Water-Powered Flourmilling on the New England Tablelands of New South Wales

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This paper presents a historical and archaeological survey of the technology of four nineteenth-century water-powered flourmills in the New England region of New South Wales. This is informative on a number of aspects of the use and adaptation of water-power in the flourmilling industry in nineteenth-century Australia. Significant among these were the inability of the New England climate to provide a reliable water supply, its relative isolation from the nineteenth-century industrial economy, and limitations on the skills available for the construction of sophisticated watermill technology. These factors are reflected in the materials and methods used in the construction of the mills in the area. The single most important influence on the basic form of the technology and the scale on which it was used was the economic climate into which it was introduced. The troubled history and abrupt demise of some of the mills discussed is indicative of the fact that they faced competition from steam mills, and were built at a time when the New England grain and flour industry as a whole was entering a decline caused by competition from imports from other parts of the country from which it never recovered.

This paper presents the results of research carried out on four nineteenth-century watermills in the New England Tablelands region of northern New South Wales (Fig. 1). It represents part of the database for research undertaken by the author for a Doctorate in the Department of Archaeology and Palaeoanthropology at the University of New England, Armidale, from 1991 to 1995. The aim of this research was to construct a model for industrial technology transfer and adaptation between England and Australia in the nineteenth century. To do this, published literature on international technology transfer was surveyed to isolate important environmental, human, industrial, economic and sociocultural factors influencing the process. Differences in these factors between the two countries led to hypotheses about how an industrial technology might have been modified as a result of its transfer. The hypotheses were then tested using a comparative survey of nineteenth-century watermill technology in both countries as a case study. The resultant model emphasizes production inputs and resource endowments in the recipient country as the most important selection pressures, with the presence of skilled operators and supportive industries for the technology in the recipient country and the cultural makeup of both the donor and recipient countries also important. The aim, rationale, methodology and results of this research have been published in more detail previously in this journal.[1]

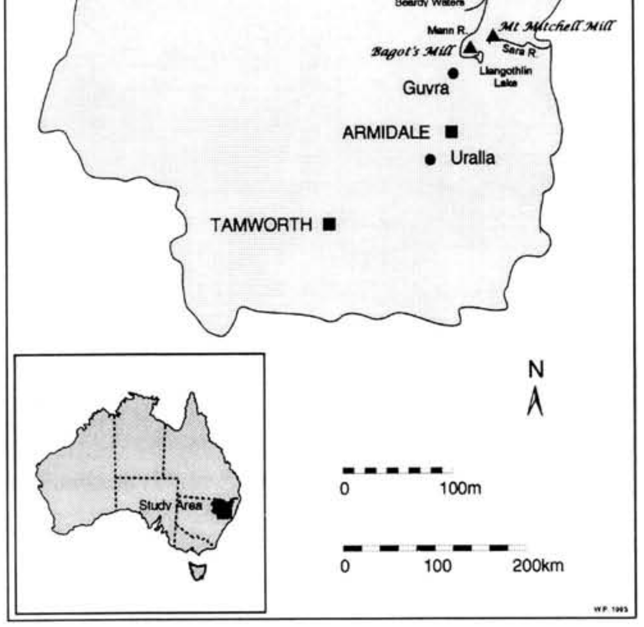

Fig. 1: Location of sites mentioned in the text.

Because of a lack of published research on nineteenth-century Australian watermills, it was considered that much of the database of the Ph.D. research warranted publication in its own right. This has taken the form of two papers. The first of these, again published previously in this journal, dealt with the history and technology of a sample of water-powered flourmills in nineteenth-century Tasmania.[2] The present paper contains a detailed description of the technology of four water-powered flourmills in the New England region of New South Wales, set in a contextual discussion of the early development of the flourmilling industry in the colony and the New England region, and the application of water-power to it. The history and technology of the mills is very revealing about conditions for the adaptation and use of water power in the nineteenth-century flourmilling industry in New South Wales, in an area which was marginal, both for the use of watermill technology, and for the flourmilling industry. Consequently, there are marked differences between the history and technology of the water-powered flourmills in this area and those in other, less marginal, areas of Australia, such as Tasmania. These differences may be explained in terms of differences in various economic, environmental, industrial and human factors. They are elaborated upon in the conclusion.

FLOURMILLING IN NINETEENTH-CENTURY NEW SOUTH WALES

The first water-powered flourmill erected in the colony of New South Wales was on Norfolk Island rather than on the mainland. It was built early in 1795 and powered by an overshot water wheel.[3] The mill was built and operated by Robert Nash, and was capable of grinding and dressing 18 bushels of flour per day.[4] The mill operated only a few years before the Norfolk Island colony was transferred to Van Diemen's Land, where Nash was recompensed with land on which he built the first watermill in that colony also.[5]

The first watermill to be erected on the mainland was built at Government Farm, Parramatta. It was begun in 1798, but not completed satisfactorily until 1804.[6] The mill was described as having a wheel of overshot construction, 18 feet [7] (5.49 m) in diameter and 18 inches (0.48 m) in width fed by a long water race.[8] Governor King described the mill as being built 'of stone, with two strong and well-constructed dams, and the situation such as no floods can ever affect it.'[9] The dams were made of compacted earth, and can not have been as strong as Governor King thought, because they were washed away in floods in 1804 and twice in 1805, the second time after having been reinforced with timber piles, and again in 1806, after having been rebuilt as a stone weir.[10] To cap it all, when the dam was not being damaged by floods, the mill was beset with an undersupply of water, as Governor King wrote in 1804:

> I am sorry to say, that the great labour which has been bestowed in constructing an excellent watermill and dam at Parramatta will not in any manner recompense the labour that has been bestowed upon it. This mill and dam has been erected on the same spot designed by Governor Hunter, as the only situation likely to be supplied with water, but the experience of the last three years sufficiently proves that the water is insufficient for the purpose, except in periods of much rain.[11]

The Government watermill was finally abandoned in 1806.

Despite the problems for those attempting to construct watermills in New South Wales presented by the example of the Government Farm Mill, further attempts were made soon after, all on the part of individual, non-government concerns. The first of these was the convict Thomas West's flourmill, erected in 1811-1812 at a place then called Barcom Glen near modern Rushcutter's Bay, Sydney. On 14 January, 1812, Governor Macquarie wrote of this mill in his diary:

> . . . went to see West's water-mill . . . . the first ever erected in Sydney
>
> . . . This mill is turned by a great wheel of 18ft [5.49 m] diameter, and fortunately commanding a good head of water.[12]

Owing to the absence of streams with a reliable flow and a good fall of water, according to Wentworth,[13] West's mill appears to have been the only watermill erected within the settlement at Sydney, until the erection in 1828 of a wind and watermill complex on or near the site of the old Government Mill at Parramatta by George Howell.[14]

Other early watermills were erected in more outlying locations. By 1820, the Lachlan swamps at Botany Bay had been harnessed to drive the Waterloo Flourmill and the Lachlan Flourmill, operated in tandem by a partnership including the wealthy ex-convict Samuel Terry.[15] Other early watermills outside the settlement at Sydney included two flourmills erected by Benjamin and James Singleton, migrants from England, near Wiseman's Ferry and at Kurrajong on the Hawkesbury River, in 1818 and 1830 respectively.[16] Both were powered by tide-driven undershot water wheels.

By the 1830s, watermill construction was following the spread of settlement north, west and south from Sydney. Among the first of these were flourmills built on the coast north of Sydney, at Clarence Town in 1829 and Stroud in 1832-1833.[17] The example of the Australian Agricultural Company's flourmill at Stroud indicates that the colonists were still learning the lessons that had been taught twenty years previously at Parramatta. During the entire period of activity of this mill, water-supply

Table 1

	FLOUR MILLS			
YEAR	Water	Horse	Wind	Steam
1837	23	15	23	13
1838	27	11	27	16
1839	24	9	27	17
1840	**31**	**14**	**34**	**26**
1841	21	8	27	29
1842	27	27	31	32
1843	27	26	33	35
1844	33	25	37	39
1845	33	32	32	48
1846	31	30	29	48
1847	34	30	27	53
1848	43	38	26	65
1849	41	29	28	70
1850	**45**	**22**	**28**	**75**
1851	33	25	25	68
1852	28	19	20	78
1853	28	20	23	72
1854	27	17	22	74
1855	29	17	19	82
1856	26	15	21	92
1857	19	18	19	101
1858	23	13	23	110
1859	22	20	17	118
1860	**24**	**15**	**20**	**134**
1861	22	12	16	134
1862	19	19	12	131
1863	20	18	13	129
1864	16	11	12	135
1865	18	8	14	135
1866	13	6	10	130
1867	15	8	10	155
1868	15	10	10	146
1869	14	8	10	151
1870	**16**	**8**	**8**	**155**
1871	14	9	7	160
1872	13	10	6	159
1873	15	7	6	154
1874	12	13	5	142
1875	11	1	2	147
1876	8	4	2	150
1877	8	3	1	151
1878	10	2	1	152
1879	9	4	1	147
1880	**7**	**2**	**1**	**140**
1881	9	1	1	148
1882	7	2	8	156
1883	9			145
1884	8			153
1885	7			152
1886	5			128
1887	5			122
1888	3			107
1889	2			101
1890	**5**			**97**
1891				
1892	1			71
1893	2			85
1894	2			81
1895				87
1896				81
1897				81
1898				80
1899				80
1900				86

