The Water Powered Machinery that Drove King Cotton
The Water Powered Machinery that Drove King Cotton

Al Lorenzo

2009
## Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>4</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>4</td>
</tr>
<tr>
<td>1 A Look Back at east Chelmsford.</td>
<td>6</td>
</tr>
<tr>
<td>- The First Step.</td>
<td>6</td>
</tr>
<tr>
<td>- Examining the Route of the Canal.</td>
<td>9</td>
</tr>
<tr>
<td>- Finally the Revelation.</td>
<td>11</td>
</tr>
<tr>
<td>- The Power Canals and that Damn Hill.</td>
<td>14</td>
</tr>
<tr>
<td>- Genius or the Result of Dogged Determination.</td>
<td>15</td>
</tr>
<tr>
<td>2 Nature, Gravity and Paperwork</td>
<td>17</td>
</tr>
<tr>
<td>- The Mechanics of the Millpower.</td>
<td>23</td>
</tr>
<tr>
<td>- Form of Lease of Waterpower at Lowell.</td>
<td>25</td>
</tr>
<tr>
<td>- The Mechanics of Backwater.</td>
<td>25</td>
</tr>
<tr>
<td>3 “I have spent more money underground”...Kirk Boott</td>
<td>29</td>
</tr>
<tr>
<td>- The Footprints of History.</td>
<td>29</td>
</tr>
<tr>
<td>- Rules and Regulations for Making a Fortune.</td>
<td>29</td>
</tr>
<tr>
<td>- The Headgates of Wealth.</td>
<td>31</td>
</tr>
<tr>
<td>- The Construction of the Underground Raceways.</td>
<td>34</td>
</tr>
<tr>
<td>- A View of the Source of the Water Power</td>
<td>35</td>
</tr>
<tr>
<td>- The Very Start of Our Tale at the Racks</td>
<td>37</td>
</tr>
<tr>
<td>- The Shape of the Underground Raceways</td>
<td>40</td>
</tr>
<tr>
<td>- Just Another raceway – The Penstock</td>
<td>41</td>
</tr>
<tr>
<td>- The Role of the Forebay</td>
<td>42</td>
</tr>
<tr>
<td>- The Wheelpit and it’s Function</td>
<td>43</td>
</tr>
<tr>
<td>4 The Water Wheel</td>
<td>48</td>
</tr>
<tr>
<td>- Was to Cast a Long Shadow in Lowell</td>
<td>48</td>
</tr>
<tr>
<td>- The Rise of the Waterwheel</td>
<td>49</td>
</tr>
<tr>
<td>- The Tub Wheel</td>
<td>49</td>
</tr>
<tr>
<td>- The Undershot Wheel</td>
<td>51</td>
</tr>
<tr>
<td>- The Overshot Wheel</td>
<td>53</td>
</tr>
<tr>
<td>- The Advent of the Breast Wheel</td>
<td>55</td>
</tr>
<tr>
<td>5 The Construction of the Vertical Water Wheel</td>
<td>58</td>
</tr>
<tr>
<td>- A short course on the birth of the power</td>
<td>58</td>
</tr>
<tr>
<td>- The Millwright, the Master Mechanic</td>
<td>63</td>
</tr>
<tr>
<td>- A single step preempts even a long journey</td>
<td>64</td>
</tr>
<tr>
<td>- O.K. millwright-do your stuff</td>
<td>67</td>
</tr>
<tr>
<td>- Laying out the wheel</td>
<td>68</td>
</tr>
<tr>
<td>6 The Iron Water Wheel</td>
<td>73</td>
</tr>
<tr>
<td>- Goodbye nails-hello forge</td>
<td>73</td>
</tr>
<tr>
<td>Page</td>
<td>Section</td>
</tr>
<tr>
<td>------</td>
<td>----------------------------------------------</td>
</tr>
<tr>
<td>7</td>
<td>The Birth of the Turbine</td>
</tr>
<tr>
<td></td>
<td>- Every journey begins with a single step</td>
</tr>
<tr>
<td></td>
<td>- The turbine water wheel, how it all began</td>
</tr>
<tr>
<td></td>
<td>- Scientific principals take over</td>
</tr>
<tr>
<td></td>
<td>- Lowell’s hydraulic genius and his turbine</td>
</tr>
<tr>
<td>8</td>
<td>Transmitting the Millpower</td>
</tr>
<tr>
<td></td>
<td>- The mechanical ingredients</td>
</tr>
<tr>
<td></td>
<td>- The early power train</td>
</tr>
<tr>
<td></td>
<td>- A little look backward</td>
</tr>
<tr>
<td></td>
<td>- The advent of metal shafting</td>
</tr>
<tr>
<td></td>
<td>- Adapting iron technology to the gearing</td>
</tr>
<tr>
<td></td>
<td>- Those shafts and gears just won’t go away</td>
</tr>
<tr>
<td></td>
<td>- The leather belt takes over</td>
</tr>
</tbody>
</table>
Preface.

“In preparing this historic outline, my chief purpose has been to seize on the salient points, fact, incidents and events of our urbane history, together with such incident and episodes as have any local interest; and to weave the whole together in the form of a reliable and interesting narrative ion or a parade of rhetoric. The solemn monotony and stately dignity of history – the painful particularity and prudish precision of chronologers (sic) and almanac-makers – have been freely sacrificed for the lively flow of stories.”

From “A Handbook of Business in Lowell with a History of the City”
by Charles Cowley 1856

The paragraph quoted above says it all, the end result that ultimately every writer of history is trying to convey and maybe not too well in some cases but still the effort is there. And if this effort to present the history of the Lowell Canal system falls short, it isn’t because of lack of effort in writing or research, just of lack of necessary forte that couldn’t be overcome by the best of intentions.

And if the author needed help from Mr. Cowley to introduce this book, he needed a lot more help from the fine people who even made this volume possible in the first place.

What can be read in an hour belays the time spent in research and editing. The people who gave it the most in their help can’t be thanked enough. The order of their listings takes away nothing for my appreciation to all.

The Center for Lowell History, UML, was a prime source of information and Martha Mayo not only put up with my many visits, she also edited much of the work. Janet Pohl certainly deserves all of the thanks that I can give her, plus.

The National Park Library steered by Jack Herlihy also contributed much material and much of his valuable time. Dan Walsh is now in his justly deserved retirement but he was always willing to give his first rate help. And thank you Dave Blackburn; the doors were always open.

Bud Paquin was instrumental in producing the finished product that you are reading and his workmanship added greatly to the authors endeavor.

Thank you.
Chapter One

A look back at East Chelmsford

The first Step

This doesn’t have to be the first read book out of the proposed six books in the series covering the Lowell Canal System, and it doesn’t have to be the last. But it should be read to have an overall grasp of what constituted the motive power of the canal system and how it served to propel the machinery that wove the cloth that fostered the textile industry in Lowell. It operated an entire industry using the most basic fundamental processes that have been around since the earth was a mud ball; the kinetic energy stored in the action of a cascade of falling water.

The difficult decision in putting this work together, the fifth book in what will be a series of six altogether, was where to start in the telling so as not to be so repetitious that the reader gets bored and says to himself, “oh no, not more of this”, and turns on the TV. If the reader has read any of the other books in this series, he would be well acquainted at least with the process of diverting the waters of the Merrimack River through the canal system and the methods employed in utilizing the abundant waterpower from the waters of the river. If not, we’ll do our best to try to create an informative picture here as we progress, beginning with a brief outline of the beginnings and moving right along.

The prime object of this book though is to explain the function of the waterwheels, turbines, shafting and gearing, and the associated machinery involved in the process of extracting the waterpower and directing it into its desired usage, powering up the Lowell mills. We will begin with the planned canals and underground raceways that directed the water flow into the mill site and follow the transmission of the motive power from the wheels generating the power to the looms weaving the cloth and accompanied by illustrations and text where available in the research material.

A brief synopsis of the history of the creation of the Pawtucket Canal and its evolution into the great power canal system that it evolved into is called for first.

AN ACT

Incorporating Dudley Atkins Tyng, Esq., and Others, for the Purpose of Rendering Merrimack River Passable with Boats, Rafts and Masts, from the Divisional Line of New Hampshire and Massachusetts, to the Tide-Water of the Said River, by the Name of the Proprietors of the Locks and Canals on Merrimack River

Special Laws, 1792

The original charter for the building of the Pawtucket Canal was issued by the Massachusetts Legislature in 1792 to a group of Newburyport businessmen who formed a corporation entitled the Proprietors of the Locks and Canals on Merrimack River (PL&C), and holding the investors to the obligation of building a canal around the Pawtucket Falls and clearing the Merrimack River itself of any and all obstructions on its
journey to the Atlantic seaboard (the later stipulation was never quite lived up to by the PL&C but the Legislature never seemed to hold them to the stipulation either.)

Prior to the construction of the Pawtucket Canal, the timber cut in New Hampshire and floated down the Merrimack River in rafts had to be removed from the river at a landing above the Pawtucket Falls, the rafts taken apart and transported overland using teams of oxen or horses to a landing in the calm waters at the junction of the Merrimack and Concord Rivers below the falls to be reassembled into rafts and from there continue the trip downstream to Newburyport.

So the initial reason for the conception of the Pawtucket Canal in the first place was to move the cut timber from the forests of New Hampshire to the Atlantic coast and Newburyport and for no other reason, regardless of the final destiny of the waterway in evolving as a power producing waterway to provide motive power to a textile empire. Supporting the great ship building yards of Newburyport was what it was all about and also supplying timber to Boston.

But lets not get ahead of the story outlining the development of the area then known as East Chelmsford and the eventual digging of the new canal that would follow. Actually the path of the canal utilized the same bed that carried the little known Speen’s Brook. The brook left the Merrimack River at a point several hundred yards above the falls and followed its own path around Wamesit Hill (now School Street Hill)² to skirt the turbulent waters until emptying into the relatively calm waters of the Concord River below the falls.

This nondescript flow of water in Speen’s Brook was to be the answer to the prayers of the lumbermen for a watery path around the main obstacle that stood in the way of ferrying the lumber from the woods of New Hampshire to Newburyport, the Pawtucket Falls.

Over the length of the falls, the treacherous rocky path was to provide a drop in the waters of the Merrimack River of 32 feet but in no way through a sudden falling off from one level to another or even through several smaller falls. Instead the water roared and tumbled among the huge wildly piled stone and outcrops of granite ledge for about a mile³ reaching the calm waters where the Merrimack merged with the Concord. These were the notorious Pawtucket Falls that a way around was being sought for.

During the high water in the river at spring time it was recorded that sometimes it was possible to float the rough logs over the swollen rapids of the falls but at the risk of life and limb for the men who often rode the logs on the perilous trip to try to prevent jams, and when there were jams, to untangle the mess without becoming part of the floating fish food.

But in no way would the comparatively small trickle of water that flowed through Speen’s brook float the shots (a portion of a raft assembled for easier handing) of cut timber on the journey between the Merrimack and Concord Rivers. The banks had to be widened and the depth increased (at least 30 feet wide and three feet deep as quoted from the PL&C Directors minutes of March 16, 1793) to even contemplate such a trip. Also
the 32 foot drop in the water level between the two rivers would have to be overcome by lowering the water level in successive stages along the length of the proposed canal.
Examining the Route of the Canal

The canal took five years to dig and complete from its conception including the four locks necessary to lower the shots of timber in gradual stages until reaching calm waters again, opening in 1797 and from 1797 to 1821 that was the only role for the canal. It also carried produce and trade goods downstream but it was a one way trip. No like traffic in the opposite direction was found mentioned in the records until the steamboat ventured the trip in later years.

The place to start our story is at the beginning and the beginning was the semi-circular course of Speens brook and the widened and deepened of the brook to create the Pawtucket Canal and allow the timber to be floated downstream in the now increased volume of water.

The path of Speen’s Brook was dictated by the irregularities of the landscape. In the sketch below it is shown describing an arc in the lower part. This map accompanied the original proposal for the construction of the canal.

Plan as submitted to Legislature with Acts of incorporation for PL&C. 1792
Proprietors of Locks and Canals #165

The single line sketch above illustrating the course of the brook looks cut and dried but in reality the waterway had to be dug from the Merrimack River to a small pool.
at the head of the brook called Lily Pond and the lower half was no more that a imaginary path through a swamp for the remainder of the trip to the Concord River.

The course of the Pawtucket Canal pretty much followed the layout of the brook. The path from the Merrimack River to Lily Pond at the head of the brook was probably straightened to accommodate the large rafts of lumber and the rest of the brook enlarged for the same reason.

Map of East Chelmsford in 1821 by John G. Hales

Historical writings tout that the canal was fast decreasing in importance as the completed Middlesex Canal opened in 1804, providing a shorter and more convenient route to the markets of Boston. But few mention that what complicated matters even more so for the neglected Pawtucket Canal, and terminally sealed its doom was the sandbars blocking the harbor at Newburyport\(^4\) preventing much heavier tonnage traffic and depriving that town of its lifeblood of building larger ships. By 1820 the Pawtucket Canal was a has-been in the history books.
Finally the Revelation

The concept of utilizing waterpower was well known in the comparatively primitive industry of the day. Prior to the introduction of the existence of the Pawtucket Falls on the Merrimack River, a water powered mill had been set up in Waltham Massachusetts in 1814 and it was known as the Boston Manufacturing Company, which was a very successful manufactory for cotton products on its own located on the banks of the Charles River.

Still even this company had to have a prototype in some previous operation and in this case it was the British power loom. How the technology became to be transferred across the sea to a country that they had just fought a war against deserves telling and it should be read. For our purposes it is enough to say that Francis Cabot Lowell stands out among the investors who saw the opportunity and took it forward when none else believed it was feasible. But Lowell would be recognized as the chief actor in the enterprise, responsible for furthering the methods of spinning the cotton into cloth and performing all operations involved under one roof. This he achieved in the Waltham mills of the Boston Manufacturing Company, and he had the foresight with others to transfer the technology to the rural outpost of East Chelmsford. He was eventually rewarded by having the City of Lowell named after him.

But the capability of the Charles River that powered the Waltham mills to support more industry was already exhausted. A new and more powerful source of waterpower had to be found if expansion of the successful textile industry was to be considered and pursued by the investors.

Patrick Jackson was the largest stockholder in the company and had the most to lose if the mill operations became stagnant so joined by the Boston merchant Nathan Appleton they toured the area of the Pawtucket Falls at the suggestion of Ezra Worthen, an acquaintance of Paul Moody who was in charge of the Waltham mills immediately recognized the potential of the waterpower waiting to be released in the raging action of the falls. And even this credit for the suggestion of the Pawtucket Falls as a site for the future expansion of the Waltham Manufacturing Company is in dispute by some but it wouldn’t be history without some conflict involved in the retelling.

Why it took all of these 23 years to realize the potential of the power in the Pawtucket Falls is almost unfathomable. Especially in the 1700s and early 1800s when waterpower was the elected motive power of choice of what industry there then was. The existence of the Pawtucket Falls had to be well known by all in the surrounding area and was most likely discussed freely amongst themselves even if only in passing remarks. And if Worthen was acquainted with the Merrimack River and the Pawtucket Falls from his youth, everyone else in the surrounding area would most likewise be in on the secret.

But there was still one unknown left out of the formula to complete the process for generating the waterpower. And that was a very necessary ingredient; a dam to pool the water in a reservoir in the river above the falls. The water flowing over the falls alone wasn’t the answer. The difference in the water level above and below the falls held the
answer. This is what would create the head necessary to turn the waterwheels. By 1824 the first crude structure would span the Merrimac River.

Enough about the Pawtucket Falls has been written to at least justify a glimpse of the churning waters passing over the glacial bed of rocks that was destined to steer its course for all time, at least all of our time. And a view of the same falls and a dry bottom will give a good comparison of the conditions confronting the lumbermen moving the timber and why a route around the falls was sought.

As mentioned before, the lumbermen would ride the timber the length of the fall during high water such as this to try to steer the bucking logs through the raging turbulence and avoid jamups if possible risking life and limb.

Lowell National Historical Park
Photo ID# LOWE 617

A different picture presented itself in the dry season and it was in this situation the rafts would have to be broken down and the timber hauled around the exposed river bottom by teams of oxen or horses.

Lowell National Historical Park
Photo ID# LOWE4390

Any reference to a lack of knowledge about the power available in the Merrimack River from the earliest days of the settlement along the river is at best a misinformed denial by the observer for there were documented smaller industries that made use of the waterpower generated by the Merrimack and Concord Rivers, at least as far back as the early 1700s.

Probably not the first but at least the first we can document as taking advantage of the waterpower of the Merrimack River was Judge Tyng, credited with erecting the first dam and mill on the Merrimack River. A John Ford was to become owner of this
property and the map of Speen’s Brook on page five shows Ford’s Mill located at the beginning of the Pawtucket falls and the end of the falls stood another called Tyler’s Mill.

Saw and grist mills were always the first erected as those operation were what the colonist desired the most to cut the lumber and grind the grain for their very existence. Even before 1710 John Varnum was credited with erecting a grist mill on the Dracut side of the Merrimack River. In 1737 Nicholas Sprake (Sprague) pre-empted the development of the industrial city of Lowell as a center for the cotton industry by erecting the first fulling (step in textile manufacturing) textile mill on the Concord River and it represented the first textile plant within the confines of what would become Lowell.

In 1813, Phineas Whiting and Josiah Fletcher erected a wooden building for the manufacture of cotton goods at a point above where the Pawtucket Canal entered the Concord River and the fledging industry enjoyed the waters of the Merrimack River emitting from the canal as it operated the mill’s machinery. It wasn’t much of a mill in comparison of the massive structures that were to follow, only 50 by 60 feet in size but it served the purpose of their operation. Thomas Hurd bought the factory in 1818 and fitted it up for the manufacture of woolen products. It still wasn’t much with only 16 looms being tended by about 20 persons but it served his purpose at the time.

From Hurd’s humble beginnings in the woolen business in this non-descript surrounding was eventually to evolve the Middlesex Manufacturing Company and lay the foundation for the wealth and fortune of the Lawrence brothers. These two brothers and their families over time were to support the very development that foresaw the Lowell Mills expansion into the empire it became.

So with a little study of past records it becomes quite obvious that long before the Boston Associates themselves were even thought of, more that one thriving business was benefiting from the power produced by the Merrimack. It makes the question of what took so long for the others to follow a little more baffling.

And many other small industries would precede the dreams of the often referred to Boston Associates as the boys from Waltham would come to be called in the records. Over the years, canals would be dug and wing dams jutted into rivers and flumes constructed to announce to the world that the enterprising Yankees had arrived. The one common denominator of these infant industries was that they were all powered by waterpower.
The Power Canals and that Damn Hill

In a perfect world, all that would be necessary to produce a continual supply of waterpower would be two waterways running parallel to each other, say for our purposes one with an elevation of 10 to 20 feet higher than the other. Dig a raceway between the two waterways, mount a waterwheel with buckets attached to the face of it in the resultant downhill flow of water, and the weight of the water in the buckets would turn the wheel and shaft creating a circulative motion of the wheel and viola, waterpower.

But the world isn’t perfect. Smack dab in the path of a would-be straight Speen’s brook had to be placed that mound of granite known as Wamesit Hill back then, and dictating that forever the Pawtucket Canal would have to flow around it.

The Pawtucket Canal was at this point the only feeder canal in the system. In its mile and a half arc around the barrier of the hill, power canals would have to be cut from the Pawtucket Canal to feed the water to respective mill sites located between the canal and the river. Ironically would be longest of all of the power canals was the first dug, the Merrimack Canal. As the Pawtucket Canal continued on its trip to remerge with the river the distance between the two lessened because of the contours of the land and the length of the power canals became shorter to the point where the Middlesex Mills located at the end of the Pawtucket Canal were built right on the banks of the canal and the Concord River just before it merged with the Merrimack in a couple of hundred yards.

By 1838 the drain on the canal system was vastly over extended. In the dry summer months, and likewise in conditions of ice in the canals, complaints from the mills were common about the lack of sufficient water to keep the machines running up to capacity but by now the drain on the amount of water that the system could supply continuously was in question and the answer doubtful. This left no alternative except to consider a new source for an added supply into the already over burdened canals.

To the new chief engineer of the PL&C fell the charge of seeking a solution to the problem and James B. Francis was up to the task. Several remedies were proposed by Francis and as usual cost was a factor. The maximum return for the least expense naturally and any expansion of the canals had to be well justified.

A new canal from the Merrimack River paralleling the existing Pawtucket Canal to below the Francis Gates was the first rejected because no matter how much added volume would be made available, it would all still flow into the already choked lower Pawtucket Canal that was constantly overwhelmed by the existing four power canals it fed. Expanding the width of the Pawtucket was ruled out for the simple reason that the mills had built right on top of the canal banks and dredging would have entailed digging right to the canal banks requiring much driving of piles to support the new banks and the mill buildings sitting on them.

Everyone involved was just as aware as Francis that none of the offered plans were feasible but every option had to be examined. In the end a proposal that had been originally offered by Patrick Jackson in a letter to the PL&C Directors in 1839 was
reconsidered. A new canal running from the Merrimack River would be cut from just below the entrance to the existing Pawtucket Canal but above the falls and be constructed so as to connect with the Western Canal. The planning predicted that this increased supply would flood the Western and feed the Suffolk, Tremont and Lawrence Mills directly. It would add to the water supply in the Eastern Canal through the Boott Penstock, an underground raceway that would be built from the Merrimack Wasteway to back feed the Eastern Canal, and supplement the water supply to the Boott and Massachusetts Mills. The plan also dictated that the waters from the new canal would back up into the Swamp Locks Basin to provide an added volume to that reservoir. The new canal was a no-brainer and construction on the Northern Canal took two years, 1846-48. The Moody Street Feeder and the Boott Penstock were built at the same time to aid in distributing the added waters throughout the canal system.

Below is offered a sketch of the complete canal system and the mill complexes it supplies with waterpower. The problem created by Wamesit Hill is quite evident dictating that the Pawtucket Canal flow around it and leaving every canal in the system ‘at the end of the line’ so to speak. To the reader, examining the offered sketch, the Northern Canal answers all of the problems of supplying the needed water into the thirsty power canals. Ah, hindsight.

The Lowell canal System. Drawn by Mark M. Howland

Genius or the result of dogged determination

But before the first shovel full of dirt was turned, the PL&C and the mill owners had to sit down and agree on the real need for the new canal, how the waters would be appropriated amongst the mill sites and how the costs would be divided and it took many
months, no years to resolve all of the issues. The minutes of the Directors meets are peppered with discussions and appointed committees but the first effort to bring all of the proprietors together appears to have been proposed at the Directors meeting of October 16, 1840.

Even though the actual planning and engineering was described in the text above, the Directors of the PL&C and the mill owners still had work to do before the canal construction finally was to begin in 1846 and it was major. For starters there was no money to fund the ambitious project. Also the legalese of responsibility amongst all parties was yet to be determined: who would get what when all of the smoke cleared and the new waters began to flow was prime.

In 1845 the PL&C sold the machine shop and a large amount of land. Next the stock was called in and new stock issued to the mill corporations based on the quantity of their leased millpowers. Now the corporations became the owners, they would be the decision makers, the masters of their own fate.

The new canal was a go.

Now that finances seemed secured and the decision was made to construct the new canal, how, and where became the obvious questions to be answered and this was the dilemma confronting Francis. The construction of the canal through Wamesit Hill would be through mostly solid granite and this Francis was well aware of. Cutting through it was the shortest route but common sense dictated it bordered on an impossible solution and the construction undertaking for the day would have proven a tremendous challenge. But there was a known longer route that had been previously offered and now it probably seemed the easier path all things considered and it was decided on eventually. That was around the hill. This was to follow the original suggestion by Patrick Jackson mentioned above.

So the Northern Canal was constructed around Wamesit Hill, the northern side as the name of the canal suggests, by achieving almost the impossible, no, just the impractical but not for those days. That course may also have solved the problem of building a canal to bypass the rapids at the falls to move the lumber and in a much straighter line if extended to the Concord River and almost parallel to the Merrimack. But for the expense and practicability of this alternative in the 1790s, it probably would have proved to be excessive just to move lumber. For that job, the course following Speen’s Brook would do nicely. But by the 1840s it was to prove expedient as a supplemental source of waterpower to propel the waterwheels that would operate the looms but it was a different era and the promise of added fortunes to be made would entice the expenditure.

Now the problem that presented itself was how to get around the Northern side of the infamous hill. The answer was to build not on the northern side of the hill itself but in the river around the northern side of the Hill. It required the construction of a massive granite wall about 2,300 feet long still known to this day as the Great Wall, to separate the river waters from the waters now funneled into the new canal leaving the Merrimack River at the gatehouse built as part of the Pawtucket Bridge (renamed the James F. O’Donnell Bridge).
In the photograph below is the Great Wall with the raging Merrimack River tumbling over the falls to the right. In some cases the wall rose as much as 36 feet from the river bottom. Its construction was coursed granite lined with rubble laid in cement and founded upon rocky ledge.

The Great Wall was not a simple structure thrown together to separate the Northern Canal from the Merrimack River. It was a massive structure meant to hold back the waters of the Northern Canal. Once the canal water left the river above the falls, the difference in the height of the Great Wall off the river bottom as the two waterways flowed parallel to each other reached as much as 36 feet\(^19\).

In a report of the Lowell Historic Canal District to the 95\(^{th}\) Congress of the United States about 1976 describing the structure, probably to be catalogued and registered in the federal archives, the Great Wall was described as “a massive wall of coursed granite lined with rubble laid in cement and was founded upon rock ledge\(^20\)”.

Just before the bend in the river where it set its course for the sea, the path of the Northern Canal was altered so it turned inland, still paralleling the river, but now creating a spit of land several hundreds of feet wide before emptying into the Western canal, and its waters utilized to supplement the existing overburdened canal system. The map on page 11 is well suited to illustrate the path the Northern Canal followed in relation to the rest of the canal system as the circuitous path it followed out of necessity to skirt the Wamesit (School Street) Hill.

This history of the headwaters that fed water from behind the Pawtucket Dam and through the Pawtucket and Northern Canals into the Lowell Canal System can be read in its entirety in the book, *The Canals that Built a Textile Empire*. 
If the reader has read any of the other books in this series, he will easily spot many repeats of the text and illustrations but there is only so much material available to compliment the contents of five books. They just aren’t producing history any more, and certainly not from the era of our interest.

Many of the terms used in the text to describe the machinery and accompany the description of the operation may be alien to a first time reader but most will define themselves as the text unfolds, or will be explained when introduced with a term or action. For the most part the same terms were used repeatedly in the materials throughout the research so they do become familiar. The photographs, illustrations and sketches speak for themselves.

But the historical text as offered by different primary and secondary sources can and do differ in some cases. If a source for the contradictory statement is offered, the author will consult the original if possible. If the statement contradicts common accepted facts or what are assumed to be and can’t be verified, it will still be included with a note as such. After all, it may be correct so to be as true to the research as possible, both versions will be presented.

In any case the reader should just place his tongue in his cheek and reread the quote by Charles Cowley in the Preface on page two. One big advantage is nothing can change now no matter which is right or wrong or how interpreted.
Chapter Two

Nature, Gravity and Paperwork

This narrative doesn’t have to begin at the headwaters of the Merrimack River and follow each and every drop of water as it combines in the 110 mile trip downstream until the falls at Lowell are reached but it should serve as the catalyst of a most interesting story if it is told right and the reader enjoys the telling. The reader and the water are at the same point here, at the Pawtucket Falls.

And a good place to start with the definitions is right here with a description explaining the roll of the Proprietors of the Locks and Canals on Merrimack River (from herein the PL&C). The company controlled the land that was to form the core of the town of East Chelmsford and eventually the City of Lowell, and the canals and the water that flowed in them, and consequently the process whereby water flowing in a canal and falling from an upper canal into a lower canal generated what is called a head as it dropped from a higher to a lower level. That is the simplest description of the prime source of waterpower to the mill complexes and that’s what all of the land and water is all about.

The prime product of the PL&C was water or rather the result of the process whereby water flowing in a raceway generated waterpower as it dropped from a higher level to a lower level at each falls as it changed elevations. In its journey down the raceway from the feeder canal and then funneled into the forebay housing the waterwheel, the falling water would pass over and fill the buckets mounted on the face of the waterwheel and the weight of the water would cause the wheel to turn on its shaft producing the motive power.

The resultant different levels of the water at each falls generated the head, and the changing elevations in the canals from higher to lower utilized this head by dropping through the waterwheels in each mill as described above. The shaft that the wheel revolved on or the toothed cam attached to the perimeter of the wheel carried the same circular motion with it and conveyed the motive power that was transmitted through shafting, gearing and belting throughout the mill to feed the resultant power to the looms or whatever machinery it was called for.

