand."[11] The enlargement of the Pawtucket and the renewal of the locks came first.[12] The Pawtucket was made to run sixty-feet wide and eight-feet deep. Work commenced on this operation in 1822 and was completed a year later at a cost of $120,000.[13] The canal actually was not widened along its entire length. As noted above, the lower half of the old Pawtucket Canal meandered through lowlands; its width in these areas was often considerably greater than sixty feet. In this region, then, the channel of the canal was narrowed and restrained.[14]

When renewing the locks along the Pawtucket, the Merrimack Company completely removed the Minx Locks. This allowed water to flow without interruption from the Guard Locks to the Swamp Locks Basin. To increase the amount of water entering the canal the company constructed a granite dam at Pawtucket Falls.[15] This structure, 950 feet in length, was completed in 1825. It deadened the current of the Merrimack for eighteen miles, forming a reservoir of about 1,120 acres.[16]

The lateral canal from the Pawtucket to the river, the Merrimack Canal, was begun in 1822 with the aid of Irish-immigrant labor.[17] Completed in 1823, the canal was 2,586 feet in length. Drawing its water from just above the Swamp Locks, it afforded the readiest way of utilizing the full thirty-foot fall of the Merrimack River.[18] The Merrimack Manufacturing Company placed its mills between the Inner Canal, a branch of the Merrimack Canal, and the Merrimack River. The first mill commenced operation in 1823.[19]

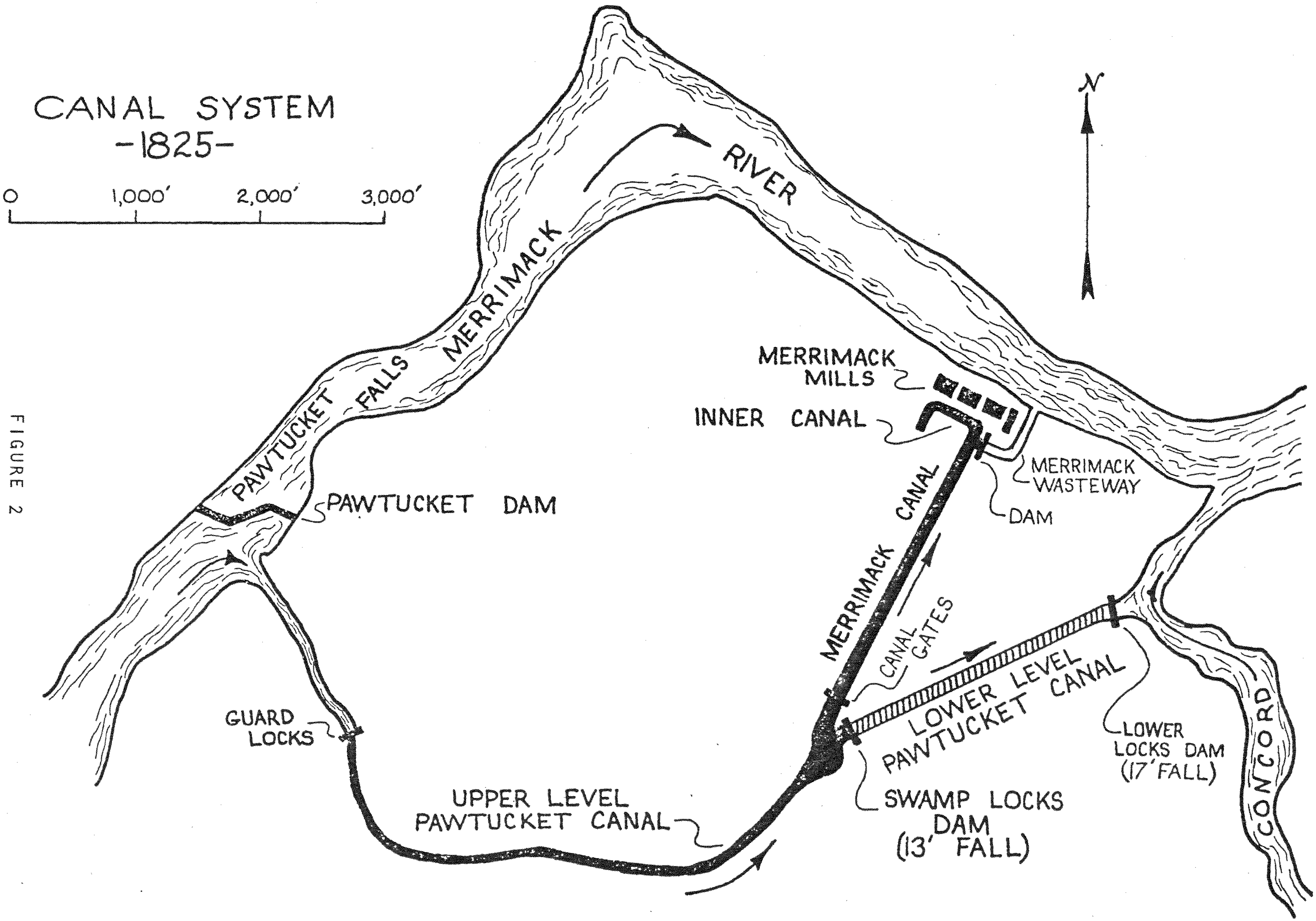
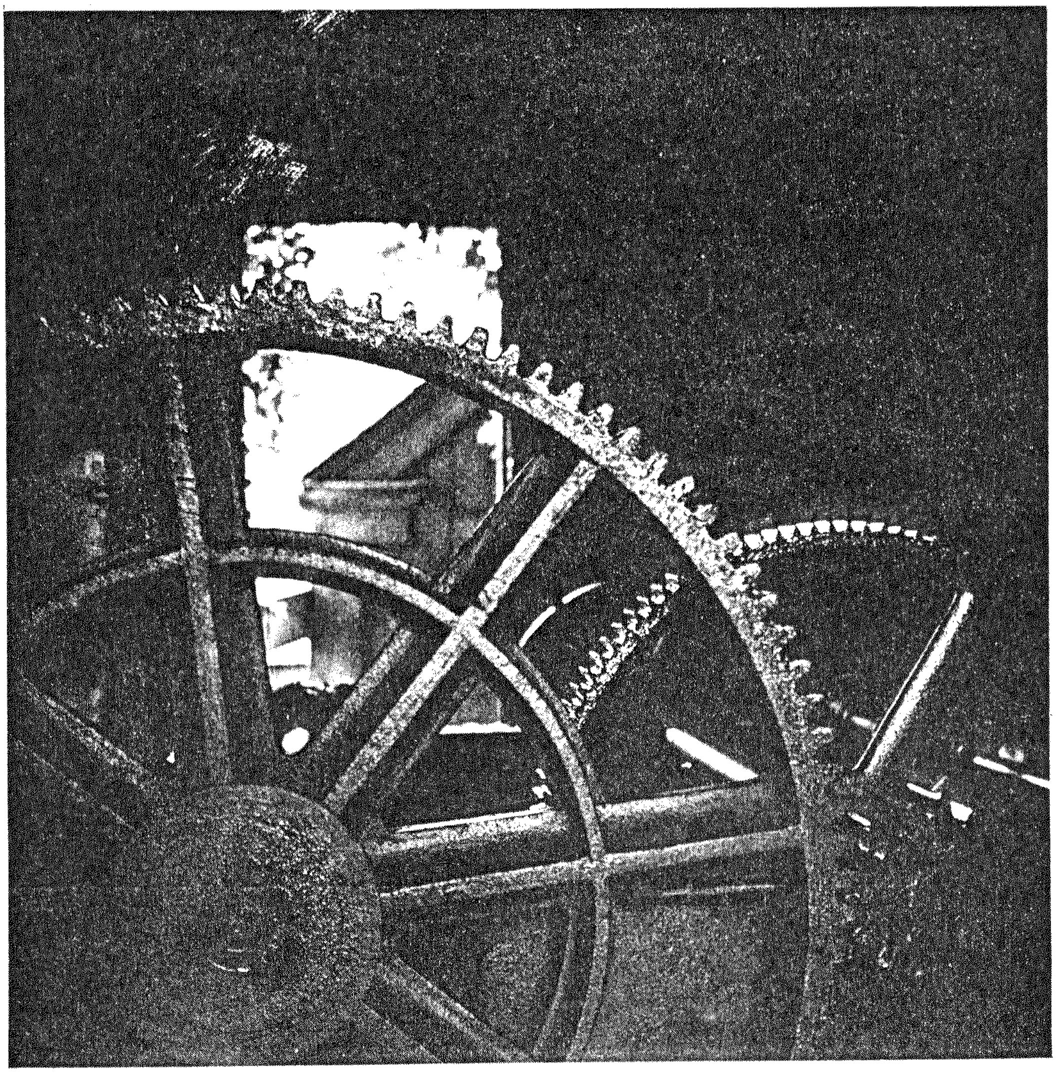

CANAL SYSTEM
-1825-
0
1,000'
2,000'
3,000'
N
RIVER
MERRIMACK
PAWTUCKET FALLS
PAWTUCKET DAM
MERRIMACK MILLS
INNER CANAL
MERRIMACK WASTEWAY
DAM
MERRIMACK CANAL
CANAL GATES
LOWER LEVEL PAWTUCKET CANAL
LOWER LOCKS DAM (17' FALL)
CONCORD
GUARD LOCKS
UPPER LEVEL PAWTUCKET CANAL
SWAMP LOCKS DAM (13' FALL)

