Waterpower in Lowell: Engineering and Industry in Nineteenth-Century America is published by Johns Hopkins University Press in Baltimore, Maryland. The author, Patrick M. Malone, is Professor of American Civilization and Urban Studies and Director of the Urban Studies Program at Brown University. The book is a case study of the development of waterpower in Lowell, Massachusetts. Its thesis is that waterpower was the resource that made possible America’s first great industrial city. Lowell became a thriving center for textile production and machine building when Boston capitalists harnessed the energy of Pawtucket Falls, on the Merrimack River. The city’s remarkable economic success, efficient workforce, attractive architecture, and tree-lined canals made it a model for other communities.

Much of the book focuses on James B. Francis, an English immigrant who joined Lowell’s Proprietors of Locks and Canals as a young man in 1834 and rose rapidly to become both the company’s chief engineer and its managing executive. He was arguably the finest engineer in nineteenth-century America. For almost fifty years, his technical expertise guided the expansion and refinement of the two level canal system and the use of scientific engineering for flow measurement and turbine design. His promotion of corporate landscaping enhanced the built environment of Lowell.

The intended audience includes readers of American history, college students in courses dealing with urban or technological history, and visitors to the popular Lowell National Historical Park. The first chapter sets the stage for the creation of a new city by the falls. Then there are four chapters covering the period from 1821 to 1885, as well as a thematic chapter on scientific engineering and a postscript that brings the story to the present.

This is the first book about Lowell to make extensive use of material evidence, technical drawings, and engineering notebooks. Among its original contributions are close investigations of the role of the chief engineer in a power company that served multiple manufacturing complexes; the origins of American industrial research; the environmental impacts of waterpower development; the overlooked importance of hybrid steam/waterpower systems; and the occasionally tense relations between Lowell’s citizenry and its corporations.
Online Notes for *Waterpower in Lowell*

In order to reduce the length and cost of *Waterpower in Lowell*, the author and Robert J. Brugger, his editor at Johns Hopkins University Press, decided to limit the published notes to the quotations in the book. A much more complete set of notes (full citations) would be made available online for research scholars and other serious readers. You are now reading those online notes, which are stored at the American Textile History Museum (Chace Catalog) and at the Center for Lowell History of the University of Massachusetts Lowell. The author thanks archivists Clare Sheridan and Martha Mayo for including the complete notes to *Waterpower in Lowell* in the websites of their respective institutions. He is also grateful to Rebekah Souder-Russo, a student at Brown University, for helping him to compile the notes and put them in proper form for online use. Brown University generously provided a Humanities Research Grant to pay for this compilation. The online notes are referenced by page and paragraph number. They are much more extensive than the published notes, which are referenced by numbers in the printed text. Everything in the published notes is included here, but it is referenced by page and paragraph for online use. The paragraph numbers (#) refer to the order of paragraphs on a given page. If a paragraph continues to the next page, it is listed as the first paragraph on that page (not on the page where it begins).
Abbreviations in Citations

ATHM  American Textile History Museum
ASCE  American Society of Civil Engineers
ASME  American Society of Mechanical Engineers
CLH  Center for Lowell History, University of Massachusetts Lowell
CORHA  Contributions of the Old Residents’ Historical Association, Lowell, Mass.
JBF  James B. Francis
LHE  James B. Francis, Lowell Hydraulic Experiments
LNHP  Lowell National Historical Park
MMC  Merrimack Manufacturing Company
MHS  Massachusetts Historical Society
PL&C  The Proprietors of the Locks and Canals on Merrimack River
PL&C-Baker  Locks and Canals Collection, Baker Library Historical Collections, Harvard Business School
PL&C Directors  Records of the directors and proprietors, Proprietors of Locks and Canals Collection, Lowell National Historical Park
PL&C-LNHP  Proprietors of Locks and Canals Collection, Lowell National Historical Park
Introduction


p. 3, #4. Ibid., 298-299; Slater Mill, online data at Library of Congress, Historic American Engineering Record, HAER RI, 4-Pawt, 3.


Chapter 1. Harnessing the Merrimack River


p. 11, #1. JBF memo on Pawtucket Canal, Mar. 1876, DB-8, 393, PL&C-Baker.

p. 11, #2. PL&C Directors 23 Aug. 1792; “Speen’s Brook,” plan of East Chelmsford dated 25 May 1792, in Massachusetts Archives.

p. 12, #2. Duke de Rochefoucauld, quoted by Bland Simpson in *The Sierra Club Wetlands Reader*, ed. Sam Wilson and Tom Moritz (San Francisco, 1996), 29; JBF memo on
Pawtucket Canal.


p. 13, #2. Ibid; PL&C Directors, 11 Sept. 1795, 16 Dec. 1796, and 22 May 1797. The original lock chambers were 32 feet by 150 feet. The history of this canal, and of the several changes in its locks is covered in Anne Booth, “Historic Structure Report: Pawtucket Canal and Northern Canal Lock Structures,” (Denver: National Park Service, 1982). See also Al Lorenzo, “The Building of the Pawtucket Canal,” (Al Lorenzo, 2005 - copy at CLH), which looks closely at questions regarding the number of lock chambers.


p. 17, #1. Gary Kulik and Patrick Malone discovered the only governor for a vertical waterwheel known to survive in America. This artifact was in the Moffett Machine Shop in Lincoln, RI and is now in the collections at Slater Mill Historic Site in Pawtucket, RI. It is more complex than early forms illustrated in British and American publications. See, for example, the illustration in Allen, 274, which was the principal model for the re-created 1820’s governor installed with the waterwheel in the Wilkinson Mill at Slater Mill Historic Site.


Charles Parrott found this map, which is evidence for many of the conclusions in this book, in the basement vault of the Proprietors of Locks and Canals. It is now in the PL&C collection of the LNHP. See also the J. G. Hales map of 1821, reproduced on page 14.