The Merrimack River normally had a fall of 32 feet throughout the distance of the Pawtucket Falls but this fall developed a head that was enough to generate a total of about 10,000 to 13,00021 horsepower that was available for use in the canal system. The elevation of the water in the canal system itself was regulated by the PL&C to sustain a constant 30 foot level. The theory that the more water in the canals presented the best of possible circumstances will be dispelled further into this chapter and it will make sense of why the 30 foot level was implemented and maintained by the set of the boards at the gates and dams.

The water would in each canal drop 13 feet at the first dam location and 17 feet at the second dam for a total drop fall through two dams on each of the Pawtucket and Western canals respectively, for a total of 30 feet before being returned to the river. But it
generated enough horsepower to support 44 mills and their print works, machine shops and whatever other machinery was necessary.

To the reader who fully understands how the waterpower is generated, transmitted and utilized at the final destination, the above explanation may seem overly simplified or even unduly repetitious but the aim is to familiarize the person who is having his first encounter with waterpower in the Lowell Canal system with the basic workings of it.

In a classic example of a perfect situation all that would have to be done to harness this waterpower was to place a dam in the path of a river or canal, a canal for our purpose. Two separate canals would now leave from this point; take the Swamp Locks for example. The dam straddling the Upper Pawtucket Canal at the Swamp Locks would serve two purposes. First it would allow a canal to be dug beyond and lower than the dam (this would be the Lower Pawtucket canal) so the waters behind the dam could empty into it when the gates were opened and develop what is known as a head because of the change in elevations of the water as the water fell into the lower level of the Pawtucket Canal beyond the dam, 13 feet in this case.

Lowell National Historic Park   Photo ID# LOWE 7148

At this point above the dam at the Swamp Locks, a second canal (the Hamilton Canal) would be dug from the basin formed by the water backing up behind the dam, following a path parallel to the now lower Pawtucket Canal that the dam is emptying into. The map of the canal system on page 11 shows this very clearly.
This difference in elevation of the waters of the two canals is what is described as the head. If a raceway (penstock or headrace) should be dug from the higher canal that is being fed from the basin behind the dam, through the spit of land separating the two canals, and empty into the lower canal (through a tailrace) that was dug to receive the waters that were allowed to flow through the gates at the dam, the water would rush from the upper down into the lower canal. Any waterwheel placed in this sluiceway would be propelled in a circular motion by the weight of the rushing water. Just the weight of the water falling into buckets built onto the circumference of the wheel would supply the motive power to do work. Construct a mill over the wheel and the goal of the falling water is achieved. The waterpower is now millpower.

If a gate were placed in the headrace before the wheel, actually where the raceway or penstock left the feeder canal, adjusting the opening in the gate would regulate the flow of water in the penstock and thus the motion of the wheel.

This tale of the development of the canal system is akin to the song, “the tail bone is connected leg bone, and the leg bone is connected to the ankle bone, etc. etc.” The Merrimack River flows into the feeder canals, either the Pawtucket or the Northern and the feeder canals into one of the power canals, the Merrimack, Lowell, Hamilton, or Eastern from the Pawtucket and the Western and Lawrence from the Northern. The power canals then feed water into the headraces or the penstocks that directly supply the water into the mill wheels and it’s really at the gates of the headraces that our tale will begin.

But all of the horsepower that was available at the Pawtucket Falls to produce the motive power to run the looms at the mills was generated in the 32 foot drop over the length of the rapids starting at the Pawtucket Dam. Why does the author keep harping on the drop in the water level in the passage over the length of the Main Falls below the dam? What does that have to do with anything? Simple, it is everything.

It is not by luck but by choice that the flashboards at the dam are set at 5 feet (they have been at 2, 3 and 4 feet at various times) over the height of the granite blocks comprising the construction of the Pawtucket Dam to maintain the best operating level of the water of about 86+/- feet above sea level and the level of the Concord at about 42+/- feet where the two rivers meet. This is the drop in the water level that is always being talked about at its extreme height conditions.

Any large variation in either higher or lower levels will produced negative effects in the results of the canal operation. The height of the water in the Merrimack River entering the canals can be regulated at the Francis Gate so the level in the canal system can be kept at a more or less constant elevation. But the height of the water at the merger with the Concord River fluctuates with its own flow from surrounding waterways that empty into it and if it varies too much from over the 42 feet, it can interfere with the flow of water out of the wheels. This is the term known as Backwater and the consequences of the high water in the wheel pits will be explained forthcoming.

As usual nothing is as simple as it is made out to be on first mention and this includes the above description of the part that each canal mentioned above played in the
overall canal distribution picture as outlined above. But whether designated as a feeder or power canal, and most were both in their role in the system, together they functioned as a whole and best we leave it at that for the time being.
The Mechanics of the mill power

And as the mill power is the defined unit that is used to measure the waterpower supplied to the mills by the controlling agency of the PL&C, the method of calculating it should be examined first. The term mill power (or mill privilege as it also called) has to be defined here and now in order to explain the basis for the calculation of the waterpower that each mill contracted for from the PL&C and this term will be repeated many times in the coming text.

And why defined as mill power? The force of the water dropping through the falls was defined as horsepower and James Watt had labeled a horsepower as “equivalent of the sustained labor of eight to ten men.” As good as any definition for want of a better. But the Waltham experiment was to prove unique and their label for the mill power as a unit to perform work was likewise. It was based on “the power required to drive 3,584 spindles, together with the preparatory machinery and looms for weaving the yarn”.

So mill power became the term used as a measurement of the unit of waterpower contracted between the PL&C and the mill corporations to propel the necessary machinery in the cotton mills of Lowell. The PL&C leased the land the mills were built on to the corporation specifications and the necessary mill powers based on the formula developed from the experience from the operation of the Waltham experiment.

When the Merrimack Canal was built to feed the wheels of the Merrimack Manufacturing Company, a definition of the power of the water necessary to propel the massive 30 foot wheels using the full 30 foot head supplied directly from the Merrimack River wasn’t deemed necessary. This mill site was considered to be a continuance of the Waltham System so why should the waterpower be measured; for what reason? The so called Boston Associates owned the Merrimack Mills and all of stock in the PL&C and by that virtue, all of the water rights plus all of the land in East Chelmsford. What was to measure?

With the success of the Merrimack Manufacturing Company projecting visions of great achievement and wealth on the horizon, the Associates expanded the canal system by digging the new Hamilton Canal from above the Swamp Locks parallel to the Lower Pawtucket Canal envisioning the construction of many more mill sites, all no more than an extension and controlled by the Merrimack Manufacturing Company. But they were learning that successful managing of the manufacturing process and the managing of large amounts of land to be developed along with the water privileges were two different matters.

The original charter granted to the PL&C in 1792 was rewritten in 1825 with the necessary changes and the PL&C resurrected as a separate entity by a new act of the State Legislature just to handle the developing and leasing of the land and the now enormous water rights. An entire machine shop plus the accompanying foundry was also built under the control of the newly formed PL&C to equip the mill buildings that were being constructed by the company under contract to the corporations.
And the Locks and Canals (common name for PL&C) held all of cards in the quest for land and waterpower in Lowell. As George Gibb observed in his knowledgeable study, the Saco-Lowell Shops, “No enterprise could locate advantageously in Lowell except on Locks and Canals land, and no wheels could turn except by means of Locks and canals water.”

The cost of leasing the land the mills were built on was secondary. Build the mill buildings. Furnishing the machinery was also cut and dried. All of the mill buildings were more or less the same size, 40x150 feet and four or five stories. From the Waltham and Merrimack Mills experience it was known exactly how many looms a mill of that size would run and how many spindles (held the bobbins and cotton yarn) each loom would carry.

The first mill complex built in Lowell was the Merrimack Manufacturing Company and the canal dug to feed the water to the mills from the swamp Locks was likewise named the Merrimack (known as the factory canal when first completed). In an article in the Boston Comerial Gazette in 1826, it stated that “five mills with 4000 spindles each had been erected.” Just to bring into perspective how mill expansion effected the total number of spindles involved in the operation and the amount of the cost involved, by 1882 the Merrimack was running 153,552 spindles. The total number of spindles in the year in the whole system was 742,286 being run on 20,052 looms.

“During the early years leases were made at rates of $2.50 to $4.00 per spindle varying with the times and the market, but were eventually stabilized at the latter figure, which amounted to $14,336 per mill power, based on the 3,584 spindles of the second Waltham Mill.” This quote from Waterpower doesn’t give a source but it isn’t to far removed from the cost of $12,000 per mill power plus a $300 fee for the annual “rent” of the mill power taken from a correspondence between head PL&C engineer James B. Francis and Abbott Lawrence of the Lawrence Mills in 1859.

The number of spindles was the all important factor in determining the amount of mill power necessary to operate the mill at its peak. But how much water was required to supply such a mill building with the needed amount of mill powers to operate the looms that would be necessary to sustain the manufacturing process within to its maximum? Keep in mind that the elevations in the canal system changed at each Fall and the drop in the elevations varied at 13, 17 and 30 feet. This fact would in effect vary at whichever mill was supplied by the drop in water depending at what point along the canal that the mill was built taking into consideration the formula stipulated in the lease every corporation had agreed to and signed.

The article reproduced below was signed by the PL&C and each Mill Corporation and in this case printed in 1853. Prior to this agreement the mills were allowed to draw water from the canals 24 hours per day but the 15 hour restriction was placed in effect to enable the water in the Merrimack River to pond behind the dam at night to increase the amount of water available for the next day operation.
**Form of Lease of Waterpower at Lowell**

Article 1. Each mill-power or privilege at the respective Falls is declared to be the right to draw from the nearest canal or water course of the said proprietors so much water as, during fifteen hours of every day of twenty four hours, shall give a power equal to twenty-five cubic feet per second at the Great Fall, when the head and fall there is thirty feet – to forty five and a half cubic feet per second at the Lower Fall, when the head and fall there is seventeen feet – and to sixty and one half cubic feet per second at the Middle Fall, when the head and fall there is thirteen feet.

As a way of explanation, the Great Fall in the document is referring to the Pawtucket Fall against which all the head in the canals is measured. The Middle Fall is the Swamp Locks and the Lower Fall is just that at the end of the Pawtucket canal just before it empties into the Concord River. The ‘head and fall’ is describing the drop of the water level at each point in the river or canal.

The cost of the mill power was cut and dried in the Lease Form. It was stipulated in part in Article 1 on page 5 of the lease that the said party of the second part hereinafter contained to pay to the said Proprietors the yearly sum of three hundred dollars for each and every mill-power hereby granted... Very clear and concise, yes?

Not quite.

Here’s the best the author can do to avoid clouding the historical record of the article that was just presented to the reader. That is to claim, maybe.

It turns out that the $300.00 per year as specified in the Lease was a yearly rent for the mill power, not the total cost of the delivery of the mill power nor the inclusion of the price of the land that the mills were built on. The information given in the authoritative book *Waterpower* states that “in the early grants or leases of the waterpower, one or two acres for building sites were conveyed with each millpower, a practice shortly modified to the right of the lessee to buy some four acres with each millpower.

Many words have been offered up in the explanation of term mill power presented above to try to aid in the reader’s understanding of the basic measuring unit of the waterpower furnishing the mills by the PL&C. The author trusts it succeeded at least somewhat.

But one more main topic has to be covered before going on to the machinery that utilized this waterpower. Its known as Backwater and its effects can strangle the motive power of the best of the wheels.

**The Mechanics of Backwater**

Backwater is probably the least understood and certainly the least mentioned of all of the effects of high water in the river or canals. Yet its presence is nature’s nemesis to the successful operation of the canal system. A cure for the condition known as
Backwater was never discovered at least during the time that the waterwheel was the prime source of power. Both the PL&C and the mill corporations had to learn to live with it as long as the motive power depended on the waterwheel.

When the term Backwater does appear as the result of a high water condition, the many negative effects that accompany the mention of its presence is sort of talked around as if maybe it would go away. Wrong.

This explanation should go a long way to explain why high water isn’t the end all answer to increasing the waterpower in the canal system as promised on page 15. Talk is cheap and you get what you pay for so let’s go to the old standby and start right off with an illustration. Familiarize yourself with it and the reading of the text should answer most of the unasked questions.

The drawing is meant to schematically duplicate a typical breast wheel that was in common use in all of the mills in Lowell before the advent of the turbine wheel in 1847. Water is flowing in the sluiceway (A) in the upper right of the sketch from the headrace and falling onto the face of the wheel between the buckets or fins (B) and the breast (C) that keeps the water from spilling out. This is the normal operation and the weight of the water turns the wheel to produce the motive power. The coloration present in the bottom of the sketch is backwater filling up the tailrace with the excessive water present in the
canal or river and causing the friction of the wheel moving through the backwater to slow down or stop its circulative motion.

The waterwheels will be covered further on in the book but it will suffice now to state that the reason the Lowell mills as one choose the breast wheel to the exclusion of all other types was that this design tended to perform the best in high water conditions. All wheels will produce a motive power under the influence of either the velocity or weight of water but some a little better than others. In this case it was the breast wheel that won out.

It’s easy to picture the water pouring down the headrace and sluiceway and filling the buckets on the face of the wheel to propel its circular journey and thus produce the motive power. And the popular theory is to increase the water flow, spin the wheel faster, and tap the resultant excessive abundance of waterpower and lo and behold, more mill power will appear.

In order to accomplish the above simple procedure all that is necessary then is to increase the volume of water in the canal system. Easy solution. But in truth when the mills needed more water and more water was added to the system, “the increased current produced friction that actually dropped the level of the water in the canals, reducing its potential to produce more power”.

But keep in mind, this added volume is to all the canals, not just a select few and dictated by the placement of the mills along the waterways. Half of the mill complexes and their feeder canals aren’t even with hailing distance of the mother load of water that is the Merrimack river but its influence is never erased. The water comes from the river and it has to return to the river.

And herein unknowingly lies the problem. Let’s take this one step at a time and it’s really the only way to do it because the whole picture of the canal system has to be presented but as individual pictures like snap shots as it were and not a fast moving movie film. Just keep the drawing above in mind of the tailrace and bottom part of the wheel under water in the pit and the text should fall into place.

The Pawtucket Dam and the flashboards on top are there to cause the water in the Merrimack River to pool behind the dam and back up in the basin as far as eighteen miles. This reservoir when filled at night because of the mills not operating is what provides the storage of waterpower for 15 hours of operation the following day in quantity enough to provide top efficiency at the mill looms. But what happens when there is excessive water in the river to start off with such as during spring freshlets or simply high water for any given reason?

It pours over the dam naturally and increases the height of the water below the Great Fall proportionately to the water pooled behind the dam in the river. The tailraces of the Merrimack, Lawrence, Boott and some of the Massachusetts Mills exit the spent water from the wheels into the river. Now because of the increased height of the water in the river, water begins to back up in the tailraces preventing the discharge from the tailraces and submerging the lower section of the wheel. This in turn causes the wheel to
run slower because as it turns the now elevated height of the water presents a braking action as the buckets on the face of the wheel try to overcome the water barrier and empty the buckets. This is what is known as Backwater.

The height of the flashboards that cap the dam can’t be added to so as to restrain any increased volume of water pooled in the basin behind the Pawtucket Dam, because to do that flooding would occur along the river above the dam and that is an ongoing complaint to this day as it is. The residents want the flashboards lowered, not raised and it has been a concern ever since the dam was built. In the original Acts of Incorporation issued by the Legislature, Special Laws, 1792, Section 3, it states emphatically, *Provided notwithstanding, that nothing here in contained shall be construed to authorize the said proprietors to obstruct the main passage of said river, by erecting any dam or dams across the same*.

The proprietors completely ignored this provision when they built the dam and many lawsuits resulted over the years brought by both individuals who’s lands were flooded and companies who claimed the raised levels of the river had caused extensive backwater in their wheelpits causing loss of production.

Enough local history outlining the negative effects on the upstream neighbors of the PL&C effects by the illegal construction of the Pawtucket Dam. It’s still there.

Would adding to the amount of water in the canals overcome the Backwater problem by increasing the flow into the headraces and so into the wheels solve the problem? Somewhat probably but by the same token that would increase the water height in the Lower Pawtucket Canal into which the Appleton and Hamilton canals discharge their spent water via their tailraces. As explained above, an increased water level from whatever source was a self defeating remedy.

Now the reader should be beginning to understand what a really finely tuned machine that the canal system is. It’s far from a hodge-podge of ditches whose only reason for being is to steer water from point ‘A’ to point ‘B’ but more important to calibrate its eventual effects on the mill operations. The 30 foot constant that the water in the system was held to begins to make much sense.
Chapter Three

“I have spent more money underground”...Kirk Boott

The Footprints of History

The whole idea to render this part of presenting the canal system interesting and entertaining is to introduce each segment of the procedure of power generation and transmission as it follows in its place in the overall picture. And just reading over the preceding sentence, that isn’t going to be as easy as it sounds. This is because since almost no part of the underground machinery chain is even visible, even given the outside chance that it managed to survive the rigors of time and neglect.

No greater sins against history could have been committed than those that were carried out against the remnants of the once proud textile empire. Just blind dumb is the only description of the action that was fostered in Lowell, indeed against the City as a whole that in its entirety was a historical gem. Thank heaven for the Lowell Historical Society and the Lowell National Historic Park. Between them at least they trumpeted the unseen value of what mill buildings were left and being destroyed by the wrecking ball for the concept of the Lowell Plan in building the New Lowell in its haste to propel itself into the future.

The paragraphs above that decries the loss of a past culture sort of renders the philosophy of one of the premier teachers of historical researcher moot at best when she emphasized, “go to the prime source” in The Modern Researcher. For us, it’s been hauled away in dump trucks or buried in landfills.

Rules and Regulations for Making a Fortune

The place to start is at the starting point, and once again it is with the Form of Lease of Water Power at Lowell that the textile corporations and the Proprietors of the Locks and Canals on Merrimack River (PL&C) signed together as co-partners really. Every time a point of contention arose between the two, the wording contained in the lease was referred too, and quoted by both parties to make a case for their separate arguments.

Specifically, Article II governs the flumes and raceways, that is referring to the waterways beyond the gates constructed at the canal walls and controlling the flow of water from the canal into the mill headraces and on to the wheel pits and thus feeding the waterpower to the waterwheels.

Beyond these gates constructed by the corporation to fulfill their obligation to the contract for the mill site and to obtain the necessary mill power to run the looms, (the actual work was contracted out to the PL&C), and its design and designation dictated by the PL&C, all responsibility fell on the shoulder of the individual mill owners, as long as they adhered to the specifications as dictated by the PL&C.

This document is quite involved, comprised of a total of eight articles over a span of 18 pages and meant to erase any doubts of obligations and responsibility from either
party, the favor leaning toward the PL&C naturally as they are the party who dictated the format.

Article II of the Lease begins and reads in part, “The flumes and raceways of the several mills of the said party of the second part and their assigns are to be made, maintained and kept in repair by them at their own expense, and so secured as to prevent leakage and waste of the water. The said party of the second part and the assigns shall always have and maintain good and substantial gates at the head of each flume or opening.”

All else that is presented in the document pertaining to the raceways that left the canals simply expands on that basic tenet. There is no need to reproduce the entire document word for word here but any part of it that touches on any part of the text quoted here will be referred to and expanded on as the history unfolds.

The legalese that’s being quoted in the Lease does no more than stipulate the fact that the PL&C’s obligation stops at the wall of the canal. The nitty-gritty of the nuts and bolts aspect contained in the operations of producing the actual mill powers as far as the PL&C was concerned stopped at the set of head gates where the headrace (also referred to as penstock or flumes in the source material) that the mills were required by the contract to construct on their own. From there on, the corporations were responsible for engineering, construction, maintenance and babysitting their entire operation of which they were no way capable of any but the last.

Hamilton Mill Headrace with remnants of trash racks by Janet Pohl

So just as the PL&C provided the land and the waterpower, built the mill buildings and then fabricated the machinery that equipped the mills, the digging
of the underground raceways by the PL&C was just another day’s work. Might just as well throw in the construction of the waterwheels and later the turbines and all that was left for the investors to do was move in the furniture and make it all work. Just turn the key.

In the presentation of the conception of the construction of the underground waterways, water wheels and associated machinery, all the text in the world would have a difficult time to really present a clear picture to a reader, especially if it is a first time exposure to the canal system. The easiest method of explanation is to revert to a tried and true method used in past books.

So in this chapter the mother of all clarity will make a re-appearance...the illustration and/or photograph. Enjoy.

The Head Gates of Wealth

Now that the ground work has been laid and a brief history of the Pawtucket canal and the seeding of the textile industry of Lowell has been outlined, a small step will be taken into the main topic of this tome, that is the mechanical machinery that made the whole process possible. But one step at a time.

The first sentence in Article II demanded its own presence but the construction as all construction dictated and followed its own pace. It was either broach the canal wall first and then build the head gate immediately to served as a sort of coffer-dam while the rest of the digging of the raceways proceeded unimpeded by any flow of water from the working canal; or dig and stone the tailrace, wheel pit and the headrace including under the mill buildings and lastly broach the canal wall and connect the headrace to the canal with the head gate. Either way, the head gate would serve the purpose designated by the PL&C and that was the only real concern of either party until the gate was opened and the flow of water being held back was unleashed upon the great waterwheel.

Actually the only obstruction between the canal and the head gate was the trash rack that was built at the entrance to the headrace at the point where it left the canal proper. The rack was built of wooden slats spaced about 1¼ inch apart overlapping the entrance to the penstock or headrace and the racks only job was of diverting trash and debris from flowing into the penstock or headrace and on into the wheel pit. There is reference to a finer rack built right in front of the wheel pit to further prevent debris from clogging the wheel but in any case these primary racks served to eliminate at least the larger debris from entering the wheels. Later they were constructed of steel and those are what can be viewed in their rusted states today when the canals are drained of the water.

The photograph below is a perfect example showing the trash rack guarding the entrance to the Lowell Canal which even though termed a canal, in reality served as no more than a headrace to the wheels of the Lowell manufacturing Company. The waterway is now blocked off.
Beyond the racks the head gates would allow the flow of water, either wide open or completely closed to shut off all water flow through the wheel and thus all motive power. As far as controlling the amounts of water into the wheel buckets, a sluiceway was usually constructed from the end of the headrace or penstock directly feeding a smaller stream of water into the wheel and at this point a smaller gate would be mounted that could be adjusted to vary the flow and thus the desired speed of the wheel.

The shuttle (B) was raised and lowered by a rack and pinion so a stream of water flowed over the shuttle and onto the waterwheel. This “sliding hatch” was introduced in the 1780s by a British engineer, John Rennie.

The design of the equipment utilized to produce the motive power was simplicity in itself. This so called simplicity, purposely mislabeled by the author, not the builders, was the high tech of its day and what machinery still exists is still able to function over 150 years after its installation. In 2009, at least nine of those turbine/generating sites still
operate. Instead of directly providing the motive power to turn the shafting and belts, not the cumbersome waterwheels but their predecessor the turbines turn generators to create electricity, still powered by that antiquated waterpower that supply the motive power to the new class of modern machinery. But in most cases, the same head gates and penstocks and wheel pits and tailraces are still pressed into use to direct the flow of water through the wheels from an upper canal to a lower canal or empty into the river.

The last surviving example of a water system employing the original headrace, wheel pit, turbine and tailrace is present as a picture window into the past in the still existing Suffolk mill building being fed from the Northern Canal, the mill building now referred to as the Wannalancit. There, an exhibition has been set up and maintained so the machinery can be viewed and explained by rangers of the National Park and it is impressive.

The wheels in the Suffolk Mill buildings were originally supplied their waterpower from the Western Canal all vestiges of which have long disappeared. When the Northern Canal was put into service in 1848, new penstocks were built running from the recently completed canal into the Suffolk Mill and four new wheel pits constructed with the view in mind to either house waterwheels or the new turbines that were to replace the wheels. The waterwheels were never installed. During this time of 1848 it coincided with the advent of the turbine and at this location two turbine were installed. The wheel pits, casings that house the turbines, shafting and associated machinery are all available for view in a permanent exhibition manned by National Park Rangers at the Visitors Center in the Suffolk, now Wannalancit mill building.

The shafting and gearing alone that is on display accompanying the exhibition is almost mind-boggling. The weight of the iron gears and shafts that the falling water could propel in a circular motion by turning a simple water wheel would probably not be believed if this exhibition of the original machinery didn’t exist.
But there was nothing simple about the end results that allowed the creation of a great industrial empire that produced finish cloth from raw cotton and the fostering of huge fortunes (for the investors, not the workers). All made possible by the channeling of a flow of water directed over the buckets of a massive water wheel or in later years, through the blades of a turbine.

The Construction of the Underground Raceways

The reader must keep in mind that the subject we are talking about are raceways, by whatever alternate designation they are referred by. Whether the terminology applied to describe these waterways is penstocks, head or tailraces, or sluiceways, they all meet our criteria of leaving a canal after the rack and gateway and feed or remove the water that propelled the wheels or turbines that power the mill machinery.

Once again our broad definition of an underground raceway is a waterway that leaves a canal after the gateway that controls its flow and supplies waterpower to a mill or mills, and allows the removal of the spent water, period.

The Moody Street Feeder is about as underground as you can get but its job is to furnish a water flow between two canals, the Western and the Merrimack. Out. The Boott penstock is underground for half of its length but its purpose is to allow a flow from the Merrimack Canal to the Eastern. Out.

How about the Inner Canal. The description of this waterway as being a canal probably was justified at its conception and was apt in its function. Because of the Merrimack Canal running perpendicular to the Merrimack River, it’s course could have created a problem digging raceways at right angles to the Merrimack canal to feed a multitude of mill buildings that were planned. So the Merrimack Manufacturing Company that was being fed their waterpower from the Merrimack Canal dug a second canal, an extension if you would have it, from the end of the Merrimack Canal into their mill site. This canal is indicated in the map on page 11 as a jug handle breaking to the left from the end of the Merrimack Canal inside the circle designating the location of the Merrimack Mills. And the fact that all of the mill buildings that were constructed at the mill site were fed waterpower from this waterway qualifies this as a legitimate canal and not an underground raceway regardless of how much of its length was covered by buildings. Out.

Now that those dubious waterway that didn’t actually begin behind any of the gateways originating from a canal has been eliminated by definition and example, we can begin to study the primary object of this chapter, the underground raceways that furnished the waterpowers to the wheels that supplied the motive power to the mill machinery.

These often referred to as underground raceways didn’t necessarily start out as buried underground. In fact some were never covered except by buildings constructed over them. The Suffolk tailraces built when the wheels were fed waterpower from the Western Canal were exposed in the mill yard until the freezing up of the water flow
during the winter months forced the mill corporation to cover them over with planks and fill as described in the records\textsuperscript{39}.

In truth there are very few mentions that the author found of how any of the raceways were treated once the water started to flow. Who was interested at that time, or now, except researchers interested in the history of the subject of the hidden waterways directing the waterpower within the mill sites.

A View of the Source of the Water Power

The first step in the overall scheme was to harness the horsepower of the Pawtucket Falls. The Boston Associates had moved swiftly but quietly buying whatever land they could at the cheapest price possible and likewise all of the almost worthless stock of the PL&C in rapid succession. One fine day when the sun rose, it was shining on the Associates and their partners in complete control now of the Pawtucket Canal and 700 surrounding acres\textsuperscript{40}.

Now the investors, one and the same for the most part of the Associates in the organization of the Merrimack Manufacturing Company had control of the waterpower to power the great planned mill complex. The means to funnel it to the water wheels to power the looms was still just a dim future in the planning stages, in fact not even having reached that point at this time in the scheme.

The 1794 charter granted by the state legislature to the PL&C that gave the corporation the right to construct the canal stipulated that it was a transportation canal and had to provide access around the falls whenever the weather conditions in the Merrimack River allowed it excluding ice and drought conditions\textsuperscript{41}. That meant that the locks and water height in the canals had to be maintained in such a condition that regardless of any secondary usage of the waterway; “boats, barges and timber” had to be able to navigate the Pawtucket Canal or the charter would be negated.

Almost half of the course of the Pawtucket Canal was comprised of a watery path through swamp and marsh and that was why the Upper Dam was referred to as the Swamp Locks. The basin formed behind this dam and locks was to be the reservoir of the Factory Canal\textsuperscript{42} that was to power the Merrimack Mills and later be known as the Merrimack Canal throughout its existence and down to today.

But first the Pawtucket Canal between the Merrimack River and the Swamp Locks had to be enlarged to supply the required volume of water that would be necessary to operate the proposed mill complex, plus provide enough volume of water to satisfy the transportation stipulation in the original charter\textsuperscript{43}. Even at that early stage in the planning, the investors had visions of many mill sites all controlled and operated by the Merrimack hierarchy and they drew on the successful experience at Waltham for the design.