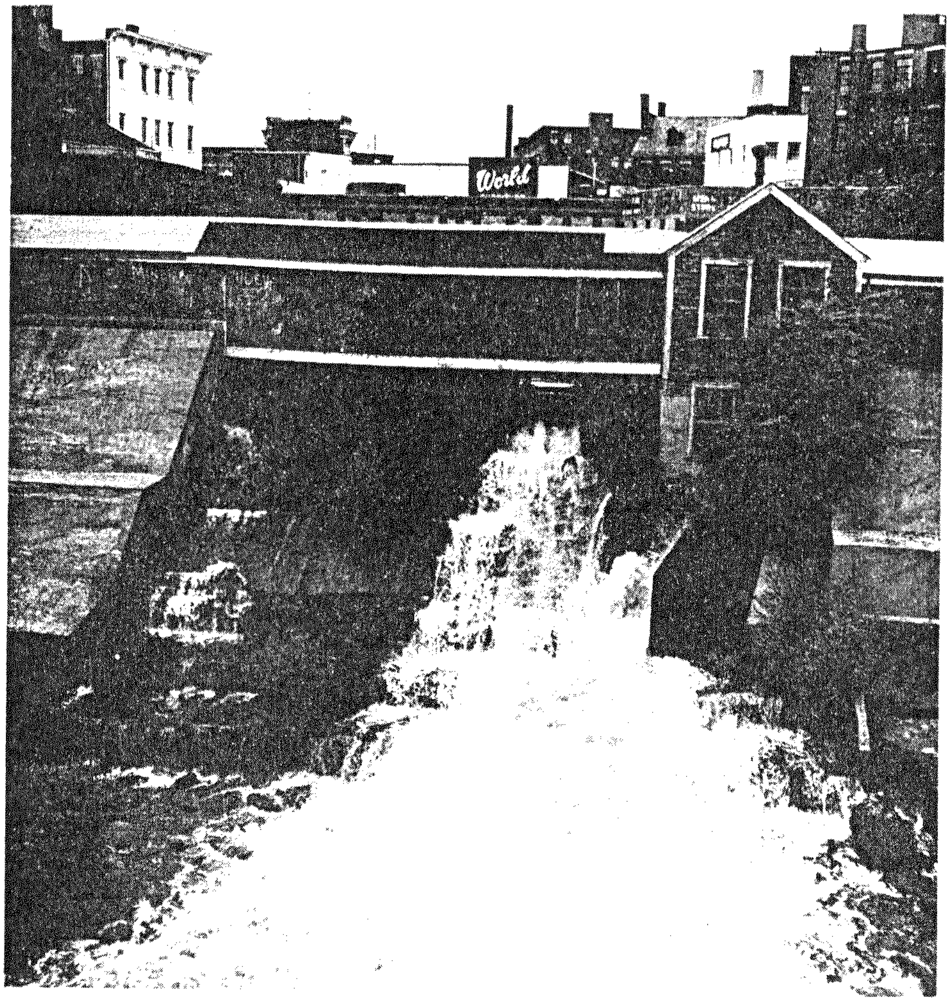
FIGURE 2

The above improvements, all completed by 1825, are shown in Fig. II. The canal system at this time worked in the following manner. The Pawtucket dam slowed and held back the water approaching Pawtucket Falls; this effected a rise in the Merrimack River. Water diverted into the Pawtucket Canal above the dam flowed down to the Guard Locks, where gate controls determined the amount of water allowed to flow further into the system. Before the second set of locks was reached, the water was divided, running into the Merrimack Canal as well as the Pawtucket. At the end of the Merrimack Canal the water passed through gates into underground penstocks leading to the Merrimack Company's wheel pits. Here the water fell onto wooden breast wheels thirty feet in diameter and twelve feet wide. The water entered buckets near the top of the wheels and because of its weight caused the wheels to spin.[20] At almost the bottom point of the wheels' rotation the water fell from the buckets and flowed through wasteways back to the Merrimack River. Gears, drive shafts, and leather belts transmitted power from the waterwheels to individual machines throughout the mills.[21]

The water that did not enter the Merrimack Canal continued down the Pawtucket to the Swamp Locks. At the Swamp Locks dam the water dropped approximately thirteen feet into the "lower level" of the Pawtucket Canal. (Water passed over the dam or was sent through sluice gates or the set of locks on the side.) This water level in turn was maintained until the Lower Locks were reached. Here the water made its final descent of about seventeen feet, again passing over a dam or through sluice gates or locks. The water then entered the Concord and flowed back to the Merrimack. In 1825, then, the Merrimack was an operating power canal, while the Pawtucket served as a feeder and, with its locks, as a transportation canal.



Gear Wheels -
A set of gears used
to control sluice gates
at the Swamp Locks.



The Final Dam on the Pawtucket Canal -
A drop from the lower level canal
down to the Concord River.

The Merrimack mills, as expected, used only a fraction of the water power available at Lowell. By 1825 the owners of the Merrimack Company were planning further construction of canals and the sale of land to other textile companies.[22] They decided to set up a separate corporation to sell land and water power, build canals and mills, and supply textile machinery. This corporation would maintain the expanded canal system but would not manufacture any cloth. The Merrimack Company thus sold its water power and unused land in 1825 to the Proprietors of Locks and Canals, the same corporation which the company had bought out in 1822. "Locks and Canals" then began the construction of new canals to bring water power to additional mill sites, and the Merrimack Company turned its attention to the production of textiles.[23]

The first project in this new era of canal building was the Hamilton Canal, completed in 1826.[24] 1,771 feet long, the Hamilton ran from the Swamp Locks basin on a line parallel with the lower level of the Pawtucket Canal. This canal served as a power source for the Hamilton Mills (incorporated 1825) and the Appleton Mills (inc. 1828). While the Merrimack Company operated off a fall of thirty feet, these companies utilized a thirteen-foot fall and breast wheels of the same diameter.[25] Water from the Hamilton flowed through these mills and discharged via raceways into the Pawtucket Canal below the Swamp Locks dam.[26]

The Locks and Canals Company completed the Lowell Canal in 1828. This short canal, only 500 feet long, ran from the Merrimack Canal through the yard of the Lowell Manufacturing Company (inc. 1828).[27] After dropping thirteen feet through the Lowell Mills' wheel pits, the water entered the lower level of the Pawtucket at a point nearly opposite the raceways of the Hamilton Mills.

In 1830 the Proprietors of Locks and Canals planned the construction of yet another canal, one that would supply power to three new textile mills. The

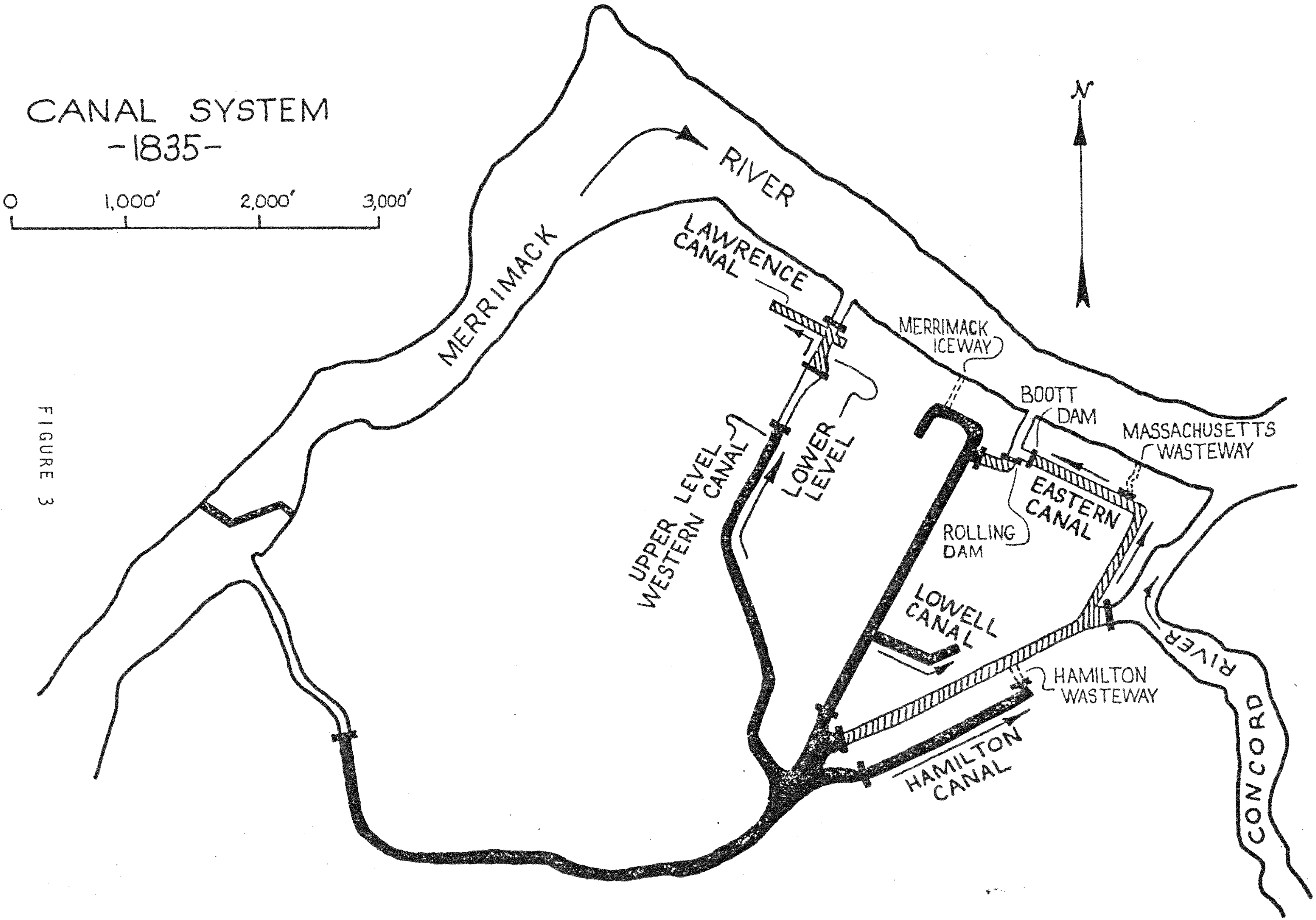

CANAL SYSTEM
-1835-
0
1,000'
2,000'
3,000'
N
MERRIMACK
RIVER
LAWRENCE CANAL
MERRIMACK ICEWAY
BOOTT DAM
MASSACHUSETTS WASTEWAY
UPPER LEVEL WESTERN CANAL
LOWER LEVEL
EASTERN CANAL
ROLLING DAM
LOWELL CANAL
HAMILTON WASTEWAY
HAMILTON CANAL
CONCORD
RIVER

FIGURE 3

Western Canal was dug in 1831-1832 at a cost of $70,000.[28] Almost a mile in length, the Western, like the Merrimack and Hamilton Canals, drew its water from the upper level of the Pawtucket at the Swamp Locks Basin. As pictured in Fig. IV, the Western Canal was divided into two levels. The first level served the Tremont and Suffolk Mills (inc. 1830). The fall from this level through the mills was thirteen feet. Mill raceways running under the mill yards carried discharged water to the canal's lower level.[29] (Water could also enter the lower level via the Tremont wasteway.) This lower level provided power for the Lawrence Company's mills, situated on a branch of the Western called the Lawrence Canal. Water passing through the Lawrence dropped seventeen feet and discharged into the Merrimack River. By dividing the Western into two levels the Locks and Canals Company sent the same water into more than one mill, first dropping it through the Tremont or Suffolk, and then through the Lawrence Mills.