Chapter 2. Building a City at the Falls, 1821-1836


p. 23, #2. Ibid.


p. 24, #2. “Plans and Deeds,” 1-3, overall plan of lots, deeds #27-33. PL&C-LNHP; J. T, Spofford to Mr. Gilman, Nov. 13, 1872, mss. in CLH.


p. 27, #4. Parker, Kirk Boott, 32-40. See also Alfred Gilman, “Sketch of the Life of Kirk Boott,” CORHA 2 (1880-83), 3; JBF, “Kirk Boott and His Experience in the British Army,”
CORHA 3 (1884-87), 326, and Montgomery, *A Practical Detail of The Cotton Manufacture*, 163-164 n. Boott must have developed some competence in engineering while on the job in Lowell: JBF kept a sheet of 1832 power estimates by Kirk Boott in his files: A20, File#107, PL&C-Baker.


p. 31, #2. *LHE* (1855), 104, Plate XII.


p. 32, #2. Drawing of Merrimack Mill signed by Patrick Tracy Jackson, 1822, PL&C drawings, CLH. The wheel diameter was planned as twenty-eight feet. All dimensions recorded after completion give thirty feet in diameter, matching the fall selected by Moody. See for example, JBF, “Experiments,” notebook, Dec. 14, 1843, PL&C-LNHP. For the design of high breast wheels, see Terry Reynolds, *Stronger than a Hundred Men: A History of the Vertical Water Wheel* (Baltimore), 282-288, and Terry Reynolds, “The Emergence of the Breast Wheel and Its Adoption in the United States,” in Robert Weible, ed., *The World of the Industrial Revolution* (North Andover, MA, 1986), 55-88. Also useful for comparative perspectives is Richard Hills, “Steam and Waterpower: Differences in Transatlantic Approach,” in the same volume edited by Weible, 35-53. CLH has a number of PL&C waterwheel drawings, including one of the “Old Machine Shop Water Wheel” in 1844, Shelf 109, No. 935. See also the drawing


P. 33. #1. Nathan Appleton, MS. Dated Apr. 15, and surely written in 1823, Nathan Appleton Papers, MHS.

P. 33, #2. Ibid.

P. 34, #1. Ibid.

P. 34, #2. MMC Directors Records, Report to the Proprietors, August 9, 1823.


P. 36, #3. See two different plans in January, 1824, with the same title: “A Plan of the land on the South Side of the Pawtucket Canal,” shelf 106, drawing 599, CLH.

p. 37, #1. undated plan for what would become the Eastern Canal, shelf 118, drawing 272, PL&C-LNHP.

p. 37, #2. MMC Directors’ Records, Oct. 19, 1824.

p. 37, #3. Ibid.

p. 39, #1. Ibid., Nov. 22, 1824.


p. 42, #3. Joseph Frizell, assistant to JBF, said they divided the water at Lowell and Holyoke to get “as large an area of ground as possible for the placing of mills and appurtenant buildings.” This created many difficulties in managing the system and caused waste of water. He predicted it would not be done again. See Frizell, Water-Power (NY, 1905), 414-416.

p. 43, #1. George R. Baldwin, “A Plan of Land and Buildings belonging to the Merrimack Manufacturing Company, with the Neighboring Farms, Roads, etc. at Pawtucket in the Town of Chelmsford” (1825), PL&C-LNHP.

p. 43, #3. MMC Directors’ Records, October 23, 1824.

p. 43, #4. Ibid., June 1, 1825, and Locks and Canals, “Plans and Deeds of some of the Land Acquired by PL&C 1792 to 1928,” nos. 58-60, PL&C LNHP.


p. 45, #2. JBF Records H, PL&C-LNHP, 111.


p. 46, #1. John McPhee, The Founding Fish (NY, 2002), 29-31, 95-98, 255-257. Not only juvenile fish return to the sea. Many shad in New England rivers do not die after spawning but return quickly to the sea. However, since this incident took place in the fall, most of the shad that were let over the dam were probably juveniles in an outmigration. See also Steinberg, Nature Incorporated, 173-174, which covers the problems caused by Merrimack River dams to fish moving both upstream and downstream, and Mark Herlihy, “An Environmental History of Lowell, Massachusetts,” report for the LNHP, July 8, 2001.


p. 46, #3. Ibid. Henry David Thoreau, A Week on the Concord and Merrimack Rivers (Mineola, NY, 2001), 54, describes old shad returning to the sea in August, followed by young fish in September.


p. 47, #2. JBF researched the origin of the name Merrimack and shared this information with local historian Alfred Gilman, who published “Merrimack River, its Sources, Affluents, etc.” in CORHA, 2 (1880-1883), 206-211; Thoreau, A Week on the Concord, 51, 71.

p. 48, #1. JBF Records H, 111-121, PL&C-LNHP; “Sketch of Pawtucket Dam,” March, 1923 (with historical development) Shelf 128, No. 1795 and “Pawtucket Dam,” Jan. 21, 1921, Shelf 153, No. 28, PL&C-LNHP.


p. 50. # 3. By March, 1822, Boott was the agent and treasurer of both the MMC and the PL&C. Parker, Kirk Boott, 43, 47, 56. For the roles of corporate officers and managers, see Steven Lubar, “Corporate and Urban Contexts of Textile Technology in Nineteenth-Century, Massachusetts,” (Ph. D. diss., University of Chicago. 1983), 41-55.

p. 51, #1. Allen Emmet, “Kirk Boott [Sr.] and the Greening of Boston,” Arnoldia 47, no. 4 (Fall, 1987): 4-34; Parker, Kirk Boott, 40; Harriet Robinson, Loom and Spindle: or Life among the Early Mill Girls (NY, 1898), x; Steinberg, Nature Incorporated, 72-75. I am grateful to Hunter Dupree for advice on the horticultural and botanical interests of Boott family members.

p. 51, #2. Essex Gazette (Salem, MA), Aug. 12, 1825, quoted in John O. Green, "Historical Reminiscences," Proceedings in the City of Lowell at the Semi-Centennial Celebration of the Incorporation of the Town of Lowell, Mar. 1, 1876 (Lowell, MA, 1876), x.


p. 57, #1. Penn, “The Development of the Leather Belt Main Drive,” 1-14. Penn shows that Ithamar Beard made important contributions to multiple belt drive technology after leaving Lowell and also wrote on the subject.