The work was began in 1822 by Irish laborers hired by Kirk Boott, who after a walk from the Boston docks and herded to the Lowell canal site by Hugh Commiskey their head boss-man, walked to East Chelmsford for the rumored work. A brief stop at a
tavern hosted by Boott provided the impetus to start work on improving the dimensions of the Pawtucket Canal immediately\textsuperscript{44}. The pick and shovel accompanied by the wheelbarrow and aided by blasting powder were the only tools available at the time.

![Image of canal construction](image)

Center for Lowell History   Locks and Canals Collection   ID# BB
University of Massachusetts, Lowell

Obviously no picture can exist from the digging of the Pawtucket Canal but above is a view of work being done on the unimproved canal in the late 1800s.

A brief description of a canal work site is given by a gentleman by the name Samuel Lawrence who lived in the area at the time. Its one of “his most vivid memory of the event, the noise of pickaxes swung by the Irishmen and their Yankee counterparts”\textsuperscript{45}. If the reader can imagine the scene, it portrays a seemingly unbelievable undertaking but when this story unfolds from beginning to end, the so called extraordinary event will simply portray the every day labors of the canal construction work. And we were only visiting the first. There were to be six more to follow. And these were only the canals themselves. The raceways were to follow on the heels of the canals and the mill foundations were to require more digging, this time down to bedrock in many cases, or deeper.

Let’s assume that for our purposes the digging of the canals represents a separate entity and just emerged in the landscape. This speed forward in the story of the canal construction will allow us to continue on our merry way to pursue the story of following the penstocks from the walls of the canals and through the waterwheels.

From here, we move on to the proliferation of the underground raceway network that fed the waterpower to the mill machinery. And this network was extensive to ay the least. Kirk Boott in referring to this very topic once made what is usually treated as a jest in most writings. “that he had spent more money below the ground than above it”\textsuperscript{46} in constructing the waterways in the system. Whether or not he said it with a smile isn’t
recorded and he wasn’t far from being wrong. So that’s where this text will start, defining the path of the water from the gates at the head of the penstock or raceway leaving any of the power canals and following he course of the water as it developed the motive power through the wheels.

The Very Start of the Tale at the Racks

Here at least is evidence of the entrance to the penstocks and headraces that have survived the rigors of time. Maybe not well but never the less some of their remains can be examined at least when the canals are drained if at no other time. The original wooden construction of the protective slats has long rotted away to be replaced by steel bars but they would survive the aging until the mills themselves followed.

The racks were built of 11/4 stock in lengths necessary to cover the distance from top to bottom of the raceway plus a given height above the top. This would afford the maximum protection that could be expected from the rack and divert the largest part of the debris being carried along in the canal waters. We assume that the wooden slats and certainly the later steel strips were angled toward the flow of water coming down the canal from upstream to prevent turbulence as the waters entered the headrace.

The racks were constructed in as many different overall sizes as were necessary to cover the many varied dimensions of the openings to the headraces, each made to do a certain job the best that could be done. The two longest racks remaining are by far those that shield the penstocks under the Boott Mills in the Eastern Canal. In some cases no rack is visible covering the opening to a certain penstock or headrace when the canal is full of water only to be discovered laying on the bottom somewhere along the length of the canal when drained. Where no evidence of a rack is ever determined to have protected the penstock, best to assume that current, rot and rust have prevailed.

The alternative to that theory is that the opening was never used as an entrance to a penstock or headrace but more likely as a wasteway. This design use for these dedicated channels was meant to allow debris and ice buildup to flow out into the river when they were opened and clear the canal and aid in emptying it of debris during those times when necessary. Still, there are some arched openings that certainly led to mill wheel pits, such as those that provided water to the wheels of the Prescott Mills that have never showed evidence of the presence of trash racks at the canal entrance. Most likely indication of their one time presence was simply overlooked in the search because of the looker’s inexperience as to what was being looked for. It’s hard to believe with six entrances leading to the wheels in the Prescott that some signs wouldn’t be apparent upon an examination.

Let’s use the many openings leaving the Eastern Canal as an example. The first encountered is met when traveling downstream away from the Lower Locks Basin. There are offered six arched openings in three groups of two each. These penstocks used to feed water into the wheels of the Prescott Mills. Very few old sketches of the raceways indicated the racks and even the old photos taken when the Prescott Mills were operating and the canal emptied of water does not indicate trash racks.
Yet the long blocked entrances to the Massachusetts Mills penstocks just beyond are fully covered. This view was taken when the old Trash Racks were removed for replacement exposing the wooden supports and the headraces.
The wasteway gatehouse adjoining just downstream likewise is unprotected but here there is no reason for a rack. It’s meant to empty the canal of everything considered debris, plus ice, period.

Photo Journal of Lowell Canals

Again the headraces of the Boott Mills further along are fully protected for almost the entire length of the mill complex, constructed of steel and in excellent condition but these racks have to be maintained as there are still working turbines at this site turning electric generators.

Photo Journal of Lowell canals
The Shape of the Underground Raceways

If you’ve seen one you’ve seen them all, right? Well, yes and no. The typical arched entrance of the headrace leaving the canal exhibited some remarkable workmanship, shaping and finishing the granite stone that enhanced the overall construction of the opening in the canal wall. Many do not realize this stonework wasn’t the result of simply haphazardly stacking blocks of granite until this result was achieved to everyone’s liking. Each and every one of these granite blocks were cut and shaped to exact specifications supplied by the engineers of the PL&C and shaped at the quarry sheds, and numbered before being delivered to the site.

Regardless of larger or smaller, all the granite archways had the identical symmetrical shape and that was for strength. The archway was supporting itself and the ground and/or buildings above it. It would be far fetched not to assume that some arches probably collapsed along the way, and in some cases the underground raceways that also utilized that same arched format for the construction but if so no record of the failure was found in our search of the records that were available and examined.

And the openings of the tailraces that enter either the Merrimack or Concord Rivers are treated the same in most cases but are usually of larger dimensions as a rule, and many times rectangular. The reasoning is probably because a tailrace can handle the spent water from several wheels and has to be built extra wide especially to reduce the height of the water level at all times, even to aid in keeping the level of any backwater down where possible.

The hauling and erecting of these blocks of granite, the weight involved and the crude implements (to us) available at the time to accomplish the resulting excellent and lasting work should serve to put modern day engineering to shame. Today, seeming with endless periods of consultation before a project even begins, certainly an abundance of
class ‘A’ materials, bottomless pockets to draw on and the most topnotch talent that can be provided for design and supervision, all they have to fall back on as an excuse for their enormous flops is labor; it must be the fault of labor. Pathetic.

Before taking leave of the underground raceways and the construction methods employed, it should be mentioned that in many cases only the entrance and exit were framed in this shaped and finished granite. The interior work was comprised of vaulted brick in many cases that followed the same contour as the granite arches. The Moody Street Feeder comes to mind. Even stacked cobbles were used effectively to line tunnel walls and support whatever load was overhead.

Now to return to the underground raceways being built to carry the waterpower to the wheel pits. Many if not all of these raceways probably originated as simply open ditches whose only function were to funnel the water from the canal to the forebay before being distributed to the individual wheels. Because every square yard of space at the mill site would sooner or later be called on to support another building, a lot of prime surface acreage was going to waste if the raceways were allowed to remain open. This in itself dictated the covering over of the very necessary raceways, if not with earth then by other buildings.

And the fact that most of these covered raceways would be supporting buildings, or in the case of the Moody Street Feeder, heavy traffic, the arched overhead was naturally adopted because of its ability to support heavy overhead loads because of its design. In at least one mill site (the Suffolk) the raceways were covered over with just planking and then backfilled where it was exposed between buildings in an effort to prevent the water flow from icing as mentioned above. But regardless of individual circumstances that would dictate the preferred construction configuration overhead, all raceways were built with granite block walls and planked bottoms if for no other reason but to reduce friction from building up and erosion of the banks during the course of the water flow and reduce the head any further.

Just Another Raceway – The Penstock

After the 1900s iron pipe became the favored material of which to build the penstocks and was at least offered as an alternate to brick, block or lumber which continued to be utilized. As early as 1855 iron pipe was offered to be used in a plan to extend a direct waterway from the Western Canal at the point where the Northern Canal merged, and tie to the Inner Canal of the Merrimack Manufacturing Company. Iron pipe was used in the final rebuilding of the Boott Penstock in 1898. There are also the remains of three nine foot iron penstocks that carried water from the Lawrence Canal to turbines in building #5 in the lower Lawrence Mill yard. The end of these pipes have been prettied up with wood veneer and benches for the tourists strolling the Merrimack Riverwalk but their shapes can easily be perceived and their paths can be followed as large grass covered mounds jutting up between the Arena and the Lawrence Wasteway.
As shallow as the effort may seem by even this much preservation by the National Park, at least something from the past remains of the past glory.

The Role of the Forebay

Here is where our tale of the majesty of the machinery that was to actually transform the coursing waters of the Merrimack River and directed by the warren of canals and raceways begins. This is the forebay where the waters from all of the headraces feeding a mill or wheelhouse were directed to before dispersing through penstocks to feed the water to whatever number of water wheels there were. The
operation of each wheel would be controlled separably by an individual gate mounted in the sluice through which the water would pass from the forebay to each wheel.

The only remnants of a working forebay still visible and open to the public is in the basement of the newly constructed St. Jean D’Arc Administration building facing on Morrissette Boulevard. This building is built on the site of the Old Tremont textile mill complex. More specifically built on top of the remains of the wheelhouse that housed the turbines that supplied the motive power to the mills. Water was drawn from the Western Canal directly across from where the Northern Canal merged into it, the location of the headraces only evident now as a concrete slab poured into the Granite stonewall of the canal, the trash still being held back by wooded timbers in front of the site.

As to the accessibility of the forebay today, the current plans call for the stoned walled area of what was the forebay to be turned into a lounge. Will the penstocks that leave the forebay and lead into the wheel pits be open to the public as well? And will the massive gates that hung at the entrances to the penstocks likewise be re-installed? All of these questions can only be answered at the whim of the developer in the future.

Enough of the descriptions of the locations that the reader has probably one hundred percent never seen and a good chance never will see so the place to start is to view the original building and go from there.

All remains of the wheelhouse before it was demolished. Both the floor and the roof had long ago collapsed and a hazard to anyone risking venturing inside. (Quote from first hand knowledge). View from now closed Tremont Street

Photo of Wheelhouse by author

The Wheelpit and its Function

The wheelpit was no more than just that. A depression or a foundation constructed of granite blocks built on a level lower than the power canal that was feeding the water. Either from the walls of the wheelpit or some other supporting structure mounted in the pit, the water wheel would be mounted. As usual when great strength was required for any purpose, granite blocks were the answer back then, and supporting the water weighted revolving wheel certainly required great strength. As any other application of a later date, concrete would become the material of choice but that was not to happen until well into the twentieth century and long after the wheels were removed in favor of the turbine.
With the wheel mounted on an axle through its axis and firmly secure, a sluice would be run from the speed gate to a point just below the top of the wheel. Why below the top will become clear into the text covering the water wheel.

All that is left now to complete the underground map of the raceways that nobody ever sees or in many cases is not even aware of is to return the spent water back into its source, the Merrimack River. This is the last trip for the wasted water being ejected into the river through the tailrace that leaves the wheelpit and ends its journey as an arched opening in the granite wall of the river. But the tailrace isn’t treated as no more than a sort of sewer. As was brought out previously in the description of the problem with backwater, the tailrace is extremely important in helping to control the negative results on the consequences of this natural development in the efficiency of the wheel as a result of high water flooding the raceways. The extra width of the tailrace was not wasted money but a sound engineering decision in controlling, and trying to reduce the level of the water flowing back into the wheelpit during a time of high water by increasing the volume that the tailrace could handle.

The cycle of the Merrimack River water is complete. It is for all purposes the same water that started its course through the Lowell Canal System above the Pawtucket Falls. It looks the same as when it left, is just as wet, weighs the same per gallon and will flow on interrupted to the sea after a like trip through the canals at Lawrence. But there is one unseen difference, the most important of all, the only reason for the digging of the canals, the only reason for thousands of people to build the mills and slave in them day after day over the machines.

The endless flow of water is now devoid of the horsepower that turned it into liquid gold.

Unfortunately at the time of this writing the wheelpits weren’t accessible because of the ongoing work of demolishing the wheelhouse and construction of the new building to replace it. In our ramblings on the next few pages a wheelpit that housed a turbine will be shown but the scope of the structure that was necessary to carry a full sized waterwheel will be forever lost. If the opportunity to photograph this wheelpit presents itself in the future, it will be added to this book even if it has to be on the last page.

Enough spewing of word to describe what can be illustrated in a few photographs. Let’s take the same trip the water followed from the Western Canal to the return to the Merrimack River. Every step has been outlined in the text.
Straight ahead is the Tremont gatehouse with the arched gate openings to the Lower Western Canal below. To the right is the wooden barrier diverting the trash from the now blocked off headrace that led to the forebay under the Tremont Wheelhouse.

The forebay area being cleaned out from the remnants of the debris from the demolition of the wheelhouse that was once over it. The forebay received the water from the Western Canal through the headraces seen at the far end of the picture now blocked off in the picture above. The penstocks that carried the water to the wheels leave through the wall on the right shown on the next page.
At this point in the photo journey the machine cleaning out the forebay is visible between the headraces to the left and the penstocks leading to the wheelpits.

Only one penstock opening is showing in this picture. It is the only view in which the remains of the mechanism that lifted and closed the gate can be seen attached to the top of the flange welded to the iron pipe that constituted the entrance.

Because the forebay wall housing the penstock openings was built on an angle facing the headraces to reduce friction in the flowing water, these openings couldn’t be seen in the photo of the headraces on the previous page. They can

After the water served its purpose of turning the wheel, it had to go somewhere after being ejected into the tailraces. There were actually four tailraces, two emptying into the Lawrence Canal, now buried, and these two emptying into the Lower Western Canal below the Hickey/Hall Dam.
The reader should by now have a pretty fair idea of the purpose and function of the underground channels that funneled the water from the power canals and through the systems of raceways that would provide the motive power to the mills. Multiply the number of mills by the number of wheels and come up with the number of underground networks that were dug, planked, walled and covered over and maybe the reader will come away with the reason for Kirk Boott’s headache.

One common thread that ran through all of the mill construction was consistency. Every mill building was the same size, length, width and height. All the wheels were placed slightly off center in the basement of the mill building until separate wheelhouses came on the scene. And any variance in the underground was certainly even more limited.

The planned scope of this book is simply to describe the water-powered machinery that provided the motive power that played the tune that the mill spindles danced to. The route the water followed from the power canals to the wheels is fully outlined in another book in the series, *Hidden Waterways of the Lowell Canal System*.

And this chapter was just one more stroke of the brush on a large canvas. Hopefully enough groundwork has been covered so far in the book to support the rest of the yarn as we move on into the mechanics of the water wheel. In the following chapter we leave behind the dirt and planks and stone as large a part it all played from the beginning to the end of moving the waterpower.

To be sure the down trodden Mick was thought of as no more than a buffoon suited for ditch digging at best but he did his job and the results are still with us many decades later. Time to return to his Paddy Camp for a well deserved rest and let his sons fill his shoes and bask in the light of his efforts.

And they made it.
Chapter Four
The Waterwheel

Was to cast a long shadow in Lowell

How far back can this simple but most efficient machine be tracked? Not far enough, that’s probably for sure if one’s trying to come up with a date that the wheel turned in its first revolution propelled by a flow of water. The Chinese were no slouches and they were recorded as having already “abandoned an elaborate water-driven spinning machine” in the fourteenth century.

What this process exactly was we will never know, and its discovery and use was most likely duplicated beside every stream at some time or the other so a valiant search into the history of the wheel for our purposes could, should and will focus only on its development and use in Europe, and of course the good old USA as the wheel turned to foster its local industry. Just picture a young boy even back then drowning a worm and marveling at the swift current in the stream. From such dreams eventually grew the source of the Waterpower of the Lowell Textile industry.

Now the reader will enter the world of probably the greatest natural gift of nature that was ever willed to mankind and that was destined to pull him, no he did the pulling, really up into the civilized world as we know it today. It was the waterwheel that imbued the greatest source of power that was known in the world up until that time, and provided the energy to propel the stepping stone for many aspects of industry and any who would grasp it.

It isn’t as if the power of the wind wasn’t well known for previous centuries but their uses were fairly primitive. Northern Europe was loaded with windmills and they ground and pumped and all of the other things that allowed the people to survive in an agrarian era always looking up at the ocean. There was enough of a demand for windmills right in our own back yard to foster a company that produce windmills right in Lowell, Massachusetts.

Sailors would have been known as landlubbers without the force of the wind. Dreamers spent their lives watching the great birds soar on the currents of the wind and look where those dreams got us. So the power of the great winds was well known and utilized for centuries.

The previous description of even the most basic of uses of wind power shouldn’t be described as primitive. That perception is in the eyes of the beholder and looking back from 500 years in the future certainly doesn’t qualify that remark with any sort of satisfaction. If people could have looked 500 years ahead from 1400 AC they would have been called sears, or worse even, witches, and treated accordingly.

The waterwheel was the first, if crude supplier of the motive power for the operation of any sort of a mill at least in our culture so we’ll begin at the beginning, at least our beginning. In many of the past chronicles reference is frequently made to a
watermill. For all practical purposes, that’s exactly what the textile mill of the 1800s was, and the sawmill and the gristmill and every other piece of machinery that did its work powered by water. A little history is good for the soul. Of course there’s positive and negative but we’ll try to stick to the former and skip lightly over the later.

The Rise of the Waterwheel

Ancient history is just that and there’s no need to dwell on a concept that the reader (or author) can’t even conceive. Any waterwheel that the reader will be exposed to is simply a wheel with some part of it affected by either the force or the weight of a flow of water acting on it. Credit is given in *A History of Technology* to the Norse Mill as introducing the earliest form of waterwheel. “it was a horizontal wooden wheel with scoops rotated by a running stream”\(^{50}\). The Romans in the forth century with their implementation of their Vitruvian wheel\(^{51}\) is far enough back, and we’ll leave it at that and return to our own world.

The Tub Wheel

Probably the simplest and cheapest and easiest wheel to construct what was referred to in this country as the Tub wheel and it literally could run on damp grass. Well to be a little more truthful if a stream had any kind of a flow of water at all, it would most likely do to turn the drum wheel placed in the horizontal position in the stream, mimicking afore mentioned Norse wheel. (This contraption unknowingly would eventually replace all of the waterwheels when it was to evolve in the future as the turbine).

The normal horizontal positioning of the Tub wheel also dictated that the shaft it revolved on was in the vertical position. For example a grist wheel could be mounted directly on the shaft or a saw could be belted off it eliminating the need for extensive gearing and shafting that would be associated with the waterwheels mounted vertically to transmit the circular motion of the wheel. For the farmer or for any average country application the easier the better and this wheel was a boon in the field. It didn’t produce much power but it did the job.

The normal horizontal positioning of the Tub wheel also dictated that the shaft it revolved on was in the vertical position. For example a grist wheel could be mounted directly on the shaft or a saw could be belted off it eliminating the need for extensive gearing and shafting that would be associated with the waterwheels mounted vertically to transmit the circular motion of the wheel. For the farmer or for any average country application the easier the better and this wheel was a boon in the rural field. It didn’t produce much power but it did the job\(^{52}\).

Having a basic understanding of the theory and mechanics of this simple wheel will go a long way toward assuring that the reader will comprehend the mechanics involved is describing any of the waterwheels that are to follow. The Tub wheel is mounted horizontally where the waterwheels used in the mills were mounted vertically in the water flow. But especially helpful will be converting the motion of the Tub wheel to the turbine as will be seen later in the text.
In this photo of a Tub wheel the wooden casing is removed to expose the paddles mounted in the classic position on the bottom of the vertical shaft that supported and turned with the wheel. The water would enter the pit from a sluiceway in the rear striking the paddles and causing the wheel and shaft to turn in a circular motion. Here a pulley is mounted on the top of the shaft for a power take-off but it just as easy could be a stone for grinding grain.

This little sketch is drawn as If looking down on the Tub wheel and its operating mechanism. The water leaves the flume and is moved into the wheel casing through the sprout which has a down slant creating a force in the water as it strikes against the paddles causing the wheel and the shaft to revolve on their axis generating the motive power.

The Old-Time Water-Wheels of America. Joseph P. Frizzell 1893
The two previous wheel types of the earlier centuries were brought out first in the chapter to illustrate how the force of the flowing water can be harness by the simplest of methods. And to be sure the early records would go back to the very beginning to where probably just a stick held in the water would be thought of as doing work but we are going to bypass that lesson and concentrate on the application of the waterwheel to utilize the water power of the Merrimack River and the resultant canals that funneled the water through the headraces to provide the motive power to the mill machinery.

Several different types of waterwheels would evolve throughout the development of the vertical waterwheel, and each had its own built-in advantages and disadvantages. The three basic configurations will be hashed over here. There is no good or bad about any of the designs, just the applications and it will become obvious as to why the breast wheel ended up as the selected wheel of the millwrights for installation in the Lowell cotton mills.

The resultant reaction by the action of the flow of the water, either by the force or the weight of the water would be the necessary import to provide the circular motion of any waterwheel regardless how the waterpower was applied to the different configurations attached to the face of the wheel for the water to act on.

The Undershot Wheel

With the advent of the vertical waterwheel, this simple circular wheel was also constructed from wood which would serve as the building medium for the immediate future for all wheels, with a paddle or fin or such mounted on the face of the wheel and meant to dip into a stream or river with the water flowing underneath the wheel and acting against the submerged paddles or fins. This applied a force on the face of the paddles creating a revolving motion in the wheel that in turn could be tapped from the rim of the wheel or a revolving axle or shaft that supported the wheel producing a motive power to do the required work.

“"The undershot wheel is the simplest and cheapest kind of water wheel, but it is employed only in situations where an abundant supply of water is obtainable."" Zachariah Allen from The Science of Mechanics (1829)
Outside of running simple watermills such as saw mills, and grinding grain of one sort or another; pumping bellows at iron forges was another application that was mentioned in past records, the low efficiency of the undershot wheel in the beginning left much to be desired. And again that old nemesis, backwater, completely choked this wheel to a dead stop. The paddles, floats or what have you were normally partially submerged in the water flow of the stream and in cases where the water were to rise any distance because of heavy rain, freshlets or just spring melting conditions of snow of ice, the operation was out of business.

But just as the tub wheel was to evolve into the vastly superior turbine, the design of the undershot waterwheel would progress to the point that it would provide the motive power to all of the mill sites in Lowell until the late 1840s when the turbine begin to make its justly deserved inroads into the power chain. Some of these improvements were labeled with different names and the reader my inquire into “why”, their so alike. But the accomplished millwright was aware of the conditions that prevailed in a particular water source, and all rivers, streams, penstocks probably had their own obstructions or deficiencies that had to be overcome. Thus the different design of the wheel.

The first rudimentary development of the undershot waterwheel appears to have been to lift the wheel free of the stream of water supplying the force against the paddles. The water now impacted on the paddles higher up on the circumference of the wheel with more

From The Young Mill-wrights
Oliver Evens  1795

And a quote from the same bible, “In the Undershot wheel a narrow swift stream of water was shot through a flume or penstock (A) directly onto the wheel blades from below. The speed of the water and the force of its impact, rather the weight of the water, are the motive forces”.

Until the advent of the turbine, this was probably the only wheel to utilize the impact of the water rather than the weight. Notice how straight the fins attached to the face of the wheel are drawn in the illustration.
The Overshot Waterwheel

Now into the world of motive power appeared the Overshot wheel.

In the mechanics of the Overshot wheel the water was directed over the top of the wheel from a sluiceway placed over and just behind the crest of the wheel and the water was allowed to cascade into the buckets on the face of the wheel from the sluice as they passed over the top of the wheel and in theory would empty out at the bottom of the cycle of the wheel. Here, it was the weight of the water that provided the force to propel the wheel in the same direction as the flow of water that was feeding it but like any good thing, there’s always a fly in the ointment.

With an Overshot wheel, the sluiceway feeding the water to the wheel was built to pour water into the buckets or blades as they reached the top of the wheel, the theory being that the weight of the water would fill the buckets and the effect would be to turn the wheel for 180° before emptying out of the buckets at the bottom of the half-cycle but in reality the water would begin to spill out of the buckets at about 90° in the arc of the cycle of the wheel. This meant that the generating procedure was losing much of the effects of the water power and not getting the greatest amount of work from the waterpower that the mill was paying the Proprietors of the Locks and Canals on Merrimack River (PL&C) for in the cost of each of the millpower they had contracted for.

Another problem with the overshot wheel was that the flow of water supplied to the wheel had to enter the buckets at the top of the cycle. If the pond or river or canal or whatever the source dropped lower than the entrance to the sluiceway, the resultant effect was total. There was no way to compensate for the lowered water level, that is raise the water to the level of the top of the wheel. All motion stopped, completely and wouldn’t resume until the water supply was replenished and elevated. Of course any water driven machinery would suffer the same fate if it ran out of a supply of water.

This is exactly why all waterwheels are fed water from a pond or reservoir held back by a dam to increase the volume and sustain the necessary elevation. The backup of a large volume of water is absolutely necessary for the smooth and continuous operation of any water driven operation. And the problem with the overshot wheel is there is no room for variance. Its black or white with no gray area for a breather. There is either a total water flow higher than the wheel providing full power from the wheel, or the wheel stops.

To control the water flow onto the wheel from a full reservoir, a gate is installed in the sluiceway and is made accessible to the mill operator.

But there was a lot of work done by the engineers of the day in further developing the Overshot wheel. Its construction was straight forward, no elaborate planning was necessary. The buckets were shaped so the configuration allowed only an opening at the top of the bucket to receive the flow of water. The first innovation was the addition of sideboards to encompass the buckets and to aid in containing the water within the buckets and thus the weight of the captured water. Keep in mind that the water represented the
liquid gold of the fuel to propel the waterwheels, no matter their individual characteristics.

The upper drawing illustrates a 12 foot wheel and is referred to as a low overshot wheel.

The lower illustration is showing a very high overshot wheel. This wheel was built with a 30 foot diameter.

Young Mill-wright and Miller’s Guide. Oliver Evans 1807

Why are the wheels built in different sizes? Why not one size fits all? The fall of the water feeding the wheel is a large factor in determining the diameter of an overshot wheel. A 30 foot wheel would have great trouble being rotated by a fall of water that was only eight feet. The water level wouldn’t even be up to the height of the axel, never mind be high enough to fill the buckets at the top of the wheel.

And likewise a 12 foot wheel probably wouldn’t last too long being fed from a 30 foot fall with the water cascading 18 feet before reaching its buckets.

These wheels operate under the weight of the water that has filled the buckets on the face of the wheels and not on the strength of a force acting on the face of the buckets. In the prior case there simply wouldn’t be enough water from the little that managed to pour into the buckets to turn the wheel and in the latter case the water would simply make one big slash when it hit, leaving many empty buckets.
The Advent of the Breast Wheel

The pitchback and breast wheel can be lumped together for all intents and purposes as they are the same wheel. The pitchback wheel is simply arranged and rigged as a high breast wheel54 and that’s the way it will be left, especially as there is so little mention of that specific type of waterwheel in the literature describing the employment of the pitchback wheel in the different mills in their power train.

In any case receiving the water on the face of the wheel facing the water flow supplying the wheel still had the same handicap of losing a portion of the volume of water the buckets had accumulated at the top of the wheel, actually the 0° point of the wheel’s cycle as the wheel passed through the 90° point in the downward spiral of the wheel. It didn’t take the millwrights of the day too long to realize a method to prevent the excessive spillage and contain the water in the buckets for a longer period of time in the cycle was needed.

Innovations in the design of the buckets themselves did help to alleviate some of the problem in retaining the water in the buckets during the downward part of the cycle. Increasing the height of the front of the buckets and the shaping of the front more into a scooping angle helped as did providing small openings in the buckets to eliminate the air becoming trapped and preventing the water from filling the buckets to the utmost capacity55. Every idea was tried to increase the efficiency of the operation of the water wheel.

It is doubtful there were any studies by committees that preceded the adaptation of the simple shroud to fit snuggly over the buckets and cover them during the wheels downward part of the cycle to serve the purpose and help retain the volume of water that filled the buckets. Common sense prevailed. Nothing fancy. Some preferred masonry shaped to fit the contours of the wheel and covering the path of the buckets from just above the axle to the lowest point of the cycle of the wheel. In this area, shaped metal answered the call. But whatever, it worked.