In 1830, when plans were being drawn for the Western Canal, provisions were also made for the only mill which derived power directly from the lower level of the Pawtucket Canal.[30] The Middlesex Mill (inc. 1830) was unique in several ways. Unlike all the other major mills in Lowell, the Middlesex was a woolen, not a cotton, mill. And its power came not from the Pawtucket alone, but also from the Concord River (Fig. V). The fall from the Pawtucket through the Middlesex Mill was seventeen feet.

While the lower level of the Pawtucket directly helped to power only one mill, it did serve as a feeder to the Eastern Canal, constructed in 1835 at a cost of $35,000.[31] A waterway of 1,913 feet, the Eastern branched off from the old canal just above the Lower Locks.[32] From there it ran on a course perpendicular to the Merrimack River. Then, making a ninety-degree bend to the left, the canal ran parallel to the Merrimack River but in the opposite direction. Along its route were gates that admitted water into the Prescott, Massachusetts, and

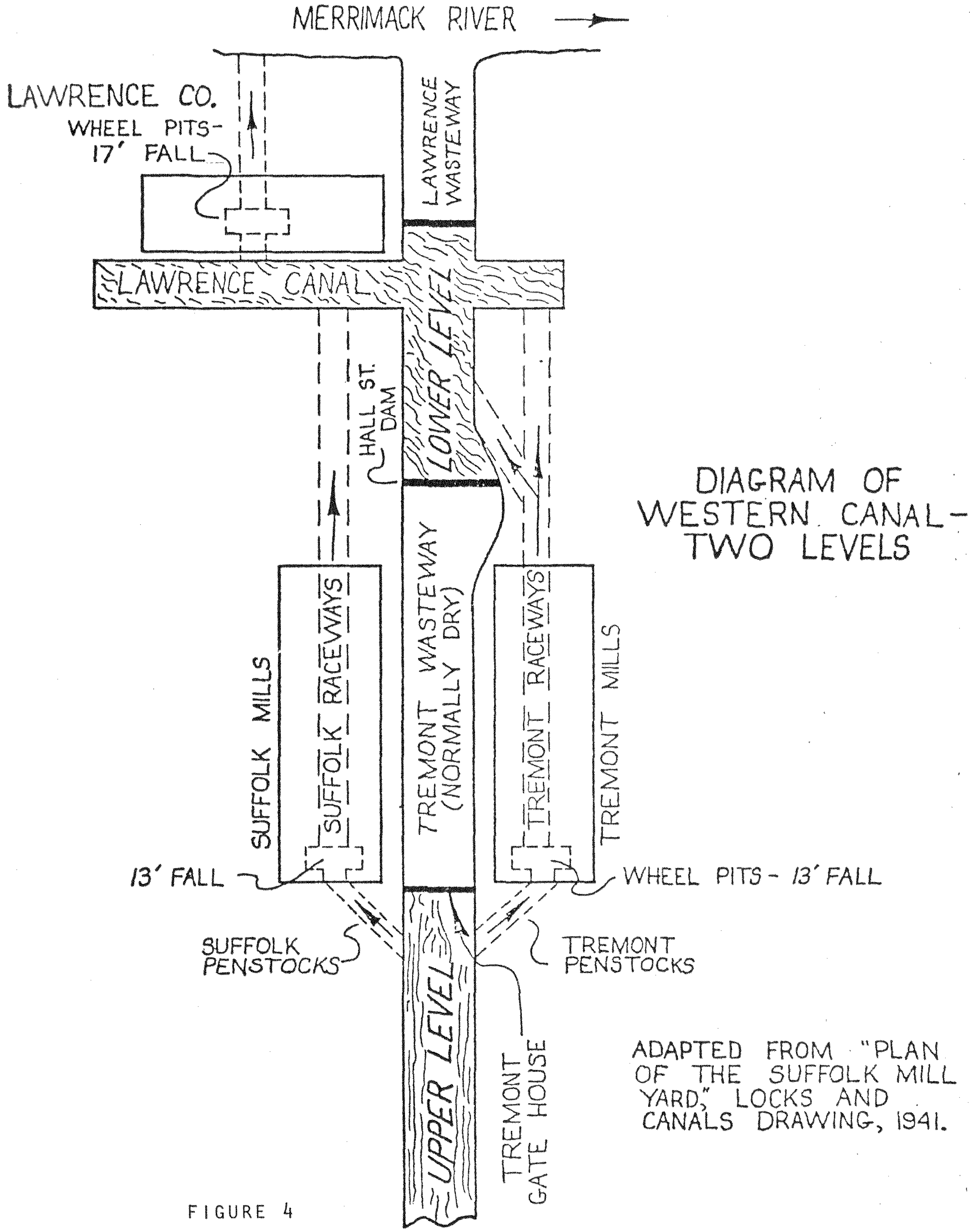

MERRIMACK RIVER
LAWRENCE CO.
WHEEL PITS-
17′ FALL
LAWRENCE WASTEWAY
LAWRENCE CANAL
LOWER LEVEL
HALL ST. DAM
DIAGRAM OF WESTERN CANAL- TWO LEVELS
SUFFOLK MILLS
SUFFOLK RACEWAYS
TREMONT WASTEWAY (NORMALLY DRY)
TREMONT RACEWAYS
TREMONT MILLS
13′ FALL
WHEEL PITS - 13′ FALL
SUFFOLK PENSTOCKS
TREMONT PENSTOCKS
UPPER LEVEL
TREMONT GATE HOUSE
ADAPTED FROM "PLAN OF THE SUFFOLK MILL YARD," LOCKS AND CANALS DRAWING, 1941.