p. 57, #2. Robert Israel to Lewis Waln, Aug. 9, 1831, in Waln Collection, Historical Society of Pennsylvania. I am grateful for a copy given to me by Steven Lubar and Michael Folsom.


p. 59, #2. See three items in PL&C-LNHP: an 1833-1834 notebook with millyard plans by Boyden; Uriah Boyden, “A Plan of a Part of Merrimack River Between Nashua and Lowell,”
(March 1833); and “Plan of Part of City of Lowell - from surveys made in 1833-34 by U. A. Boyden with additions by James B. Francis, May 1837” An indication of Boyden’s diverse interests can be found in The National Cyclopedia of American Biography, vol. XI (NY, 1909), 88.

p. 59, #3. JBF, autobiographical sketch, in PL&C-LNHP, gift of Samuel Francis.


p. 60, #2. JBF Records H, 120, PL&C-LNHP.

p. 61, #1. FitzGerald, Davis, and Freeman, “James Bicheno Francis,” 1-3.

p. 61, #2. PL&C Directors, Aug 1, 1835 and Sept. 12, 1840.

Chapter 3. Expanding the Waterpower, 1836-1847.


p. 63, #1. Statistics (Jan. 1, 1837 to Jan. 1, 1845); P. T. Jackson report, PL&C Directors, Sept. 21, 1841, PL&C-LNHP; George Gibb, The Saco Lowell Shops (Cambridge, 1950), 98-100. Gibb shows how corporations helped each other out with funds during the financial crisis. However, the value of L&C stock fell from 1836 to 1842, and there were concerns about the end of large textile machinery orders after the Massachusetts contracts were filled.

JBF to Benjamin Saunders, Oct. 21, 1864, DB-3, 565-571.

p. 63, #3. Plan of Swamp Locks area, c. 1830, Shelf 124, Drawing 2915, PL&C-LNHP;


p. 64, #3. PL&C Directors, Report by JBF, 5 February 1848. Here Francis defines ordinary and extraordinary low water.


p. 65, #3. JBF to Theodore Lyman, Oct. 28, 1865, PL&C-Baker, DB-3, 719-721. This refers to the use of surplus power but offers a fine description of how more flow produces more friction head losses and thus draws the water down even more: “...the trouble continues in an increasing ratio.”


p. 67, #1. “Plan of the Proposed Canal from Pawtucket Dam to the Western Canal,” Shelf 114, Drawing 1, PL&C-LNHP. Baldwin also produced a detailed set of canal sections in 1839, based on surveys done in June and July: J. F. Baldwin, “Experiments...1839,” PL&C-Baker, NG1, 14-22. For a description of the plan, see P. T. Jackson to Directors, Sept 13, 1839.


p. 67, #3. Ibid.

p. 68, #1. “Report of the Committee on the Subject of a New Canal” (Boston, 1840), 4-5.

p. 68, #2. Ibid., 11.
p. 69, #1. Ibid., 12-13.

p. 69, #2. Ibid., 14-15, 20.

p. 69, #4. PL&C Directors, Jan. 9, 1841.


p. 70, #1. PL&C Directors, Sept. 20, 1842.

p. 70, #2. Ibid., Sept. 9, 1842; Oct. 14, 1842; Jan. 28, 1843; and May 29, 1843.


p.71, #2. HAER team directed by the author and Charles Parrott found the remains of the Lower Western Canal lock in 1974. Plan Book A, p. 15 (now in PL&C-LNHP, with a photocopy in HAER survey, 1975) has a plan showing the locks, probably drawn by Uriah Boyden, c. 1833. Canal toll receipts are in FC 1-3, PL&C-Baker. Rates allowed by 1835 state legislation are on a toll sign in the collections of the Lowell Historical Society (and replicated at the Guard Locks). Forest products predominate. See also Booth, 114, 165.


p. 73, #1. Ibid.


p.73, #3. PL& C Directors, Sept. 21, 1841, Sept. 25, 1844, March 10, 1845, and April 5, 1845.


p. 75, #1. JBF to Benjamin Saunders, Oct. 21, 1864, DB-3, 568, PL&C-Baker.

p. 76, #1. JBF to John Morse, Dec. 6, 1845, A34, #177, PL&C-Baker.


p. 77, #4. Webster's New World Dictionary of the American Language (New York, 1970), 857. The term also referred to a game and would later be applied to certain shopping areas. See "Shattuck Mall" and James Francis' use of "mall" later in this article. For an impressive explanation of the New England fascination with elms, see Thomas Campanella, Republic of Shade: New England and the American Elm (New Haven, 2003). Campanella, however, overlooks the extensive planting of elms by corporations in Lowell and other industrial communities of the region.


p. 80, #3. New England industrial communities that were influenced by the Lowell pattern often had landscaped corridors along power canals. Examples include Dover and Great Falls, NH; Lewiston, ME; and Lawrence and Holyoke, MA. Some smaller mill villages, such as the Crown and Eagle Mills in North Uxbridge, MA also had this feature. For the latter, see William Pierson, Jr., *American Buildings and Their Architects*, vol. 2, part 2, *Technology and the Picturesque: The Corporate and the Early Gothic Styles* (Garden City, NY, 1978), 50-54.


p. 82, #1. *The Protest* (Lowell), Nov. 25, 1848. Copy provided by Michael Folsom, from his extensive collection of materials on Lowell.


p. 84, #1. Samuel Lawrence to Charles Hovey, Feb. 8, 1875, “Three Letters of Samuel Lawrence, Esq.,” *CORHA* 1 (1874-79): 288-89.