Table 1: Statistics collected by the Colonial Secretary's Office of New South Wales between 1837 and 1900, for water-powered flourmills in the colony. Numbers of flourmills of other types are included for comparison. Collated from Statistical Register of New South Wales 1849/58-1900 (Mitchell Library).

problems in the form of recurrent droughts forced the owners of the mill to experiment with supplementary power sources.[18]

By 1837 there were a total of 23 water-powered flourmills in use throughout the colony, in addition to 13 steam-powered flourmills, 15 animal-powered flourmills and 23 wind-powered flourmills (Table 1). The first steam-powered flourmill had been erected by John Dickson at Cockle Bay, Sydney, in 1815.[19] The first wind-powered flourmill was erected in Sydney in 1796, with a second being completed in 1802.[20] As with the first watermill in the colony, both were Government-owned. Early privately-owned, wind-powered flourmilling ventures in the colony included John Boston's mill, built sometime before 1801,[21] and Nathaniel Lucas' mill, built in 1805.[22]

Not much is known of the muscle-powered flourmills in use during much of the nineteenth century. Most probably comprised a small building just large enough for a horse or bullock to walk around in a circle, tethered to a pole to provide power via gears and shafts to a single set of millstones.[23] These would mainly have found use in isolated rural areas where no other power source was available. The power for such mills was not always of the four-legged variety, however. The very first flourmill to have operated at Sydney Town is known to have been powered by convict labour. It was built in 1793 by the convict carpenter James Wilkinson, and operated on the treadmill principle. It was described as a

> ... walking mill, the principal wheel of which was fifteen feet [4.58 m] in diameter, and was worked by two men; while this wheel was performing one revolution, the mill stones performed twenty.[24]

Wilkinson constructed a second treadmill in 1794, powered by a wheel 22 feet (6.71 m) in diameter, in which up to six men could walk.[25] A third man-powered flourmill, built by John Baughan, was also in operation by 1794.[26] This was powered by nine men pushing horizontal capstan bars, similar to the operation of an animal-powered mill. None of these mills were able to operate on a commercially successful scale, however.

The number of watermills in use in New South Wales peaked at 45 in 1850 (Table 1), while wind- and animal-powered mills peaked at 37 in 1844, and 38 in 1848 respectively. The last watermill ceased operation in the early 1890s, with the use of wind and animal motive power ceasing in the early 1880s. These power sources were replaced by steam-powered mills, the number of which first overtook those of other power sources in the early 1840s and increased rapidly, to a maximum of 160 in 1871. 86 were still in operation at the turn of the century.

These patterns in the numbers of flourmills in New South Wales during the nineteenth century can be linked to trends in grain production in New South Wales and other colonies. By the beginning of the nineteenth century, according to Linge, the Hawkesbury area of New South Wales was the main source of colonial grain and flour.[27] However, this role was taken over by Tasmania in the early 1840s,[28] and South Australia during the late nineteenth century.[29] The progressive settlement of new colonies in Australia provided domestic markets for the flourmills of New South Wales, Tasmania, and South Australia successively throughout the nineteenth century, until these colonies too became self-sufficient. External markets were provided by countries such as New Zealand, the United States and Britain.[30]

While the reliance on flour from New South Wales by colonies such as Tasmania provided the impetus for expansion of the flourmilling industry in the Hawkesbury area, the expense and difficulty of overland transport encouraged the widespread construction of numerous small mills serving local markets only.[31] With the coming of the railways and the growth of large population centres towards the end of the nineteenth century, this trend reversed towards a major reduction in the number of small-scale rural flourmills, and an increase in the scale and mechanisation of operations in those remaining, with these becoming concentrated in large population centres.[32]

The extent to which the early development of the flourmilling industry in New South Wales was powered by water can be seen in Table 1. In 1840, for example, watermills contributed approximately 30 per cent of the power for the industry, while windmills contributed approximately 35 per cent, and animal mills about 10 per cent. Steam mills contributed approximately 25 per cent. However, it was steam mills that powered the rapid expansion of the industry into the interior of the colony, in the second half of the nineteenth century. The drier and less predictable climate of the interior suited the more reliable and adaptable steam engine. While some wind and water mills were constructed in these areas, many had steam engines added from the mid-nineteenth century to remain competitive for longer. At the same time, outbreaks of rust disease in some of the longer established wheat growing districts, such as the Hawkesbury, forced the premature closure of many wind- and water-powered mills serving these areas.

WATERMILLS AND FLOURMILLING IN NINETEENTH-CENTURY NEW ENGLAND

The New England Tablelands were one part of the interior of New South Wales where several water-powered flourmills were constructed during the nineteenth century (Fig. 1). The geography of this area is characterised by a consistently high altitude above sea level and a relatively high rainfall.[33] However, it took the settlers some time to realise that, although relatively high, the rainfall could also be highly variable, consequently rendering the flow of the rivers and streams unreliable for supplying water to power mills. This lesson is borne out in the histories of the watermills constructed there.

Isolation from the more settled areas of New South Wales, and the high cost and difficulty of transporting foodstuffs, meant that the nineteenth-century occupants of the New England Tablelands required self-sufficiency in flour production until the coming of the railway in the 1880s. This and the dispersed, pastoral nature of settlement, meant that many of the large stations incorporated small-scale flourmills to grind their own grain. Among the first of these were windmills built on Salisbury Station in 1842 by M. H. Marsh,[34] and Stonehenge Station in about 1845 by Archibald Boyd.[35] These were followed by watermills on Mount Mitchell, Yarrowford and Bolivia Stations in the 1850s and 1860s (see discussion below). The first steam-powered flourmill on the New England Tablelands was erected on Tenterfield Station in 1854 by R. J. Traill.[36] Other stations known to have erected their own steam mills included Ingalba,[37] Gostwyck[38] and Bundarra.[39]

In 1866 wheat production in New England exceeded consumption for the first time.[40] Together with the growth of towns such as Armidale, Uralla and Glen Innes, this saw a move toward commercial flourmilling enterprises, based closer to markets and transport routes and, of necessity, powered by steam. From the mid 1860s to the early 1870s the number of flourmills in the New England area rose to 15,[41] with four in Armidale, three in Uralla, two in Glen Innes, several in Inverell[42] and two in Walcha.[43]

The growth of the larger, commercial mills rapidly led to the closure of the small, rural mills. The last water-powered flourmill ceased operating in New England in 1881 (Table 2). However, the commercial steam mills were themselves victims of a similar fate, when competition from a superior South Australian product brought about their demise in the 1880s and 1890s.[44] The New England mills were too small to afford the expensive new roller technology which was being introduced in the larger city-based steam mills in places such as South Australia. Roller-grinding produced a finer, whiter flour than conventional millstones. Increased competition from outside after the opening of the railway in the late nineteenth century, contributed to a rapid decline in demand for the coarser local product.

With the exception of Bolivia and Bagot's Mills, the mills

Table 2	
Year	No. Mills
1860	1
1861	
1862	1
1863	1
1864	
1865	2
1866	
1867	1
1868	1
1869	1
1870	1
1871	1
1872	1
1873	
1874	
1875	2(8)

Table 2: Water-powered flourmills listed in the Armidale area in the Statistical Register of New South Wales from 1860 to 1875. The number in brackets is a combined horsepower figure. From the New South Wales Statistical Register 1849/55-1900 (Mitchell Library).

discussed below were small-scale rural flourmills, constructed around the mid-nineteenth century. Bagot's Mill has a more complex history and technology. In common with all other known watermill sites in New South Wales, none of the mill sites retain substantial remains of buildings or machinery. For the most part only portions of earthworks survive. This required the extensive use of archaeological field survey techniques, supplemented with documentary sources, to allow a reconstruction of their technology. The techniques and approach used to retrieve information from these sites should be relevant to the study of other such sites.