FIGURE 4

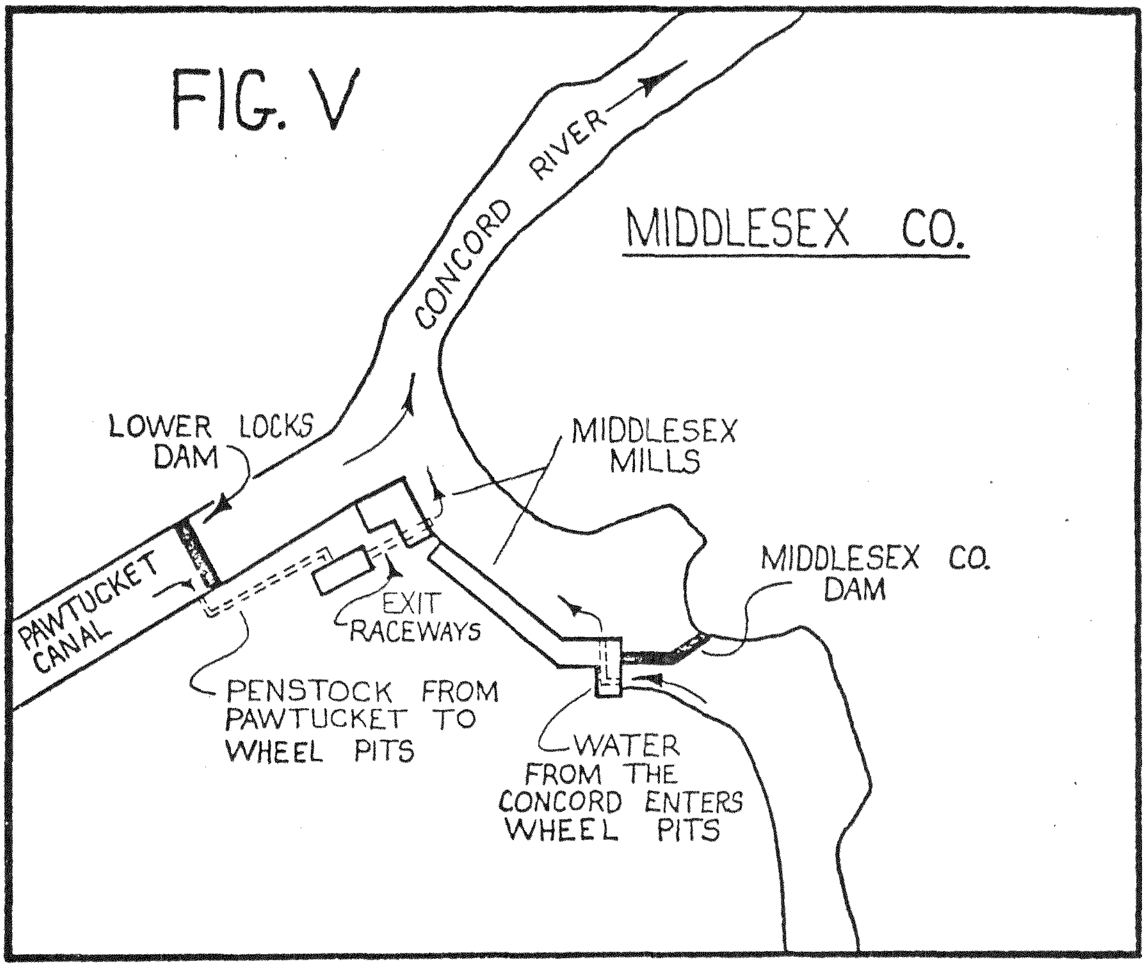
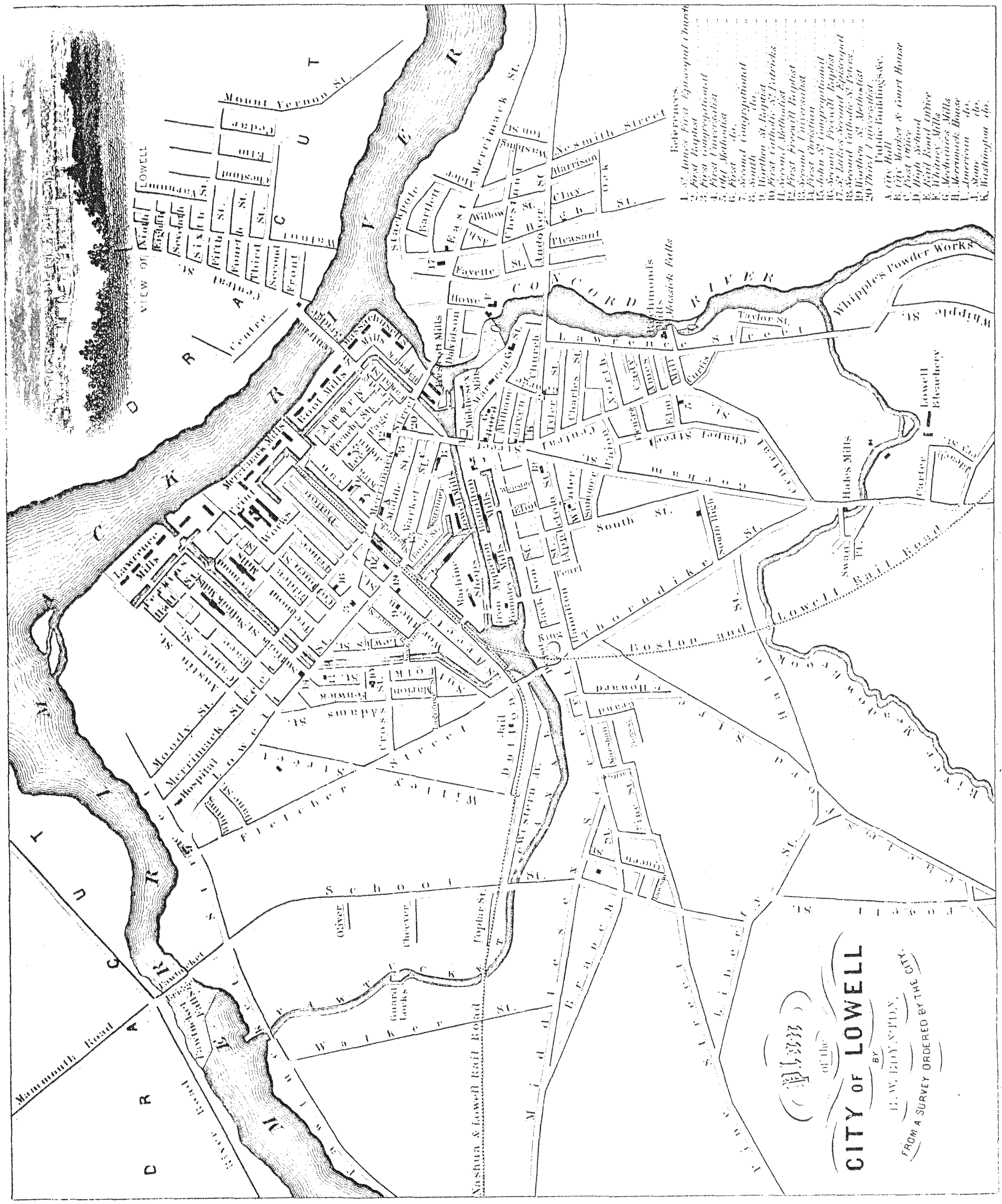


FIG. V
CONCORD RIVER
MIDDLESEX CO.
LOWER LOCKS DAM
MIDDLESEX MILLS
MIDDLESEX CO. DAM
PAWTUCKET CANAL
EXIT RACEWAYS
PENSTOCK FROM PAWTUCKET TO WHEEL PITS
WATER FROM THE CONCORD ENTERS WHEEL PITS

FIGURE 5



III. City of Lowell - 1845 - by G. W. Boynton

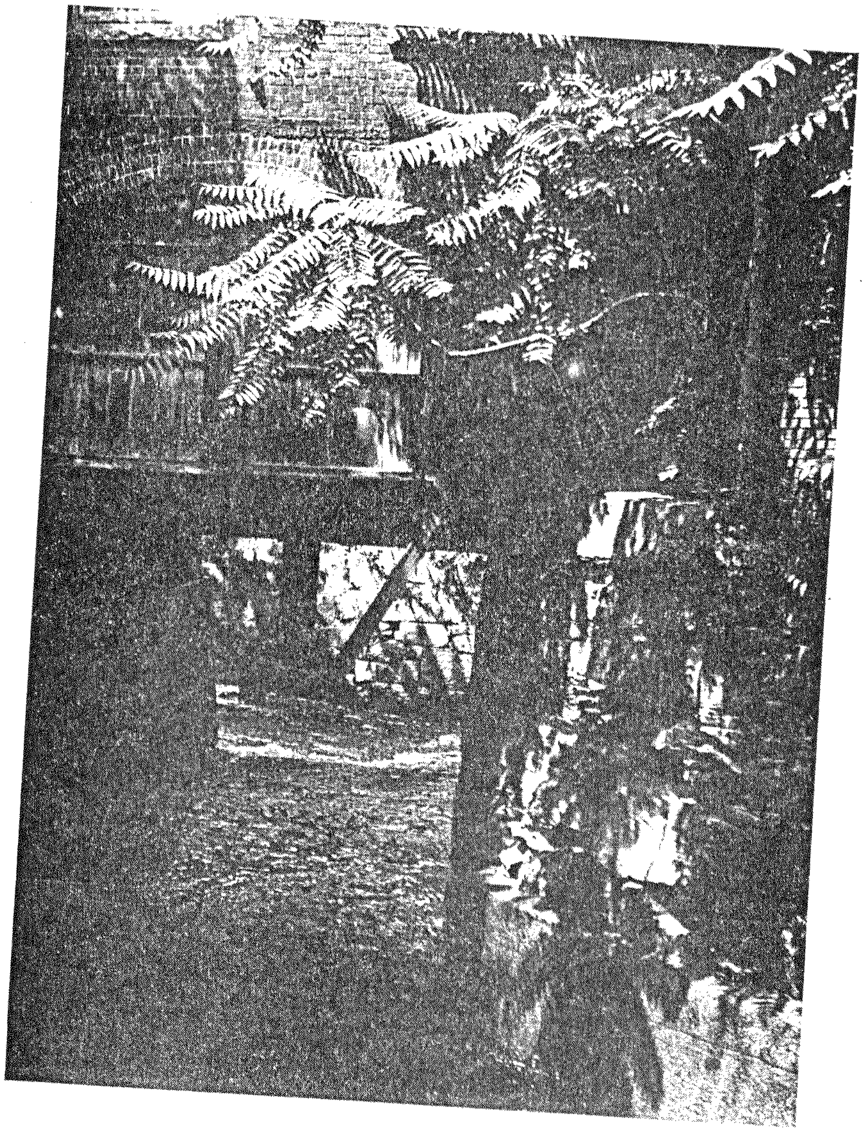
Collection of the Lowell Historical Society

FIGURE 6

Boott Mills. Each operated from a seventeen-foot fall. The Prescott Mill discharged into the Concord River; the Boott Mill into the Merrimack River; and the Massachusetts Mill into both. The construction of the Eastern completed the canal system as laid out in 1825.

The Proprietors of Locks and Canals granted each mill company in Lowell the right to draw water power in definite quantities called mill powers. For every mill power granted to a company, the company obtained the right to draw so many cubic feet of water per second for fifteen hours of each working day. The Merrimack Company, for example, was granted 24.67 mill powers, each of which gave it the right to draw 25 cubic feet of water per second over its thirty-foot fall. The Locks and Canals Company, therefore, was obliged to deliver a minimum of 616.75 cubic feet of water per second to the Merrimack Mills (24.67 X 25). Mills operating on a lesser fall were granted more water per second. Those on a fall of seventeen feet were granted 45.5 cubic feet of water per second per mill power; on the thirteen-foot fall each mill was to receive 60.5 cubic feet per second per mill power.[33]

Supplying each mill with the promised amount of water was not an easy task, and the two-level system only complicated the problem. On the Western Canal, for example, the Tremont and Suffolk corporations received water directly from the upper level of the canal. The water from their wheels then emptied into the lower level of the canal to run the Lawrence mills. If the Tremont and Suffolk mills did not discharge water at a rate at least equal to the intake of the Lawrence mills, then the water level in the lower canal would drop, and the Lawrence mills would not have adequate power. In such a case the Proprietors of Locks and Canals would have to send additional water through the Tremont wasteway, an undesireable expedient because water power would be wasted by bypassing the upper level mills. A similar arrangement at the



The Boott Wasteway -
Water leaving the Eastern Canal
at the Boott Mill is rushing
back to the Merrimack River.