The breast wheel looked and performed identically to all other waterwheels. Large and cumbersome even in motion; and pretty much like most water wheels of the day had to be built in place because the size dictated that it could never be moved as was. There was actually no difference in the construction of any of the vertical waterwheels we are discussing except probably in the angle of the buckets or types of blades mounted on the face of the wheel.

Where the Overshot wheel received the water at the top of the wheel thereby filling the buckets and turned in the same direction as the flow of the water that was pouring onto the wheel, the water entered the undershot wheel (of which the breast wheel was but a hybrid) anywhere from just below the to about half way down the wheel on the side opposite the flow.

So what’s the big deal one may ask?
Well one may answer this apparently no-brainer of the reverse direction was to allow the breast wheel to operate, and very well, with a full or less than a full head in the fall available in the source reservoir. Because the breast wheel can accept a flow of water within a fairly large tolerance between the source level being full or even much lower due to a fairly simple device called among other terms a sliding hatch that was to allow the breast wheel to receive the water on the face at any point from just below the crown of the wheel to about even with the axle. This simple devise heralded the demise of the pure undershot wheel for all time in favor of the breast wheel.

A definition of the sliding hatch which was invented in the 1780s by British wheel builder Smeaton is given in The Iron Water Wheel, C1750-C1850 with engineer John Rennie receiving credit for perfecting it. Basically the devise was a ”False or movable crown, a piece of wood that was added to the top of a (masonry) breast, raising its height when the water level was high. When the water sank too low to run over the movable crown, the crown was removed to

This sketch illustrates Rennie’s improved version of the sliding hatch that won overall acceptance as the favored tool. In the drawing ‘B’ represents Rennie’s shuttle operated by the rack and pinion to allow a stream of water over the shuttle and onto the wheel from the maximum height.( copied from text)

Reproduced from text in ‘The Iron Water Wheel’

This innovation allowed the wheel to operate with uncommon efficiently because the water source fills the buckets on the side of the wheel facing the water supply. Depending on the setting of the sliding hatch at the sluiceway feeding the water to the wheel, the water supply can be varied in the height that the water entering the buckets on the wheel. It can enter closer to the top of the wheel or halfway down on the wheel and still provide a motive power to propel the wheel.

There were many variations of both the over and under shot wheels each with its own advantages and disadvantages. The final choice for the mill installation probably rested with the preference of the builder. But a second redeeming factor of the breast wheel was its superior performance in a backwater condition as described on page 22.

Common sense dictates that a wheel such as the earlier undershot wheel that was propelled by the force of a stream of water striking its buckets partially submerged in the
stream under every day operating conditions, will stop dead if the stream rises to the point that is actually producing a braking action on the motion of the paddles. This is what happens in a backwater condition when the water level backs up and gets higher in the tailrace in times of high water and floods the raceway through which the wheel is emptying.

The buckets on the face of the breast wheel are at no times submerged unless the water level in the Merrimack River becomes excessive. In fact its height is normally set so the bottom of the wheel buckets average 18 inches above the height of the water in the tailrace. This seemed over the years of observed usage to be the best clearance for the efficient ejection of the spent water from the buckets and allows that much more leniency to handle any backwater condition except the most excessive.

And not to be caught off guard, the PL&C manned a series of stations on their Merrimack River between the lakes in New Hampshire that served as reservoirs for the canal system, and the Pawtucket Dam to give warning to any imminent increase in the level of the water on the river. A sudden rise in the level of the river could be because of a freshlet, melting snow in the mountains or any number of causes but the end results when the surge reached the canals could be disruptive to the mill operations if not predicted and compensated for by the PL&C.

Communications left much to be desired but every effort the PL&C could muster was exerted to gather the information, some of it laughable today. And believe it or not, postcards with the observed water heights along the river were still being mailed daily from the stations into the late 1800s.

The people that worked around these waterwheels all day, everyday for probably their entire lives weren’t stupid people. They built the wheels from scratch, a good chance that they maintained them throughout their lives or at least the live of the wheel, and tinkered here and adjusted there over time, a long time. Experience was their textbook polished by observation and common sense their apprenticeship. Over time they won the title of millwright and if the reader thinks that designation was just to differentiate one dirty-neck bumpkin from the next, just take a little time and glance through a trade handbook of the time that the millwrights consulted such as Young Millwright and Millers Guide by Oliver Evans and first published in Philadelphia in 1795. You might be mildly surprise at the sophistication of the knowledge in use in the trade back then and the ability of the mechanics to interpret and apply it to building those wheels.
Chapter Five

The Construction of the Vertical Water Wheel

A short course on the birth of the power

In the early days of the watermills, only a few waterwheels were required to be so large as to produce massive amounts of power. The needs of the first mills in the infant industries were slight with most of the work being done by simple hand tools, maybe supplemented with an early form of an inanimate prime mover. To be sure, the waterwheel had a place on the production line but like anything else one step followed the other. First the tools had to advance to the point where they could be better utilized by a larger supply of power and remain functional.

As we saw before the simple tub wheel required only a very small amount of manufactured components and could be operational in about two weeks, its use to be determined by the necessity of the day. Even the mounting of the tub wheel in the stream was a minimum problem but that was to be the first major problem to be encountered in the vertical water wheel.

In the transposition to a vertical water wheel other factors entered the picture.

A depression of sorts would have had to be constructed in the bed of the stream or headrace in order for the then much used undershot wheel to set down into the stream of water so the blades mounted on the face of the wheel could be acted on by the stream of water meant to turn the wheel. The blades were distributed evenly around the outside circumference of the wheel and depending on the diameter of the wheel spaced so at least three blades were always immersed in the stream58.

This immediately produced another obstacle to overcome, and that was some sort of a mount to support the axle that the vertical waterwheel would turn on. We haven’t even arrived in our story of the building of the wheel and we’re already somewhat overwhelmed with problems to solve but some sort of wooden or stone support is apparent in many of the illustrations in the research texts. This raceway feature should have already been constructed, termed a wheelpit when discussing the wheel’s position in a mill so let’s get on with the building of the wheel.

Ignore the bicycle laying on the ground to the left of the waterwheel and concentrate on the waterwheel if possible. The stream of water entering the wheel at the top easily identify this wheel as an overshot wheel, filling the buckets on the face of the wheel with water and propelling the wheel by the accumulated weight of the water in the buckets. The mounts supporting the wheel and the pit the wheel is recessed into are easily discernible in the photograph and to illustrate those features alone is why the photo was presented.

Even though built more than 350 years ago, very little has changed to this day.
Photographs of the old wooden mill waterwheels especially mounted in mill basements are none existent for one simple reasons. Cameras hadn’t been invented when they were in use. When the camera came into common usage, the wheels were now made out of iron or had been replaced by the turbine. Even though this mill race was built in 1643, this wheel was installed at a much later date as a replacement for what was many prior wheels over the years.

There’ll Always be Water Wheels
Neil M. Clark

The earliest water wheels that were put into use grinding the grains and sawing lumber aside the Merrimack and Concord Rivers were probably of a size where they could most likely be partially built laying on their side and then raised and placed on the shaft of axle to be completed. Very few dimensions of any of the wheels in the smaller mill sites from the 1700 or early 1800s were left for posterity but why should they have. Nobody realized or gave a second thought that we, 200 years down the road, would really be interested in the way the colonist conducted their business. But for the sake of future comparison, the average diameter of an undershot wheel in 1735 is given as 14 to 16 feet in *The Traditional Wheel, c1500-c1750*.

If we can assume that a record of any one wheel would do to construct a general picture of all millwheels of the day around East Chelmsford prior to the 1820s, or close enough, let’s go with the waterwheel that Hurd had inherited with a mill he purchased on the northern bank of the Merrimack River. It never was put into operation at that locality but that’s another story. Anyway to stay with the question of how large was practical for a wheel of pre-Lowell industry, Hurd’s operation was bought out by the PL&C to gain control of both sides of the Merrimack River to assure them of riparian rights necessary to build their dam across the river.

Rather than waste a perfectly good water wheel (in those days nothing was throw away) he dismantled his fledging mill site on the Merrimack River and floated the wheel down stream to the Concord River where he had already procured a new mill alongside the Lower Locks. Here he set the wheel up anew and went to work in his new woolen mill. Hurd’s mill received waterpower from the Pawtucket Canal via a canal that he constructed himself.
The only reason for the telling of this tale is to bring out that the wheels of the early 1800s were of a size where they could easily be handled.

The cotton mills of Lowell didn’t just spring from the virgin ground because somebody had a dream. The scheme was developed in Waltham with Boston investors and their Boston Manufacturing Company was built along side the Charles River. The operation wasn’t moved to Lowell because it failed at that location but because it was a great success. To good in fact and the water flow in the river wasn’t great enough to handle expansion. The tale is told earlier in the book of how a few men with a vision were steered to the Merrimack River and the 32 foot fall in the level of the river over a mile of rapids. So they simply moved the “bale to bolt” experiment they had followed at the Waltham site to recreate their successful textile empire at East Chelmsford.

The Boston Manufacturing Company had also been blessed with the king of machinists, Paul Moody. Moody was a great believer in very large water wheels. He was a master wheel builder and had proven his worth in Waltham. When the Merrimack Manufacturing Company was incorporated in East Chelmsford by the Boston Associates it only made sense to give Moody his head. The water wheel, like a shoe, came in all sizes. If it was good fit it did the intended job and was comfortable to have (in the mill). If it didn’t fit properly and tended to hobble the gait when in motion (machines in the mill), the owner was never to be satisfied and would have to try for another and better fit.

Those idyllic images of a water wheel turning majestically in the stream along side a quaint mill in the countryside doing whatever local job it is performing out of sight behind the ramshackle building with the shingle walls would be far out of place in Lowell. The water wheels in Lowell were buried deep in the bowels of the mills where the water acted on them and propelled the wood and steel wheels, shafts, gearing and belts that would translate the wheels circular motion to the power chain and serve as the transmission medium for the motive power that was the lifeblood of the textile industry.

Take a good look at a mill building in Lowell. They are more or less identical with four or five floors enclosed by an average of one million bricks surrounding the linear measurements of 140/160 feet by 40/50 feet. The clanking machinery that occupied the floor space even back in the mid 1800s was capable of spewing out two million yards of cotton cloth a week from about 320,000 spindles.

This textile empire was to make many storied fortunes for the investors and many more stories of miserable conditions for the souls that toiled at the altar of the cotton looms.

Whereas the stream was slowly turning the water wheel of the past indicating the grinding of grain was taking place behind the shingled walls, or maybe the sawing of timber logs into planks or even a forge hammering on white-hot iron, none of this was apparent in viewing a cotton mill building. The stream of water was funneled between buried granite walls with great piles of brick giving the appearance that the only function the brick performed was framing thousands of windows.
There was no indication that the water was doing anything except following the course dictated by the direction of the canal that it flowed in. Only when the canal was empty would the grated openings cut into the granite walls become apparent even if the purpose wasn’t evident. Through these grates the water from the canal would pour into unseen raceways built under the mill buildings and emerge hundreds of feet away into a like raceway but lower and ejecting the water into a lower canal or river. Only an acute observation would notice the difference in the elevations between the raceways and deduce that some action had taken place under the mill in the course of the water flowing from one channel to the other.

Photograph of grate covering entrance to the Lowell Canal. This waterway left the Merrimack Canal and fed water to the wheels of the Lowell Manufacturing Company, falling 13 feet before emptying into the Lower Pawtucket Canal.

From the Photo Journal of Lowell Canals by author

And this action was that of the water flowing over the peripheral of the water wheel mounted in the basement of the mill building and propelling the wheel in a circular motion as the weight of the water filled the buckets attached to the outside circumference of the wheel. This circular motion that was thus produced from the endless journey that the wheel traveled was what would power the machinery that could be heard clanking above from the shaking floors. This motive power was the prime mover that turned the shafting and gearing and belting and finally transferring the power to the looms and that was what it was all about.
This is a smaller detail of a sketch outlined in the chapter to follow on the extensive shafting in the cotton mills to illustrate the location of the wheel in the mill building and the transfer of the motive power that it produced.

Beneath and surrounded by all of this brick, supplied with the endless torrent of water that was directed from the Merrimack River through the granite walls of the canal, sat the water wheel on its supporting mounts. In all of the gloom of the dark cellar the wheel prevailed in its own grandeur turning on its own axis around and around with only the pouring rush of the water dictating its never changing course. As long as the wheel turned, there were none to map the daily thousands of trips around the only path the wheel would ever follow.

The millwright who brought the wheel to life was probably there to nurse it and to listen with a trained ear to every creak and moan produced by this creation that had escaped from his own hands as it worked. The wheel could be called ugly by the uninitiated observer but to the millwright it was as beautiful as an innate object that found life in the stream of flowing water can get. And the millwright probably had tended the wheel from the inception just as surely as any creator.

In the beginning the wheels were constructed from the only building materials that were convenient, and of wood there was abundance. Wood represented a medium that could be easily shaped with the tools available to the millwright and it was flexible enough so the design and shape of the wheel could be altered as the work of building the wheel progressed if it was fancied to improve the wheels intended performance.
The 100 % use of wooden construction is quite evident in this photograph. The picture bears a caption of “History of Water Wheels and Engineers, 1922”. It is described as an overshot wooden water wheel as part of an attached dam system in North Carolina.

Lowell National Park
Museum Collection
LOWE 11597

Credit for the first all metal water wheel to be constructed in the United States was claimed by the Fitz Water Wheel Company. 1852 was the recorded date it was built in the history of the company by Theodore R. Hazen.

The Millwright, the Master Mechanic

The distant history of the millwright is vague at best. He must have been somewhere before the advent of the waterwheel, performing a function involving something. Where did his previous training come from; his background for the limited technical information that did appear in such text that existed to direct the craft. Prior to 1750 there is very little information. The craft had to be carried on by a more or less apprenticeship, the student watching and listening to the master and absorbing what expertise he could to ply the craft himself. The education would most likely have had to be by word of mouth as reading ‘riting and ‘rithmatic were probably not the strong point of the tradesman’s education at the time.

All we can do is inquire into the earliest available record that even cares about the millwright’s past and construct the history from there. The following brief description of millwrighting dates from 1747:
The Trade is a Branch of Carpentry (with some assistance from the Smith) but rather heavier work, yet very ingenious, to understand and perform which well a person ought have a good turn of mind for Mechanics, at least to have some knowledge in Arithmetic, in which a lad ought to be instructed before he goes to learn this art; for there in a great variety in Mills, as well as in the Structure and Workmanship in them, some being worked by horses, some by Wind, other by Water shooting over and others by running under. And why not in Time by Fire too, as well as engines. Considering the qualifications set forth above and taking into consideration the era of this observation it would be most likely that many were called and few were chosen. But as we finish the quote it appears the author is going to sum up his short discourse in one final sentence without the flowery oration of the foregoing paragraph.

They take an apprentice L5 to L10, work from six to six, and pay a journeyman 12/- to 15/- a week; but L50 or L100 worth of timber and L50 to spare will make a master of him.

To be fair to all sides of the picture that is being presented of our faithful tradesman, a few snippets of later observations will be offered here that were mentioned at later dates and by men that may have been more versed in the trade as time had passed. William Fairbairn was a British engineer of some repute and offered in part this description of our millwright in 1840. He described the attributes of the millwright as the engineer of the district in which he lived, a kind of jack of all trades who could equally facility work at a lathe, the anvil or the carpenters bench. Thus the millwright of the last century was a itinerant engineer and mechanic of high Reputation.

It appears that Fairbairn was quite taken with the millwright’s proficiency in his preparation for his trade as he exemplifies his respect for the tradesman even further. He could calculate the velocities, strength and power of machines: could draw in plan and section, and could construct buildings, conduits, or water courses, in all the forms and under all the conditions required in his professional practice.

And scanning the recorded observations of some acquainted with the attributes of those in the trade of the millwrights of past years, this portrayal of their qualifications took these descriptive traits with a tongue in cheek.

A single step preempts even a long journey

But as the wheels were called on to produce more and more power, the size would gradually increase to the point where the wheel couldn’t support its own weight, especially at the most crucial points of the construction, frequently at the hub and the axle for example. As the diameter of the wheel increased to accommodate more buckets to fill with more water and develop more horsepower to meet the demand of the mills for more motive power, the effort was becoming self-defeating. The number of buckets that could be attached to the soal or face of the outside circumference of the wheel had been determined by trial and error over the years and probably polished with a few timely calculations and to exceed that number in the hopes of producing more power appeared to be a useless endeavor.

In an article that appeared in the American Cotton Spinner in an 1851 edition discussing the ‘Speed of Water-Wheels’, “It is an established rule with the best mill-
wrights, to allow three buckets to each foot in the diameter of the wheel. A wheel 12 feet in diameter should contain 36 buckets.  

And the diameter of the wheel was more or less restricted to the available space under the mill building. The raceways and wheelpits were constructed along with the foundations of the buildings. It could be very difficult to excavated under the building to gain more headspace for larger diameter wheels and not cause any damage to the structure. But length-wise was more practical. If nothing else several wheels could be ganged on one shaft. Taking the Hamilton mills as a prime example, there were three waterwheels each 13 feet in diameter and 14 feet in width so each wheel had buckets 14 feet long giving each bucket an accumulated length of 42 feet.

But the wooded monsters were beginning to groan in protest.

The wooden shafts were made as large as two feet in diameter but still the off-set center of the wheel with the weight of the water centered on only the down side of the wheel was bound to cause overly excessive wear and eventual breakage. The point where the spokes were supported by the hub was another constant trouble. The weight of the waterwheel had reached its limit of its ability to function efficiently, or in some cases to function at all.

As expensive as iron parts for the wheel would prove to be, there was no choice but to go with the iron replacements especially in the wheel hub and to re-enforce the wooden shaft. It wasn’t too far in the future when the entire shaft would be cast at the foundry. The term wooden and iron waterwheel began to be used more often to describe the wooden wheel construction now aided by a few iron additions at critical points for added strength and it wouldn’t be to long before that term evolved into an iron and wooden wheel as the forbidden iron expense became more and more acceptable in the construction.

In these musings the author is hoping to chronicle the construction of the vertical water wheel as such that the reader will understand and take a pleasure in what he is reading and take the experience with him to interest others in the great history that Lowell has to offer in the canals, the mills and the machinery that together formed possibly the greatest single piece of machinery ever assembled with one goal at the end, take raw cotton and give finished cloth. ‘Bale to Bolt’ was the term coined at the Boston Manufacturing Company to describe the process of all operations under one roof in Waltham.

And the coordinated results of all of this machinery taken together did constitute a single machine. If only one piece failed, the entire mill could fail and all suffered, owner and operator alike, be the weak link metal or man.

At least now the millwright had a beginning to his endeavors or at least a starting point from which to launch the building of the wheel. The wheelpit was dug, the granite blocks to provide the support for the wheel in place, likewise the raceways before he even showed up. It is interesting to dwell on the question “where did the layout and dimensions come from to construct the head and tail races and especially the wheelpit.”
Only one fact was definitely known. That was how many spindles the mill had to run to produce the profits for the investors.

An educated guess by the reader would be to parrot a like educated guess put forward by the PL&C as they were the company that contracted to build the proposed mill (the only game in town) and the buildings and underground raceways that would eventually tie into the nearest power canal to feed waterpower to the mill machinery.

First the headrace that will receive the water from the power canal and feed it to the water wheel must be built. The water wheel itself must be constructed to take the water provided and produce enough motive power to efficiently operate the mill machinery. And how much water (mill power) is necessary to do the job and the size of the headrace? How big the wheel? The tailrace has to be large enough to handle the discharge from the wheel plus the backwater. What is the starting point for all of the calculations?

It all begins at the lowly spindle. In *Webster’s New World Dictionary*, “one of the rods holding the bobbins on which the thread is wound as it is spun” defines the spindle and tells it all. The total count of the spindles that the mill carries determines everything, from the number of looms necessary to operated the number of bobbins and so the amount of cotton yarn that the mill is capable of weaving into cloth, the number of operators to be hired to operate the looms, the size of the mill building to house it all and naturally the necessary millpower purchased from the PL&C to fuel the operation. All this deduced from one little stick.

It never ceases to amaze that this ‘one little stick’ could dictate the lives and fortunes of so many for so long. And were talking about the ability to harness the most powerful forces of nature as well as the fortunes of vast portions of New England here, as well as undermining the textile industry of the greatest industrial power on earth at the time, the British Empire.

An abbreviated description of the spindle is taken from the *Encyclopedia of Textiles*. In part it reads, “a long thin rod that is used on certain textile machines or twisting and holding textile fibers”. And, “the spindle is one of the oldest textile devices known to man.”

Below is an illustration of what is termed a Cotton slubber/spinner in the catalog it is taken from but by any term it is a genuine older-type spindle on which the bobbin wound with cotton thread on the loom revolved, and it should acquaint the reader with the device we have been discussing.

The World of Wooden Bobbins

The deductions for the amount of power needed from the water wheel to operate the number of spindle was predetermined by the great Waltham experiment that produced
all the calculations in the operation of the Boston Manufacturing Company and simply transferred to Lowell. The power requirements for the spindles and looms were in themselves comparatively small. One horsepower would handle the needs of 100 to 300 spindles or alternately ten to 12 looms.

All of the figures and rules and regulation for governing the motive power necessary for the successful operation of any cotton mill power-wise are outlined on pages 18-20 in this book. We’ve had enough theory...let’s build a water wheel.

O.K. millwright-do your stuff

All of the planning, calculations and formulas could be hashed over ‘till the cows came home’ but the final design of the water wheel still rested with the whims of the individual millwright. And each and every wheel was to be sure just as individualistic as the mechanic who built it. Each millwright favored a certain characteristic in his wheel, developed over years of hit and miss in pursuing his craft. The hits were bragged about and the misses forgotten...except by the mill owner that ended up with the miss groaning and creaking alongside or under his mill building, and not much else from the bad wheel.

As far as the availability of raw materials to build the wheel, all of New England was still blanketed with timber prior to the Civil War. So did the mechanic that was going to build the wheel just walk into the woods and start swinging his axe and sawing up whatever tree that fell? Of course not, and the selection of the type of wood was just as important, maybe more so, to the success of the finished wheel as the finest craftsmanship that went into the construction of the wheel.

Oak was reported to be the mainstay of the wood material used in the water wheel construction and especially the axle. But even the choice of wood for the axle was influenced by the personal preference of the builder though and two different wheel builders, Allen and Weisbach favored pine for the axle where as the strength of oak was usually the preferred choice by others. But strength wasn’t always the prime factor in selecting the wood for different needs and wood for the different parts of the wheel could vary greatly, again depending on the builder.

It would be stretching it to assume that the average reader of this book would get engrossed in every application of every type of wood the various wheel builders favored, and compare one over the other, for this or that critical part of the wheel. Running through the list of woods that were utilized in the wheel construction and accumulated in the research is probably enough. Tarmarac and Black Ash, and elm, beech ash or redwood fir were mentioned also for different uses within the wheel construction.

But there were special applications that demanded types of wood because of some specific quality the wood possessed that was being sought or favored over other woods. For example Elm was favored for use in parts of the wheel that were constantly exposed to the water because when wet, a slimy coat would naturally form on it and helped to protect the wood from decay. Pine and cypress were used for the floats (buckets) in this country for the same reason.
And even with all of the care in selecting the materials to go into the construction of a wooden wheel, the average life expectancy was only ten years and even that was with much TLC. It was stated that as soon as five years after a wheel was placed in operation needed repairs were noticeable and at eight years of use repairs could be extensive. But to keep the costs down, and this actually meant the lack of use of iron in the wheel construction, many wheels were built entirely out of wood including pegs and trunnels (also called treenails—all defined as wooden pins) instead of nails.

Laying out the Wheel

How did the millwright hold this whole mess together while it was being assembled on the shaft that would serve as the axle? It was brought out earlier in this chapter that with the older smaller and lighter wheels, the wheel could be built while laying on its side and simply lifted into position with enough manpower or with the aid of some sort of a device. A lever or block and tackle for example. When the weight and dimensions of the wheel reached sizes the prohibited this simple effort, the main parts of the wheel were still laid out and fitted into the shape of the finished product while on its side. Then with the axle and hub mounted in place, the remaining work of assembling the precut and fitted pieces of the future wheel could be handled more easily in the eventual upright position.

Many water wheels were in existence in the eighteenth and nineteenth centuries, their numbers becoming prolific as the need of growing industries demanded and likewise the number of manuals produced by the master wheel builders of the day multiplied just as fast to provide the instructions to the beginning millwright. No way could they all be in lockstep with each wheel builder naturally favoring his own method but from the surviving manuscripts this one was selected as typical. Also many manuals now out of print or in a foreign language contributed to this selection by the author, but mainly from the 1795 book by Oliver Evans.

Order of Assembly for a Traditional Vertical Water Wheel

1. Construct a work stand. It should consist of a center post (representing the axle or shaft of the water wheel) and a number of stakes (equal to the number of spokes which the wheel will have) spaced at uniform intervals around the center post and at a distance approximately equal to the water wheel’s intended circumference.
2. Lay out the arms or spokes of the water wheel so that the ends lie on the stakes and their centers on the center post. Notch the arms as they will be joined in the axle of the wheel.
3. Lay out the planks for the rims and/or shrouds on the end of the arms or spokes. Mark the intended periphery of the water wheel on the planks and trim them so when joined they will form a circular, segmented ring.
4. Make the cuts and notches necessary to join the rim and/or the shroud to the spokes and temporarily assemble the rim or shroud and join it to the spokes.
5. Mark off the notches or mortises needed to fix the flat boards to the rims or shrouds and make the appropriate cuts.
6. Prepare the axle, making the mortises needed to insert and link the arms of the wheel in the axle. Install the gudgeons in the axle or shaft.
7. Set the axle or shaft up in its working position.
8. Install the arms of the wheel in the axle or shaft, fix firmly, and align.
9. Install the rim or shroud segments on the arms or spokes of the wheel and align. Permanently link the rim or shroud segments to the arms.
10. Line the inside of the wheel with planks (i.e. install the soal if the wheel is to have one).
11. Permanently fix the float boards in place.

Following the above given instruction surely must have provided the guidelines for even a semi-skilled carpenter to achieve some prominence as an accepted builder of water wheels and eventually the title of millwright, of which Evans was both. Evans also gained enough of a background in the millwright skills to be accepted as an engineer because of his writings and instructions pertaining to the craft. And he didn’t just rest on his laurels. Recognizing that the nature of the construction of the water wheel was evolving to suit the needs of the craft, he re-printed and updated his 1796 training manual to instruct the beginners in the craft of building wheels in 1821, adding a section that itemized the parts that were necessary ingredients to complete construction of the wheel, including the now common addition of iron parts.

Material Required to Build an Overshot Water Wheel (18 feet in diameter, 2 feet 2 inches wide, including axle and large cog wheel.)

Wood: 1 shaft, 18 ft. long x 2 ft. diameter.
8 arms, 18 ft. long x 3 in. wide x 9 in. deep.
16 shrouds, 8.5 ft. long x 2 in. thick x 8 in. deep.
16 face boards, 8 ft. long x 1 in. thick x 9 in. deep.
56 bucket boards, 2 ft. 4 in. long x 17 in. wide.
140 ft. of boards for soaling.
3 arms for cog wheels, 9 ft. x 4 in. x 14 in.
16 cants, 6 ft. long x 4 in. x 17 in.

Metal: 2 gudgeons, 2 ft. 2 in. long; neck 4.25 in. long x 3 in. diameter.
2 bands, 19 in. inside diameter, x 0.75 in. thick x 3 in. wide.
2 bands, 20.5 in. inside diameter x 0.5 in. thick x 2.5 in. wide.
2 bands, 23 in. inside diameter x 0.5 in. thick x 2.5 in. wide.

Why after so long a time of rejecting the use of expensive iron in the construction of the water wheel was it now accepted in this 1825 treatise? The axle was by far the most important single part of the vertical water wheel. In later years it would be the first of all the iron components to be utilizes, solid or hollow. But in the eighteenth century, the axle would still be shaped of oak, turned to a diameter of ‘15 to 24 inches’, large enough to support the weight of the wheel and the water trapped in the buckets which could be well over 10,000 pounds.

And so entered the first metal item on the list provided by Evans, the iron gudgeon which is no more than an extension of the axle to prevent excessive wear in the end that sat in the bearing. Two feet might seem like an excessive diameter of the finished wooden axle but to be faced with a failure of that super-major component would be shear disaster to the mill. Any other part could be probably be replaced in the course of another necessary repair but to replace an axle! There had to be a method of doing the
job without removing the entire wheel, and it turned out that there was, thanks to the final acceptance of iron parts becoming widely used in the latter waterwheels.