Mount Mitchell Mill

According to William Gardiner, who was himself employed there during the mid-nineteenth century, Mount Mitchell Station, southeast of Glen Innes on the New England Tablelands (Fig. 1), was first occupied by H. Nowland in 1842.[45] Sometime between this date and 1854, when the first record of it appeared in the form of an illustration in Gardiner's *Products and Resources of the Northern Districts of New South Wales*, a small water-powered flourmill was built on the station. According to the *Armidale Express*, the mill was still in operation four years later.[46] It is possible that one of the two watermills recorded for the Armidale area in the *Statistical Register of New South Wales* for 1865 and 1875 (Table 2) was the Mount Mitchell Mill, with the other being the Yarrowford Mill (see below). However, in the absence of corroborating evidence, there is no way of confirming this, save that of the only other known watermills in the New England region. Bagot's Mill on Ben Lomond Station was not built until 1874-1878, and Bolivia Mill near Tenterfield is listed under a separate entry for that area in the statistics. Thus, in the absence of any evidence to the contrary, it is possible to speculate that Mount Mitchell Mill was in operation as late as 1875.

As with other flourmills erected on stations in the area at this time, such as Yarrowford Mill, the economic rationale for the construction of Mount Mitchell Mill was most probably to overcome the isolation of the station and make it more self-sufficient. By enabling some of the station's own grain to be ground into flour, the mill would have reduced the dependency on an unreliable supply of flour transported over long and difficult routes to what was then by far the most distant and isolated region from the more settled areas of New South Wales.[47] The Sara River was the water source for Mount Mitchell Mill. In siting the mill and its water-supply system, use was made of a naturally occurring large, flat granite outcrop which acts to dam the flow of the river into a large pond with a single, small outlet (Fig. 2). This is seen both in Gardiner's contemporary drawing (Plate 1) and in a modern photograph taken from approximately the same location (Plate 2).

Although he takes considerable licence with other aspects of the scene, such as the flora and fauna, Gardiner's drawing presumably is reasonably accurate with regard to details of the mill and its construction, as this was the object and centrepiece of his illustration. With a marked lack of archaeological evidence at the site, it is the best and only evidence available. At the outlet of the pond Gardiner shows what appear to be two small weirs, loosely constructed of large boulders. These acted to retain the water in the pond at a reasonably constant level, to allow overflow into the natural bypass channel around the rock platform and to direct water into a short headrace across the rock platform to the wheel. No trace of these weirs now remain, but part of the headrace does. A drilled blasting hole in the rock platform marks

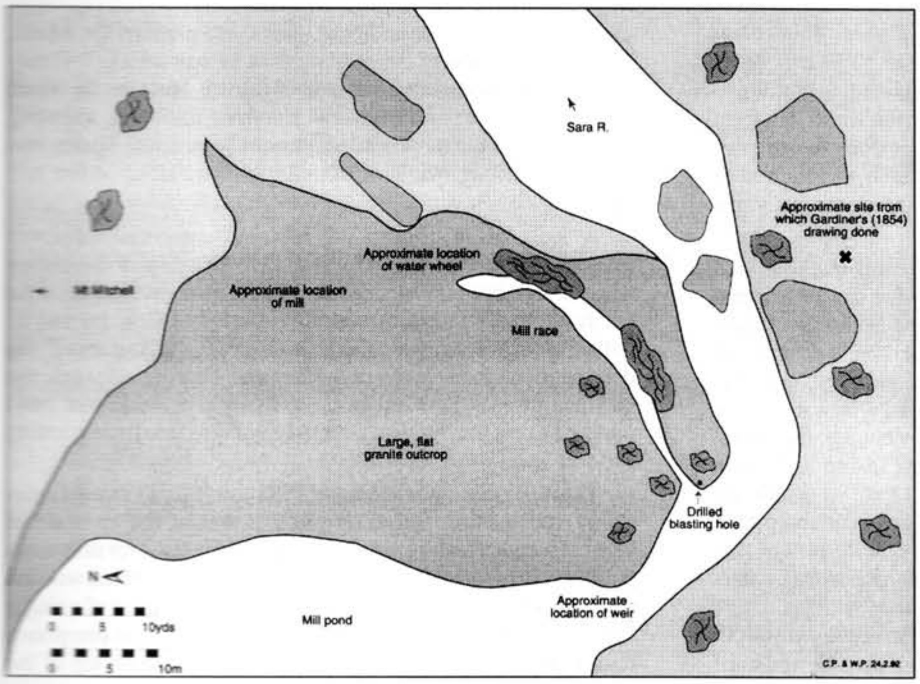

Fig. 2: Physical and archaeological features at the Mount Mitchell Mill site.

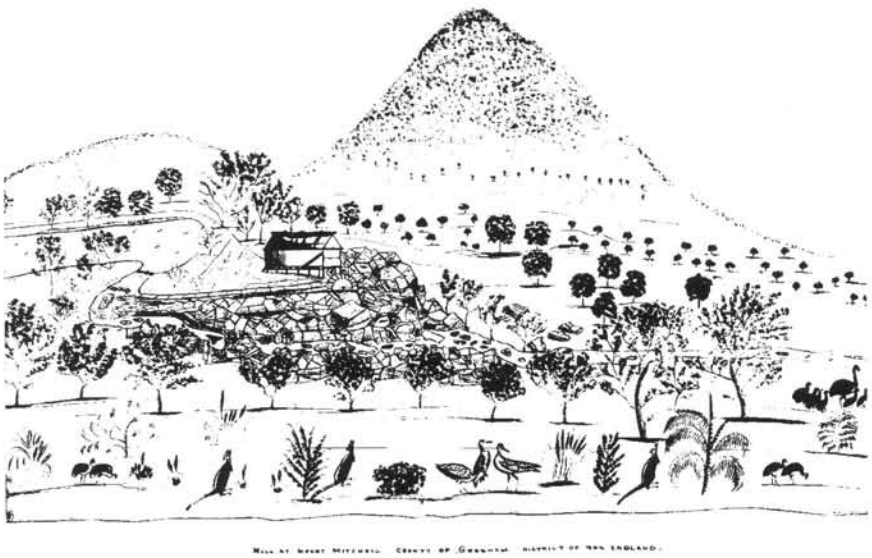

Plate 1: Drawing of Mount Mitchell Mill from Gardiner's Products and Resources of the Northern Districts of New South Wales (1854 vol. 2:101). Note the stylised flora and fauna in the foreground (photo, courtesy of Mitchell Library).

Plate 2: A 1991 view of the Mount Mitchell Mill site taken from approximately the same vantage point as Gardiner's drawing was done. Mount Walker is in the background on the right. The river passes by the rock platform in the foreground, and a line of tea tree shrubs across the centre of the rock platform marks the location of the millrace. The millpond is to the left of the rock platform, with the location of the mill on the far right edge of the rock platform (photo by W. Pearson 1991).

the entrance to a 30 yard-long (27.42 m) channel, four to six feet (1.22 to 1.83 m) wide and two to three feet (0.61 to 0.92 m) in depth, blasted from the rock platform and lined, according to Gardiner's drawing, to act as the headrace to the wheel. No form of sluicegate is apparent from either the documentary or archaeological evidence, but this would have been required to regulate the flow of water onto the wheel and shut it off when necessary.

No physical evidence for the construction methods and materials of the water wheel exists, save what can be gleaned from Gardiner's drawing. This shows a low breastshot wheel with the water entering it at the 3 o'clock position.[48] The wheel is situated half below the level of the rock platform, with the axle resting in bearings on masonry supports. Given its size in relation to the mill building in Gardiner's drawing, the wheel was probably in the vicinity of 10 to 12 feet (3.05 to 3.66 m) in diameter by three to four feet (0.92 to 1.22 m) in width. As illustrated, the wheel was equipped with a rim gear and pinion wheel power take-off system. With this method, power was transmitted to the machinery via the rim of the wheel, rather than via the axle of the wheel. The rim gear system was more complex to build, but more efficient in transmitting power.[49] The use of this, together with the small size of the axle and arms suggest iron construction for at least these parts of the wheel. Given the isolation of the settlement at Mount Mitchell, it may be reasonably speculated that at least the iron parts for the wheel were made in one of the several foundries that were operating by this time in the more settled areas of New South Wales, and transported either whole or in parts for installation at the mill site.

At least one set of gears was required to transmit the power thus generated from the vertical plane of motion of the pinion wheel to the horizontal plane of motion of the millstones. As Gardiner states in his manuscript, stone suitable for use as millstones was readily available in the New England area,[50] so it is possible these were manufactured locally, although the services of a skilled miller or millwright would have been required to cut the intricate pattern of grooves into their grinding surfaces.