Swamp Locks could send additional water through sluice gates from the upper to the lower level Pawtucket, but sometimes the total supply of water was insufficient to keep all the canals at their proper levels.[34]

Regardless of such arrangements, by the early 1840's the capacity of the Lowell canal system was outgrown. Textile companies had built large mill complexes and each mill building within a complex usually had two or three breast wheels. Also, the number of textile machines had greatly increased, and they ran at much higher speeds than earlier equipment. The Lowell mills had operated 116,000 spindles in 1835, but the companies were pushing for greater productivity and constantly expanding their operations. In 1848 the number of spindles would reach 300,000.[35]

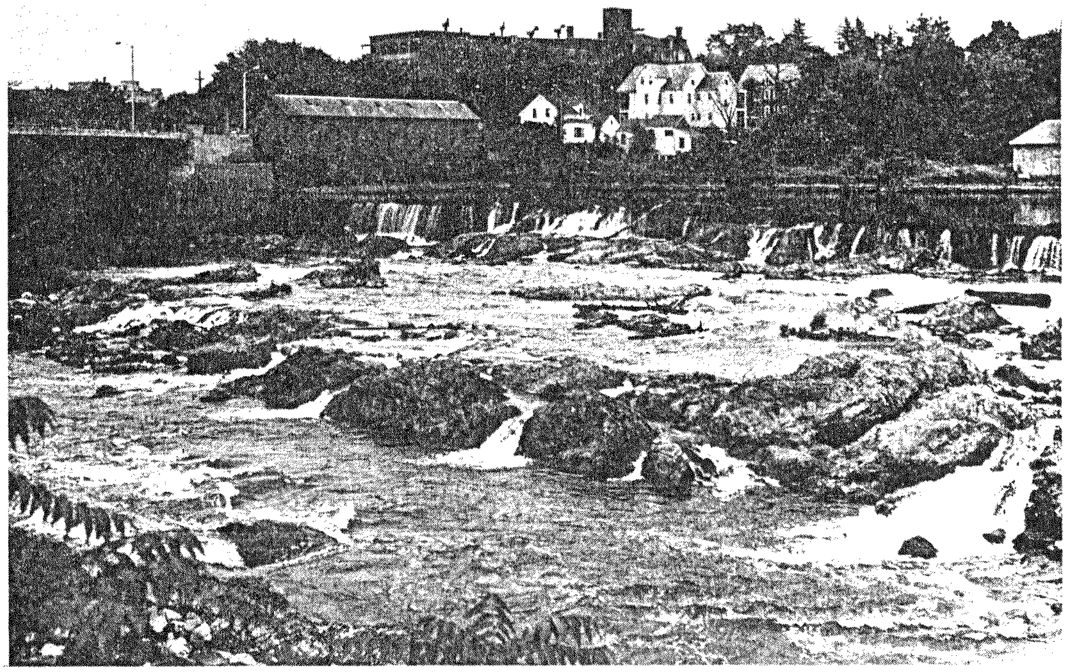
The Locks and Canals Company was hard-pressed to provide individual corporations with all the water they wanted. In an attempt to correct this situation, the company was reorganized in 1845. Private stockholders would no longer run the company; instead the textile corporations using the canal system would take control, holding shares in the same proportion in which they held water rights.[36] The company would use its capital resources to make the improvements necessary to supply the allocated power demands of each mill complex.

Unusual periods of drought in the early 1840's had created apprehension among the Lowell corporations because of falling water levels in the Merrimack River and the canal system.[37] An immediate task for the reorganized Locks and Canals Company was to make the river a more dependable source of power by increasing the water available at Lowell during dry months.[38] To accomplish this, in 1845 the company purchased the outlets of several lakes in New Hampshire that fed the Merrimack River. Ownership of these outlets and of the rights to control the flow of water through them allowed Locks and Canals to construct dams at each outlet and to hold back surplus water in the spring.

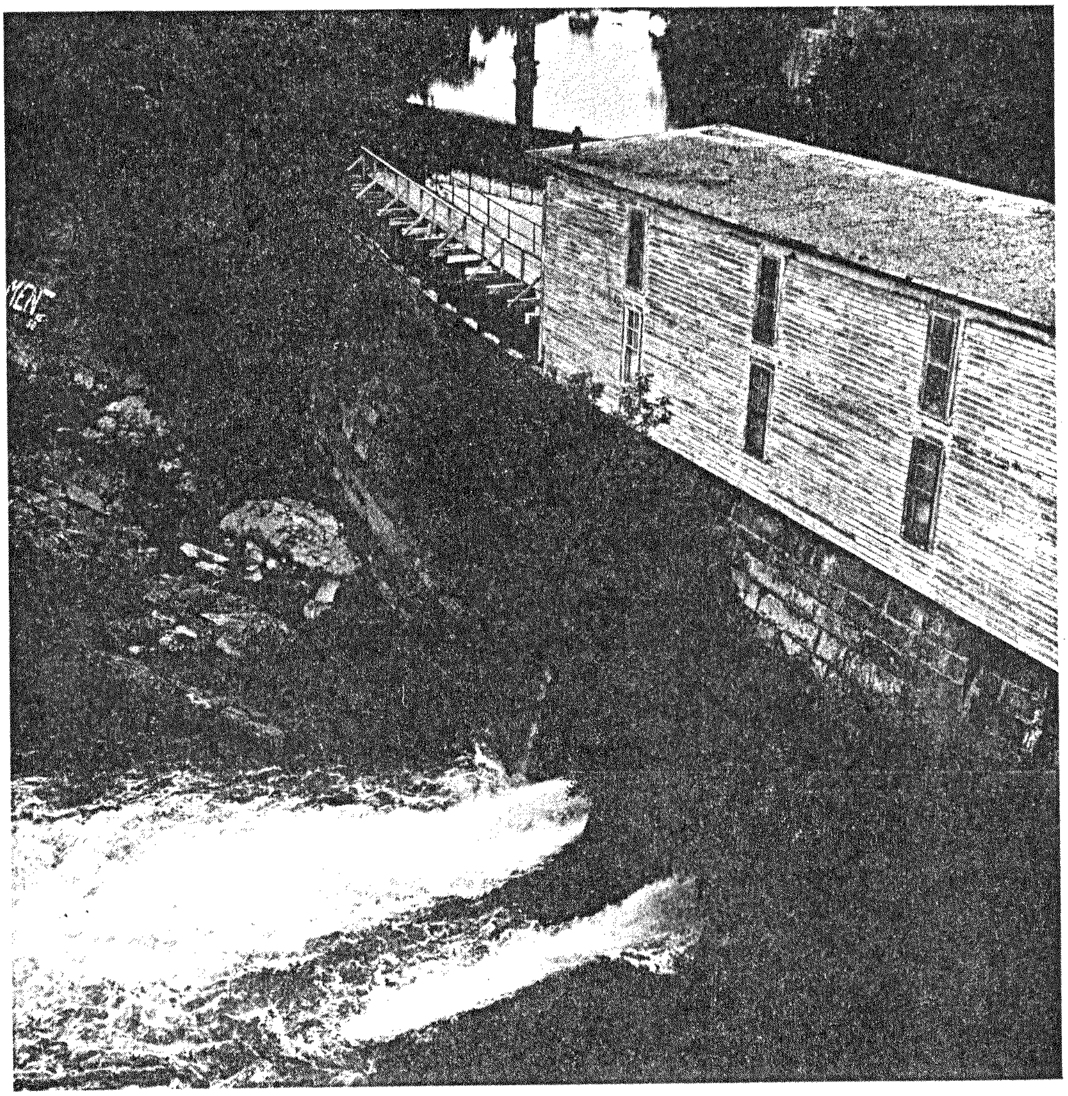
The company thus created reservoirs which totalled one hundred square miles in area and stored water at a depth of three to five feet.[39] The water was released to raise the level of the river when needed. A similar water conservation program at Lowell kept water from flowing through the canals when the mills were not in operation. Closing the first gates on the Pawtucket canal on Sundays, at night, and at other non-working hours, caused water to pond in the broad channel above Pawtucket Dam. When the mills reopened again, the retained water supplemented the river's normal flow.[40]

The reservoirs provided more water for the Merrimack; a new canal was needed to bring that water into Lowell. Under the greater demands for water, the Pawtucket Canal had proved too small as a feeder into the system. The strong currents produced by increased amounts of water coursing through the Pawtucket's narrow channel and the even more constricted channel of the Western Canal actually impeded the action of the breast wheels in Lowell mills.[41] James B. Francis, engineer for the Locks and Canals Company, sought to solve this problem by designing a new canal that would reduce the current in the canal system and provide "a fuller head," or greater height, of water "in all of the several canals that feed water into the flumes of the various mills."[42] A fuller head of water in the canals meant a greater fall through the mills, which in turn meant an increase in the power available to drive machinery.

The Northern Canal, completed in 1848, took eighteen months to construct and cost $500,000. Built of granite, as were Lowell's other canals, its 4,373-foot length ran from the eastern end of the Pawtucket Dam to the upper level of the Western Canal, just above the Suffolk and Tremont Mills. The dam was modified at the same time to channel water more directly into the new canal. The Northern was generally 100 feet wide and fifteen feet deep; in those places where the width was less than 100 feet, the channel was made deeper.[43] The head gates on the Northern, located in the gatehouse beside the Pawtucket Dam, were



Pawtucket Falls -
The Pawtucket Dam leads to the
gatehouse of the Northern Canal.