Text and Evan’s original working sketch will be presented together here and by following both and referring to the material list as the items are installed on the shaft, the reader should come away with a fair concept of what was being accomplished. What is somewhat confusing in why the author of Stronger Than a Hundred Men from which we quote below describes the use of the gudgeon on the wooden axle as “probably equipped with iron gudgeons.” There had to be some positive indication of the use of the iron gudgeons such as artifacts or remnants at an investigated site to even suggest its use at the end of the axle or why even be included in the material list.

Well let’s forego the devil’s advocates role and continue on with the construction of the water wheel.

One of the most widely used of forms of gudgeon in the later years was the wing gudgeon pictured in figure 3-19 (shown). The butt end of an oak axle would be mortised so that the wings could be inserted, leaving the cylindrical part of the gudgeon, commonly between 1.5 and 3 inches in diameter and 3 to 6 inches long, projecting from the end of the axle. It was on the cylindrical projection that the wheel turned.

The descriptive text and accompanying sketch on the following page should easily simplify the understanding the role of the gudgeon in the strengthening of the water wheel. The iron bands were added around the perimeter of the end of oak shaft after the gudgeon was installed in the butt end of the wooden shaft acting as the axle. The axle required the most attention and the constant wear at the point of contact where it rode on the stone or metal supports couldn’t be overcome even with the application of the crude lubricants that were available at the time. So damn the expense, there was no choice but to substitute iron at the point of contact. Webster’s defines the gudgeon as “a metal pin or shaft at the end of an axle on which a wheel turns.”

On page 65 is a list of Material Required to Build an Overshot Water Wheel compiled in 1825. Under the heading of metal, only the gudgeon and the bands necessary to strengthen the end of the wooden axle, mortised (cross cut) to accept the wings of the gudgeon, are listed. The construction of the wheel can still be defined as wood and iron.

The type of gudgeon was probably determined by many factors, not the least being the millwright’s preference. On the smaller water wheels the gudgeon could suffice just being driven into the end of the wooden shaft or even pinned in place. In later years as the wheels became larger, and consequently the wooden axle a larger diameter, the wing gudgeon became more into use. It presented a larger surface when mounted inside the mortised cuts and less chance of loosening up with the strain on the shaft as it turned with the weight of the water.
The above sketch illustrates common methods in use at the time for installing the gudgeon in the end of a wooden axle. Two different types are shown but in any case the bands to strengthen the end of the axle where the gudgeons are recessed into the wooden shaft were always employed.

A, B and C identify the bands with Z being the iron extension of the wooden axle that would turn in the support bearing. The first two sketches show a gudgeon simply driven into the end of the shaft and held tight by the bands. The third sketch shows a single wing gudgeons facing the mortise cut in the end of the wooden shaft that it will be fitted into.

The bands were always applied to the wooden shaft of the axle white hot so that when they cooled and shrank, they would cinch the end of the axle tight around the mortise cut and assure that the gudgeon wouldn’t slip out or the wood split from the strain of the weight or the revolving motion.

This wing gudgeon sported four wings at angles to provide more surface area in contact with the cuts mortise into the butt end of the wooden axle.

In the illustration above, the iron rings identified as (r, r) were heated and driven on the butt end of the wooden axle and when they cooled they shrunk and served to reinforce the axle at the mortised cuts. The wheel rotated on the cylindrical part (A) of the iron gudgeon.

The water wheel of the eighteenth century was described as being constructed of all wood being available in the local forest. As iron parts were introduced to strengthen the vital components of the wheel that were most likely to fail because of the weight and
stress, the term wood and iron wheel became more suitable. Eventually more and more parts were converted to iron, and iron and wood wheel suited the description better.

And the expanding textile mill’s demand for more and more motive power would far exceed the capabilities of the wooden water wheel no mater how many iron components were adapted to strengthen the structure. The weight had become prohibited and when it was figured that the average life of the wheel was only ten years with constant repairs and replacements to the weakest parts of the wooden wheel, the iron wheel began to look almost attractive as an investment.

And unknowingly when the millwright laid aside his hammer, chisel and saw and picked up the first wrench to tighten that bold on the bearing he had ordered to better support the wheel on the axle, he had sealed his own fate. That hand that reached for the iron casting that had been forged and machined by metal workers was transferring the craft skills of the millwright to the metal worker and no longer would that beauty of the wheel be his own creation. The machinist and blacksmith gladly picked up the mantle.

But the awe of the craft of the millwright still fascinates and to this day the name has followed the tradesman who toils on the machinery and gearing of modern industry, even in the high-tech environment of today.

Is the millwright the artisan of yesteryear? No. He is in most cases in modern industry an assembler of mechanical parts into a whole to form the complete machine utilizing his own skills and training, yes, but still he creates nothing from scratch in the since that his forerunner did. And his experience with wood in any form is probably limited to the pallet or crate that the metal was shipped on or in.

The wooden water wheel is finished and the millwright can stand back from his creation and gloat in his accomplishment. When the gates in the canal wall at the beginning of the headrace are opened to unleash the torrent of liquid gold that will fuel this great assembly of fitted woods, he can bask in his just deserves as the water pours onto the face of the wheel and fills the buckets, the accumulated weight forcing the turning of the wheel and thus producing the circular motion which will be tapped by the connected gearing, transmitted by the shafting throughout the mill building and finally to spin the belting, tight now on pulleys mounted on the end of the power train and providing the looms and associated machinery with the necessary motive power to produce the finished cloth.

And that was what it really was all about.
Chapter Six

The Iron Water wheel

Goodbye nails—hello forge.

And so we write the end to another success story that was so successful that it destroyed itself. The wooden water wheel carried the burden of industry from its infancy in the earliest of records and up into the first half of the nineteenth century when the excessive power demands made on the wooden wheel was the cause of it being build larger and larger until it simply self-destructed from its size alone. Like many other tried and true mechanism that was carried into ‘popular demand’ over the years, it too had arrived at oblivion fostered by its own evolution.

As iron began to be mined and worked to be cast into parts for the iron waterwheel, it was the wooden water wheel that pumped the water from the pits, forced the air from the bellows that heated the flame that tempered the iron white hot to be worked, that powered the trip hammers that forged the white-hot iron and thus helped to foster its own demise.

The iron wheel was no different than its wooden forerunner in its basic design. Both ran on an axle, the hub gripping the arms or spokes that supported the great circular wheel with the soal (plates forming face of wheel), shrouds (to prevent spillage of water) and buckets in the same relative locations as on the wooden wheel. But for every weakness that wooden construction amplified simply because of the inherent deficiencies of building with wood, and its working life exposed to the stress and strain of the demands placed on it to continually be build larger and heavier and the constant exposure to the wetness eventually causing the supporting parts to loosen and warp and fail, iron overcame.

This illustration of a segment of a water wheel, wood or iron construction, outlines the same components regardless of the materials used in the building of the wheel.

In the everyday course of providing the motive power to operate the mill machinery, the wheels were deluged with the water that propelled them, occupational
hazard so to speak. All wood swells to some degree when wet, some more than others and of course contracts when dried out.

It was not that just some wooden wheels would have had all of their parts replaced after only five years\textsuperscript{75}; it was standard for all wooden wheel and this in spite of constant maintenance. The damp, dank locations of the wheels in the basement of the mill buildings weren’t exactly conducive to the life of the wooden wheel either. But that was all that the early millwrights had to work with, and make it work they did.

Pound for pound the iron was much stronger than its wooden counterpart. The same part on the wooden wheel that was duplicated in iron would normally be lighter for the simple reason that the wood inmost cases had to be comparatively massive to possess the strength to do the job that it was called on to do. For example the wooden axle could be 24 inches in diameter or more to carry the wheel. The iron axle could be as little as six inches, solid or hollow to do the same job; no a better job, much better.

Yes, there were failures on iron parts just as with the wooden counterparts, especially in the beginning of their usage. Let’s stick with the axle because that’s where we started. Working the iron was a science still in its infancy. It could be brittle because of the poor quality of the early bog iron ore and not much better production methods that left holes in crucial points in the casings. When the failures of the solid cast axles couldn’t be overcome, hollow iron axles were produced. The cast iron axle was recorded as first made by John Smeaton in 1769\textsuperscript{76}.

Top figure illustrates a solid ribbed cast iron axle. The gudgeons are cast on the ends and turned down on a lathe. Bottom is a tubular cast axle with the solid gudgeons added later.

Iron Water Wheel
Chapter on “Change”

Improvements in the components of the wooden water wheel realized by the substitution of iron for the wooden parts resulted in the discarded shaped wooden parts to fall in heaps
around the mill wheels. For example the buckets that accepted the water and mounted on
the circumference of the face of the wooden wheels were usually made of one inch pine
as adverse to one quarter inch metal plate when replaced with iron buckets. This meant
that even though the same number of buckets would be mounted on the face of the wheel,
there was a greater space between the face of the buckets eliminating the excessive
splashing and spilling of the water as it filled the buckets and resulting in a greater
volume of water in the buckets. The added weight from the greater accumulation of the
total amount of water contained in the buckets added to the horsepower output of the
machine considerably.

Still the diameter of the breast wheel was limited to the height of the fall of the
water that supplied them, whether wooden or iron construction. Such was dictated by the
design of the installation that allowed the wheel to operated at its maximum efficiency
when the water entered the wheel no higher than the line of the axle on which it turned
and was supported by. But the use of the much stronger iron wheel that would resist
warping because of excessive strain place on only one side or the other alone, and would
destroy the revolving action of the wooden wheel, allowed the capacity of the iron wheel
to be increased by lengthening the breadth of the wheel. In both the Tremont and Suffolk,
each mill had iron wheels 14 feet in length and had three such wheels ganged on each
shaft totaling 42 feet of length.

Another often overlooked capital advantage of the adaptation of the iron buckets
on the wheel face was the comparative ease of venting them which constituted a major
headache with the wooden buckets. The sides of the breast wheel had to be tightly
enclosed with shrouds to contain the water on the downward travel of the wheel. This
tight encasement also caused a large amount of air to become trapped between the water
and the bucket itself when the bucket filled at the top of its cycle as mentioned on page
50. This entrapment of air meant less volume of water would fill each bucket with the
result being less weight and consequently less motive power developed by the
waterwheel. The venting system allowed by the construction itself of the iron buckets
solved this problem.

As in any other improvement, more than one solution was offered and naturally more
than one was utilized, just a matter of the builders choice, really. To illustrate the basic
concept behind the ventilating of the iron buckets we will go with William Fairbairn’s
design for no better reason than the source gives the clearest text and a good selection of
sketches to choose from several different adaptations of the iron ventilated bucket.
In this scheme the wheel had no soal plates. The base of the buckets are bent and overlap each other to serve the purpose of the soal and thus leaving openings for the air to escape.

Fairbairn’s design for ventilating wheel buckets operating under low heads.

Another vast development allowed by the iron construction of the wheel itself was the installation of the toothed segment gear on the outside perimeter of the wheel itself. When gear teeth were mortised into the side of a wooden wheel the constant barrage of water would eventually loosen them but just the strain applied to one side of the wheel continually to transfer the motive power from the wheel to the shafting through the gears was enough to cause the wheel to warp and hastening its early demise. The gearing on the outside of the iron wheel proved not only practical but eliminated most of the heavy gearing and shafting that rode on the shaft of the axle. This arrangement of gearing on the outside of wooden water wheels was in itself deemed the “very worse place that could be selected” in an article published in the American Cotton Spinner. It goes on to proclaim that with this arrangement, journals and axles would give way, loosing and straining the timbers of the wheel, and occasions a loss of power.

A pit wheel which is no more than a smaller geared wheel attached to the shaft to transfer the motive power is recommended to solve the transmission problem. In the case of the top illustration below, the motive power is transferred from the geared pit wheel on the shaft or axle by the action of a belt but the result is the same. In the bottom illustration in shown the conventional segment gearing mounted on the side of the wheel. Both of these sketches are from the Fitz Water Wheel Company of West Virginia.
Fitz Water Wheel equipped with a spur Master wheel on the end of the wheel shaft.

The Fitz Water Wheel Company

Fitz Water Wheel equipped with segment gearing.

Fitz Water Wheel Company

Shed of the excessive weight of the gearing attached to the axle, the axle and shafting that the gearing was mounted on could be made of a smaller diameter. Likewise the wheel itself was made much lighter with the iron replacing the wood in the construction of the wheel. By ridding the massive gearing to transmit of the motive power, much of the cumbersome drag of the unnecessary weight (it was estimated that up to 25% of the total power output was absorbed by the need of the waterwheel to carry the burden of the shafting and gearing just to transmit the motive power it was generating) even the size of the arms that supported the wheel itself on the hub could be reduced.

In fact that improvement to the size of the arms went one step further. They were eliminated altogether to be replaced by spokes. This is what was referred to as a floating waterwheel or suspension wheel and their introduction into the wheel design was to reap several unheralded benefits. For one thing the weight reduction was obvious from the beginning. Another was the use of comparatively thin wrought iron rods as spokes, only 2
to 2.25 inches in diameter as the supports for the exterior wheel itself. These rods were attached between the hub and wheel with threads and nuts and by adjusting the tension on the rods, a little more or a little less as called for, it allowed any distortion introduced into the shape of the wheel from the continual grind of the daily workload to be removed by adjusting the tension on the rods serving as the spokes for the wheel.

The suspension wheel, such as one portrayed in the sketch to the right was introduced almost extensively after c1820 by a T.C. Hewes.

The Iron Water Wheel
Chapter titled “Change”

It was no earth shattering invention or unforeseen development in the overall design of the wheel that produced these innovations. As mentioned before iron had been making inroads in usage of parts to strengthen the wheel over a period of time. Cost was one of the hold ups of greater use. Wood was commonly available in the area. Iron had to be mined and the ore transported from where it was obtained and in the early days it was treated as a precious commodity. Wood was easily worked with common tools of the day and almost every tradesman was familiar with working it at least to some degree.

It required furnaces to heat the iron, and coal, coke or charcoal and huge supplies of air to work it. The blacksmith could shape small parts but it took forges and the skills associated with the operation to handle the more demanding production of the needed axles, gears and the wheel itself that could be cast in sections to be assembled at the site. But it was at the point where the increased demand for more motive power by the mills mandated that wood had to be abandoned as the material of choice in the waterwheel construction. The increase demand on the power load necessary from the output of the wheel erased any cost savings in the material choice of wood over iron.

And there were problems with the wrought iron that the early furnaces produced also. Sections of the casting could cool faster than others causing hidden weak spots that not only broke because of a strain placed at that point but even a sudden jerk because of a
momentary fluxion in the supplied motive power because of demands of another mill or overload on the supplied machine could be enough to fracture a shaft. Another cause of failure could be if the waterwheel suddenly received a large influx of water because of another mill being taking off the line for any given reason releasing a surge of surplus water into the penstock. Even exposing the casting to freezing operating weather conditions could hasten failure of the piece and stop the mill process.

The solution was to come in the form of first cast iron and then steel. Crude at first yes, but a vast improvement over the unavoidable discrepancies inherent in the wrought iron the fledging forges had been struggling along with to shape the iron. But all of the practical innovations that the industry was advancing to improve the quality of the iron and the efficiency in the performance of the waterwheel that was producing the motive power for the textile mill as they knew it would prove to be a losing battle to outdo the emerging supremacy of the turbine in the long run.

But the iron water wheel wasn’t about to give up the battle without a fight. The frequent repairs to the wooden wheels were hard to justify but the adoption of the iron wheel erased many of those sins, and the newly acquired ability to build larger and more efficient wheels certainly could have hindered the development of the turbine for a time. For example in the book, *Treatise on Mills and Millwork, p.126*, one of the more prominent millwright of his time (William Fairbairn) comments on an iron breast wheel built for the Catrine Textile mills (Britain) in 1825-27. During 30 years of service, the great iron breast wheels measuring 50 feet in diameter by 12 feet in breath “required little or no repairs, and ... remain nearly as perfect as when erected”.

The reliability of the iron waterwheel was proven time and time again by its performance in the field providing the motive power in the mill, any mill serving any purpose. Because the example of a long lasting iron wheel given above was build by a William Fairbairn and likewise the introduction of ventilated bucket as illustrated on page 72, do not assume that he was the sole instigator of every, or even the most important improvements to the iron wheel. There were many great ones, a list many names long, and there is no particular reason why the author chose one over the other except for convenience of the available material at the time. None of the names is particularly recognizable to any but the student of the wheel development in any case.

As seen on the previous pages, the death knoll of wooden water wheel was trumpeted at every substitution of iron to replace its like wooden components. Not the least was the size of wooden breast wheels limited by their very restriction due to excessive weight, failure of the wheels due to the many negative effects of the water acting on the wooden parts and the constant strain of producing and transmitting the motive power to the machinery it was built to supply.

And a fair definition of the greater efficiency of the construction of iron versus wooden wheels as taken from *Stronger Than a Hundred Men* tells the rest of the story of the demise of the wooden wheel.

1) Wooden wheels over 40 feet in diameter did not perform reliably.
2) The corresponding limit for iron wheels was around 70-80 feet.
Still the average diameter of the wheels, wooden or iron, tended to hover around 14 to 15 feet although some were built much larger\textsuperscript{82}.

Why the seemingly self-imposed limits by anyone and for what reason? Here the author is going to venture several possible explanations that could possibly account for the size restrictions in the diameter of the wheels. The very location of the wheel was a prime deciding factor for one thing. Many wheel pits were constructed in the basements of older mills so for example, as a failed wooden wheel was replaced by an iron wheel, the size restriction was already in place dictated by the amount of room available under the building. Another factor to take into consideration as to the wheel size was the water level of the source of the water. For example even though the breast wheel did operate with some leeway, the average breast wheel operated best with the water entering the wheel bucket around the height of the line of the axle. The breast wheels that powered the Lowell mills had a diameter constant with the fall of the head in the canal feeding the wheel, 13 or 17 feet. Very difficult to rearrange either.

But not so the width. Most wooden wheels were around two or three feet wide with a ratio of diameter to width of 1 to 5 or 6. Some were wider and a few much wider but on the average they tended to be relatively narrow in relation to the diameter\textsuperscript{83}. The iron wheels tended as a rule to be many times wider. True, the iron wheels were much lighter in relation to strength per pound and many times stronger and this certainly was a factor in the larger width being possible. And iron wheels weren’t wobbling around warped out of shape on massive axles hewn out of two foot plus oak shafts. The axles the iron wheels depended on were comparatively high-tech with at least semi-machined wrought iron supports and gearing.

In any case, as common sense would dictate, the use of the iron saw no limits in the construction of vertical water wheels until technology caught up with the development of the vertical wheel in the form of the superior horizontal water wheel, aka the turbine.

Still, the vertical water wheel was a great machine. Two Fairbairn constructed iron wheels 50 feet in diameter, 10.5 feet in diameter and developing 120 hp each were dismantled in 1947 after 120 years of continuous operation, and outside of adjusting the spokes every few years, were found to be true within less than 1/8 inch. Eat your heart out modern engineering\textsuperscript{84}.

On the next page is a partial copy of a longer list assembled by Paul N. Wilson and offered in, “British Industrial Water Wheels”. Some editing of data and figures has occurred because of corrections by Terry S. Reynolds, the author of Stronger Than a Hundred Men, the book that this list appeared in page 313.
Some Large Industrial Water Wheels of the Nineteenth Century

Some of these wheels were nowhere amongst the largest but several would easily fit right in with the most powerful in terms of horsepower generated. Enough words have described the size and capacity of selected water wheels and this small sampling will at least offer a glimpse into the results of the practical engineering available to the millwrights of the past industry.
The two illustrations on this page should easily clarify any misconceptions the reader may hold as to his understanding of the final construction of the iron water wheel and the relationship between the diameter and width that produced the maximum horsepower available from the falling water that filled the buckets.

In this sketch the separate individual sections of the wheel are ganged together with the buckets of each section staggered to achieve a smoother revolution with the buckets filling at delayed intervals on the face of the wheel rather than all at the same time that could result in a minor jerking effect in the circular motion of the wheel in its revolution.

This iron wheel was identified as an iron pitchback wheel of the type used in Lowell during the nineteenth century, specifically as being installed in the Prescott Manufacturing Company in 1844 and made largely of cast iron.

Iron Breast Wheel, Lowell, 1844
Safford and Hamilton, 1922
The previous sketches on page 78 probably illustrate the pinnacle of water wheel construction of the early nineteenth century. But the claim that the identified Iron Breast Wheel offered in the lower sketch was installed at the Prescott Manufacturing Company in 1844 though may have to be examined a little more closely.

This is the only reference that the author has found that claimed there was ever a vertical water wheel was positively installed in that mill complex. This statement and the illustration of the Breast Wheel were attributed to Arthur Safford in a reference found in publication, *The Mixed Flow Turbine*. At one point in the research, this author recalls a mention, either text or a sketch of this exact wheel but not specifically as being installed in the Prescott. This little tidbit of information now appears lost forever in the endless files and notes somewhere in the research.

But it can be pursued in other works that have commented on the development of the Prescott Manufacturing Company, primarily for our use *The Cultural Resources Inventory (CRI)*, researched and assembled for the Lowell National Park by Sheple, Bulfinch, Richardson and Abbott.

First off, no mill buildings existed in 1844 on the property that the Prescott was to occupy and build their mill buildings on. The first of the eventual two lots wasn’t purchased from the Proprietors of the Locks and Canals on Merrimack River (PL&C) until August 29, 1845 and no mill powers (privileges) were contracted for at that time. The second lot was purchased at the same time and 4 ½ mill privileges were included. These two purchased would encompass the entire holdings of the Prescott land area bounded by the Lower Pawtucket Canal, Concord River and Prescott and Merrimack Streets, and bisected by the Eastern Canal.

Another pertinent item that appeared in the deed for the second lot purchased from the PL&C with the mill privileges was the stipulation that the first annual payment for the rent of the mill privileges was not to be paid January 1, 1847. So it is from this date that the *CRI* attributes the probable date of the completion of the Prescott Mills.

If one thread consistently runs through the history of the PL&C and likewise the investors who financed the cotton mill corporations, it wasn’t attached to spend thrift, money-dumb individuals. If the first payment for the mill privileges was on a given date, the PL&C certainly wasn’t giving away the power before that date and if the Prescott mill wasn’t using the power before that date, its pretty certain they weren’t paying for it. *CRI* appears to be right on target with their assumed completion date of the Prescott mills.

Given this now accepted date of 1847 to begin operation provides a little more indication that it is doubtful the Prescott Manufacturing Company ever had a vertical water wheel installed at their site and bypassed the vertical water wheel installation for the turbines. On page 4 of the chapter covering the Prescott Mfg. Co. (sic.) in *CRI*, a statement is quoted from material offered at the U. of Lowell library, ‘Plan for a turbine’, that states “Existing primary and secondary sources do not describe original water wheels.” It adds, “at least one turbine was installed in the mills in 1847.”
If as the quoted evidence seems to support, a turbine was in operation in 1847, the installation of a vertical water wheel just prior to this selection of the prime motive supply has to be ignored. Besides in no case has any positive proof or even any valid indication for a vertical wheel even arose in defense of the argument for its existence as a source of the motive power in the Prescott mill site.

But the best efforts for all was all for naught. By the time the innovators stood back and beat on their combined chest to signal the victory of iron over wood in the evolution of the vertical water wheel, all of their efforts were pointed in the wrong directions.

The vertical waterwheel was a dead duck, and it was the turbine that would cook its goose.

But let’s take minute and check out the cook.

A good portion of them were out and out frauds but back in that era, minor cases of skulduggery appeared to be accepted if the perpetrator committed no harm. And surprisingly some of these know-nothings produced some surprising result with their hammer and tong methods and were even recognized for their contribution to the development of the turbine.

For one example the author will select John B McCormick who invented the ‘astonishing Hercules wheel, which at a stroke trebled the output of wheels of its diameter’. “He had no drawings or method of procedure, and the ‘cut and try’ process was the system followed.” according to a valuation placed on his work quoted from Declining Use and Advancing Technology on page 359 in Waterpower by Louis C. Hunter.

In a handbook for millwrights titled Evolution of the American Type of Water Wheel, on pages 888-889, Tyler offers the following observation in important improvement to the turbine with ‘pontifical assurance (sic)’: “And may I ask to whom we are indebted for this valuable light? To the man of scientific knowledge, or the practical mechanic? We say, to the latter...Learned theoretical investigations have never accomplished much for our advantage in the improvements of the mechanic arts of the country.”

Even James B. Francis who without a doubt holds the premier title of father of the turbine in Lowell, and after all that is our prime interest, made a comment about who is to be credited for the success of the turbine motor in his Lowell Hydraulic Experiments. On page two he offers in part, “A vast amount of ingenuity has been extended by intelligent millwrights on these wheels; and it was said, several years since, that not less than three hundred patents relating to them have been granted by the United States Government.”

Pretty hard to knock success.
Chapter Seven
The Birth of the Turbine

Every Journey Begins with a Single Step

Of all the tales told about the early machines that were fueled by waterpower, probably the best documented are the turbines. Oh, there were plenty of chronicles of the massive vertical waterwheels in the basements of the Lowell mill buildings rumbling away under the weight of the canal waters that turned them on their endless circular journey to nowhere, and long before that even but our prime interest is the history of Lowell waterpower and the rest can be read by those so interested. And many, many grunts labored over the machinery that was spinning and pressing and hammering without ever a glance at the behemoth that was pumping the blood of the industry that they worshiped in front of for their livelihood as such it was.

Memory and vague images do not have to be relied on for one thing to make the images of turbines real. There are still many water driven turbines operating amongst us the only difference being that the prime job of the turbine today is to generate electric power and that energy transmitted through copper wires is what provides the motive power to do the work instead the maze of gears, shafts and belts that were relied on back when. But it’s immaterial what work the turbine performs. As long as the water acts on the submerged wheel motive power will be produced and the spinning shaft can be tapped any which way desired to utilize the effects of the power created by the wheel’s circular motion.

No illustration of the simplicity of the inner workings of a tub wheel/ turbine has been better presented than this sketch of a French wheel in use as early as the 1600s. The legend accompanying the illustration fondly names the machine a “roue a’ cuve” and describes the wheel as a true reaction turbine. The small sketch at the top indicates the shape of the buckets mounted on the face of the wheel.

De’partement du Gard
France 1620
But it is still inherently true that all development must follow the single step that was taken ahead of it in order to progress further and that step is in the order of following the one before that and so on back into history and likewise forward into the future. At a certain point in time and development the vertical waterwheel reached the furthest it could evolve as a work producing entity. In no way was it replaced with the turbine “right now”. There were still vertical waterwheels in operation in the 1900s.

There were a legion of skeptics with the attitude, “show me” and they can’t be found fault with for wanting to see for themselves how a wheel only one quarter of the size of the wheel it supposedly was going to replace would perform in the actual mill conditions. And some were to flunk along the way and that too has to be expected. Over time, and the closely examined results that unfolded before their eyes, the doubters were slowly convinced to at least give the turbine a try. And today they power most of the world’s electrical plants so the turbine can finally be rated as a success.

There were many men of all cuts of cloth involved in the eventual success of the turbine and their backgrounds were as varied as the developments they introduced. Engineer, machinist, millwright, blacksmith and just plain tinkers, they all played out their role and no one could really be pointed out as the sole or even the foremost inventor of the turbine wheel any more that anyone else on the long list of those who contributed to the wheel’s evolution in industry.

The Turbine Water Wheel

How it all began

The lowly tub wheel was discussed and illustrated on pages 44-45 in Chapter Four, ‘The Water Wheel’ and it was characterized as being quite crude and the simpleton of water wheels, just as the same machine was described in its earliest days of adaptation into industry. It was no more than a vertical water wheel, and a poorly constructed one at that laid on its side for whatever reason, low water in the sluice feeding the wheel probably as good a reason as any and extremely simple in operation and construction. Around two weeks or less of work on the wheel, maybe even installed on the vertical shaft. If enough labor was available the small sluice from a convenient source of a water supply, even if of infrequent dependability, could be dug and the mill was in business.

Until basic mechanical principals were applied in France around 1827 by Benoit Fourneyron, developed even earlier by a professor of his in college by the name of Burdin, the turbine remained not much more than the tub wheel propelled by a stream of muddy water. Even at this early date, the inventors and builders had two basic designs to choose from. The more successful reaction principal of introducing the water into the runner chamber was already well known. And from the practical results of either theory or a combination of both, the mills of Europe were humming away much to the covetous envy of the millwrights across the pond.

But by us selecting the mid-nineteenth century as the birth of the turbine is really only dated for our purposes, the arrival of that particular type of wheel in the United
States from Europe where it was in use for quite some time and our own development of the machine to replaced the vertical waterwheels of the cotton mills. And many stepped forward to adapt the European wheel to the power hungry cotton mills of New England.