The mill building as shown in 1854 comprised a small single-storey structure supported on piles. It was of the economical vertical wooden slab construction commonly used for utilitarian buildings in nineteenth-century Australia, with a gabled wooden shingle roof. As the mill building is shown to consist of a single storey only, it is likely that the grain feed to the stones comprised only a small hopper mounted on a wooden frame on top of the millstones, without additional chutes from overhead bulk storage bins. The millstones would have been located on a raised wooden staging inside the mill to allow for the collection of the ground flour from underneath them. In line with the small scale of operations, it is unlikely that any powered hoist mechanism was required for handling large volumes of grain or flour. The small size of the mill building, and limited amount of power available would also have precluded the use of auxiliary grain cleaning or flour sifting machinery, common in larger nineteenth-century flourmills.[51] In any case, the domestic market being served by the mill would not have required a product of commercial standard.

The small scale of operations and simple construction of Mount Mitchell Mill are indicative of the isolation of the outpost it served. The effort and expense of transporting an iron water wheel and gearing parts over long distances with no roads is indicative of the importance of the task the mill performed.

Yarrowford Mill

Yarrowford Station, situated north of Glen Innes on the New England Tablelands (Fig. 1), was first occupied by Archibald Boyd in 1838, according to Gardiner.[52] Sometime between this date and 1850, Boyd had constructed a water-powered flourmill on Beardy Waters, a large river running through the property. In an advertisement for the sale of the property, carried in the *Sydney Morning Herald*, the presence of 'a never failing stream' which supplied 'a water mill which grinds the wheat for the supply of the whole establishment' is quoted as a major selling point.[53] Boyd is also known to have erected (in 1845) one of the two windmills established in New England. This was on Stonehenge, another of his stations.

According to an advertisement for flour from the mill in the *Armidale Express* of 1858, Yarrowford Mill was in operation at that date, and obviously catering for a wider clientele than the station only.[54] If Yarrowford and Mount Mitchell Mills are accepted as the only possible candidates for the two water-powered flourmills listed in the *Statistical Register of New South Wales* for the Armidale area in 1865 and 1875 (Table 2), then it may be conjectured that the mill remained in production until at least the latter date. During the period of operation of the mill in the 1860s, Yarrowford Station was part of the pastoral empire of Oswald Bloxsome and his son, who owned other stations on the New England Tablelands and in western New South Wales.[55] However, the running of the mill would have been left to resident managers.

As stated in the 1850 advertisement, the mill was supplied by the flow of Beardy Waters. At the point where the mill is situated, an extensive granite outcrop forces the river into a series of pools and rapids (Fig. 3), creating enough natural fall over a short section of the river to make the site favorable for the location of a watermill. To take advantage of this, and to create a pond of suitable size to allow enough water to be stored to enable the mill to be operated for extended periods, substantial hydraulic engineering works were required.

The water-storage and supply system for the mill consisted of a single, massive dam wall, together with a series of low retaining walls further upstream to contain the pond created by the main dam. Extant remains indicate the main dam wall was constructed of concrete and anchored to the rock with large steel bolts (Plate 3). A ragged line of one and a half inch (3.81 cm) diameter holes drilled in the rock, some retaining six to 12 inch (15.24 to 30.48 cm) long steel bolts and small sections of concrete still adhering to the rock indicate the position of this wall. While these remains do not allow a reconstruction of the width or cross-section of the dam wall, it is possible to estimate its height at greater than three feet (0.92 m), as the present water level is three feet below the bottom of the headrace constructed to convey water from the millpond to the water wheel. The dam wall was approximately 40 to 45 feet (12.2 to 13.73 m) in length.

Water was conveyed from the pond to the wheel via a short headrace. This measures 42 feet (12.81 m) in length, two feet (0.61 m) in width at the bottom to six feet (1.83 m) at the top and on average is four feet (1.22 m) in depth (Plate 4). The use of the natural rock outcrop as part of the main dam wall (Fig. 3), meant that the headrace from the dam had to be blasted through solid rock. Numerous one and a half inch diameter (3.81 cm) drilled blasting holes along its entire length reflect the difficulty of this task. At the outlet end of the headrace, two one and a half inch (3.81 cm) diameter iron bolts set in the rock and further remnants of concrete indicate the probable location of a sluicegate, required to regulate water flow to the wheel. From this point to a feature indicating the likely position of the wheel, a distance of 72 feet (21.96 m), the water was carried in an elevated wooden flume, to deliver it to the top of the wheel.

From the original water level of the pond when full, to a point at the base of the likely wheel position, a fall of 18 feet

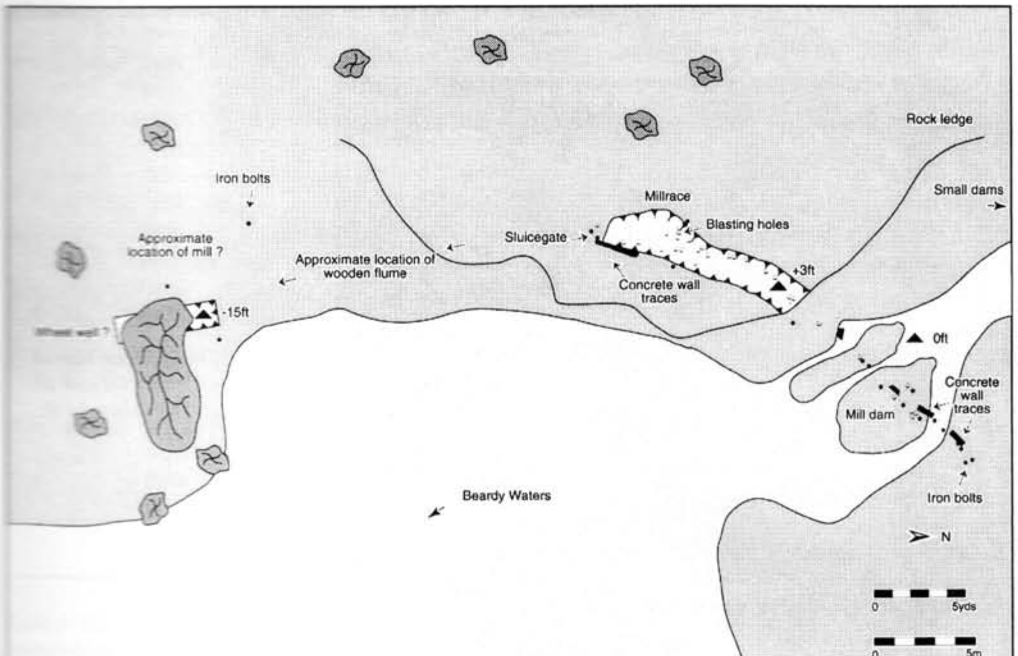

Fig. 3: Physical and archaeological features at the Yarrowford Mill site.

Plate 3: Remains of the main dam wall at Yarrowford Mill, comprising large steel bolts and traces of concrete adhering to the rock surface (photo by W. Pearson 1991). Range pole divisions are 20cm (approx. eight inches).

(5.49 m) was available. This would have allowed for the use of an overshot wheel of that diameter. No archaeological or documentary evidence regarding the construction materials or methods used for the wheel is available. However, given the isolated location of the mill, it can be speculated that the locally abundant hardwood may have been used extensively in its construction, with probable limited use of iron for such parts as hubs, axle and bearings, as at Mount Mitchell Mill. The bottom of the wheel may have been situated in a shallow well feature, two feet (0.61 m) deep, carved out of the bedrock (Fig. 3). This would have required its bearings to be supported on raised trestle-type frames. Nothing is known of the power take-off system from the wheel.

Given the small scale of operations, it may be speculated that the mill was of similar single-storey construction to that of Mount Mitchell Mill, with the millstones again set on a raised stage to allow collection of the flour from underneath them. The feed to the stones is also likely to have been similar to that at Mount Mitchell Mill, with a small overhead hopper sufficing to cope with the small amounts of grain processed. In order to satisfy the quality requirements of the wider market being advertised to by 1858, it is possible that the mill contained at least a simple flour-sifting machine by that date. Despite the claim of the 1850 advertisement, it is unlikely that the highly variable local rainfall patterns provided a 'never failing' supply during the period of operation of the mill. However, the small scale of production would have allowed for periodic shutdowns during times of low water.

Bolivia Mill

Bolivia Station, near Tenterfield in the north of the New England region (Fig. 1), was purchased by the Irby brothers in 1843.[56] However, it was not until the early 1860s that Edward Irby's venture into water-powered flourmilling on the station got underway.[57] This suggests that the rationale for the construction of the mill was not merely to ensure the self-sufficiency of the station. There had been a steam-powered flourmill on nearby Tenterfield Station supplying the area since 1854.[58] Rather, the growing needs of what had, by the early 1860s become the township of Tenterfield, must have encouraged Irby to enter into competition with the steam mill to supply the local market.