<u>The</u> <u>Northern</u> <u>Canal</u> -
Water is flowing from the canal
through discharge gates
into the Merrimack River.

water-powered by a Francis turbine and worked so smoothly that they were shut when necessary at noon to pond and retain otherwise wasted water.[44] Discharge and dredging gates were located in the wall separating the canal and the Merrimack River. (All the canals in Lowell had wasteway systems so that individual canals could be drained for the purpose of making repairs or removing accumulated rubbish and silt, tasks usually performed on Sundays so as not to interfere with production in the mills).[45] The banks of the Northern were "lined with a double colonnade of trees, tastefully laid out, with green plats, and beautiful summer prominades[sic]."[46] This, the greatest of Lowell's power canals, was the fashionable place to walk on warm, sunny days. One resident described the scene which attracted every level of society in Lowell, from laborers and female operatives to mill executives:

> Years ago, it was one of the sights of the city, for its citizens on Sunday afternoons, to promenade from Cabot Street along the side of the Northern Canal, up toward Pawtucket Street under the high bridge; and along the stone dividing wall, between the canal and the river, thence to the Pawtucket Falls bridge. The writer clearly recalls the hundreds, who enjoyed the walk, which presented a singularly attractive view of its entire length, and was known as the Canal Walk.[47]

The Northern Canal had an impact on Lowell's social history; it also radically changed the operation of the canal system (Fig. VII). First, it increased the falls through the various mills by one to three feet, giving thirty-three feet of fall to the Merrimack Company, fourteen feet to the other mills on upper level canals, and a final nineteen feet to mills on the lower level canals.[48] Second, the large supply of water in the Northern turned the Western Canal's current around and sent water flowing back to the Swamp Locks' basin for further distribution in the system.[49] While the Northern now supplied

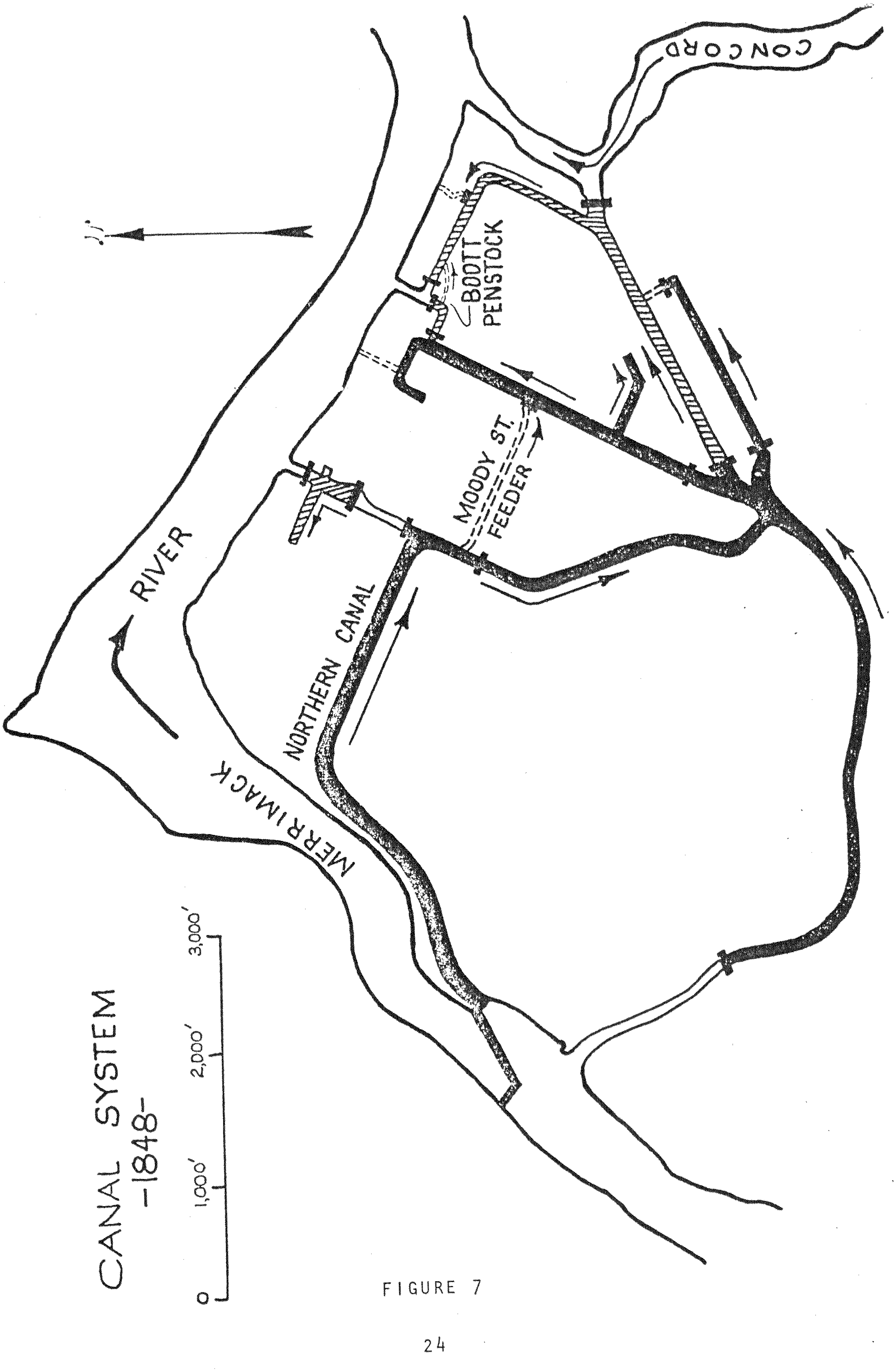

CANAL SYSTEM
-1848-
0
1,000'
2,000'
3,000'
MERRIMACK
RIVER
NORTHERN CANAL
MOODY ST.
FEEDER
BOOTT
PENSTOCK
CONCORD

FIGURE 7

water power directly to the Tremont and Suffolk mills, and indirectly to the Lawrence mills, the Western Canal became an important supplement to the flow of the upper level Pawtucket Canal at the basin where the Hamilton and Merrimack Canals branched from it.

Another part of the Northern Canal plan was the construction of the Moody Street Feeder, an underground waterway also completed in 1848. 1,375 feet long, this trunk connected the Western and Merrimack Canals.[50] The Moody Street gates, when necessary, allowed water to flow from the Western to the Merrimack, contributing to the supply of the Merrimack Mills.

The Moody Street Feeder also functioned as a "regulator to the Boott [Eastern] Canal."[51] This process appears to have worked in the following manner.[52] The Moody Street Feeder, gates open, raised the head of water in the Merrimack Canal. With a surplus in the Merrimack, water could be sent through gates at the Merrimack dam. Here the water dropped about fourteen feet, putting it nearly on a level with the Eastern Canal. A gate located in the rolling dam gate house could then be opened to send this water into the Boott Penstock, a channel running alongside the Eastern but in the opposite direction. Openings in the Boott Penstock released additional water into the larger canal, thus helping to regulate its head of water.

The Northern Canal and the Moody Street Feeder were the last waterways constructed by the Proprietors of Locks and Canals. The company, continued, however, to superintend the use of the canals, to make additional improvements, and to devise ways of gleaning more power from the water of the Merrimack River. The great machine shop of the company produced improved hydraulic machinery and other equipment that put into practical application the results of scientific experiments conducted by James Francis and other Locks and Canals engineers.[53]

James Francis was one of the world's greatest hydraulic scientists as well as a highly successful practicing engineer. Born in England in 1815, he received practical engineering training on British harbor and canal projects and on American railways. In 1834 he came to Lowell as the assistant engineer to Major George Whistler. When Whistler went to Russia to introduce railway technology in 1837, Francis became the chief engineer of the Proprietors of Locks and Canals. For almost half a century he held that important post and used the canals of Lowell as his scientific laboratory. His extensive series of experiments on water flow and turbine design brought him international acclaim and a respected position in the scientific community. Part of his work, published as Lowell Hydraulic Experiments in 1855, was widely read by European experts. It was republished in an expanded edition which became a standard work in the field of hydraulics.