The overburdened wooden waterwheels clanking away in the bowels of the mills were doing their job just as they were suppose to, and therein lay the problem. The level of those machines had reached its zenith. The brick skin of the cotton mills could barely contain the expansion demanded by the investors; more spindles, more looms and more cotton cloth was the cry. But the vertical wooden waterwheels simply couldn’t be pushed any further and breakdowns became the rule and more commonplace.

Substituting iron in place of the often failing wooden parts of the vertical wheel did result in a longer performance from the wheels and even added substantial amounts of horse power to handle the increased work demand of the mills. New designs resulting in all iron wheels, comparatively thin iron spokes in place of the heavy wooden arms between the hub and the wheel rim bearings supporting the hubs and the shafts to reduce the friction caused by the weight of the wheel with its load of water all served to lighten the massive weight of the wheel and aided greatly in increasing the horsepower output. But the vertical wheels could no longer fill the bill. Knowing eyes began to pay attention to the newly developing turbine in Europe.

It is true that substituting belting and rope driven pulleys in place of the all too familiar massive gearing and shafting in order to transmit the motive power throughout the mill to drive the looms and associated machinery in the process of weaving the cotton cloth aided greatly in reducing the friction of the mill power transmission and thus increased the horsepower output of the same mill power input. But it is also true that this would be the same result whether the driving force was created by a vertical wheel or a turbine or even water or steam driven wheels so that argument did little to prevail in extending the live of the vertical waterwheel. It was simply outperformed by the turbine.

While the tremendous amounts of water were being funneled through the buckets of the vertical waterwheels to the accompanying chorus of the creaking and clanking, orchestrated by the meshing of the gear teeth and shafting being driven by the created motive power of the wheels, plans were in the near future to test that operation against the performance of the turbine in a Lowell cotton mill. The Appleton Manufacturing Company was gearing up for the test and that day came in 1844.

Uriah Boyden built the first turbine and submitted it to the Appleton Manufacturing Company to satisfy all it would work as well in the field as on his workbench. The design was an improved version of a wheel invented by Benoit Fourneyron of France but new to this country. It developed only 75 horsepower with an efficiency rating of 78%. This performance was enough to place the turbine head over heels above the vertical waterwheels then in operation in the Appleton.

When the results of the operation were evaluated, by amongst others James B. Francis the chief engineer for PL&C, the colors in the winners circle were raised and Boyden received a contract for two more turbines to be installed by 1846. To be sure the original performance wasn’t simply a fluke by the first time turbine builder, the profit
from the job was to be determined by the efficiency of the wheels. 78% was enough to gain Boyden a $4,000 bonus in his pocket\textsuperscript{92}.

At this point we should take a breather and present the entire layout of the basic configuration of the turbine and the water flow in a schematic diagram. This simple sketch should be self-explanatory as all of the components of the arrangement are identified as to its purpose in the flow chart.

Schematic representation of a typical turbine arrangement

A primer on Water Turbines  by Robert A. Howard

Boyden too had the advantage of knowing when dealing with the mill investors, top dollar would be paid for top performance of the wheel so no expense was spared to use the best of materials in the construction of the Boyden wheels\textsuperscript{93}.

The performance of the turbine was to impress every mill corporation but most of all the PL&C was figuring the savings in the amounts of water necessary to pass through the turbine to do the same work as the vertical waterwheel which demanded much larger volumes in its buckets. So needless to say the PL&C approached all of the corporations to change over as soon as renovations could be made in the support structures to adapt to the much physically smaller turbine.

And all of the advantages of the rapid change over to turbines as the prime mover presented to the mills were loudly touted by the PL&C, and the corporations were listening. Smaller amounts of water to carry the same number of spindles meant that the amount of looms per mill could be substantially increased using the same mill powers that the individual corporations paid for annually. That translated into more profits for the investors with little expense involved up front. It was a go.
There were many other advantages also in the daily operation of the turbine vs. the vertical wheel. Maintenance of the wheels was a big item. It has already been brought out that the older waterlogged wooden wheels had to have many if not all of the parts replaced every five years, and while the replacement with iron parts greatly extended the life of the now composite wheel, the all iron water wheel completely eradicated what weaknesses remained structurally with the wooden vertical wheel. And as the wheels were expanded lengthwise to increase the horsepower they produced, the volumes of water necessary to feed the wheels increased proportionately.

But probably the biggest problem that the turbine solved was the machines ability to operate in backwater conditions. The turbine wheel did not rely on the weight of the water to propel the rotating buckets as the vertical water wheel did but on the reaction of the water acting on the face of the blades. And right here is an appropriate place as any to include a differentiation of the term water wheel as applied to the vertical waterwheel and the turbine water wheel. Taken from *A Primer On Water Turbines* by Robert A. Howard, he state’s that “In the 19th century the term waterwheel was applied to both what we call waterwheels and what we define as water turbines. To compound the confusion, both wheels and turbines are found oriented horizontally and vertically. In order to differentiate between wheels and turbines, anything with buckets or blades each in a single plane is a waterwheel, and anything with curved vanes is a turbine”

And as a simple reminder as to the definition of backwater, it was the effect of the water backing up into the tailrace from the canal or river it was discharging into from whatever type of wheel. As the backwater rose in the tailrace that the water wheel was usually suspended about 18 inches above, for if the buckets became submerged in the water being removed from the wheel into the tailrace, the drag on the rotating buckets would increase to the point of interfering with the circular operation of the wheel and in extreme cased completely stop the revolving motion of the wheel shutting down the mill. In the turbine the rotor was completely encased in the drum and it was removed from the effects of water rising over the turbine and so could operate while completely submerged.

And last but not the least advantage of the turbine over the vertical wheel was its greatly reduced size in comparison to the vertical wheel it was replacing. It was common for iron waterwheels of a 13 foot diameter to be ganged on the same shaft to produce the desired horsepower output, sometimes reaching a combined length of 42 feet. One or two turbines 11 foot in diameter could easily fill the bill and likewise tandem turbines could be mounted on the same drive shaft. Turbines could easily be adapted to be horizontally or vertically mounted in the waterway as necessary saving the excessive headroom that was required to mount the vertical wheels, freeing up much basement area in the mill building.

It would seem from all of the glowing reports of the turbine wheel vs. the vertical wheel that the answer to producing the motive power to run the Lowell cotton mill was solved without a hitch. But it seems that there is always a fly in the ointment somewhere along the way. It had nothing to do with the mechanical operation of either machine really but just emerged as one of those little glitches that have a way of rearing their ugly
head to raise a stink in the smoothest of performances. That was the grit suspended in the water flow that no screening could prevent because of its minute size.

The effect these particles had on the massive vertical water wheels was zero. The water simply poured down the headrace, into the penstock and flue, filled the buckets on the face of the wheel and then was dumped into the tailrace when its weight was spent at the end of its revolution to return to the source, river or secondary canal, the particles of grit and sand still suspended or being dragged in the water flow.

Not so the effect on the often referred to as the well tuned turbine and it was frequently described as by just those terms, at least once being compared to a finely machined watch. Any rough particles at all; sand, grit or small pieces of stone grinding away on the blades as the water made its passage through the turbine was a prelude for failure of the wheel. But it couldn’t be helped and had to be accepted as an unavoidable consequences of the process of the water flow being tapped for its mill power. The turbine would still outlast the iron vertical wheel by about three times to one.

This dissertation tends to give the impression that the turbine was the perfect machine, very far from reality. Even though many essays will tout the ease of maintenance over the waterwheel, this is not necessarily the case. For one thing the turbine itself is usually totally encased in a metal shroud or cylinder for protection of the moving parts plus to aid in directing the water flow around the chute case. In many instances the machine is also submerged. Common sense predicts a very difficult approach to any maintenance job.

Also like the finely tuned instrument the turbine was described as earlier in the chapter, it can be just as fickle. The machine runs most efficiently only at the water flow it was designed to operate at. All installations were equipped with control gates to control the amount of water that was supplied to the turbine but the operation of the turbine decreased if the flow was varied from its design rate. In areas where the water flow varied because of weather or just over usage by other operations, some mills converted back to waterwheels since they are more consistent in their performance over a wider range of flow. (Why the Suffolk mill was dissatisfied with the turbine performance installed in that mill in the beginning will probably never be known, at least to this researcher.)

The various types of turbines along with the manufacturers stood roughly at 40 in production in 1873 and twice this number five years later. The types of wheels varied with all that entered the market with small improvements to produce better machines and sometimes resulting in worse. Some manufacturers used the same molds over and over and some always changed to introduce improved models. The problems usually resulted with the smaller wheels and few of these were ever tested for efficiency in horsepower or performance but simply left to whatever the purchaser ended up with for the end result of the wheel, for better or worse.

Scientific principals take over
One of the decisions the author had to make with writing this chapter was whether to start off with the technical description of the turbine along with available illustrations and photos or provide a little sketch of the introduction of the turbine into the world of the vertical wheel. As you can see the latter was the choice. The choice was only a judgment call as to which offering would hold the readers interest and keep him interested.

At the very beginning of the chapter the operation of the turbine and the tub wheel were cast as alike’s but in truth nothing could be further from reality. The tub wheel was no more that a simplistic series of paddles arranged one behind another horizontally on a vertical shaft in a flow of water. The current of the water flow acted on the paddles created a circular motion that was transmitted through the revolving shaft to accomplish whatever work was desired.

The turbine is a highly sophisticated piece of machinery. Once it was proven to work by practical application, the dirty necks with the tools and dreams waded in to the fray and long before any of the makers and shakers knew why, the end results were achieved there were plenty of turbines in operation\(^9\). It would remain for the practical results of the turbine operation to be scrutinized and analyzed and all the observed effects of the water flow on the enclosed blades to be translated into design jargon before really efficient and superior machines would be built. Now knowledgeable engineering types could predict the expected efficiency of the turbines they built and justify their predictions of the projected performance of horsepower and efficiency. Also if several machines were ordered and expected to give the same performance, the expectations would be justified. The turbine was now subject to the science of hydraulics and not the whims of local blacksmiths and what have you’s.

Now the terms reaction and spiral were frequently to enter the picture to describe the application of the action of the water flow as entered the turbine case and acted on the shape of the blades mounted on the turbine runner that resulted in such a smooth motion of the wheel carrying its horizontal shaft in the circular orbit that would produce the sought after power necessary to run the looms. Other terms began to be bandied around to describe the exiting direction of the water as it left the wheel chamber of the turbine inward and outward flow. This process was to greatly reduce the turbulence created as the spent water left the hydraulic motor and a smooth entrance and exit of the water flow was the key to the greatest efficiency of the turbine operation\(^4\). Our concentration is about the machines of Lowell and the design features we will present to the reader will center on the development of the turbine as applied to its usage as the hydraulic motor in the Lowell cotton mills but it matters not that much. If one design can be understood, all can be if so studied by the interested reader.

For our purposes and our only prevailing interest in the chapter on the cotton mills of Lowell, the first turbine introduced to the cotton mills of Lowell, and therefore the beginning of the conversion of the mills from the vertical water wheels to the turbine, is our baptism to the world of the turbine as a prime mover. Boyden was given the rightly deserved credit. And from there begins our introduction to the turbine hydraulic motor.
This very simple schematic showing a cutaway view of a working turbine following should more than familiarize the reader not previously exposed to the basic parts of the turbine with the knowledge necessary to understand the operation of the machine. The drive shaft, coupling and bearings are everyday mechanical components and should be self-explanatory.

Primer on Water Turbines  Robert A. Howard

Gate control – as indicated here is a remote control that varies the amount of water that enters the turbine through the adjustable openings in the gates and controls the revolutions produced by the turbine.

Runner - the only part of the hydraulic motor that the flow of water entering the turbine through the gate openings that is actually acted on by the water flow, forcing the runner to revolve on the shaft. The resultant motive power developed by connecting gears, belts, etc to the shaft is the mill power that its all about.

Draft tube- This is no more than a section of pipe the same diameter as the bottom of the turbine casing. The length can vary and in some cases the draft tube is non-existent but rule of thumb says no more than 20 feet. The spent water is discharged from the turbine into the draft tube which terminates in the tailrace. It is designed to somewhat improve the efficiency of the turbine by acting as a
suction devise to aid in the smooth ejection of the water flow leaving the turbine.

The statement was made at the beginning of the chapter that there were still plenty of turbines in operation today and I suppose that this statement inferred that one could simply observe the machine at its finest whirling away propelled by the waterpower it was fed with. The observing part is the difficult part of that statement. Boott Hydro operates half a dozen or so turbine driven generators producing electricity at the site of the Boott Mill complex at the foot of John Street but the facility is off-limits to the public to my knowledge.

The building that houses the power house that is the site of the hydroelectric generators of the Massachusetts Manufacturing Company site on Bridge Street is again private property but even then all that is visible of the equipment are the generators. The actual turbines are beneath the concrete floor of the generator room. The tailraces emptying into the Concord River can be viewed from the sidewalk alongside the Lowell Auditorium building just off East Merrimack Street but that is the extent of the examination of this turbine location.

The best bet to actually observe a turbine in the operating mode is the Eldridge Fields Hydro-electric generating plant built on the Northern Canal just off Pawtucket Street. The author is sure arrangement are required for a conducted tours but the Enel personal that run the plant are extremely cooperative and a pleasure to tour the facility with.

The turbine exhibition at the Wannalancit is a class ‘A’ display of the original wheel pits in the basement of the Suffolk cotton mills and the raceways of the head and tailraces leading to and from the casing that housed the turbines. Notice that these turbines too are fully encased but at least on the main floor of the exhibition one of the original turbines is on display, removed from the casing and dismantled so all of it’s operating parts can be viewed. Also mounted on the main floor is a display of the massive shafting and gearing that transmitted the motive power throughout the mill building to operate the cotton looms and this in itself is quite impressive. Why this exhibition of the mill machinery is locked away from public viewing by people strolling the canals and having an interest in the life blood of Lowell of yesteryear is another government secret.

The previous paragraphs outlines what can’t be seen of the intricacies of the hydraulic turbine motor so we have no choice but to examine sketches and photographs, primarily the latter if possible, of the internal components of these machines to at least gather an appreciation of the workings of this great innovation of the water wheel. For the really mechanical minded of the readers the best way to describe the working innards of the hydraulic turbine is to illustrate them in an exploded view where each part of the machinery is shown in relation to the next and it’s use can be inferred by it’s overall position.

The turbine wheel installed in the Suffolk Mill was a Victor. The page this expanded view was taken from indicates it was produced at The Stillwell-Bierce & Vaile Co. in
Now for the test.
Assemble all of these parts together in your mind and produce a hydraulic motor that looks something like this. No, it doesn’t have to perform, just appear as if it is possible for this presentation.

If you pass the test, your capabilities are far beyond those of the author and you should continue writing the text from here.

But the fact is the turbine is probably the simplest and the most efficient prime mover ever conceived. When the statement was made that there are still many of these machines in service it wasn’t referring to tub wheels in the back woods grinding grain in
simple grist mills either. In the 1950s Lowell alone had about 55 hydroelectric units on the line powered by water turbines as indicated in the sketch of the power generating grid below.

In a *Preliminary Report On The Development Of The Existing Hydroelectric Capacity At Lowell, Massachusetts, 1978*, it states that “old records indicate that during the 1930s, the total installed nameplate capacity for hydroelectric power at Lowell was approximately 15,000 KW. At the present time, Boot Mill is the only entity generating electricity at Lowell (1978) and it operates approximately 6,600 KW of its reported 7,300 KW of installed generating capacity.”

All of this power was produced from turbines driven by the water furnished from the canal system constructed in the previous century to produce the motive power to operated the cotton mill looms with shafts, gears and belts. Can’t beat a winner.

From Report Prepared by the Essex Development Associates
Proprietors of the Locks and Canals -1953  Revised 1954

The enormous electrical output of Boulder (Hoover) Dam generated by 17 hydro-generators producing 2080 megawatts that powers a good section of the southwest section of this country is powered by water turbines installed in the bowels of the dam. 101.
This hard to imagine, the entire flow of the Colorado River backed up in Lake Mead flowing through these turbines at 85 mph but that is the volume that these turbine can and do handle. This turbine is quite a machine, no?

One very good reason for the use of hydroelectric power plants seldom mentioned in the forever ongoing controversy between water and steam driven turbines is the water drive turbines have the ability to vary the amount of power generate, depending on demand. Steam power plants do not. These are only two examples to justify the statement that there are turbines running and producing the motive power that fuels industry to this day and the performance of the water driven turbine in the power system is identical in theory and practice to almost 200 years ago.

We keep deviating from the basic topic of the construction of the turbine but one tale creates a second. Words flow as if the reader can visualize the descriptive phrases describing the workings of the turbine but that belief is a little far fetched. The illustration and photograph beat all and a few pages full of them will serve to save many trees.

These two photographs, on the next page, are most likely from the same late 1890s time frame but not necessarily for the same machine. Never the less taken together they do perfectly show the two main components of the turbine regardless of whether designed as inflow or outflow discharge of the spent water.
This photo labeled Tremont Mills, 48” Victor, new 1895, is of the Chute Case that directed the water flow through the gate, Cylinder or Register type, and onto the blade of the Runner or revolving part of the turbine.

And this is the runner that the flow of the waterpower acts on to create the circular motion in the vertical or horizontal shaft to provide the motive power.
Lowell’s Hydraulic Genius and his Turbine

Given all of the text and given all of the photographs and illustrations that have been offered in the presentation of the turbine reaction water wheel, to satisfy our interests about the history of the Lowell cotton mills, all of the previous blather means nothing without mentioning by far the greatest hydraulic engineer to come out of Lowell, or to come out of anywhere else at that time for that matter, James B. Francis.

The question that probably enters the reader’s head right about now was why did it take so long in the presentation to mention Francis. At this point they are assuring themselves that there is going to be a lot more to the story of Francis so why wait so long? Well for one thing it’s not the story of Francis that’s being told here but that of the Turbine hydraulic motor. Yes, he was the biggest contributor to the adaptation of the turbine into the Lowell mills, pushing the conversion from the Vertical wheel to more usage of the turbine wheel for the simple reason it used much less water than the huge Vertical wheel to do the same job. And with his basic design and engineering work with Boyden and Howd (pioneers in the turbine field) he certainly deserves the accolades that came his way. Strangely on the list of his accomplishment the work on the turbine is hardly mentioned104.

In 1834 he was hired by the PL&C as a draftsman in the locomotive shop. In 1841 he was entrusted with securing the data needed to determine the quantities of water drawn by the cotton mills form the canals. In 1845, Francis was made chief engineer at the PL&C and for the next 40 years he filled that position admirably along with acting as the consulting engineer to all of the factories using the waterpower.

Along about 1850, the turbine reaction wheel was making inroads into the long established realm of the vertical water wheel. The successful results of Boyden’s installation of his experimental turbine wheel in 1844 in the Appleton Mills was predicting the demise of the vertical wheel in the near future if not sooner. To the development of the turbine Francis now turned his attention centering his work on a machine based on the Howd patent that he was familiar with, reshaping the vanes on the runner to redirect the flow of spent water as it was discharged from the turbine. This innovation in his improvements to Howd’s turbine became known as the mixed flow or Francis turbine and the most generally used for low head installations105.

The results of his extensive testing and research on the hydraulic turbine motor and all of the water flow through the associated waterways that comprised the entire system of the power canals led to his publishing The Lowell Hydraulic Experiments in 1855, some of the data still in use today. The two statements made in this chapter about Francis’ involvement in the development of the turbine may seem contradictive but The Lowell Hydraulic Experiments is not primarily about the hydraulic turbine motors but the action of water flow in any given circumstances in the waterways on the Lowell canal system that he studied or at least designed the studies that were conducted in the mills and canals.

Francis’s designs and the conclusions he arrived at governing the development of the turbine were highly regarded and held up to acclaim by all in the industry And one
publication said it all in the fewest word; “guided and shaped by the needs of the engineering and the corporations that employed him. He was not as interested in knowledge itself as he was in the knowledge or ability necessary to design artifacts and effectively operate hydraulic works.”

With this simple straightforward philosophical approach to his own conception of engineering, his name became his monument in history extending to the grandest of engineering projects in this country, Boulder (Hoover) Dam, the granduer highlights of which we already outlined on page 92. The 115,000 Horsepower turbines installed there are built on the basic Francis design.

---

*Lowell Hydraulic Experiments, pl.1*

James B. Francis 1855

This was Uriah Boyden’s outward flow turbine that Francis conducted his tests on at the Tremont Mills that led to Francis publishing his famous studies on the results in his *Lowell Hydraulic Experiments* in the chapter, ”Rules for Proportioning Turbines”.

The turbine, or at least crude pre-turbine types had been around for a long time in France before Fourneyron built his first in 1827. Europe in no way had the abundance of free running natural waterpower that this country had. It took a lot less water to turn a turbine than a waterwheel so it made sense the development of the turbine was favored. And when the huge stocks of coal were mined making it the choice fuel for creating steam, well steam can’t turn a vertical wheel.
Before the reader escapes from the extended technical romance of the demise of
the vertical water wheel under repeated accolades touting the superiority of the turbine
wheel, let’s take the time to revue a few positives for our old mate, the vertical wheel
before we cast the last shovel of dirt on it’s sepulture with the dirge vaguely heard in the
background to the tune of “So Long...its been good to know you...”

The turbine was being touted as the eighth wonder of the world by many who
rushed to its acceptance but not by all. James Abernathey in his 1880 *Mill Building* noted
on page 93, “The turbine wheels have many defenders because there are many makers,
while the overshot has no defenders, unless, perhaps now and then a conservative
individual, who does not take up with new-fangled notions very readily.”

The turbine wheel in any case was not a universal instant success. In some
applications it was nowhere a success at all, rejected hardly for the old standby, the
vertical wheel. Britain had access to the French developments of the turbine wheel at an
early stage of its introduction but much of the country was more or less water starved in
comparison to France and Germany both of which embraced the turbine as their own
savior of industry. And one respected British Journal noted with respect to the turbine,
“This machine is frequently employed in France...but is not much known in this
country.”

Again and again the general lack of any great amounts of heavy water flows in the
streams that attracted the building of factories and mills along side was offered as the
reason for the rejection in most cases of the turbine in favor of the vertical wheel. As Paul
Wilson pointed out on page 219 in *Early Water Turbines*, “The water turbine had certain
advantages over the waterwheel, but for the heads and flows of water generally used in
Britain, and for the type of machinery to be driven, the advantages were not
overwhelming.” It is hard to believe but in a 1962-63 survey conducted in an area of
Britain (around Dorset) of the watermills, ‘the surveyors found evidence of 99 vertical
wheels, but only 26 water turbines’.

Not to beat the drum proclaiming the advantages of the vertical wheel too loudly
least one mistake the beat as accompanying it’s final gasp rather than announcing it’s
advantages but the overshot wheel could more than hold it’s own. All steel overshot
wheels could be constructed with an efficiency of 90%. A small turbine seldom exceeded
70 to 75%. Already discussed was another deficiency in the operation of the turbine, that
is to run effectively it must run at full gate. The overshot wheel could run just as
effectively at quarter or half gate, just as efficiently as at full.

This flexibility of the overshot wheel in the ability to operate in a wide variety of
conditions over which the manufacturer or the purchaser had no control once it was
installed in itself was a very large advantage of performance in the field. Add the simple
construction, ease of repair, reliability and longevity of the iron or steel overshot wheel
with the ability to perform well under varying heads and falls and this machine certainly
gave the turbine a run for it’s money.
The turbine too could and did post some superior performances of its own, not the least of
being submerged didn’t affect the output of the machine and this alone deserved a gold star allowing full performance in back water conditions.

Another top-notch advantage for the turbine was much faster shaft speed for the output and in electrical generation high rotational velocity is a must This could only be achieved by the vertical water wheel through cumbersome shaft gearing that simply added friction and great weight from the iron used in the castings of the necessary gears and shafts to transmit the resultant power from the wheel to the machine loads. And the turbine design could utilize steam in the stead of water as its own motive power. The vertical wheel couldn’t.

Even on this side of the pond, problems existed with the change over from the vertical water wheels to the turbines. All of the testing in the world cannot hypothesize actual performance of individual machines in the field no matter how carefully each is duplicated in the manufacturing process. And the Suffolk Mills appeared to have suffered a melt down in their conversion from the vertical wheels to the turbines.

The only information available is written in the records in the form of letters or notes amongst the people involved in the mill operation at the time. The ability to read between the lines can be quite an asset for the researcher trying to interpret the actual meaning of those earlier phrases and words and their intent in the records and place it in context of the historical importance to the scene being studied.

The Suffolk and Tremont corporations were virtual carbon copies of each other, starting right with ownership and management. They agreed to build four wheel pits in each mill that could support either vertical or turbine wheels “if we should ever wish to resort to them”, the ‘them’ meaning Breast wheels. The Tremont wheels seemed to perform up to par right from the day of installation. Never a complaint was heard about the operation of the turbine water wheels and Francis successfully performed his hydraulic tests on the turbine with never a recorded snafu at any rate.

Not so the Suffolk Mill experience with the turbine wheels, supposedly the exact duplicates of the Tremont. In a letter from John Wright to Henry Ward on February 8, 1862, he writes, “The [turbine](sic) wheels failed to meet our expectations—nevertheless, the room remained”.

And this conclusion arrived at and noted in the Historic Structure Report \textsuperscript{110} on the Suffolk Mills; “Maybe the success of the Appleton Company experiments had encouraged the Suffolk to anticipate too much from turbines.” The pros and cons of both machines covered above could sustain that assumption on the part of the Suffolk of over performance, and also a let down with the actual results of the turbines. And the Report continues with, “perhaps there were faults in the design or construction. Whatever may have caused the problems they were accentuated and complicated by the unusual periods of drought experienced by Lowell during the 1840s.”

The Suffolk’s problems were more than just bad luck. The Suffolk agent wrote to J. B. Francis in 1869 indicating that the problems continued for many years. “We have
run only three (3) of our turbine wheels since June 12, 1869 and four (4) for a short time only, previous to that date, while we were making an alteration in the driving arrangement of our Picker."

A great amount of detail could be added to the Vertical Wheel vs. the Turbine but what purpose would be served. The only point in the descriptive text between the two was to prevent the reader from closing the book with the impression that the advocates of one or the other of the two machines was being chastised for his support. Each, in it’s own time, played an important part in the role it was cast in.

But the vertical wheel or turbine creating the motive power, regardless of it’s mechanical attributes or lack of them compared with others in the power system, should be applauded for the role it did play in fostering the American industry. And the Lowell cotton mills played a very large part in the evolution of these machines as well.

Without a doubt, the turbine revolutionized the field of power generation, first as a producer of mechanical motive power along with vertical wheels that propelled cast iron shafts and gearing, transmitting the motion to hungry machinery. After decades of milling gain for bread, pumping bellows for iron forges and more pumping of water out of flooding mines and enough other back-breaking chores to fill a book, the vertical wheel left the scene to the turbine. The turbine was much more adapted to spinning the generator that would produce the newest wonder of industry workhorse, the electric motor.

Those ever present prophets of gloom and doom are still in the wings predicting that soon steam power will render water power obsolete, and to be sure even today steam powered turbines do fill needed and important roles in the generation fields. But the water driven turbine has one great advantage in the ‘green’ society of today...the driving force is renewable energy.
Chapter Eight

Transmitting the millpower

The mechanical ingredients

Shaft —-- a bar supporting or transmitting motion to a mechanical part.
Shafting – a system or group of shafts as for transmitting motion.
Belt —--- a wide endless strap or band for transmitting motion from one wheel
or pulley to another or others.
Gears —---- a system of two or more toothed wheels meshed together so that the
motion of one is passed on to the other.
Gearing – a system of gears or other parts for transmitting motion.

All Mr. Webster can do for the mechanic is inform him as to the correct spelling
for a particular piece of equipment. Regardless of the name given to any prefabricated
shape, whether wooden, iron, steel or any composite, just lying on the workbench erases
its identity. Until the object is actually utilized in its intended function or at least mounted
in such a position relative to other objects so that its eventual task is evident, doubt can
cloud the reason for its even being present.

If the blather in the last paragraph was the answer to a crucial question in the
millwright’s exam, there is a good chance there would be no mechanics earning that title.
But in all seriousness, the terms above are the meat and potatoes of the mechanical
transmission of motive power from the water wheel (vertical or turbine) that is our
interest to the looms in the cotton mills of Lowell.

The description of the wheels producing the motive power through the weight of
the water in the buckets of the vertical wheel or the reactive effect of the water on the
blades of the turbine have been discussed in detail throughout the previous chapters in the
book. No matter whether the wheel is mounted vertically with a horizontal shaft or if the
wheel is mounted horizontally resulting in a vertical shaft, the end result is a rotative
motion. Now it is time to put that developed motive power to work.