p. 86, #1. Steinberg, *Nature Incorporated*, 82, 107-114; 260; JBF to Thomas Carey,
“Summary of Payments,” PL&C-Baker, DA-4, 226-233; Francois Weil explains “local
dynamism,” and critiques the way scholars have used the terms “Boston Associates” and
“Waltham-Lowell System” in “Capitalism and Industrialization in New England, 1815-1845,”
p. 86, #2. Merton Sealts Jr., ed., The Journals and Miscellaneous Notebooks of Ralph
p. 86, #3. Henry David Thoreau, A Week on the Concord and Merrimack Rivers
(Mineola, NY, 2001), 53.
p. 87, #1. D. Spencer Gilman to Moses Jr., Mar. 15, 1846, D. Spencer Gilman Letters in
J. I. Little MSS, CLH.
p. 87, #3. Samuel Lawrence to P. T. Jackson, May 1, 1845, A1, #3, PL&C-Baker.
p. 87, #4. JBF Wastebook, no. 5, Jan. 19, 1848, PL&C-LNHP; Gilman to “Canadian
PL&C Directors, March 20, 1846 and Sept. 15, 1846.
p. 89, #2. See extensive series of plans, elevations, and sections of the Northern Canal,
Shelf 115, and Jan., 1846, plan of entire canal, Shelf 114, #3, PL&C-LNHP; Franklin Forbes’s
Waste Books, # 1-4, 1845-1849, PL&C-LNHP; “Notes Respecting Northern Canal,” A18, #94,
“Specifications” for each of 3 sections, and contract with Boody and Ross, C-8, PL&C-Baker;
“The Northern Canal,” Lowell Courier (Jan. 1, 1848); Patrick M. Malone, "JBF and the Northern
Future (NY, 1986), 10-18; Donna Mailloux, "JBF and the Northern Canal," report for LHNP.

p. 91, #2. Samuel K. Hutchinson, “Northern Canal, 1846-1847,” in small notebooks, LNHP.


p. 93, #1. Lowell Advertiser, July 21 and 23, 1846; Lowell Courier, July 26, 1846, and Oct. 27, 1847. Martha Mayo, director of CLH, has compiled an accident file which suggests that construction work in the millyards at this time was more dangerous than employment on the Northern Canal.

p. 93, #2. Lowell Courier, July 9, 1847.

Chapter 4. Testing the Waters: Scientific Engineering in Lowell
p. 100, #1. *LHE* (1855), xi.


p. 101, #2. Uriah Boyden’s Scrapbook, 1833-1862, 15-23, and 36-43, CLH. For the earliest known interest in flow measurement at Lowell, see an undated document titled “Calculations No. 2. Water Power & Velocity of Rivers” and attributed to an encyclopedia entry by “Buat [DuBuat],” PL&C-LNHP. This was sent to Kirk Boott in Boston and must date from the early 1820s.


p. 102, #2. *LHE* (1868), 146-148.

p. 102, #3. Storrow’s book included applications of calculus which were beyond the mathematical capability of almost all American engineers of the 1830s. See Charles S. Storrow, *A Treatise on Water-Works for Conveying and Distributing Supplies of Water* (Boston, 1835).


p. 103, #2. Ibid., 148-150.

p. 103, #3. Desmond FitzGerald, Joseph P. Davis, and John R. Freeman, “JBF: A


p. 104, #3. JBF Records A, 125-27, PL&C-LNHP.


p. 110, #1. LHE (1868), 18-19.

p. 110, #2. Some weir formulas also account for the number of end contractions (a fixed number that is easily recorded) and the velocity of approach, but the latter is usually not a significant factor in most testing flumes.

p. 111, #1. “JBF” notebook, Dec. 22, 1844, and JBF, “Experiments and Translations” notebook, 5-7, both in PL&C-LNHP. See also JBF “Formulas used at different times...,” A18, File #90, PL&C-Baker.


United States,” Transactions of the ASME 7 (1886-87): 364. For addition of a hydraulic regulator during experiments on the Old Machine Shop Water Wheel, see JBF, Records A, 81-93, PL&C-LNHP.

p. 112, #3. LHE (1855), 2-6.


p. 113, #2. JBF, “Experiments and Translations” 12-23, 72.


p. 117, #1. Ibid.

p. 119, #1. Ibid., 18.


p. 119, #3. Courier (August 30, 1870); Mr. Burke to JBF, Lowell Machine Shop proposals, Nov. 1, 1850 and April 21, 1851, A34, PL&C-Baker. Detailed lists of turbines installed over time in Lowell corporations can be found in Book of General Information, Tabulations, Diagrams, etc (in large notebooks), PL&C-LNHP. Gray Fitzsimons gave me the very important Courier article, and many others, from his extensive research in Lowell newspapers.

p. 120, #1. LHE (1855), 6-7.

p. 120, #2. Ibid.


p. 121, #2. LHE (1855), 39.

p. 121. #3. LHE (edition abridged for use at MIT, 1885), 12; JBF to Luigi D’Auria, Feb. 25, 1878, A-16, #76, PL&C-Baker.


p. 123, #1. *LHE* (1883), xi.

p. 123, #3. In addition to working on a small scale, most European experts did not test weirs of “considerable length in proportion to depth.” This is the particular application for which Boyden suggested a formula in 1846. Three years later, Boyden also helped Francis with another formula dealing with discharge and provided a demonstration. See *LHE* (1855), 71-75, 80, 99, 117-118, 126-133.

p. 125, #1. *LHE* (1855), 80-102. In 1848, Francis had gone back to the Pawtucket Gatehouse, after testing his hoisting wheel, to investigate the effects of the depth of water on the downstream side of a weir. The remains of a weir are there today in the tailrace.

p. 125, #2. Ibid, 103-111, Plates XII-XIII.

p. 127, #1. Ibid., 118-19, 133-35.


p. 130, #2. Discharge diagram for “Centre Vent Water Wheel at the Boott Cotton Mills” (Mar. 1868) and table of “Quantity of Water Discharged” by a turbine at the Lawrence Manufacturing Company. Copies of both provided to the author by Al Lorenzo.


p. 133, #2. *LHE* (1855), xi.


p. 134, #2. JBF, *LHE* (1868), 146-150, 156-158.

p. 135, #1. Thomas Mann, “A Treatise on Rivers and Canals,” in *Philosophical Transactions of the Royal Society of London*, vol. 69 (1779), 555-656. See page 577 for rod description. Charles Parrott, historical architect at LNHP, and the author have worked together on the subject of the use of tube floats for flow measurement and plan to soon produce an article with more details and sources than this book provides. This section of the book reflects our joint research on the topic (the sections on corporate landscaping reflect other work we have done together).