The *Statistical Register of New South Wales* for the Tenterfield district shows a watermill in operation from 1861, with two water-powered flourmills in the Tenterfield area in 1865 (Table 3). It is known that the Irbys also owned and operated a

Plate 4: The headrace blasted and carved from solid rock at Yarrowford Mill (photo by W. Pearson 1991).

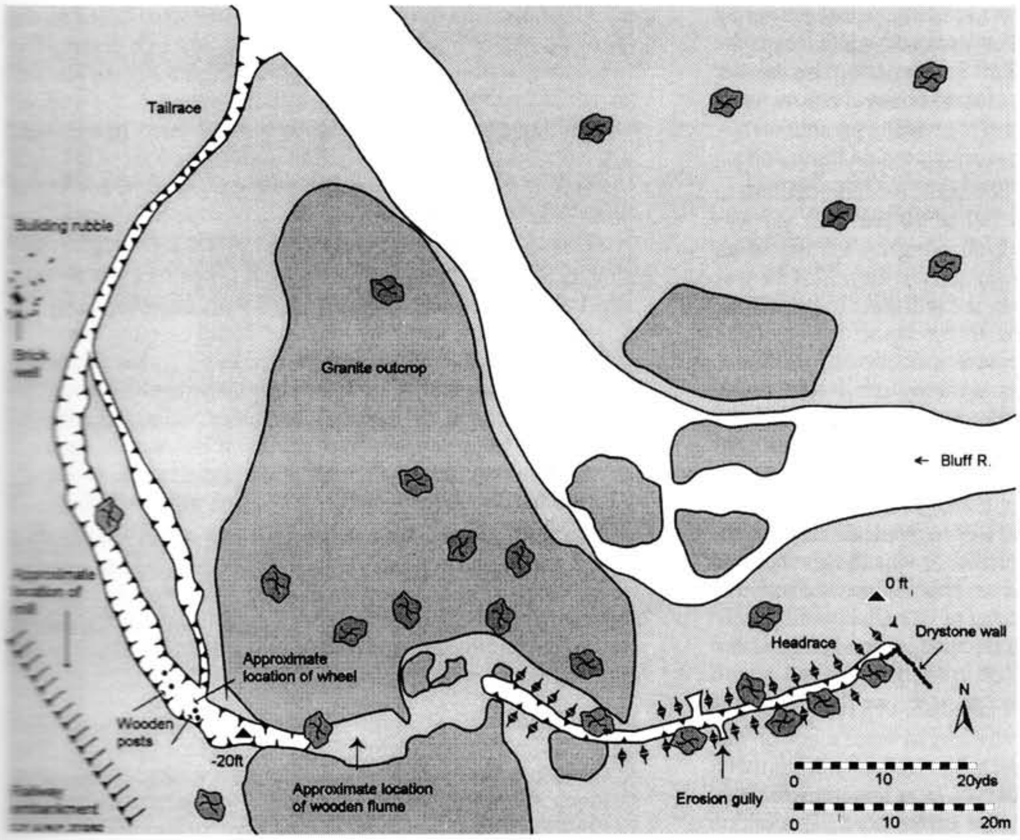

Fig. 4: Physical and archaeological features at the Bolivia Mill site.

second water-powered flourmill in the township of Tenterfield itself.[59] Given an assumed construction date just prior to 1861, the mill at Bolivia did not have a long life, as Irby was forced to close when construction of the Northern Railway line, which was opened in 1886, required eventual destruction of the mill.[60] Nevertheless, Irby's flourmilling interests were successful enough to permit his purchase of the nearby and long-defunct Dundee Steam Flour Mill in 1872, and the removal of milling machinery from it for use in his two mills at Tenterfield, including the Bolivia Mill.[61]

Table 3

Year	No. Mills
1861	1
1862	1
1863	1
1864	1
1865	2
1866	1
1867	1
1868	1
1869	1
1870	1
1871	1
1872	1
1873	1
1874	1
1875	1(7)
1876	1(7)
1877	1(20)
1878	1(8)
1879	1(18)
1880	1(18)
1881	1(18)

Table 3: Water-powered flourmills in the Tenterfield area listed in the Statistical Register from 1861 to 1881. The figures in brackets are horsepower figures. From the Statistical Register of New South Wales 1849/58-1900 (Mitchell Library).

Bolivia Mill was fed by the Bluff River. As with the watermills on Mount Mitchell and Yarrowford Stations, Bolivia Mill is located at a point on the river where it flows over a huge granite outcrop (Fig. 4). This acts as a natural weir and provides a large amount of fall over a short distance, making the site a naturally advantageous place to locate a watermill. Because of the natural weir effect of the granite outcrop, it is unlikely that a substantial dam or weir was ever constructed at the site. A small loose stone or log construction just below the point where the headrace left the river would have sufficed to divert water into the headrace. If such a dam ever existed at the site, all trace of it has long since been erased by the action of the river.

The headrace that supplied water to the wheel survives for the most part. This was formed by an earth channel, measuring approximately 150 yards (137.1 m) in length by three to four feet (0.92 to 1.22 m) in width and a similar depth. Mounds of earth and rubble excavated from this race still remain along most of its length. If it was of unlined earth construction, then it would have required frequent cleaning, resulting in such mounds. Approximately one third of the length of the headrace at its intake end has been erased by flooding. However, remnants of drystone walling indicate that at least this section of the headrace may have been lined, and may have joined that part of the headrace still intact at a sharp angle. A break between the headrace and tailrace indicates the probable use of a raised wooden flume to carry the water over a final section of rough terrain.

The exact location of the wheel is unclear from the physical evidence at the site. It may have been approximately 20 yards (18.28 m) from the southern end of the tailrace. Circumstantial evidence in the form of several wooden posts standing in the tailrace at this point lends weight to this conclusion. These may have served as supports for the wheel. The mill would thus have been positioned on the western side of the tailrace, close to its southern end.

The heavily silted up and overgrown tailrace measures 160 yards (146.24 m) in length by eight to 10 feet (2.44 to 3.05 m) in depth and six to eight feet (1.83 to 2.44 m) in width at the top, sloping to four to five feet (1.22 to 1.53 m) in width at the bottom. No evidence of any lining was found. Twenty yards (18.28 m) from the southern end of the tailrace, a smaller channel measuring three to four feet (0.92 to 1.22 m) in depth and width leaves the tailrace, to rejoin it 80 yards (73.12 m) further north. This smaller race may have served as a bypass race, to direct overflow water around the wheel when not in use.

From the point where the wooden flume supplying the wheel probably begins, to a point in the bottom of the tailrace close to where the wheel was located, a fall of 20 feet (6.1 m) was measured with a surveyor's level, allowing for the use of an overshot wheel of 20 foot (6.1 m) diameter at the mill. This was situated half below ground level, in the tailrace. Given the fact that timber was extensively used in the construction of the flourmill building, there is no reason to doubt that the water wheel powering the flourmill was similarly constructed, with the probable use of iron for parts such as axle, hubs and bearings. Given the maximum power output of 18-20 horsepower listed for the mill in the *Statistical Register of New South Wales* (Table 3) and a 75 percent average efficiency for overshot wheels, a sufficient flow of water must have been available to generate 24-27 horsepower at the site.[62] It is unclear why the horsepower figures listed in the *Statistical Register* should fluctuate between a minimum of seven and a maximum of 20. One possibility is that the horsepower figures reflect fluctuations in average water flows per year.

This maximum output is quite adequate to have driven the two pairs of millstones referred to by Irby in notes made on the reverse of an 1868 photograph of the mill, together with auxiliary grain and flour-processing machinery.[63] If, as hypothesized, the mill was designed and built from the outset to supply a wider market than Bolivia Station, then grain-cleaning and flour-sifting machines would have been required to ensure a product of sufficient quality for general consumption, and hence a profit for the mill. Indeed, Irby refers to a 'silk dresser, for flour sifting, and all necessary machines and appliances'.[64] These machines, together with the millstones and iron parts for gearing, would have been purchased and transported from larger centres, such as Sydney, or other mills closing down in the area, such as the Dundee Mill. As was the practice at other nineteenth-century colonial flourmills, power would have been distributed to the various items of machinery via layshafts and belt drives. The three-storey construction of the mill (Plate 5) would have allowed for some form of gravity feed system between the various flourmilling processes, in which case a powered hoist would also have been required to lift grain to the top floor of the mill. The size of the mill building indicates a significant amount of bulk storage space for flour and grain, to cope with supply and demand in an extended market. According to Irby's brief description of the mill on the reverse of the 1868 photograph:

> The mill was worked by a 20ft [6.1 m] overshot water wheel, and the dam, the race and flume carrying water onto it, are at the back of the building . . . the whole property consisting of mill buildings, two sets of stones, silk dresser and all necessary machines and appliances, splendid water site for wheel and about 280 acres of land are ruthlessly destroyed and rendered valueless, to the indelible dishonour of the Railway Department of N.S.W.