Once again as has been preached throughout the books, an illustration can be
worth a thousand words, and in many cases it can be worth thousands of words.
How many times can “the shaft spins” or “the gears mesh” or “the belts flap” be written
and still make sense to the reader without his eyes getting heavy? At this point there’s a
good chance power transmission will have lost all meaning if the text is too redundant.

The shaft, gear or the belt whether the belt is comprised of leather or rope
performs the same function in a mill of today as they did more than a couple of hundred
years ago when driven by water wheels or turbines. The prime mover of today in all
likelihood is more apt to be an electric motor but even if it is a direct drive between the
motor and the machine, a coupled shaft would probably provide the connection between
the two. The big advantage of a coupling between the shaft and the driven machine is the
ease of repairs when necessary by isolating the load. A belt is no problem to remove from the line.

The ultimate purpose of shafting and belting is to transmit the motive power from the source to the driven load. That of the gearing can be much more involved and sometimes even complicated if it exists at all in the power train. It is through gearing that the power shafting changes direction, from a horizontal plane leaving the wheel for example, to a vertical direction to rise to the overhead or maybe penetrate several floors to transmit the motive power to any given machinery, even to vary the revolutions per minute through dissimilar gear ratios.

This simple sketch below will serve to visually describe the basic functions of this mechanical triarchy before a little history is examined as to the role each component has played in the development of the power train. The accompanying text is reproduced verbatim from the pamphlet produced by the Lowell National Historic Park, *The Suffolk Mills Turbine Exhibit*. Any change in the wording by the author would simply serve to take away from the descriptive intent which is perfect in its presentation as is.

To transfer power from the water wheel to the textile machines, the earliest mills used a network of rotating gears and shafting. This method tended to be slow, noisy and jarring, with frequent breakdowns. In 1828, Lowell master mechanic Paul Moody devised a leather belt and pulley system. A drive pulley or flywheel to transfer power from a main shaft to smaller line shafts, and then to machines. The use of belts and pulleys allowed for a smoother and more efficient transfer of power with fewer breakdowns periods. Soon drive pulleys and leather belting became standard in mills throughout the United States.
The Early Power Train

How was the power transferred from the wheel to the work before the sophisticated train of mechanisms that were in use in relatively recent times were incorporated into the system? The illustration on the previous page demonstrates the use of all three components in the power transmission chain in the simplest presentation.

Everyone in the industry thought that belts to replace the cumbersome shafts and gearing was a capital idea when introduced. But in fact belt take-offs were a common usage even with the simple tub wheels as shown in the photograph on page 45. The first use in Lowell was when Paul Moody substituted belting rather than gearing that also allowed for lighter weight shafting when he constructed the Appleton mills,1828, resulting in an increase in production speed because of it.

A flexible connection to the loom or any machines for that matter seems a given. To replace the machine or simply take it off the line for repairs without stopping the entire operation comes to mind. And the belt could serve as a disconnecting means to remove the machine from the revolving pulley on the shaft at the end of the shift. The operator or the mechanic could perform this act on every machine so the load would be lessened on the power source when the manufacturing process started up in the morning instead of trying to pick up the entire load of all the machines at once. (The author was witness to this process every day himself in a Lowell shoe manufactory.)

Another positive result of a flexible connection between the revolving shaft and the machine is to eliminate as much as possible the amount of vibration being induced into the solid shafting and transmitted into the building structure through the hangers supporting the shaft and attached to the ceilings or floors. Most of these mills were constructed on weight bearing exterior walls and the results of excessive reverberations of all the running machinery combined of this latitude could be disastrous in the life of the building so any elimination of vibrations into the structure itself was to be an asset. Not to mention the noise effect on workers.

The text that accompanied this photograph in the original states that belting from the overhead line shaft also conveyed power to the machines on the floor above through openings cut through over the shaft between floors.

Courtesy of the Smithsonian Institute
Before the adaptation of the belt or rope drive into the power system can be fully appreciated, the reader is going to have to trip through the clanking and grinding of the shafts and gears just as the operators in the mills had to endure. Every mill of the earlier centuries, say beginning in the eighteenth century for example so we don’t get too dated, was constructed on the spot using whatever materials were available. This just about assured wood would be the prime ingredient in any and all of the needs of the construction, the structure and the machines that were fabricated to do the job the mill was built to do.

Saw mill and grist mill were the most needed operation in any community, the former to grind the grain for food staples and of course the milled wood products that framed every structure regardless of its stature or station. In time with the discovery of metal ores in an area, after the furnace the forge would certainly be on the necessity list. The prevalent power source was the vertical water wheel created entirely from wooden parts, including the shafting and gearing that transmitted the power from the wheel to the work being done in the mill.

The wooden shaft presented probably the weakest link of all the wooden parts that constituted the early wheels. It was not only called on to support the weight of the entire wheel and the constant instability of the far from perfectly shaped wheel but also carry the weight of the water filled buckets that drove the wheel in its erratic revolutions. Several ton was not an extreme weight for a fully operation wheel and two foot or more square shafts for the axle were fairly common, round-ed only on the ends where the iron gudgeon was forced home and snugged with iron banding to provide a fairly smooth revolution in the block or bearing.

Oak was the material of choice for the axle shaft being the hardest wood growing in the surrounding forests that served as the millwright’s warehouse. The wheel itself would have had to be constructed around a solid hub of sorts with the spokes radiating from the hub to support the rest of the components of the wheel. The shaft would be inserted into and through the hub, leveled and firmed with wooden wedges so it could be replaced when the calamity of a break occured.

It only made sense during this trail of events as iron was slowly being substituted for the weakest wooden parts of the wheel to introduce iron shafts. To be sure in the beginning of the change from wood, the rough cast iron axles came with its own baggage, the whole story told in chapter Six. But then along came wrought iron and then steel, and then better machining of the shafts and better supporting brackets and a multitude of developments that resulted in a smoother operation, the entire power transmission system of which of course the shafting was the heart.

Until the advent of electricity as the motive power that allowed each machine to be individually driven by its own motor attached directly to the load, the entire transmission of the driving power had to be designed around the capabilities of the system of shafts and gears. Even the brackets that supported the shafting had taken on a importance where the choice of one over the other was dictated by the exact usage of the shafting as to location, rpm’s, torque... No more “get me a hanger...” would instruct
enough. And there was plenty of hardware to choose from as the advertisement following shows.

Advertisement of the Globe Iron Works    Line – shafting hardware

The American Turbine    1875

Up to this point in the text the best the author could do is to familiarize the reader, and sometimes himself, with the contents of the up and coming chapter on the parts the shaft, gear and belt would play by introducing random bits of information describing each in small bits and pieces. A brief historical essay of each part of the power train will be a good start to bring us up to where things stood when the first brick was laid at what would become the foremost industrial cotton cloth manufacturing site in the country, Lowell, Massachusetts,

This whole book, not only just this one chapter, has to be framed by the red brick that housed the machinery that enabled raw cotton to progress from the bales of the southern fields to be woven into finished cloth all in one continuous process under one roof, “from bale to bolt”. The machinery contained in that mill has to be envisioned as a single entity, each and every moving and stationary part dependent on every other part in the power chain from wheel to loom.

It is almost impossible to take one item, the shaft for example, and carry it through from inception to its termination in the power chain without involving the role the gearing and belting play also. There are other pieces of machinery in the mechanical puzzle that can only be described by inserting them at the proper time to explain the very
important part, sometimes a very critical one. So the best way to handle the introduction
of various machinery in the chain is simply to begin the tale of a cotton mill, or any mill,
and let it evolve on its own from there.

A Little Look Backward

When machinery from the past is salvaged from any historical site to be put on
display to interested parties, disbelief is probably the initial reaction. To try to conceive
that some of these apparently Rube Goldberg contraptions actually played a part in the
evolution of whatever industry they were associated with can be trying. And not because
they appeared too complicated to understand, but on the contrary because they were so
simple and their professed use so straightforward that they actually produced the desired
results.

The millwrights of yesteryear that were the predecessors of today’s entitled
engineers. They were the tinkers, inventors and mechanics of their day and saw the
immediate problem facing them whether it was better use of the water flow through the
wheels, innovations to the looms or the associated machinery to increase production or a
better way to transmit the motive power between them.

They simply tackled the problem that faced them head on and tried any and every
avenue that presented itself until one step led to another and suddenly in front of them
was a solution fabricated in their hands. It is doubtful any course that was followed and
tried appeared a lost cause from the beginning. There was no previous experience to
guide them on their way, just a dogged determination that there had to be a way to solve
the problem and their search was a way to make it work, whatever the solution.

Any past successes were discussed amongst their peers to evaluate the situation
confronting them and decide on the necessary action needed, No outside expert was
consulted (there were none) and the solution to a problem wasn’t put off to take place in
some future development. The afore statement is the authors own conclusion arrived at
after the exhaustive research involved in the writing of this book and the previous four. If
mistakes were made, and they were, it was simply corrected, the solution implemented
and probably noted for a next time.

For example wooden shafts were a constant problem with breakage even after the
oak axles had reached diameters of over two feet. This could be because of the constant
strain on the axle, imperfections in the wood itself or the forever exposure to the water
that fed the wheel and the expanding and contracting of the wood because of the repeated
saturation and drying out.. So it was evident that no matter how strong, how heavy or
how thick it was shaped for the job, wood was not the ultimate answer for the shafting.

If only a small fraction of the material that has been uncovered to illustrate the
iron shafting and gearing had been put into doing likewise to uncover the wooden
counter-parts, we would be awash in historical prints and sketches of the usage. Even
when the wooden parts were uncovered, few could identify their origins or use. The best
we can do is reproduce illustrations and text from material that has survived the ravages
of decades and centuries. The bibliographies of modern research material are heavy with
titles of early trade manuals that millwrights could follow to construct wooden water wheels, some later books excellent replicas of earlier editions. They can be surprisingly detailed with sketches, lists of parts to be made to complete the wheel and more sketches showing the finished wheel and associated shafting and gearing for whatever chore they were built to handle. Locating the books and availability are what present the challenge.

Every reader’s level of interest in the construction of the wooden water wheels, shafting and gearing will vary proportionately with the individual. Rather than bore the disinterested with what to those are senseless subject matter, the author has browsed the titles of manuals, journals and books that appear in the biographies of the research material used in his own exploration. The titles appearing below can all be accessed in the Internet under Google. Some only offer a summery of the information that is contained in the text. If followed by a * the entire text is presented and ** indicate illustrations as well.

The Miller and Millwright, by R. James Abernathey, 1904.

Modern Mechanism, Appleton’s Cyclopedia of Applied Mechanics, 1892.

Notes on Grist Mills and Milling in Pennsylvania, be Henry S. Engart, 1933.**

Old Time Water Wheels of America, by Joseph P. Frizell, 1893.**

The Practical American Millwright and Miller, by David Craik, 1870.

Practical Hints on Mill Building, by James Abernathey, 1880.**

There’ll Always be Water Wheels, by Neil M. Clark, 1955.**

The Young Mill-Wright and Millers Guide, by Oliver Evans, 1795.**

(select title followed by KMODDL from offerings on Google)

American Miller and Millwright’s Assistant, 1851  William Hughes*

The Millwrights Guide, 1830  John Nickolson**

Mysteries of Nature and Art, 1633  John Bate **

Do not let the brevity of this list hold you back from a wealth of information on the construction and the many uses of the water wheel. Simply enter the word mill, waterwheel, turbine, or whatever field your interest lies in to open the doors. And don’t bypass the local library. These three titles are usually available in most and in some instances inform as to the earliest wheels and cover all aspects.

Mill  1983  David Macaulay

Stronger that a Hundred Men  1983  Terry S. Reynolds
Once left behind, wooden construction in the mill regardless of the application is history (no pun included) but there should be enough illustrations and informative text accompanying the available material to present a fairly detailed story of the part that wooden shafts and gears played in the evolution of the early machinery from reliance on wood to wood/iron to finally all iron. (steel eventually) In most early illustrations the gearing plays an intricate part with shafting.

From the waterwheel in the center of the sketch radiate square wooden shafts and a conglomeration of gears in every direction to perform the multiple tasks asked of it.

An excellent portrayal of the wooden square shafting employed in conjunction with the gearing driven by a wheelwater in 1760. Several different operations of the combined mechanical aspects of the mill are depicted supporting each other. Note the rim gearing mortised into the rim of the wheel. This method of transferring the power was very common and served to reduce the strain on axle of turning the massive gearing that would otherwise be mounted on the axle as in the sketch above.
In closing the era of the wooden machinery that produced so well over its time of usage, it is too bad more of the history couldn’t be documented. As mentioned on page 104, even when the remnants of the wooden machinery presents itself, it can go unnoticed for the simple reason that the findings present an alien surrounding to the observer, even a trained one.

The presentation below is the authors favorite as he has been searching for this power train pit from the beginning, over ten years ago, and found it by accident in a folder in the upright files of the National Park Library titled naturally just as it should be, “Boott Mills: Power Train Pit: Miscellany. Who assembled the material is in doubt but the documented text and the sketch that positively identified the purpose of the granite lined hole discovered under the building is provided by David MaCaulay, 1983 with input from the National Park Curator at the time.

When this wheel pit was discovered under the west end the weave room of mill #6 it had many of the self proclaimed authorities on archival research stumped as to what function it served. The question was finally answered by a mill plan from the 1900s provided by then Park Curator Andy Chamberlain and several drawings in David MaCaulay’s book, Mill, (1983). Page 83 begins the coverage identifying and solving the mystery of the granite pit in the ground under the boott mill building #6. Once again the interested reader can gain access to this book at the Center for Lowell History.

Figure 36 that solved the mystery
And here in all of its glory is one of the few photographs available showing actual wooden gearing from a 19th century grist mill mounted on a square wooden shaft. If they hadn’t been salvaged and put on display in the collection of the Mercer Museum of the Bucks County Historical Society, we wouldn’t have this opportunity to view these working pieces. They would probably been lost forever.

Photo by Charles A. Foote  
Courtesy of the Mercer Museum

The correct term for the bucket type gear in the center of the photo mounted on the square shaft marked 4985 is a 23 inch lantern gear. The gear on the right is a 64 inch diameter crown gear. Beside transferring the circular motion from the horizontal shaft leaving the out of sight water wheel, to the vertical shaft rising to the millstone on the floor above, the second and just as important function of the two gears of dissimilar size is to increase the revolutions per minute the motive power is delivering to the millstone, from about 10 rpm leaving the wheel to about 100 rpm at the stone.

The Advent of the Metal Shafting

As the author has harped on before; it is rare that a revolutionary improvement or revelation appears over night or out of the blue. More often it is by trial and error or even utilizing the process or material for a completely foreign use before it is realized that this
item is the answer for a long sought problem, that of a substitution for the wooden mill shafting and the constant headache that it caused.

Iron was not an unknown in the eighteenth century. Neither was its use to strengthen the weakest and most troublesome parts of the wooden water wheels such as gudgeons driven into the axle ends to provide a smoother and better surface for the axle to rotate on and banding on the axle to strengthen it and help hold its shape and to firm the connection between the shrouds and the soal of the wheel. (page 66)

By the time John Smeaton appeared on the scene, iron had already been in limited use. Iron in Briton was available in much larger quantities than in this country where it was treated almost as a precious metal and the successful millwright limited its use in the water wheels and millwork. As far as assigning a descriptive title to Smeaton’s field of work, it is quite apparent from his many various endeavors he was certainly a competent millwright, in which case would also be attributed the skills of a carpenter, machinist, draftsman and maybe even a dab in the foundry.

At any rate whatever his background, he was aware of the advantages of iron over wood to considerable skepticism and early in his career attempted to introduce iron shafts, and in 1755 he designed a cast-iron axle for a windmill. He was evidently quite pleased with the result as we will quote from his Reports, 1:410-11. “I applied them as totally new subjects, and the cry then was, that if the strongest timbers are not able for any great length of time to resist the action of the powers, what must happen to the brittleness of cast iron? It is sufficient to say that not only those very pieces of cast work are still in work, but that the good effect has in the north of England where first applied, drawn then into common use, and I never heard of any one failing”.

As his career progressed, in 1760 he became a consulting engineer (sic) for the Carron Iron Works in Scotland giving him a chance to experiment with iron. So when the oak shaft of a waterwheel fractured at Carron in 1769, Smeaton recommending replacing it with a cast-iron axle. It was not until 1770 or 1771 that his recommendation was followed but success here led him to extend the innovation to other mills. But failures of the iron shafts did occur intermittently because of the brittleness of the cast-iron he was working with. Regardless of maybe a less than perfect start, the iron shaft was a given and couldn’t progress any farther any faster because that would depend on the advance of the technology of casting the iron, But by modifying the design of the axle “they came into very general use in the course of twenty years.”

Dictated by the laws of natural progression, iron shafting followed. As better methods of casting, and then machining the shafting were developed, the diameter of the shafts employed throughout the mills was reduced, resulting in a weight savings and thus an improvement in the available shaft speed with less friction in the hangers.

The heavy, cumbersome and slow wrought iron shafting with its thick dimensions gave way rapidly to a better casting and machined finished product. Machining cost money and the prevailing thinking was keep the line moving with as little expense as possible. It would take time but it was eventually quite obvious that it was the transmission system within the mill that was the deciding factor in the efficiency of the
entire operation. Competition that was willing to adapt thrust upon the rest of the cotton industry the necessity of lighter shaft weight that could allow for a faster shaft speed, and therefore higher efficiency of the transmission machinery throughout the mill with the end result being more production output from each loom. And this increase in production was from the same prime mover. That translated into more profit for each mill and that was the prime objective of the investors from the beginning.

But a massive transmission system was required to satisfy the requirements of a single mode of producing motive power such as the output of several water wheels ganged on a common shaft. And all that could satisfy this demand was shafting that could stand up to the performance expected of it and drive the power through the system with shear power. The inch and a quarter and two inch shafting that carried the motive power throughout the mill didn’t necessarily retain that slim size all the way back to the prime mover. And the photograph below reeks of an over abundance of just that power leaving the turbine and flywheel.

![Shafting Photograph](attachment:image)

Lowell National Historic Park  Museum Collection  LOWE 8295

Shafting that received power directly from the water wheels such as in the photo above would necessarily run into large sizes in the case of a large mill. Sizes of main line shafting up to ten inches in diameter were not unusual, and could require special construction of that part of the mill buildings and foundations which had to support such heavy weights-. The previous well put comment is in part from page140 (a footnote) in Samuel B. Lincoln’s 1960 *Lockwood Greene*.\(^{117}\)

The shafting wasn’t a stand alone component but one of many coordinated parts that comprised what was referred to as “a machine to transmit motion...most frequently
the largest in the establishment” as described by Coleman Sellers in his *Transmission of Motion, p.233*. He realized that the key was found in the manufacture of millwork with much of the same accuracy and precision required as the motor and the machinery driven.

So over time, it was finally realized that “A factory’s millwork, in short, was in the aggregate a great machine itself in the production and maintenance of which care and accuracy were demanded”\(^{118}\). The statement went on to include the auxiliary equipment such as the hangers, couplings and especially the pulleys to be built with the same excellent machining and care. This improvement also reduced the weight of the pulleys to correspond to the reduced weight of the shafting and wheels made of half the previous diameters.

This illustration coupled with the sketch shown on page 78 pretty much exemplify the role of the team of the shafting and gearing in transmitting the motive power throughout the mill to power the machinery. In the schematic presentation to the right the shafting is leaving the water wheel pit in a horizontal plane and transferring the power from the revolving shaft through the gearing identified as BB to the vertical shaft that rises through each floor. The gear assembly identified as CC mounted close to each ceiling transfers the motive power to the horizontal shaft that completes the power transfer from wheel to machine.

---

*Treatise on Mills and Millwork*  
William Fairbairn  1863

Adapting Iron Technology to the Gearing

The most common perception of the transfer of power from the wheel to the machine is always presented as a direct drive from the former to the later. The impression seems to be promulgated by the historians themselves, maybe unwittingly, but never the less this scene is prevalent in both text and accompanying illustrations, including those in this book. What is the author trying to say, that the records are wrong? No, but at least infer that the revolving action of the shafts, gears, belts or whatever have you transmitting the power can be traveling long distances, and at changing angles,
sometimes even leaving the premises the power originated at to provide the power to other buildings at the site.

The smooth spinning shaft revolving with its effective load of energy and well mounted or supported can probably carry on the function it was designed for great distances if need be. That in itself would most likely be termed an engineering feat, but to what advantage would it serve. For an example, would a thousand foot long shaft simply to supply power to one machine at its terminus be considered feasible? How about a mill one thousand feet long and ten feet wide with all of the machines mounted in a straight line? Both examples are ridiculous.

To utilize the shaft and the power it is transmitting to any useful extent, either gearing or belting has to be introduced. Either or both can provide the flexibility of connection or of alternating direction that is necessary for delivering the power locked into the straight spinning shaft from the prime mover that was intended when the first water poured through the wheel. But from the inception of gears and gear trains into the power transmission system, problems multiplied simply because of the nature of the beast. The millwright couldn’t live without the gears but he had a hell of a job living with them at the same time.

Incorporating iron into the fabrication of gears was a very much more complicated situation than fabricating a shaft. There were many forms of the finished gears that had to mesh exactly with other gears in the power train. True, much had been learned and carried over as the science of power transmission advanced from the days of the all wooden gear trains because of millwrights like Smeaton (and there were many, primarily from European countries) but it was possible for new innovations in industry to outrun parallel technology in the field the innovations were advancing into, and metal gearing was one of them.

Manufacturing wooden gearing was about as crude an operation as could be imagined but at least the process was easily adaptable and mistakes could be corrected with a saw, chisel and a bit and brace. Casting the required iron gears was a different story but there was no refuting that iron was the future of industrialization and those who failed to grasp the concept would be lost eventually in the advancing progress.

And with new iron gearing leading the way, the design and fabrication of millwork were transferred from the millwright and mill carpenter to pattern-makers foundry-men and machinest. The later may have been no better equipped through know how and/or experience than the former but the skills involved had no precedence among any of the fledging metal working tradesmen anyway so all of the work was virgin territory so to speak. It’s pretty hard to be held responsible for making a lasting mistake of any consequences if there’s none to correct it.

In reality, credit for advancement in gear design was attributed to European engineering but nobody ever accused American millwrights of rushing to that alter to incorporate the technology in its British form to their own use. The fact was in some cases the Americans maybe have even had the upper hand on the use of the iron gearing. It always sounds a little strange when reading the history of the innovations in shafting
and gearing that so many times credit is given to the men who worked the old mills, the flour, grist, saw and a dozen other types that where the backbone of the colonial communities. In Evans’ *Miller’s Guide* of 1795 it states in part, “In the United States some cast iron gear wheels were use in flour mills before 1800, and by 1820 cast iron bevel wheels had generally replaced the clumsy crown wheels used with lantern wheels... “In a later edition of the same millwright handbook a drawing of another mill of 1826 (fig. 110) depicted below is described as having a well advanced iron millwork.119

*The Young Millwright and Miller 1850 ed.*

Here the wooden shafting and cogwheels were replaced by cast iron shafts and wheelwork.

Justification for any positive comments as to the quality of the typical iron millwork prevalent in early nineteenth century may have to be made tongue in cheek if one takes stock in eye witness reports. There are many sources attributed to at least the intent of the quote below but using an article from *Scientific American* edition of March, 1866 should do nicely. “There were frequent comments in technical journals in the late 1860s upon gears that rattled and jarred often producing an almost deafening clatter as the teeth ground upon each other. The principals of gear cutting were ignored, declared one editor, and for every gear running almost noiselessly at high speeds there was a multitude so noisy as to prevent ordinary conversation nearby.”
The cause for this crescendo was simple. Gear cutting machinery when available was expensive. It was more expedient to mount the cast iron gears just as they came out of the cast with maybe a little hand trimming. It was only too commonly assumed that gear teeth would wear into shape by using no lubricant, by adding emery to the lubricant in a kind of compound, or by giving an uneven ratio to the number of teeth in the driving and the driven gear wheels. As late as 1876 we are told that the teeth of gearing “are too often merely smoothed with a file, or even left as they come from the foundry.”

Relief was obtained somewhat in the larger establishments by the following method, believe it or not. One widely adopted practice was giving one of a pair of matching gear wheels wooden cogs in place of iron teeth in what was known from the manner of their insertion as the mortised wheel which gave smoother and quieter running. The alternative was replacing the gearing with belting.

There were many applications where only shafting and gearing were the practical answer for the transmission of the motive power and there are many instances where another building on site was served from a prime mover located in another building or at a great distance where belting would not be feasible. We will stick to Lowell mills to provide at least isolated examples. Enough cases of remote prime movers are documented, although we can be sure not all, to at least make the concept of the installation and operation understandable.

Almost the entire explanatory format of the remote power transmission will be taken up by sketches, drawings and illustrations accompanying the text. It’s a given that some sort of shafting is almost consistent in each and every instance of power transmission if for no other purpose except to make the rotary motion from the prime mover available, whether the source be a vertical water wheel or a turbine. From that point, think of the gearing as a square steering wheel and the belting as a curved substitute to control the direction. We’re all talking about getting the motive power from point ‘A’ to point ‘B’, and we’ll give it our best shot.

One great machine. That’s exactly the way a mill and its associated machinery have to be described. The noises and vibrations from within the walls are no more than the life of the machine being spent on its task. And except for the mechanic who maintains it, even the individual machine tenders can’t possibly conceive of its complexity. The investor, and the inventor, and the builder; the results of many came together to employ the energy harnessed within the walls of the structure for each others benefit each in his own way, and it worked.

Those Shafts and Gears just won’t go Away

In some cases the transmission of the motive power could realistically only be accomplished through the use of the shafting and gearing, and it was done without a big explanation to future generations, meaning you, the reader. The millwright had no way of knowing that someday the work would be scrutinized by nosey third parties and that he would have to offer justification for his work.

A few examples that are documented, all located in Lowell, Massachusetts...
As late as 1878 the Picker Building (No.2) of the Belvidere Manufacturing Company still received power via a shaft from the wheel located in the basement of the separate main building. It doesn’t specify if shaft is in an underground tunnel. This information is from the Barlow Insurance Survey done May 24, 1878.

The Massachusetts Mills had its own powerhouse with the wheels receiving water from the Eastern canal and emptying into the Concord and Merrimack Rivers. The end of the Concord tailraces can be viewed from the bridge over the river on East Merrimack Street. The power drive shaft left the turbine wheels and encircled the inside perimeter of the connected mill buildings and supplied the motive power. The layout of the shafting is presented on page 76 of *Hidden Waterways of the Lowell Canal System* another book in this series by the author. It would seem this system had to remain operational until the mills switched over to hydroelectric generators and the machinery converted to run by electric motors in order to maintain production. The records of the PL&C stored at the Center of Lowell History yielded this sketch below showing two of the four turbines ganged together and driving the power shaft in the Massachusetts Mills. The shafting appears to be floor mounted with gearing allowing for power train take offs. This drawing is only a schematic representation and not the actual path of the shafts.

PL&C microfilm roll #3. Drawing identified as being No.F1 filed on shelf 113.

The Boott mill complex had at least one and possibly two shafts in underground tunnels. This report is taken from a copy of an inventory of improvements and machinery at the site made in 1873 and indicates at least two cases where separate buildings were powered from wheels in another location.

Under the heading, No.1 & 2 mills, it lists three turbines. These wheels are in a connector between those two buildings and operate the machinery in both. The wheels are fed from the Western canal and empty into the Merrimack River. An extended note in
the report states the same motive power will operate the proposed new machinery in No. 6 mill. Under the heading No. 3 & 4 mills also share the output of three turbines mounted in a connector between the two buildings with the same mill power source as mills No.1 & 2. A separate note continues that these wheels also drive the machinery in the Picker mill and the Cloth room. (all six turbines are still functioning as hydroelectric units)

![Floor plans of No. 6 mill with power shafts and pulley arrangements.](image)

The dotted line indicates the power shaft entering the wheel pit horizontally under the first floor of mill building No.6. From the pit the will rise vertically shaft to the second floor.

The second floor of mill No.6 shows a pulley arrangement in line with the power shaft entering the wheel pit under mill building No.6.

Both of these floor plans by the consulting firm of Lockwood and Green contracted by Boott Mills to modernize their operation in 1906.

**Courtesy Lowell National Historic Park**

The text and illustration on page 107 defines beautifully the power drive shaft entering the pit from the left and rising to the upper floors through beveled gears.