p. 135, #3. Ibid., 191-196.
p. 136, #1. Ibid., 169.


p. 137, #1. For leakage issues and deterioration of turbines, see “Measurements...1871,” small notebook in PL&C-LNHP and Paul Hill to JBF, May 22, 1859, vol. A12, #34, PL&C-Baker. Damaged gages are in Records O, 1876-1882, April 27, 1876, PL&C-LNHP. The 1880 Census provides details on problems, including blockage and obstruction: Swain, *US Census*, 28. See also critical comments by Clemens Herschel, who depended heavily on turbine discharge data at Holyoke: Clemens Herschel, “The Venturi Meter,” in *Transactions* of the ASCE, #371, vol. XVII (Nov., 1888)239. JBF provided caveats about turbine conditions in *LHE* (1868), 147. A much more positive view of turbines as gages is in Thurston, 371, 383.


p. 138, #2. JBF to Benjamin Saunders, Oct. 21, 1864, DB-3, PL&C-Baker.

p. 139, #1. Arthur Frazier, *Water Current Meters in the Smithsonian Collections*... (Washington, DC, 1974), provides a detailed history of current meters and examines some early ones owned by PL&C (pp. 61-63 and Figures 57 and 63). An alternative method became popular in the 20th century. An operator could record rotor revolutions and elapsed time while he moved the meter steadily from the surface to the bottom and back up again. From this data, he calculated the mean current in that vertical path. After completing a series of such measurements spaced across the canal or flume, he used graphical methods similar to those for floats to estimate the mean current in the entire cross section. Of course this
depended on a perfectly functioning meter and consistent vertical movement of that instrument. This method is described in a correspondence course from the International Textbook Company

_Hydraulics_ (Scranton, PA, 1907), Part 2, #38, 37.

p. 139, #2. _LHE_ (1868), 156.

p. 139, #3. JBF to Buff & Berger, Feb. 22, 1881, in Records O, 1876-1882, PL&C-LNHP. By 1888, Herschel, the brilliant inventor of the Venturi meter for easy measurement of flow in large pipes or penstocks, had turned negative on current meters. He criticized the difficulty in rating them, their “delicacy,” and problems in their use by “the average engineer’s assistant.” See Herschel, “The Venturi Meter.”

p. 139, #4. Frazier, 86; Merriman, _Treatise on Hydraulics_, 4-5.

p. 141, #1. JBF to Colonel Francis, Apr. 10, 1879 (#11 of European tour), Francis Family Collection, LNHP; JBF to Buff & Berger, Feb. 22, 1881, JBF Records O; “Stock Account, 1885-1893,” Jan. 1, 1885, both PL&C-LNHP.


Chapter 5. Protecting the People and the Profits, 1847-1865


p. 144, #3. JBF, “Great Freshets in Merrimack River,” _CORHA_, 3 (1884-1887), 252, 255-6. The “Great Freshets” article was also published in _Vox Populi_, a Lowell newspaper, on Nov. 14, 1885; JBF, Records H, 119, PL&C-LNHP.


p. 146, #1. Ibid., PL&C Directors, Sept. 21, 1847.


p. 146, #3. JBF Records A, 172, PL&C-LNHP. See also estimate from Sept. 17, 1847, C-86, PL&C-Baker, which includes both timber for “gate across locking chamber” and “stone with grooves for gate.”

p. 147, #1. Sam'l. M. Richardson to JBF, Feb. 23, 1850, A34, #176, PL&C-Baker; JBF, “Great Freshets,” 256.

p. 147, #2. JBF Records A, 160, 172; PL&C-LNHP; Franklin Forbes Memoranda, Jan. 18, 1877, PL&C-LNHP; JBF, “Experiments and Translations,” June 6, 1850 and 129-131, PL&C-LNHP; Ellen Rosebrock, “Lowell Heritage State Park: Transportation System,” by Institute for Conservation Archaeology, for Department of Environmental Management (Nov., 1980), 16, 173-175; Booth, “Historic Structure Report,” 71-76; JBF “The Preservation of Timber,” letter to O. Chanute, Esq., ASCE Preservation of Timber Committee Chairman, with discussion, Paper # 310 in Transactions of the ASCE 13 (August, 1884). Copy in bound volume;“Papers by J.B. Francis, 1860-1891,” in LNHP Library. There is some conflict in the sources over whether the pine for the gate was Burnettized or Kyanized. JBF clearly stated in Records, A, in February, 1851, PL&C-LNHP, that “The Great drop gate at the Guard Locks of the Pawtucket Canal was Burnettized.” He had considered more expensive southern pine (used earlier at the Pawtucket Gatehouse gates at the falls) but went with less costly white pine, which may have been easier to treat for preservation.


p. 149, #1. JBF, “Great Freshets,” 257.


p. 150, #2. Christine Rosen, The Limits of Fire: Great Fires and the Process of City Growth in America (Cambridge, 1986); Courier (May 5, 1871); Broadside of JBF data on Lowell mill fires, January 28, 1886, vol. 85, #464, PL&C-Baker; Betsy Bahr, “New England Mill Engineering: Rationalization and Reform in Textile Mill Design, 1790-1920,” (Ph. D. diss., University of Delaware, 1987), 93. There had been a serious fire at the MMC in 1828 that destroyed one mill. The Courier listed total fire losses in the city for every year from 1852 to 1870. Only 1854, 1865, and 1866 stand out as bad years, but the losses were still relatively modest: $118, 675; $196, 437; $224, 101. JBF notes 180 fires on corporation property from Feb. 24, 1863 to Jan. 28, 1886. Only 14 caused losses of more than $1000. None of the 118 fires after January, 1876, reached that minimal level of damage, an amazing record of industrial fire suppression. For the architectural aspects of fire prevention and control, see Sara Wermiel, The Fireproof Building: Technology and Public Safety in the Nineteenth-Century American City (Baltimore, 2000).

p. 151, #1. Lowell Fire Department Records, 1845, CLH.