The mill building was constructed of sawn timber, with a gabled, corrugated iron roof (Plate 5). The addition of two single-storey wings to the central three-storey structure renders it a substantial building, indicative of an equally substantial capital investment on Irby's part; a further indicator of the extent of the market the mill was intended to serve.

Bagot's Mill

According to Gardiner, Ben Lomond Station, originally known as Llangothlin Station, was occupied by Thomas A. Perry in 1839-40.[65] The station then passed into the successive hands of William Rawson, between 1842 and 1845, Charles Codrington, between 1848 and 1854, and finally, Christopher Thomas Bagot, in 1861.[66] Bagot received his agricultural education at a college in England, and this, together with experience gained from travel in the United States, gave him an innovative approach to farm management.[67] Among his innovations were the pioneering use of the self-closing double gate, improved pasture, and imported agricultural equipment and animal breeds. Adding to this diverse range of improvements

Plate 5: 1868 photograph of Bolivia Mill, annotated on the reverse by Edward Irby (photo courtesy of Mitchell Library).

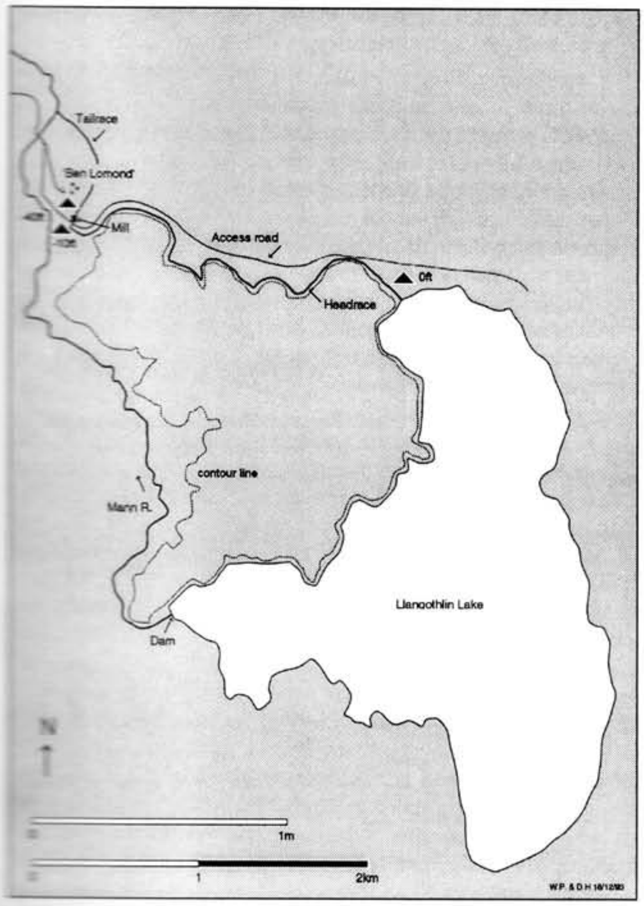

Fig. 5: Plan of the extensive water-supply system for Bagot's Mill.

to Ben Lomond Station, Bagot also began construction of a water-powered flour and sawmill, in 1874. The *Sydney Morning Herald* carried the following description of Bagot's planned mill:

> About 1½ miles [2.42 km] from the station there is an everlasting water supplying a large chain of lagoons. This Mr Bagot intends turning to account by bringing by a race to his farm the water, and using it as a power to turn a flourmill which will shortly be erected. This mill, I feel certain, will prove a great boon to the settlers around, for a good market is always open for flour around Glen Innes.[68]

A description of the very slow progress on construction of the mill was given three years later, in the *Sydney Mail*:

> On Ben Lomond, as on many other New England runs, there is water in abundance, and very great facilities for its utilisation as a motive power, if such should be needed. Mr Bagot has determined to turn this gift to a good account, and he has brought water from Ben Lomond [Llangothlin] Lake, which is a fine sheet of water seven miles [11.27 km] in circumference, situated about 1 mile [1.61 km] in a southerly direction from the homestead, to work the machinery of a saw and flour mill which he is now engaged in building close to his residence. The water is conveyed by a race which winds around the ridges in its course for about 1¾ miles [2.82 km]. The lake has been aided by a dam which has been placed across the head of the Mann River, which flows from it, and thus an increased and permanent supply has been secured. The mill now in the course of erection will be three-storeyed in size, 35 by 29 feet [10.68 by 8.85 m]. The first of these will be of rubble stone, the remaining two of wood. The water-wheel, which is now in its place, fixed firmly on two blocks of solid granite which weigh about two tons each, I may safely affirm is the finest and largest of its class in the Northern Districts. It is 30 feet [9.15 m] in diameter, 4 feet [1.22 m] breast, has 93 buckets (in depth 10 inches [0.26 m]), and attached external cogged segments around its periphery to work two pinions intended to drive the various machines. The water will be brought in a flume 160 feet [48.8 m] from the race, and after performing its work it will be used to irrigate the cultivation paddocks which are situated on the flat many feet below the level of the tailrace. Mr G.H. Goddard engineer, of Uralla, has designed and constructed the wheel; Mr McInnes of Reedy Creek, is the contractor for the masonry . . .[69]

Citing an anonymous article in the *Glen Innes Examiner*, whose author claims to speak 'with authority', Walker states that Chinese coolies were used as labour to construct the dam at the outflow of the lake into the Mann River.[70]

Although, according to an article in the *Glen Innes Examiner*, the sawmill was completed and went into operation, it is not known whether the flourmill was ever completed sufficiently to begin production.[71] This article also mentions plans for a woollen factory, for the manufacture of blankets and coarse tweeds. It is likely that construction on the flourmill and plans for the woollen mill were forestalled by the fact that by 1879 Bagot had gone bankrupt.[72] This may be attributed to accumulated losses from droughts and the pressure of creditors, recorded in local newspapers over a number of years leading up to 1879.[73]

Although there is no documentary or archaeological evidence the flourmill section was ever completed, the scale of the mill, and commensurate amount of capital invested in it, indicates Bagot intended to cater for more than the local market. Given the fluctuating fortunes of his agricultural pursuits, it is probable that the mill was intended as a scheme to diversify his interests and improve the profitability of his property.

As stated in the contemporary reports, the mill was fed water via a one and three quarter mile (2.82 km) long headrace from Llangothlin Lake (Fig. 5). This left the lake at its northern end and followed a winding route along the contour of the terrain to the mill. Little remains of this today. It measures four to six feet (1.22 to 1.83 m) in width, two to three feet (0.61 to 0.92 m) in depth and was constructed as an earth channel. Among other

Table 4

Year	Rainfall (in.)
1881	27
1882	39
1883	34
1884	29
1885	29
1886	42
1887	38
1888	25
1889	36
1890	55
1891	37
1892	50
1893	36
1894	31
1895	29
1896	32
1897	27
1898	21
1899	29
1900	29

Note: For conversion to metric 1in. = 25.4 mm

Table 4: Annual rainfall recorded at the Glen Innes Station between 1881 and 1900 (Bureau of Meteorology).

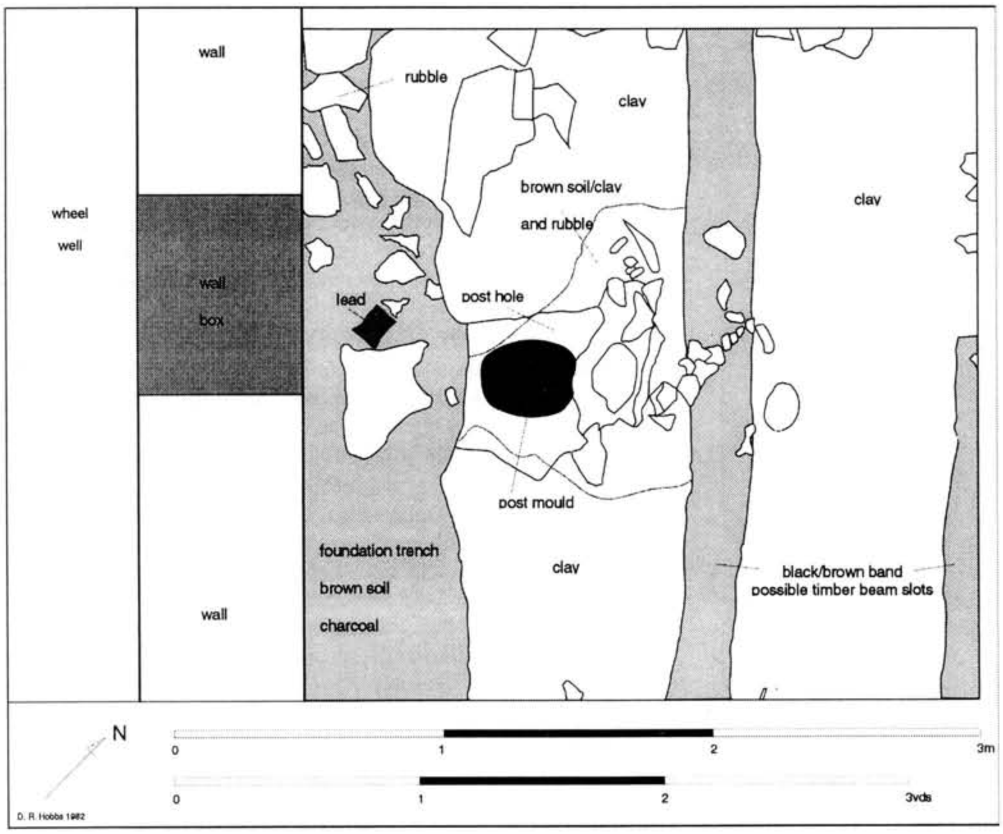

Fig. 6: Plan of features exposed in Cutting VIII in the sawmill section of Bagot's Mill. From excavations in 1979-82 (after Connah 1994).