The Lawrence Manufacturing Company will serve as the last example. This information is from a report on the “Water Power Possibly Available for Purchase in Lowell” dated October, 1927. Each corporation still doing business at the time and utilizing hydroelectric power generated by the corporation is listed along with the amount of kilowatts generated.
The only exception is the Lawrence Manufacturing Company that is listed alone under the heading “Mechanical Drive From Water Power”, and is rated at 1800 H.P. instead of a kilowatt output. On page three there is a paragraph discussing the ramifications of the Lawrence mills selling their waterpower. It states clearly that this development is entirely mechanical drive and has no hydroelectric apparatus and the buyer would have to install it or divert the water itself to make use of the mill powers.

In 1835 the Lawrence mills site totaled four buildings. Each had its own vertical water wheels in the basement that powered the machinery in that building. The company’s cost to the PL&C for the construction and equipping of the mills was $212,515.91. Not one mention of a belt or pulley in the account book.

There isn’t much to the drawing of the Lawrence Mill Complex above. Each mill had a headrace feeding water to the wheel and a tailrace to remove it as indicated by the dotted lines. Not so the overcrowded site scene of the same yard to the left. The major difference beside the mill buildings being built on every available piece of real estate is 75 years between the sketches.

The Leather Belt Takes Over

On the previous page several options that were put to use to if not stop entirely at least reduce the racket of the meshing gears to tolerable levels but one was left out of the solution. The practice of replacing the gear trains entirely by the substitution of belts in
the place of them, and this innovation was to have very wide applications in the overall mill industry. Belting was first viewed with great apprehension and in Europe it was referred to as the “American Way”. Within a relatively short period, it was an accepted method of replacing the gear trains for power transmission in all industry.

Two factors played a large part in the continued use of the gearing with its noise, vibrations and the friction induced into the power train reducing the efficiency of the entire system. It worked and it was comparatively cheap in its cast form as it left the foundry. The sole function of the gearing was turning corners and changing speed ratios. As demonstrated in Lowell (Appleton Mills for example), pulleys and belting could do the job not just as well but better in many cases. This is an excellent place to offer up the sketch below introducing the entire replacement of the iron/steel shaft and gear transmission system in the power drive with an all belt approach.

![Sketch: The Lawrence Manufacturing Powerhouse and Big Pulley Wheel](image)

*The Lawrence Manufacturing Powerhouse and Big Pulley Wheel*
Reproduced from sketch by David Redding, Lowell National Historic Park
The pronounce lines on either side of the angled belt are an enclosure surrounding and protecting the belt over a driveway between buildings.

Why, one may ask, with the excellent results of the proven system of belts and pulleys to replace gearing in power transmission wasn’t that alternative adopted at once. Why any hesitation, why keep battling all that cast iron, the weight, the noise, the resultant friction drag on the entire power output. As usual, there is always that little lone fly in the ointment and this perfect solution was no different.
The explanation is provided by excerpts from the writings of Zachariah Allen as reported in Terry S. Reynold’s, *Stronger than a Hundred Men*. Many early attempts to introduce belt drives had failed because of the low belting speeds adopted and the inadequate supporting components. “Pulleys had not been made sufficiently light and well balanced for anyone to adventure to use them with the high speeds required for leather belts to operate advantageously,” Allen pointed out. “With the slow speeds, it was necessary to strain the belts so tightly on the pulleys, to produce sufficient adhesion, without slipping around on the smooth surfaces that the lacings and texture of the leather yielded; and so frequently repairs were required, that the superintendents of mills nearly all abandoned the use of them for transmitting the power from the motors to the mill shafting.”  

The concept of belting acting as the power drive was revolutionary to say the least, and it was resisted to say the most. It happened in the case of the turbine vs. the waterwheel; in the conversion of iron components to replace the wooden; and almost every innovation in every field in every industry no doubt. As informed by Allen in the passage above shaft speed was one of the biggest detriments to the successful inclusion of belting to transmit power. Increased shaft speeds due to better steel and finer machining of the shafts and pulleys would solve that problem. The opposition stuck with the tried and true shafts and gears.

The absence of the gear-meshing and grinding, and the resulting comparative quiet in a mill that changed over from shafting-gearing transmission to belting must have been deafening and welcomed by the operators. But the millwrights, and the owners, and the investors saw appreciable gains with the conversion also. The same prime mover was spinning more spindles which translated into more yards of cotton cloth that translated into more profits. A win-win situation.

Why? Number one, as brought out before, flexibility was the byword. Belts weren’t apt to misalign as gears were from buildings settling or wooden supports distorting for whatever reason. Belt drives represented a fraction of the weight of the cost of wheelwork and shafting of equivalent capacity. In 1848, to carry sixty horsepower thirty six feet from the prim mover to the third story by cast iron vertical shafting required more than four tons of metal whereas six hundred pounds of belting would accomplish the same purpose. In a large British mill the upright shafting and gearing actually presented a structural problem to the building. The drive shaft and the gear wheels weighed twelve tons.

Enough is enough and the large advantages of belting over gearwheels should be self-evident. Shafting can never completely be eliminated until all motive power is by electrical transmission and the machines all motorized but with modern machining, supports and professional installation, it represents a tremendous asset to the power transmission system, in face one that cannot be done without,

The Pulley kept the Belts Turning

The explanatory text explaining the shafting, gearing and belting is just about exhausted. Correction...it is exhausted. The belting won out. But there were several
components that operated on the fringe of the power train that added greatly to the performance of the power train, in fact could be described as crucial. Again, there can be much overlapping in some cases but that is the big advantages of photos, sketches and illustrations. Even if the author isn’t sure of the role of the mechanism and he’s trying to wing it through a description, it is usually self evident to the reader by this stage.

The pulley and its role in the belted power train is one that was overlooked as simply an object that the leather belt turned on. No importance in the slightest was given to the success it could and would play in the system if just a little care were fostered in its installation. The oversight of the “just put anything on the shaft that turns” attitude contributed to the rejection of the belts in the transmission role of the power train until more care was paid attention to the machining and balancing of the pulley. Once this was realized and the pulley treated as a main component of the system, the power train was belted to this day. All of this was covered on pages 111-113 of this chapter.

The photo above is enough to bring tears to the eyes of a mill rat. An entire life could have been spent amongst the noise and clatter of the pulleys, belts and shafts powering the machines. But they loved it. It was a weekly paycheck.

Man and machine and water power made a great team. Together they built a textile empire in Lowell, Massachusetts.
This sketch serves to illustrate all of the ingredients of the successful mix of machinery coming together to evolve as a working “bale to bolt” cotton mill. The penstock in the lower right feeding water into the encased turbine wheel to turn the shaft and thus propel the flywheel in the circular motion. From this action, the belting supplies the motive power to the machinery on each floor.

The Science of Modern Cotton Spinning  Evan Leigh  1882

Lowell National Historic Park
Museum Collection  LOWE 6739
To provide closure to many thousands of words and illustrations, there is the one single particular item that plays out one of the most important role in the power chain. That of the completely ignored and overlooked flywheel. It is commonly used on all rotary producing equipment and serves to “regulate the speed and uniformity of the motion of the machine to which it is attached.” (Webster)

By its very use a heavily weighted flywheel will usually do the better job of power regulation. In the case of a belted power drive, the belt can be driven directly from the flywheel as shown on pages 100 and 120 for example. On direct drives, the flywheel is mounted after the power source on the shaft or axle and ahead of the load it is to regulate. All who have delved into an automobile engine will already be familiar with this device and its role in regulating the erratic output of the cylinders. Once the flywheel is revolving, it will assume a constant uniform momentum that is transferred constantly to the load. Its heavy weight will tend to absorb the irregularities in the prime source output and therefore erase the jerks and surges that are prevalent in any mechanical power output to some extent.

Where to bring the flywheel into the power train picture was handled by just letting it happen on its own. Introducing the wheel while discussing the shaft would not have fit because the flywheel was not a necessity on the output of the vertical water wheel. The water wheels doubled as the flywheel because of its size and weight. But it is necessary on the output shaft of the turbine. It is truly amazing to observe the 13 1/2 foot, eight ton flywheel at the Wannalancet wrapped in the huge oversized leather belt poised to power the looms to weave the world.

Lowell National Historical Park
Exhibit   Wannalancet Mills
The photograph below is of the Large Pulley Flywheel on the Hamilton Mills engine. This wheel weighed in at 40 ton.

Lowell National Historic Park
Museum Collection   LOWE 6664

Another mechanical component in the power train, and usually not even given a second thought too was an item known as the governor. There are several types and the mounting and construction of each different type are enough so even one familiar with their role in the speed control of the prime mover that the governor was regulating would not recognize accept for its position on either the wheel or shaft. And neither would the author so an illustration will have to suffice.

This is probably the simplest and easily the most recognized type of governor. The desired speed of the machine is regulated by the position of the two steel balls that will move in or out by centrifical force and through linkage act on whatever speed control is on the machine.
In the photo of the Hamilton mill governor above, sharp eyes can pick out the governor mounted on the machine at the end of the flywheel and framed between two windows toward the end of the room. And if the reader thinks to himself, so why is a little contraption like that so important, what’s a few RPMs one way or the other, just check out the following two photographs.

Title of this photograph is “Wreck at Boott Mills Caused by Bursting Flywheel”. The envelope that contained the photo was labeled “Eastern Canal Mass Cotton (sic) Mills 1910.”
The misspelling of ‘Cotton’ is obvious but why the mill is identified as ‘Mass Mill’ is mystifying assuming Mass was the abbreviation for Massachusetts. That mill complex also bordered on the Eastern Canal but Bridge Street separates the two. Even the article in the Lowell Sun reporting on accident identifies the site as the Boott and the collapsed wall as paralleling the River. (author’s note – Merrimack River?)

This photo identifies the interior damage as the resulting effect of the incident of the exploding flywheel exactly the same as above, word for word. The Sun did not print a picture with the article but it did report that the cause was the governor. Accidents happen but that there were no deaths is unbelievable.
For the better or worse, the entire scope of the power transmission from prime mover to the cotton looms in the mills has been summarized in these past pages, hopefully. The amount of material that would have to be covered if every single aspect of the power transmission were to be examined in detail would result in a tome that would necessitate wheels to move it and years to read through.

And it follows that some very pertinent information has been unavoidably overlooked in order to condense the material into somewhat of an interesting and informative format. And the rope drum presented here is a finale to cover up one of my overlookings. Belting probably would have been the closest classification to assign the role of the rope (or steel cable), but that certainly wouldn’t allow for a sensible description of its function either.

The rope drum runs from left center to the center with grooves for the rope to ride in cut on its surface. This is what is known as the continuous wrap system with one turn of the rope passing over the single pulley in the forefront to maintain the required tension on all of the turns\(^{128}\). To the right appears to be the power drive pulley with the main belt. (The glare is a photo defect on the film.)

This is the only rope drive installation brought to the author’s attention and it is identified as “Lawrence Sect. of T.& S. Mills-/Rope Drive Connecting Turbine With/Main Shafting” There could have been others but with the literally thousands of photos and reams of text poured over in the records, no other mention has surfaced. True,
many records of the power transmission of the Lawrence mills aren’t available but with at least six previous constructed mills and their power systems, why at this point in the power chain development did the Lawrence surface with this hybrid?

The steam engine was seen as the killer of the water driven turbine in the nineteenth century but at this stage, the power chain was still direct drive. That is no matter whether coal or water powered the wheel, the motive power was still transmitted via shafts, gearing and belting from the prime mover to the machine. With the introduction of the electric motor where each machine was individually powered, the steam as a fuel was delegated to smaller more local applications to produce the electric power. Cost was still the prime consideration. The world was to be fueled by the enormous potential locked in waterpower poring down the liquid river highways contained in the rivers and the overflow from larger bodies of water, natural or manmade behind dams

And so the curtain was raised on the hydroelectric system that is in use today and certainly will be for the foreseeable future. So whenever you chance to observe that electric motor whirring away hidden in the bowels of some piece of machinery, just give a thought as to what went before it.

Every page is meant to be a monument to the ingenuity of those that came before.
Bibliography

The Water Powered Machinery that Drove King Cotton
Chapter One
A look back at East Chelmsford

- The First Step
1. Proprietors of the Locks and Canals on Merrimack River. Directors Records Vol. #1 1792-1812 Microfilm Center for Lowell History
2. Illustrated History of Lowell and vicinity, Massachusetts Done by Divers Hands Courier Citizen Publishers 1897 pp. 98
3. The Golden Age Joseph W. Lipchitz pp. 81

- Examining the Route of the Canal
4.
5. Finally the Revelation
5. Cotton was King edited by Arthur L. Eno 1976 pp. 72
6. History of Lowell Chares Cowely 1868 pp. 36
7. “Sketch of Ezra Worthern” Contributions Vol. #3 read by W.R.Bagnall, 1883 pp. 39
8. Canals and Industry No page or author from National Park Library upright files paragraph culled from an un-number page under heading of East Chelmsford pp. 81
9. The Golden Age
10. ibid.
11. ibid.
13. ibid.

- The Power Canals and That Damn Hill
14. Cultural Resources Inventory Vol. # Lowell Canal System From inventory forms at back no page #
15. Lowell Canal System Patrick Malone mentions year round low water because of ice pp. 14
16. Letter from P.T.Jackson to the PL&C September 13, 1839 Taken from the Northern/Pawtucket Canals, final report, 1980 pp. 110

- Genius or the result of Dogged Determination
17. “Lowell”- The Lowell Canal District Report of the Lowell Historic Canal District to the 95th Congress of the USA (at Mogan) pp. 98
18. The Lower Merrimack River Valley edited by Peter M. Malloy pp. 79
20. ibid.

Chapter Two
Nature, Gravity and Paperwork
21. Cotton was King pp. 76-78
22. 5’ is stated in a fact sheet on Pawtucket Dam  D.J.Gilday  1985  No Page numbers

23. 2’ and 3’ in ‘Waterpower’ by Louis Hunter  pp. 255

24. Cotton was King  pp. 76

25. -The Mechanics of the Millpower

26. Waterpower  Louis C. Hunter  pp. 210

27. ibid.

28. Reference in Waterpower  s/s 15  pp. 213

29. Sketches of manufacturing establishments3:20 72

30. and legal opinions of Payton Tucker (never could find record)

31. Waterpower  pp. 212

32. U.S. Census Office, 1880  Report of Waterpower in the U.S.  No page number

33. Waterpower  pp. 270

34. J.B.Francis to Abbott Lawrence  July 2, 1859  pp. 213

35. adoption of uniform contract for all leases in 1853  Taken from Waterpower  s/s 17

36. From book titled “Lowell Corporation” at Center for Lowell History  pp. 6

37. Reproduction of “Form of Lease of Water at Lowell”  pp. 5

38. ibid.

39. Waterpower

-Industrial Design and Power Transmission  P. Carroll  pp. 270

40. Contained in folder in upright files at National Park Library  No page number.

41. Chapter Three

“I Have Spent More Money Underground”...

-Foot prints of History

-Rules and Regulations for making Fortune

-The Headgates of Wealth

42. From final report of the Peabody Museum, 1980, Illustration, Fig. 18  pp. 57

43. “Rack at head of new Guard Locks Flume”, J. B. Francis, 1847  Text on trash racks listed in index of “Waterpower”  pp. 602

44. History of the Vertical Waterwheel  Terry C. Reynolds  pp. 296

45. Sub-title “Stronger that a Hundred men”

46. Suffolk Mills information file  National Park Library  upright files  “Mill Yard Development” by D. Maloney  1994  No page number

47. -A View of the Source of the Water Power

48. Waterpower  pp. 212

49. PL&C Directors record  Vol. 2  January 17, 1822  Act of Incorporation of PL&C  Vol 1  1st page of microfilm records  pp. 266

132
Plan of the Land South side of the Pawtucket Canal belonging to Merrimack Manufacturing Company, Chelmsford, January, 1824

First mention of building canal in PL&C records, December 26, 1821

Cultural Resources Inventory, Vol. Industrial Canals

Chapter-Report to the Directors of the Improvements that may be made in the means of distributing the water to the several companies in Lowell.

- The shape of the Underground Raceways
- Just Another raceway – The Penstock
- The Role of the forebay
- The Wheelpit and its function

Chapter Four
The Waterwheel

-Was to cast a long shadow in Lowell

Lowell City Directory in Advertisers/Users Contents
Random checking 1892
Lowell Wind Mill 1906
Bennett Bros. Co.
Davis Williams
all gone by 1932

The rise of the waterwheel
A History of Technology, Industrial Revolution, 1750-1850
1750 to 1850, Vol. IV
Watermills, 1500-1850, A. Stower, 1958

-The tub wheel
- The undershot wheel
- The overshot wheel

Waterpower

“The Epic of Industry” Malcolm Keir, 1926
Fig. 115 The Overshot Wheel of Oliver Evans’ day

-The advent of the Breast Wheel
The Young Millwright and Millers Guide, Oliver Evans, 1795
From “Harnessing the Forces of Nature”

“Stronger than a hundred Men” the iron water wheel, 1780-1800
Terry S. Reynolds

Compiled by Al Lorenzo
Chapter Five
The Construction of the Vertical Water Wheel
-A short course on the Birth of the Power
58. “Surveying” Anthony Fitzherbert 1539 pp. 93
59. From a book written in German by Johnn Beyer 1735
   Appeared as a reference in “Stronger than a Hundred Men” pp. 173
60. History of Lowell Charles Cowley 1868 pp. 34
61. Handbook for the Visitors to Lowell
   Statistics of Lowell Manufacturing 1850 no page #
-The millwright, the master mechanic
62. “A General Description of All Trades” 1747
   Appeared as a Reference in ‘Stronger than a Hundred Men.’
   s/s 189 pp. 375
63. Treatise on Mills and Millwork William Fairburn 1863-64
   Reference in ‘Stronger than a Hundred’ s/s 190 pp. 375
64. ibid.
-A single step preempts even a long journey
64. ibid.
65. The American Cotton Spinner R.H.Baird 1851
   Chapter - Remarks on Water Wheels pp. 43
66. HAER Report No. MA-1
   Appears in “Lowell Canal System by Patrick Malone
   Appeared as a Reference in Water Power
   Other references at same source page in book
-O.K. Millwright-do your stuff
68. American Millwright Craik
   Reference in ‘Stronger than a Hundred’ p.158 s/s134.
69. Millwrighting James F. Hobart 1909
   Reference in ‘Stronger than a Hundred’ p.168 s/s136
70. Scientific American January,1858
   From Water Power p.89 s/s 36
71. Water Power Chapter ‘A technology of Wood’ pp. 88
-Laying Out the Wheel
72. Stronger than a Hundred Men 1983 Table 3-5 pp. 164
73. ibid. “ 3-4 pp. 159
74. ibid.

Chapter Six
The Iron Water Wheel
-Goodbye nails – Hello forge
75. Scientific American January 16, 1858 no page number.
76. A History of Technology vol.1 Industrial Revolution pp. 208
77. Water Power (folder upright files, NPL) David Redding 1985 pp. 9
78. The American Cotton Spinner heading of article-Master Wheel pp. 44
79. Waterpower pp. 458
Chapter Seven
The Birth of the Turbine

-Every Journey begins with a Single Step
-The Turbine Water Wheel—How it all began

89. Untitled article found in the NPS upright files—folder marked “Waterpower: Turbines: Miscellany” No page numbers.

90. Waterpower vol.#1 Louis C. Hunter Chapter, Hydraulic Turbine sub-title on “Reaction Wheel” pp. 299

91. “The Mechanical Engineer” Thurston
He states on pages that his account follows that of Francis’ “Lowell Hydraulic Experiments” closely. (from Waterpower, page332)

92. ibid.
93. ibid.


95. Waterpower pp. 331

96. “A Primer on Waterpower” pp. 50

97. ibid.


-Scientific principals take over

99. Waterpower Louis C. Hunter s/s39 & s/s40 pp. 358-59

100. Notes from “Rule of Thumb to Scientific Engineering”: SUNY at Stony Brook 1992 NPL folder Francis, Miscellany pp. 1

101. From Bolder (Hoover) Dam Wikipedia Encyclopedia file from Wikimedia Commons on google pp. 10,11

102. Ibid.
103. ibid.

104. Waterpower Chapter, ”The Hydraulic Turbine” pp. 341

105. Found in NPL folder James B. Francis: Miscellany Untitled two page tract D.A.B. written top margin

106. “Random notes, Lowell Turbines and James B. Francis” 1996 pp. 5 by Jim Rosmond folder NPL, James B. Francis: Miscellany

107. ibid.
Chapter Eight
Transmitting the Mill Power

- The Mechanical Ingredients
- The Saco-Lowell Shops  George S. Gibbs  1950  pp. 29
  also footnote on page 745
- Practical Essay an Millwork and Other Machinery  1841  Robertson Buchanen  pp. 1

-A Little Look Backward
- The Advent of Metal Shafting
- “Report” John Smeaton  pp. 288
  ibid.
- Lockwood and Green=History of an Engineering Business, Waterpower  pp. 140,141

-Adapting Iron Technology to Gearing
- The Young Mill-Wright and Millers Guide  Oliver Evans  1834 edition  footnote on page  pp. 373
- Scientific American  March 31, 1866  Practical Mechanic and Engineer 1868  footnote  pp. 209
  and other references (from Waterpower, page 455)

Science of Mechanics  Zachariah Alllen  pp. 254-260
  also many other references (from Waterpower, page 433)
  ibid. " " " " " " " " " " " " " " " " " " " 455

-Those Shafts and Gears just won’t go away
- The Leather Belt Takes Over
- From Allen’s “Transmission of Power”  pp. 20
- Economy of Power in Cotton Factories  W. Montgomery  Scientific American  6 April 1848  pp. 229
- Science of Modern Cotton Spinning  by Leigh  Chapter #1  footnote on page
- Suffolk Mills Tour Instructions (for Rangers)  Folder at National Park Library marked “Suffolk Mills:Miscellany
- Accompanies photo LOWE 6664  LNHP-Museum Collection
- “Shafting, Belting, Governors  Hubert E. Collins  1908  pp. 108
  Part of the ‘Power Plant Library’ by MacGraw-Hill
9. Chelmsford before the construction of the Pawtucket Canal. From upright files at National Park Library Historic Resources Cultural Resources Inventory.

    Lowell National Historic Park.


15. Copied from map in “The Lower Merrimack River Valley.” pp. 70 Sponsors by Merrimack Valley Textile Museum. HAER of the National Park Service.


26. From the “Epic of Industry” Malcolm Keir pp. 49 In folder at upright files, National Park Library titled Waterpower (United States): History: Miscellany

30. Photo Collection of Janet Pohl: Hamilton Canal:

32. Top Photo Journal of Lowell canals by author
32. Bottom Sub-title of material “Stronger than a Hundred Men” pp. 283

33. Wannalancet Power Train

36. Pawtucket Canal circa.1897 Addendum Box ID# BB

38. Top Photo Journal by author
38. Bottom Photo Collection of Janet Pohl

39. Both Pictures from Photo Journal (this is a collection of photographs of the Lowell canals by author)

40. Photo Collection of Janet Pohl: Lower Pawtucket Canal

42. Both photos by author, not part of Photo Journal.

43. by author not part of Photo Journal-computer file #2008-08-05 200.

45. by author Top “ “ “ “ “ “ “ or computer file


46. Bottom Photo Collection of Janet Pohl

50. Top The source of the credit for both of these photos is

50. Bottom confusing the way they are presented in the book, “Water Power” by Louis C. Hunter pp. 78

51. “Capturing Water’s Power” from file folder at National Park Library titled “Water Power

52. Young Mill-wright and Millers Guide Oliver Evans 1795 From “Harnessing the Forces of Nature” Fig.116 pp. 49

54. Waterpower Louis C. Hunter Chapter 2

56. “Stronger than a Hundred Men” 1750-1850 Terry S. Reynolds (National Park Library upright files) pp. 283
59. “There’ll Always be Water Wheels” Neil M. Clark 1955 pp. 1
   Pulled up from the Google computer site.
61. From the authors Canal Photo Journal.
   Section detailing construction of the Merrimack Canal.
62. “Stronger than a Hundred Men” Chapter Five, “Change”. pp. 270
63. Lowell National Historic Park, Museum Collection-LOWE11597
66. The World of Wooden Bobbins image #35 pp. 12
   Published by; the Discovery Collection, Somerdale, NJ.
71. “Stronger than a Hundred Men” s/s 3-18 pp. 160
71. ibid. s/s 3-19 " "
73. ibid. Chapter Five, “Change” pp. 285
   Illustration describes an overshot or pitchback wheel
74. “Stronger than a Hundred Men” pp. 301
76. ibid. William Fairburn’s design for ventilated buckets. pp. 300
77. History of the Fitz Waterwheel Company.
   http://www.angelfire.com/journal/pondlilymill/overshoot.html
78. “Stronger than a Hundred Men” pp. 293
81. ibid. pp. 313
   It seems from the notation under the chart, “Source” that
   the original chart was published in ‘International Symposium
82. Top illustration “Waterpower.” pp. 434
82. Bottom illustration “Waterpower: History of Industrial Power
   Developed and Used at the Tremont and
   Suffolk Mills. 1831-1940 Figure 9
   by David Redding 1985.
88. A Primer on Waterpower Robert A. Howard pp. 44
92. ibid. pp. 52
94. Top--------Folder at National Park Library
   Waterpower: A History of Industrial Power.
   Tremont/Suffolk Mills 1831-1940
   By David Redding 1985 written top of page-fig.30
94. Bottom------PL&C collection at Center for Lowell History #M-288
95. Preliminary Report on the Development of the Existing
   Hydroelectric Capacity at Lowell, Mass. No page#
   Folder NPL – Waterpower:Lowell:Miscellany
96. “Boulder Dam” on Google Whole file including photos of
   Intake towers and a generator room 1941. Photo of Dam pp. 1
97. Top--------PL&C collection at Center of Lowell History #241
97. Bottom---- " " " " " " " " #M-80
   Waterpower in Lowell Patrick M. Malone 2009 pp. 106
104. Suffolk Mill Turbine Exhibit Collection of LNHP
   Water Power Transmission from Turbine to Loom.
105. Line shafts and belting at the Amoskeag Mills in Manchester, NH
Courtesy of Smithsonian Institute (WP?) pp. 479
107. Line shafting hardware Ad in the American Turbine
110. Top 18th Century ore washing mill S100, Chapter 3 pp. 144
110. Bottom Suspension wheel with rim gearing S100, Chapter 5 pp. 291
111. From David MaCaulay’s “Mill”, 1983 pp. 85
112. Wooden Gearing 19th century grist mill
Mercer Museum, Bucks county Historical Society,
Dovlestown, Pa Photo by Charles A. Foote (WP)
114. LNHP Museum Collection LOWE8295
Merrimack Mfg. Co Main shaft in basement of mill #2
Bound PL&C, vol.#9 2/12/1923
115. Treatise on Mills and Millwork William Fairbairn (WP) pp. 464
British Cotton Mill main drive by gear wheels and shafting
117. The Young Millwright and Miller 1850 ed. Oliver Evans
Wooden shafting and cogwheels replaced by cast iron shaft
and wheelwork (WP)
119. PL&C microfilm roll #3 Drawing identified as F1-filed on shelf 113
Center for Lowell History
120. Top------Shaft from Building #2 (dotted line) entering wheelpit
under building #6-from Mill by David Macaulay 1983 pp. 86
120. Bottom- Shaft rises to 2nd floor- only shows pulley arrangement
on 2nd floor pp. 87
Both above sketches from folder, Boott Mills: Power Train Pit:
Miscellany: NPL
121. Top----- Original Lawrence mill layout 1831
PL&C Archives Plan Book ‘A’ pp. 15
As shown from Lawrence Mill-Large Pulley by Redding
121. Bottom-PL&C photo collection-Center for Lowell History #1721B
122. The Lawrence Mfg. Powerhouse and Big Pulley Wheel
David Redding, LNHP folder at NHL
124. Unidentified empty mill interior LNHP
Museum Collection LOWE11075
125. Top------“The Science of Modern Cotton Spinning” Evan Leigh
1882 Power Transmission by Belting
Harmony Mill #3, NY
125. Bottom-Men and women working in unidentified mill.
LNHP Museum Collection LOWE6739
126. This photo of Wannalancet flywheel copied from article in Lowell
Sun, 5/27/07 by Andrew Raven “Rollin` on the River”
127. Top------Description of wheel hand and written in margin
of photograph
127. Bottom–“Shafting, Belting, Governors” Hubert E. Collins pp. 114
1908 Power Plant Library Series MacGraw-Hill
128. Top------LNHP Museum Collection LOWE7608
    Also in Lowell Sun 1/26/1911 front page
128. Bottom-LMHP Museum Collection LOWE7609
129. LNHP Museum Collection LOWE8297
    Lawrence section of T&S mills. Rope drum connecting
turbine with main shafting 2/21/1923