“Corporation Influence,” in *Courier* (April 2, 1842); Jefferson Bancroft, “List...”, report for Mayor and Aldermen, 31 March, 1845; and “Records of Fires,” 1863-1900, PL&C volume mainly in JBF hand, both at CLH. The Middlesex fire is listed on June 24, 1866.
The volume includes ample evidence of close involvement with and advice to the city. See also many letters to corporations in Francis’s role as fire inspector and advisor after 1850, DA3-DA6, PL&C-Baker. For one of JBF’s early studies of hoses, pipes and jets, see Wastebook #5, Oct. 29, 1847, PL&C-LHNP.


p. 154, #3. W C. Appleton to JBF, Dec. 12, 1846; A34, #175, PL&C-Baker.

p. 155, #1. PL&C Directors, Feb. 21 and 28, 1848. See also report of the commission to adjust heights (again), 28, Nov., 1853, in “Sundry Papers” volume (TC175.596), CLH.


p. 155, #3. Ibid.


p. 156, #1. The most complete statement on the many proven advantages (and few disadvantages) of turbines is in a memo that Francis wrote on December 1, 1848. This was in connection with Boyden’s offer to sell Locks and Canals a license for his turbine improvements. See A10, #96, PL&C-Baker.
p. 156, #2. JBF report, PL&C Directors, Feb. 21, 1848.

p. 156, #3. Francis tested one of these turbines and reported results in LHE (1855), 61-70. Various problems with the Boott Mill site are covered in Laurence Gross, The Course of Industrial Decline: The Boott Cotton Mills of Lowell, Massachusetts, 1835-1955 (Baltimore, 2000).


p. 158, #1. Ibid., Feb. 21, 1848.


p. 159, #1. PL&C Directors, April 1, 1853; Sept. 27, 1853; Nov 1, 1853; Dec 7, 1853.

Louis Hunter made one of his few errors in Waterpower in the Century of the Steam Engine, vol. 1, of A History of Industrial Power in the United States (Charlottesville, 1979, when he said that the additional power “was distributed among the textile corporations in exact proportion to the waterpower leased by each.” See page 264.

p. 159, #2. PL&C Directors, April 1, 1853; Sept. 27, 1853; Nov 1, 1853; Dec 7, 1853.

See Table 5.1 on page 159 of this book.

p. 160, #1. Statistics of Lowell Manufactures, Jan.1853 through Jan. 1867. The Middlesex Company, a woolen manufacturer, was the last to give up breast wheels entirely: none were used with water from the Locks and Canals system after 1878. The company still had 12 foot breast wheels for Concord River water in Jan. 1889, and may have run them into the twentieth century.


p. 161, #2. JBF to J. C, Hoadley, April 27, 1857, A19, #100; JBF to S. Sawyer, Jan. 6, 1857, DA4, 194; JBF to Joseph Adams, Oct. 9, 1857, DA4, 224 (all in PL&C-Baker); drawings,
Shelf 119, #0343-0348, PL&C-LNHP. On the connection between the Pawtucket Dam and the grist mill see Arthur Safford to Frederick Flather, Dec. 1, 1949, PL&C file #1109 (on grist mill), PL&C-LNHP.


p. 163, #4. JBF sketches and notes, Apr. 1, 1848, A18, PL&C-Baker.

p. 165, #1. JBF Records A, Jan. 1, 1859; JBF to P. S. Lincoln, March 5, 1863, DB-3, PL&C-Baker; Charles Cowley, Illustrated History of Lowell (Boston, 1868), 137.

p. 165, #3. Charles E. Little, Greenways for America (Baltimore, 1990), 7-11. Olmsted's first park was Central Park in New York City, designed with Calvert Vaux. He proposed a greenway along a creek for the University of California at Berkeley in 1865 and in the following year suggested a park way linking Brooklyn's Prospect Park with Coney Island. The first connected park system may be his Buffalo, NY, one of 1868. His planning for the Emerald
Necklace, which includes greenway connectors, began in the mid 1870s. Little credits William H. Whyte with first mentioning the term "greenway" in a publication, in 1959.


p. 167, #2. PL&C Directors, Dec. 17, 1853; *Water Resources Data Massachusetts and Rhode Island Water Year 1997* (Washington, DC: 1998), 54-57. For flow into the millpond, you have to adjust the modern USGS data from Lowell. You must subtract the Concord River flow which enters the Merrimack below Pawtucket Dam but above the Merrimack River gauging station in Lowell.


p. 170, #2. PL&C Directors, April 12, 1859; “Form of Lease of Water Power at Lowell,” 1853, Sundry Papers volume (TC175.596), CLH.

p. 171, #1. JBF to Thomas Carey, May 17, 1858, DA-5, 18-19, PL&C-Baker.

p. 171, #2. JBF to Directors, March 21, 1859, DA-5, 81, PL&C-Baker.

p. 171, #3. PL&C Directors, Nov. 5, 1856, March 21, 1859, April 12, 1859. A depression in 1858 reduced production so much that Francis did no measurements that year.

p. 172, #1. JBF to Thomas Carey, Dec. 6, 1858, DA-5, PL&C-Baker.


p. 173, #1. LHE for MIT (1885), 38; LHE (1883), 201-202, 239; Lowis Jackson, Hydraulic Manual (London: Crosby Lockwood and Co., 1883) 143-145; JBF, LHE (1855), 145; Records, 1876-1882, 123, and Day Book #12, 1866-1876, 151, PL&C-LNHP.


steam produced power as well as valuable heat and humidity for textile processes and warming
of work spaces. She shows some cases in which the savings from use of exhaust steam made it
a less expensive power source than surplus water. The author is grateful for sources she
provided him during her doctoral research.

p. 175, #1. P. T. Jackson to Directors, Sept. 13, 1839, A1, #1; JBF to Corliss and
Nightingale, Jan. 6, 1854, A2, #14, both PL&C-Baker.


p.175, #3. The combined or hybrid power systems deserve more study than they have
received. Although many of these systems were designed to handle occasional shortages of
waterpower (during droughts, ice conditions, or floods), they also provided exhaust steam for
heat and processing, allowed manufacturers to enlarge mill complexes, and worked particularly
well at sites that had surplus waterpower for most but not all of the year. One of the problems
with the available data on hybrid power systems is that we may know the horsepower of installed
steam engines but not know how often or how hard they were run. That makes it difficult to
compare the use of waterpower and steam power at many sites. See Terry Reynolds, *Stronger
134–40; 161–76; and Neil Cossons, *The BP Book of Industrial Archaeology* (Newton Abbot,
England, 1973), 70, 91–92;