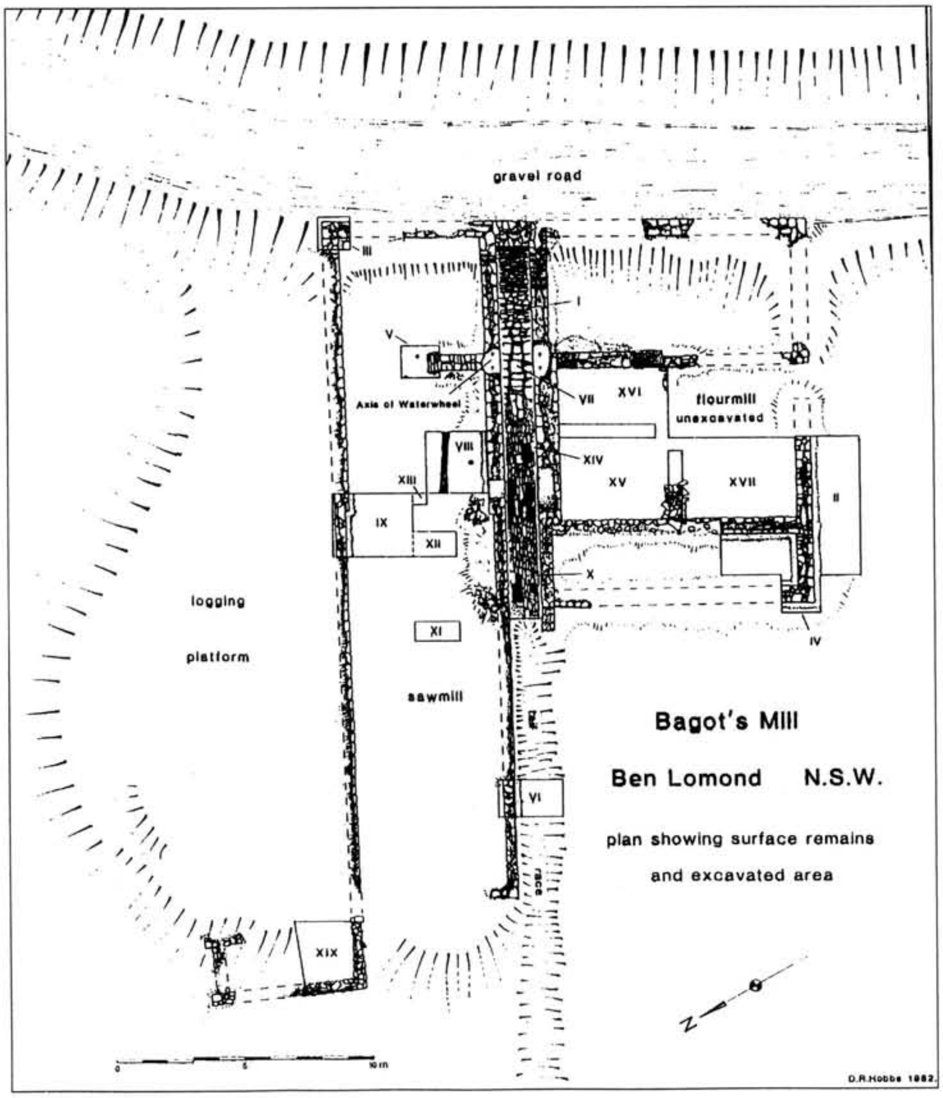

Fig. 7: Ground floor plan of Bagot's Mill, exposed after excavations in 1979-82. The sawmill side is to the left of the central wheel chamber, with the flourmill side to the right (after Connah 1994).

problems Bagot's water-supply was beset with, this very long headrace must have suffered significant water loss from seepage, evaporation and erosion.

The dam at the outflow of the lake was of earth-mound construction, and measured approximately 175 yards (159.95 m) in length, by six to 10 yards (5.48 to 9.14 m) in width and five to six feet (1.53 to 1.83 m) in height. It was equipped with a stone-lined overflow race into the Mann River (Fig. 5). While large in area, being over 7 miles (11.27 km) in circumference according to one of the contemporary descriptions, the lake thus formed is still nowhere more than about 10 feet (3.05 m) in depth, with much of it being marshy and shallow (i.e. 1 m or less in depth). This may not have represented the 'never failing supply' described in the contemporary reports. A lake of such large area and shallow depth would have responded dramatically to small seasonal and annual variations in rainfall, forming a very unreliable supply. Rainfall records for the area between 1881 and 1900 (Table 4) show a variation in the average annual rainfall between a low of 21 inches (533 mm) in 1898 and a high of 55 inches (1397 mm) in 1890, representing over 100 percent variability within the short space of nine years. Such variations are likely to have been the source of the droughts which eventually sent Bagot bankrupt. In any case, it is open to question whether, had Bagot not gone bankrupt when he did, the water-supply to his mill would have proven reliable in the long term. Oral evidence from landowners adjacent to the lake indicates that in the drier years, despite having its outflow dammed, the lake shrinks to such an extent that the headrace intake is left high and dry.[74] Thus, although of much greater area than the bodies of water impounded for other watermills in the area, the shallow depth of the lake rendered it particularly vulnerable to climatic fluctuations, and hence unreliable as a water supply for the mill.

While Bagot's water-supply scheme may appear to have been a poorly conceived attempt to make opportunistic use of the lake, its design was dictated to a large extent by the local terrain. The lake naturally occupied the lowest point in a local landscape of low relief. In siting the mill, Bagot had to find a point in the landscape where a sufficient fall could be generated to allow the use of an overshot wheel to generate sufficient power to drive a substantial flour and sawmill complex. Along with this limiting factor, Bagot also had to accommodate the need to site the mill close to his homestead and access and supply roads. Thus the situation arose whereby the mill was situated one and three quarter miles (2.82 km) distant from its water supply.

From the point where it leaves the northern end of the lake, to where it emptied into a 160 foot (48.8 m) long wooden flume to the wheel, the level of the headrace drops only approximately 10 feet (3.05 m) (Fig. 5), as measured by surveyor's level. Approximately 30 feet (9.15 m) of fall was available at the actual mill site, between the end of the flume and the bottom of the wheel well. As the wheel was said to have been 30 feet (9.15 m) in diameter, it must therefore have been of the overshot type in its mode of operation.[75]

The water wheel at Bagot's Mill is the only example of the technology in the New England region known to have been constructed by a qualified engineer or millwright, G.H. Goddard, of Uralla. The major dimensions and specifications were quoted in the 1877 article, but not the materials and methods used in the construction of the wheel. As Goddard was later owner of the Phoenix Foundry in Uralla, it is likely that he was skilled in ironwork, and that consequently, at least some of the wheel was constructed of iron. The dimensions of the wheel are near the upper limit for wheels of all-wooden construction [76] and, as the mill and water-supply already represented a large investment for Bagot, who was a man of progressive ideas, it is likely that iron was used at least for the axle, hubs and rims. The buckets were of cedar and the arms of hardwood.[77]

As circular saws were in common use by the 1870s, it is likely that Bagot equipped his mill with such a saw, together with a powered saw bench, operated by a ratchet mechanism, to feed the logs onto it. Coincidentally an original copy of an American millwrighting treatise with instructions for the construction of just such a sawmill exists in the Glen Innes Historical Society Library, and may actually have been brought back by Bagot from his visit to the United States.[78] A plan of excavated features in the sawmill section of the mill (Fig. 6) shows possible slots for timber beams forming the supports for the sawing platform, and a posthole marking the location of a vertical post which may have supported a bracket containing a bearing for the drive shaft to the saw. These features are directly in line with one of the window openings in the wall of the wheel well (Plate 6), justifying speculation that the drive shaft for the saw was driven directly from the water wheel via a pinion wheel meshing with the ring gear on the side of the wheel.