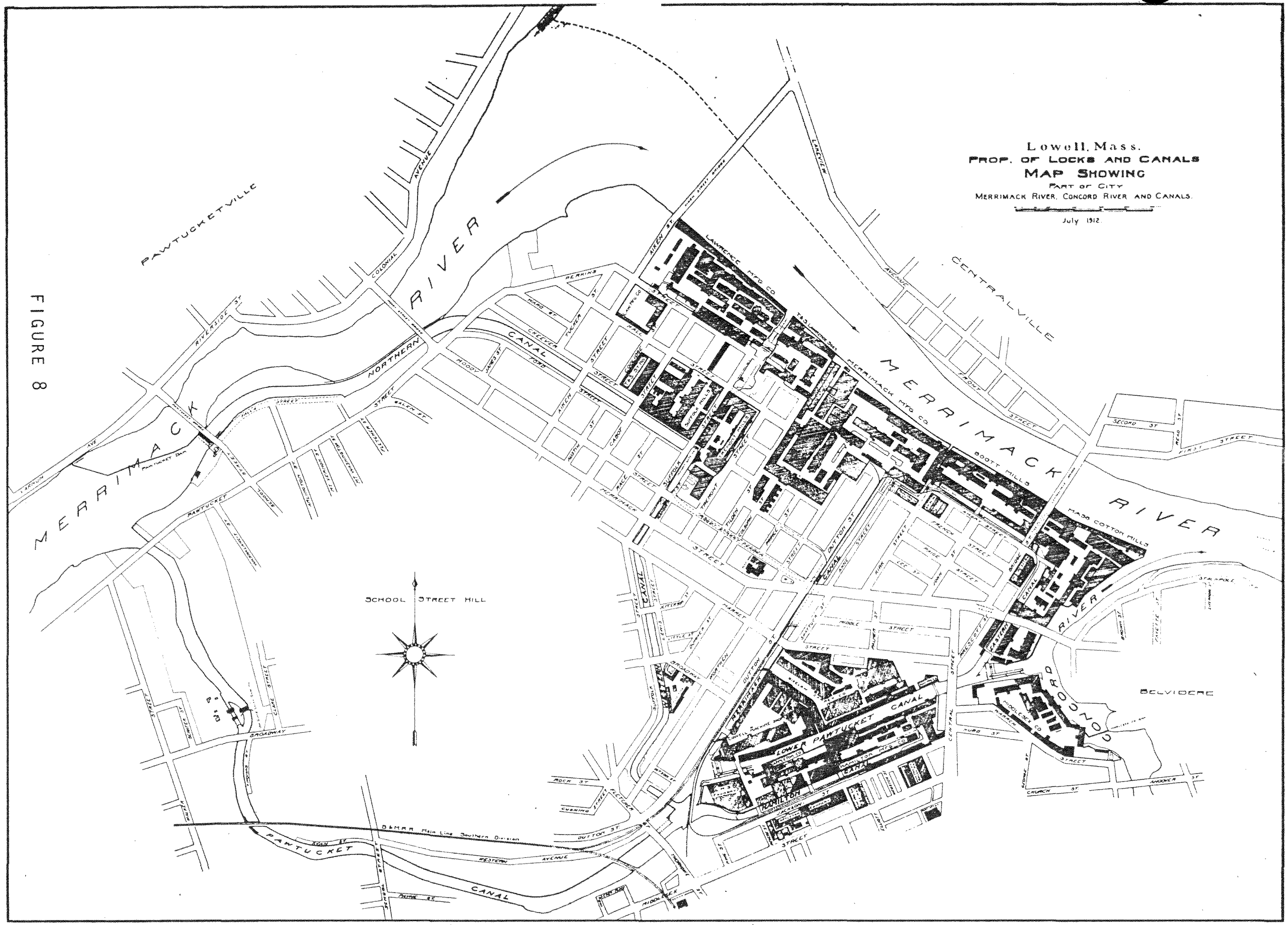
Francis kept abreast of the latest scientific work abroad while conducting painstaking experiments of his own. He served as a consultant on many engineering projects in the United States and produced learned papers for numerous professional and scientific societies. His work for the Proprietors of Locks and Canals included pioneering efforts in industrial research, conducted with the highest degree of scientific accuracy and often leading to the solution of important engineering problems. Here science, perhaps for the first time, exerted a regular and profound influence on technology.

In 1850 the canal company installed a flood gate at the Guard Locks on the Pawtucket Canal. This improvement, called Francis' Folly by skeptics at the time, was the result of a study made by James Francis on the flow of the Merrimack River. In 1831 a freshet had caused a panic in Lowell as it momentarily threatened to break the guard gates on the Pawtucket. In his study Francis discovered that a freshet in 1785 greatly exceeded the one in 1831, and if such a freshet should occur again the old gates would be swept out and flood-waters would rush through the center of Lowell. To avoid such a catastrophe, Francis designed a solidly-timbered portcullis gate that could be dropped in an emergency. That emergency arose but two years after the gate was installed. In 1852 the Merrimack River rose to a level 14'1" above the crest of the Pawtucket dam. The Francis Gate was dropped--it held--and Lowell was saved from disaster.[54] (In 1936 an even larger flood coursed down the Merrimack River. The old gate was dropped, once again saving the city.)

Because of a continuing increase in the size of mills using the canal system, by the 1850's, even with the additional water supplied by the Northern Canal, it had become "a matter of necessity that every possible measure be taken to economize in the use of water."[55] One result of this economy drive was the drafting of a set of rules and regulations concerning the use of water power. James Francis, acting as "the Chief of Police of water," drew up and enforced these regulations.[56] He also tried to monitor the amount of water drawn by each mill but could not make any accurate measurements of this without setting up special tests. As a result, most checking on water usage was a matter of noting any unusual drop in the level of a canal.[57]

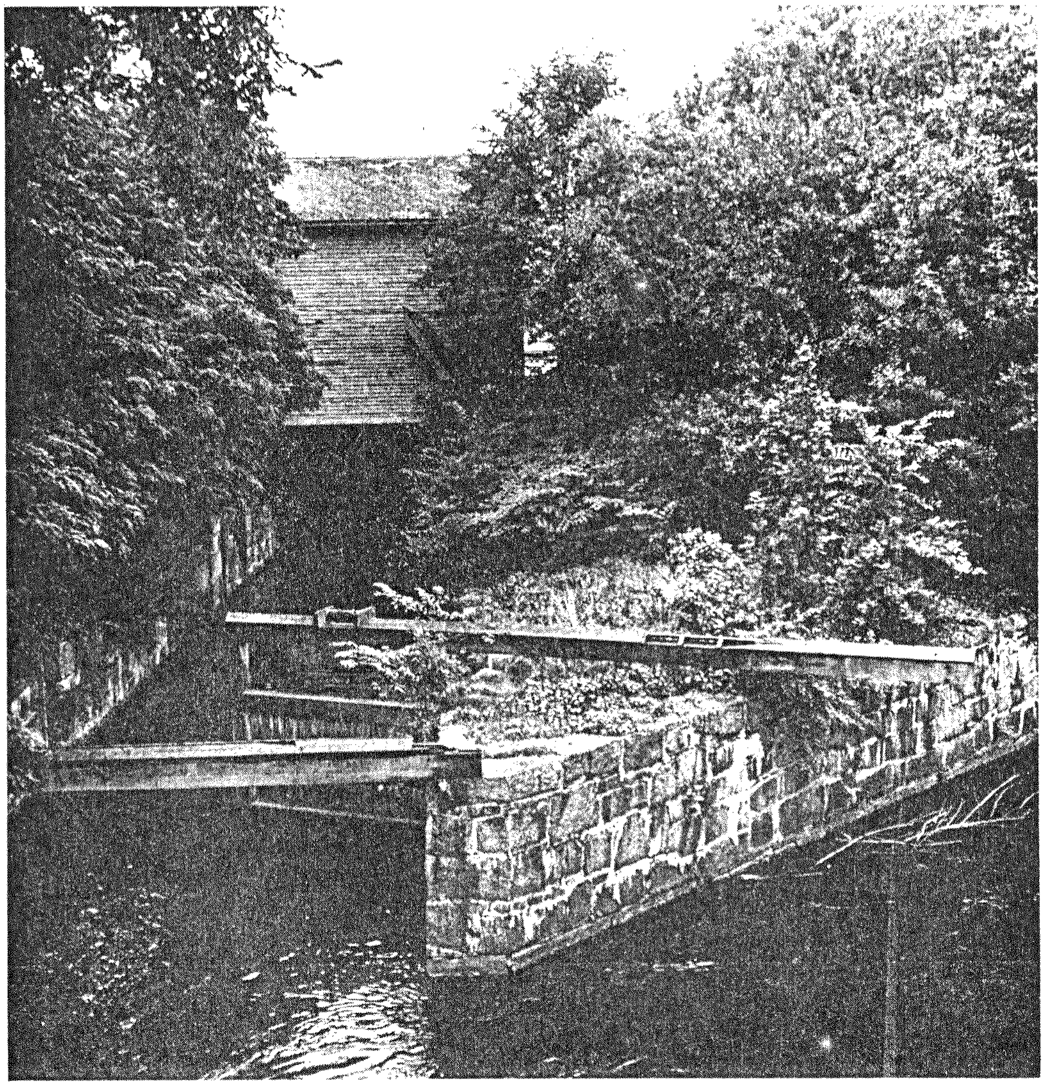
Another result of the economy drive was the development and installation of turbine wheels for Lowell mills. The importance placed upon getting peak efficiency from the water in Lowell is demonstrated in the contract negotiated

FIGURE 8

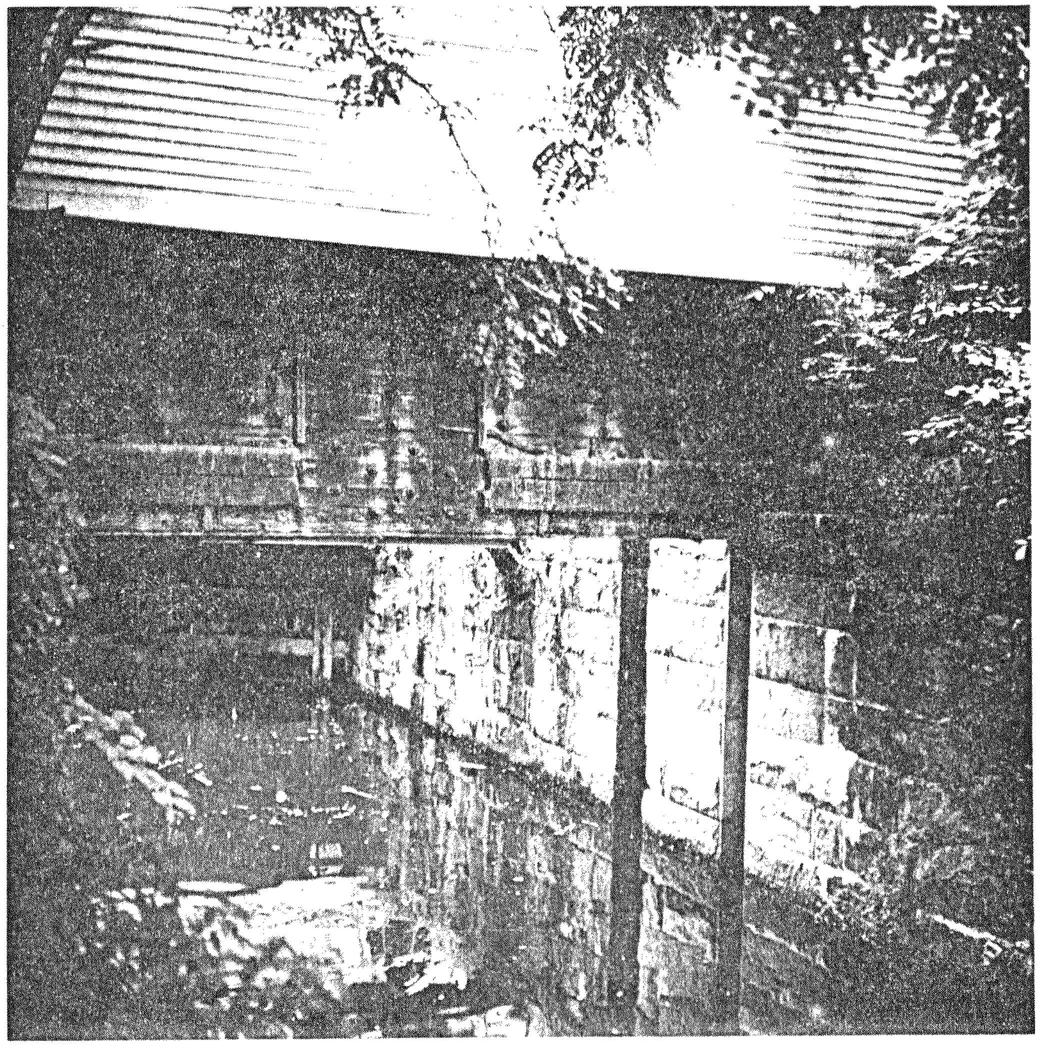


IV. Properties of Proprietors of Locks & Canals - 1912

Collection of the Lowell Historical Society



The Guard Locks -
The gates of a transportation lock are in the foreground with the elevated Francis Gate behind them.