2 of *A History of Industrial Power in the United States* (Charlottesville, Va.: Univ. Press of
Virginia, 1985), 110; Carroll Pursell, *Early Stationary Steam Engines in America* (Washington,


p. 176, #3. State of Massachusetts, Fishes, Reptiles, and Birds of Massachusetts (Boston, 1839), 104-5.


p. 177, #2. Steinberg, Nature Incorporated, 174-187; Molloy, ed., The Lower Merrimack River Valley, 41-42. The height of the “Great Stone Dam” varied from 30 feet to 41 feet depending on the conformation of the bottom.

p. 177, #3. JBF Records A, Dec. 26, 1854, 197, PL&C-LNHP.

p. 178, #2. Vernon-Wortzel, Lowell, 152, shows that Lowell corporations sold much of their stockpiled cotton for big profits in 1861-62, assuming incorrectly that the war would be over soon. For an example of wartime canal modification see “Proposed improvement of the Merrimack Canal,” Shelf 118, # 203, PL&C-LNHP.


Chapter 6. Controlling the System, 1865-1885

p. 180, #3. Time Table of the Lowell Mills (Lowell, 1868); Statistics of Lowell Manufactures (Lowell, Jan.1869). See also JBF to Theodore Lyman, Oct. 38, 1865, DB-3, 719-
721, PL&C-Baker: “Usually by morning the water is running over the top of the flashboards. When the mills start, the water begins to fall and by night it is drawn down below the top of the flashboards more or less, depending on the state of the river...”

p. 181, #1. The total number of spindles rose from 403,696 to 437,420 between 1860 and 1865. Five years later, the total had reached 526,710. See *Statistics of Lowell Manufactures* (Lowell, Jan., 1861,1866, 1871). In 1863, Francis had said that “very little of the machinery in the cotton mills has been running, during the past year owing to the higher prices of cotton (50 to 70 cents per pound).” See Records A, 235, PL&C-LNHP.


Martha Mayo, director of the Center for Lowell History, has found, however, that not all mills hired Irish and French Canadian workers at an accelerating rate. Some continued to show strong preference for Yankee women through the 1870s. Mayo also notes that there was a surge of Yankee women (including war widows) seeking mill work in Lowell immediately after the war. Statistics supporting Martha’s argument can be found in Robert G Layer. *Earnings of Cotton Mill Operatives, 1825-1914* (Cambridge, 1955); Appendix C, 70-71, is particularly helpful.

p. 182, #2. PL&C Directors, Feb. 17, 1866.

p. 182, #3. JBF to Thomas Carey, Dec. 6, 1858, vol. DA-5, PL&C-Baker; PL&C Directors, April 12, 1859.

p. 183, #1. PL&C Directors, Nov. 3 and Dec. 1, 1870.
p. 183, #2. PL&C Directors, Nov. 5, 1874.

p. 183, #3. JBF report to Directors, Sept. 17, 1855, in “Sundry Papers” volume (TC175.596), CLH; PL&C Directors, Dec. 26, 1874; “Report of the Committee on Surplus Power,” appointed Jan. 29, 1885, A85, File #462, PL&C-Baker. This reduced price did not apply when backwater was caused by ice blockage in the river. At those times there might not be a surplus of water available.

p.184, #1. Theodore Steinberg, *Nature Incorporated: Industrialization and the Waters of New England* (Cambridge, 1991), 85–88, sees the selling of permanent millpowers (often severed from land sales by the 1830s), combined with the payment of an annual rental fee for the right to use those millpowers, as an important example of the “commodification of water.” Payments for the surplus water actually taken (per day) are an even more dramatic illustration of this commodity concept.

p. 184, #2. JBF to Abbott Lawrence, July 2, 1859, A21, #110, PL&C-Baker.

p. 184, #3. Records, 1876–1882, 1 Aug. 1881, 187, PL&C -LNHP.

p. 185, #1. JBF to Thomas Carey, Dec. 6, 1858, in vol. DA-5, PL&C-Baker.

p. 185, #2. Samuel Lawrence to Charles Hovey, Feb. 8, 1875, *CORHA* 1 (1874-79): 291.


p. 186, #2. Appendix, Shedd & Sawyer Reports, 1883, vol. A17, # 83, PL&C-Baker. The heading of this table is incorrect, but one can see from the cfs data that this is the ratio of capacity to leased amounts.

p.186, #3. Records, vol. 10a (1884–1891), 18, PL&C-LNHP.

p. 187, #1. Francis had begun to lower the river channel and Hunt’s Falls just downstream of the city, resulting in more net drop (head) for mills on the lower level of the canal
system. Flashboards on the dam and higher levels in the improved upper level canals also added head. When you use the new estimate of 33 total feet of head and a conservative turbine efficiency rating of 75% to calculate the value of one mill-power (25 cfs) you get just over 70 horsepower.


p.189, #1. Handbook for the Visitor to Lowell (Lowell, MA, 1848), 11; Statistics of Lowell Manufactures (Lowell, MA, 1866, 1871, and 1881). The Merrimack Print Works could use exhaust steam for heat in its finishing processes, one reason for the early adoption of steam power in that part of the vast Merrimack Mills complex. Steam, whether as engine exhaust or produced simply for heat, was also considered the best way to warm working spaces in the city’s mills by 1850. There was an increase in steam power installation during the Civil War years, when most of the textile corporations in Lowell sharply limited or ceased manufacturing. Many of them focused instead on improvement or expansion of their mill complexes. Installing engines or planning for future use of steam power was part of some wartime projects. Because of the production cutbacks, Lowell published no annual statistics between January 1861, and January 1866. The January 1866, Statistics of Lowell Manufactures, was the first to include tabular data on steam engines and installed steam horsepower. During the war, the Suffolk Mfg. Company installed an engine, and the neighboring Tremont Mfg. Co. built a boiler house and smokestack with sufficient capacity to handle the needs of an engine when they finally decided to add one. See Ann Booth’s report, “Tremont Yard,” for the LNHP, Lowell, Mich., n.d., pp. 14, 27. For discussion of another mill complex that used a hybrid power system, see Laurence Gross, The


p. 190, #2. JBF to Thomas Carey, Dec. 6, 1859, DA-5, PL&C-Baker.