The Francis Gate -
An elevated portcullus gate which can be
dropped to keep flood water out of the canal system.

between the Appleton Company and Uriah A. Boyden. Boyden had installed the first turbine in Lowell in 1844. In 1846 the Appleton Mills contracted him to produce three more turbines. Under the terms of the contract, Boyden's compensation depended upon their performance:

> ...if the mean power derived from these turbines be seventy-eight per cent of the water expended, the Appleton Company to pay me [Boyden] twelve hundred dollars for my services, and patent rights for the appartus for these mills; and if the power derived be greater than seventy-eight per cent, the Appleton Company to pay me, in addition to the twelve hundred dollars, at the rate of four hundred dollars for every one per cent of power, obtained above seventy-eight per cent.[58]

Francis, as stipulated in the contract, tested the Boyden turbines with a dynomometer. The mean power derived was eighty-eight per cent, and Boyden received an extra $4,000 for his work, a total of $5,200. The Appleton Company, hoping for such an increase in efficiency, paid Boyden the higher sum with no objections.[59]

Francis recognized the important increase in power gained by switching from breast wheels to turbines. He estimated that the older wheels were only about sixty percent efficient in transmitting the power of falling water. Aware of the smaller turbines' multiple advantages, Francis purchased Boyden's patent rights and spurred the Locks and Canals Company to build efficient turbines and to install them in the mills of Lowell beginning in the late 1840's.[60]

The complete canal system in Lowell included 5.6 miles of waterways operating on two levels and providing the power for ten mill complexes and a machine shop.[61]

European engineers had pioneered in the development of power canals before the founding of Lowell, but they had never built a system with the size and complexity of Lowell's. Within the city, canals and the mills they powered were the dominant features of the urban landscape. Corporate housing, private businesses, and homes were built only where they did not interfere with the routing of water power and the production of textiles. The first priority in the development of Lowell was to bring water power to the best mill sites.

The great mills on the canal system nearly formed a ring around the center of Lowell.[62] Mill yards blocked obvious paths for streets to connect certain sections of the city. The street plan became a disjointed pattern of separate grids and radial projections. But despite the difficulties of building a city around and among the mills and canals, Lowell grew fantastically from 1822 to 1850. By the latter date, the rural area with two hundred inhabitants had become a great industrial city of 33,383.[63]

The canal system and the massive river which fed it enabled Lowell to prosper. Both the man-made canals and the natural waterway were also things of beauty and a delight to Lowell residents since the founding of the city. In 1920 a citizen of Lowell expressed the gratitude which many still feel for the water which built their city:

> But for the fact that we had, and still have, within our borders, the noble and majestic Merrimack River, it is possible that Lowell, or Chelmsford, as it was then named, would have remained a country town.[64]

FOOTNOTES

[1] Henry A. Miles, Lowell As It Was, And As It Is (Lowell, 1845), p. 14.

[2] Charles Cowley, History of Lowell (Boston, 1868), p. 25.

[3] Edward W. Thomas, "A Retrospect of the Early Manufacturing in the City of Lowell," in Lowell Historical Society Contributions, II, 463.

[4] An excellent map of the Middlesex Canal is contained in "The Middlesex Canal," a pamphlet published by the Middlesex Canal Association, Billerica, Massachusetts.

[5] Nathan Appleton, Introduction of the Power Loom and Origin of Lowell (Lowell, 1858), p. 14.

[6] Appleton, p. 19.

[7] Miles, p. 19.

[8] Cowley, p. 49.

[9] Appleton, pp. 23, 28; Cowley, p. 50.

[10] James B. Francis, "Statement of the Shares in the Proprietors of Locks and Canals," (Lowell: December 17, 1853).

[11] Cowley, p. 44.

[12] Appleton, p. 23.

[13] A. C. Meserve, Lowell--An Industrial Dream Come True (Boston, 1923), p. 47.

[14] "The Plan of the Land on the South Side of the Pawtucket Canal Belonging to the Merrimack Manufacturing Company--Chelmsford, June, 1824." Locks and Canals drawing, in the Rare Book Room of Lowell Technological Institute.

[15] Herbert E. Fletcher, "The Granites of Middlesex," Lowell Historical Society Contributions, II, 174.

[16] J. W. Meader, The Merrimack River--Its Sources and Its Tributaries (Boston, 1869), p. 250; James B. Francis, Lowell Hydraulic Experiments (Boston, 1855), pp. ix, x.

[17] John McEvoy, "Letter from John McEvoy," Semi-Centennial Celebration, p. 132.

[18] Illustrated History of Lowell (Lowell, 1897), p. 162; William E. Worthen, "The Life and Works of James B. Francis," Contributions of the Old Residents Historical Society, V, 234.

[19] Appleton, p. 25.

[20] James B. Francis, Lowell Hydraulic Experiments (Boston, 1855), p. 1.

[21] Charles T. Main, "Evolution of the Transmission of Water Power," in Lamb's Textile Industries of the United States, ed. by E. Eveton Foster (Boston, 1916), I, 231; Trade and Labor Council, Lowell: A City of Spindles (Lowell, 1900), p. 177.

[22] Miles, p. 30; Worthen, p. 234.

[23] Cowley, p. 48.

[24] Thomas, p. 463.

[25] "Annual Statistics on Manufactures in Lowell and Vicinity, 1835-1882," (Lowell: Vox Populi Press, 1882), pp. 22-23.

[26] Handbook for the Visitor to Lowell (Boston, 1848), p. 24.

[27] Thomas, p. 463.

[28] Miles, p. 37.

[29] Francis, Lowell Hydraulic Experiments, p. 8.

[30] Handbook, p. 24.

[31]Miles, p. 38.

[32]Thomas, p. 464.

[33]Francis, Lowell Hydraulic Experiments, p. x; Handbook, p. 25.

[34]"Report of the Commissioners appointed by the Director of the Proprietors of Locks and Canals on the Merrimack River, December 24, 1852, to adjust the Heights at which water shall be maintained in the Canals at Lowell," (Cambridge, 1881), p. 22.

[35]Handbook, p. 27; Thomas, p. 454; Worthen, p. 235.

[36]Cowley, pp. 49-50; Worthen, p. 233.

[37]Nathan Crosby, "Letter," in Semi-Centennial Celebration, p. 91.

[38]Handbook, p. 27.

[39]Ibid., p. 27; Crosby, pp. 91-92; Appleton, p. 35.

[40]James B. Francis, Lowell Hydraulic Experiments (Boston, 1868), p. x.

[41]Handbook, p. 25; Appleton, p. 35.

[42]Crosby letter, p. 92.

[43]Thomas, p. 463; Handbook, p. 25.

[44]Worthen, p. 235; Joseph Whitworth, "Special Report of Mr. Joseph Whitworth," The American System of Manufactures, ed. by Nathan Rosenberg (Edinburgh, 1969), p. 356.

[45]Easy Catechism for Elastic Consciences (Lowell, 1847), pp. 11-12.

[46]Cowley, p. 137.

[47]Thomas, p. 464.

[48] Meader, p. 250; Handbook, p. 26.

[49] Worthen, p. 235.

[50] Thomas, p. 464.

[51] Worthen, p. 235.

[52] This analysis is based upon an examination of the Lowell canal system, much of which remains intact. The following Lowell residents assisted in pointing out important features of the canal system: Mr. Joseph Kopycinski (Librarian, Lowell Technical Institute), Mr. Walter Coan (Master Mechanic, Proprietors of Locks and Canals), and Mr. Harry Dinmore.

[53] See, for example, Francis, Lowell Hydraulic Experiments (1855).

[54] Worthen, pp. 236-237.

[55] James Emerson, Treatise on the Manner of Testing Water-wheels and Machinery (Lowell, 1872), p. 5.

[56] Worthen, p. 235.

[57] Francis, Lowell Hydraulic Experiments (1868), pp. 144-148; Worthen, p. 233.

[58] Francis, Lowell Hydraulic Experiments (1855), pp. 2-3.

[59] Main, pp. 224-225.

[60] Ibid., pp. 224-225; Worthen, p. 233; Francis, Lowell Hydraulic Experiments (1855), pp. 1-2, 7-8.

[61] "Annual Statistics," p. 14.

[62] For discussions of Lowell's city plan see Coolidge, Mill and Mansion (New York, 1967), pp. 21-27; and Margaret Parker, Lowell: A Study of Industrial Development (New York, 1940), Chapter III.

[63] "Annual Statistics," p. 16.

[64] Thomas, p. 451.