p.191, #3. The best coverage of the northern reservoirs and their impact is in Steinberg, Nature Incorporated.


p. 193, #1. JBF testimony, as summarized in “Report of the Joint Special Committee . . .
Passage of Fish . . . ,” Apr. 1865, MA Senate Document 183, 17.

p. 193, #2. JBF to Storrow, Apr. 21, 1866, Essex Co. Collections, MS69, Box 26, ATHM.

p. 193, #3. JBF Records H,10, PL&C-LNHP.

p. 194, #1. Ibid.

p. 194, #2. JBF to E. A. Bracket, clipping in Day Book, 1882-1883 (Col. Francis), June 5, 1883, PL&C-LNHP.


p. 195, #1. “Report of the Special Joint Committee on the Subject of Introducing Water into the City,” Dec. 21, 1848, pp. 10-11. Two out of the three alternative plans proposed by William Worthen involved Hunt’s Falls. The third used water power from the Northern Canal. Francis would only consider Hunt’s Falls. See also a later report by another Joint Special Committee, Dec., 1865.

p. 196, #1. On local taxes paid by the corporations (and costs to them for a municipal water system), see Lowell Daily Citizen & News (Feb. 20, 1869) and Lowell Courier (April 2, 1842); Library holdings of PL&C (now at CLH) included many books and articles on public works and water supply.

Fires and the Process of City Growth in America (NY, 1986).


p. 197, #2. Lowell Courier, Feb. 24, 1869.

p. 197, #3. Lowell Vox Populi, Nov. 13, 1869.


p. 198, #2. Lowell Courier, Jan. 21, 1873.


p. 199, #2. JBF to Directors, Aug. 17, 1888, in “Legal Papers” volume, PL&C library, CLH.

p. 199, #3. JBF to Charles Storrow, Oct. 27, 1867, Essex Co. Collections, Box 26, ATHM.
p. 200, #1. JBF to Josiah French, Aug. 30, 1858, A17, #82, PL&C-Baker.


p. 201, #1. JBF Records H, Oct. 25, 1870, p. 50, PL&C-LNHP. Francis complained that the power required to hoist the gates was “greater than can be economically applied by hand.”

p. 201, #2. PL&C Directors, Mar. 3, 1870.


p. 202, #2. Turner and Scullion, Working the Water, 6-13. Many of the 19th century procedures were still in use when Turner and Scullion interviewed past and present workers. As a member of the recording team of the Historic American Engineering Record, the author spent time observing operations at the Swamp Locks in the early 1970s, marveling at the quick reactions, manual dexterity, and exceptional judgment that this work required. Electric power was then being generated at multiple locations on both levels of the system.

p. 203, #1. JBF annual report, Sept. 21, 1869. PL&C-Baker.
p. 203, #2. JBF Records H, pp. 109-151, LNHP.


p. 205, #2. JBF Records H, 131, PL&C-LHNP.

p. 205, #3. JBF Records H, pp. 122, 150, and “Measurements...1871,” both in PL&C-LHNP.

p. 206, #1. JBF to Directors, Aug. 17, 1888, in “Legal Papers.”


p. 209, #2. Mills, “The Proprietors of Locks and Canals on Merrimack River,” 3. For coverage of problems in canal maintenance and operation, as well as details on canal features, see Al Lorenzo, The Canals that Powered a Textile Empire (Al Lorenzo, 2006), copy at CLH.


p. 210, #1. See PL&C collections at CLH, LNHP, and Baker Library. Much of the literature survives in the company library of the PL&C or is referenced (or copied) in his many notebooks, scrapbooks, and journals. His voluminous scrapbook of ads and other printed material on turbines, now at CLH, is a tremendous resource for historians of technology.


p. 210, #3. JBF to Col. Francis, Jan. 24, Feb. 3, and May 5, 1879, Francis Family
Collection, LNHP.


p. 211, #2. JBF to Col. Francis, May 19 and Apr. 10, 1879, Francis Family Collection, LNHP.


p. 213, #2. JBF to Col. Francis, Feb. 3, 1879, Francis Family Collection, LNHP.

p. 213, #3. Ibid., Feb. 16, 1879.


p. 216, #2. Mills, 6-7; Lucille Kane, The Falls of St. Anthony: The Waterfall That Built Minneapolis (St. Paul: Minnesota Historical Society, 1887); D. W. Van Allen to JBF, April 27, 1888, CLH; Gardiner, R. H. Jr., “Report of the Committee. To the Board of Directors of the Augusta Manufacturing Company, “ n. d. [1857?], P93#16, CLH. I am grateful to Charles Parrott for the Augusta report which describes Francis as a referee in a local water dispute and says that he was “generally acknowledged in this country as the highest authority upon all subjects connected with Water Power.”


p. 218, #1. “Account…January 1, 1885” in “Stock Account 1885-1893” notebook,
Postscript


p. 221, #3 Theodore Steinberg, Nature Incorporated: Industrialization and the Waters of
There is a great deal of information about the adoption and increasing use of steam in Lowell in Marti Frank, “Carrying the Mill, Steam, Waterpower and New England Textile Mills in the 19th Century” (Ph. D. diss., Harvard University, 2008), which was completed after this book manuscript was submitted. Ms. Frank is particularly good on “cogeneration” practices in which steam produced power as well as valuable heat and humidity for textile processes and warming of work spaces. She shows some cases in which the savings from use of exhaust steam made steam a expensive power source than surplus water. However, in most situations, steam costs were higher than the price of surplus water, and managers tried to use the extra flow. See Patrick Malone, “Surplus Water, Hybrid Power Systems, and Industrial Expansion in Lowell,” in IA: The Journal of the Society for Industrial Archeology, Vol. 31, No. 1 (2005), 23-40.