Some standing and sub-surface remains of the mill building survive, enabling limited reconstruction. Excavations carried out in 1979, 1980 and 1982 by Graham Connah, then of the Department of Archaeology and Palaeoanthropology at the University of New England, Armidale, revealed the floor plan of the mill (Fig. 7).[79] The sawmill comprised a rectangular area 75 feet (22.88 m) in length by 18 feet (5.49 m) in width, abutted by an earth embankment serving as a log-handling platform. It is likely that this section of the mill was constructed first so that

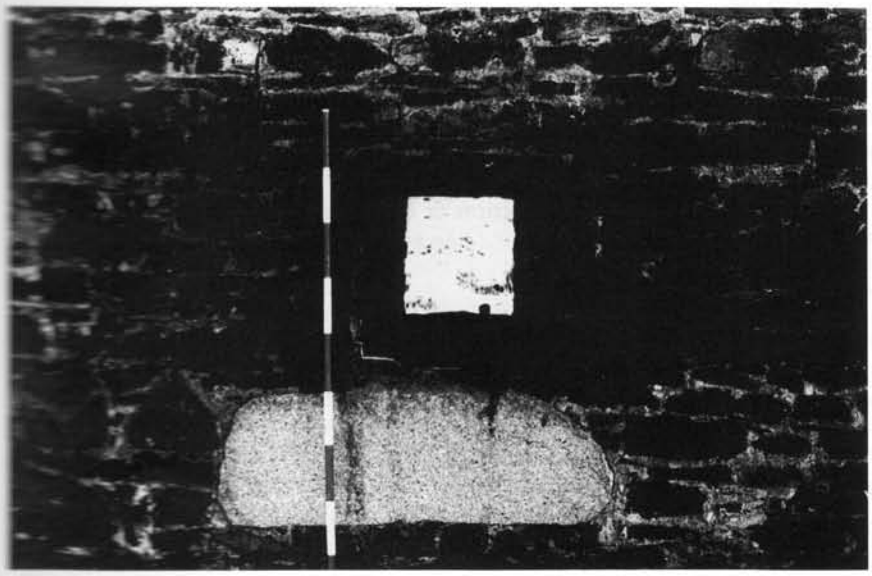

Plate 6: Standing masonry walls, Bagot's Mill. The power take-off shaft passed through the hole in the wall, with one of the bolts for the bearing mounts still visible (photo by W. Pearson 1991).

the sawmill could supply the wood for the upper stories of the adjoining flourmill.

The flourmill comprised a building measuring 30 by 50 feet (9.15 m by 15.25 m), divided into four rooms at ground floor level (Fig. 7). If the 14 foot (4.27 m) wide southernmost 'room' is interpreted as the foundations for a porch or front verandah for the mill, then the 30 by 36 foot (9.15 by 10.98 m) dimensions of the remainder of the building agree well with those quoted in the 1877 description. All walls and foundations are constructed of locally-available basalt, laid in random courses. The two most substantial walls, those forming the wheel well and supporting the wheel (Plate 6), measure four feet (1.22 m) in thickness and remain standing to a height of 15 feet (4.58 m); eight feet (2.44 m) above ground level and seven (2.14 m) below. These support two massive granite blocks, set with iron bolts, to support the axle-bearings of the wheel. Square holes in these walls also mark the position of the shafts for the pinion wheels for power take-off from the wheel. The position of these indicate that the ring gear was in fact mounted halfway along the radius of the wheel, not at its periphery as quoted in the contemporary description. The wheel well between these two walls is stone-lined, and built to fit the curve of the wheel at its 'rear', to give its buckets more efficient water-holding properties. This suggests the wheel may have been of the pitchback overshot type, which revolved in the opposite direction to the flow of water entering it, with the water descending in the buckets on the 'rear' half of the wheel, rather than in the buckets on the 'front' half of the wheel.

Bagot's Mill represents the most substantial watermill constructed in the New England region. Its failure before it had begun as a commercial venture may be attributed to Bagot's untimely insolvency. However, it is unlikely that the water-supply scheme would have been able to support the mill in any case.

CONCLUSIONS

This discussion of the history and technology of these four water-powered flourmills from the New England Tablelands is informative on a number of aspects of conditions for the use and adaptation of water-power to the flourmilling industry in nineteenth-century Australia. Significant among these was the vagaries of the local climate. Compared to other parts of Australia, such as Tasmania, the New England Tablelands may be considered a climatically marginal area for the use of watermill technology. This part of Australia not only receives less rainfall but, more importantly, the rainfall regime is much more variable, and hence less reliable. That this was not clearly understood for some time is demonstrated most eloquently by failure of the ambitious water supply scheme for Bagot's Mill. While the streams of the New England Tablelands may have been able to support small-scale mills operating intermittently, such as the Mount Mitchell and Yarrowford Mills, they were not reliable enough for the larger-scale commercial watermills which characterised more favorable parts of Australia such as Tasmania, even where elaborate water supply schemes were conceived.[80]

The fact that Bagot's Mill is the only one of the four to show evidence for design input by an engineer or millwright also attests to the relative isolation of the New England area, in terms of the skills necessary for the construction of sophisticated watermill technology. Further, in an economic context, by the time large commercial flourmilling enterprises requiring more sophisticated technology became possible in inland areas of New South Wales, watermill technology was rapidly giving way to steam. In contrast, the more favorable climate of other parts of the country such as Tasmania supported the use of water power in industry to the extent that there was a high demand for skilled millwrights.[81]

An indicator of the relative isolation from the nineteenth-century industrial economy can be seen in the materials and methods used in the construction of the mills. The contemporary image of Mount Mitchell Mill indicates extensive use of local materials, such as wood, in its construction, and a lack of architectural elaboration. Even a larger-scale commercial enterprise such as Bolivia Mill relied upon rudimentary construction materials and methods, such as wooden slab walls. While some iron parts were brought into the area, Bagot's Mill was the only mill to clearly demonstrate extensive use of the supportive industries, such as iron-working in the construction of its water wheel, for example, which mills in other, more heavily industrialised parts of Australia were better placed to call upon. The recycling of milling machinery from Dundee Mill for Bolivia Mill possibly reflects a shortage of such equipment in the more remote areas of the colony (although a prospective miller is unlikely to have overlooked locally available second hand machinery at the right price).

The single most important influence on the basic form the technology took, and the scale on which it was used, was the economic climate into which it was introduced. For the Mount Mitchell Mill and Yarrowford Mill (in its initial phase of operation), the rationale for their construction was to ensure the self-sufficiency of isolated pastoral communities in basic foodstuffs. Consequently, their scale of construction and production was very small, and they employed the most elementary technology. Bolivia and Bagot's Mills were constructed somewhat later in the process of settlement and development, when larger towns and markets existed. These mills were constructed on a larger scale as part of large and diversified rural commercial enterprises, and incorporated more sophisticated water-power and milling technology, more akin to watermills in parts of Australia, such as Tasmania, that were less economically and environmentally marginal.[82]

Furthermore, the troubled history and abrupt demise of both Bagot's and Bolivia Mills is indicative of the fact that both these mills faced competition from steam mills, and were built at a time when the New England grain and flour industry as a whole was entering a decline caused by competition from imports from other parts of the country such as South Australia, from which it never recovered.[83] Despite supporting a small-scale flourmilling industry to supply local needs, the New England Tablelands did not become the 'granary of the North' that Gardiner had predicted,[84] and could not support such an enterprise as Bagot's Mill, in the face of emerging competition from steam and roller-milling technology,[85] as could other parts of Australia better suited to the technology, such as Tasmania.

ACKNOWLEDGEMENTS

Most of the data on which this paper is based was gathered for a Doctorate undertaken under the supervision of Professor Graham Connah. The success of that project was due in large part to his expert guidance. The section on Bagot's Mill draws on work undertaken at this site by Professor Connah, and published in a previous volume of this Journal. I thank him for allowing me to use his work, and for getting me interested in molinological research. Assistance in the field, and in the preparation of the illustrations in this paper was kindly provided by my father, Cleon Pearson. While this paper has benefited from reading by referees, any errors or omissions remain the responsibility of the author.

NOTES

1 Pearson 1996.

2 Pearson 1997.

3 An 'overshot' wheel receives water at its apex, and generates power by the weight of the water descending in its buckets. These can be of two types: 'overshot' wheels revolve in the same direction as the flow of water entering the wheel, and 'pitchback' wheels revolve in the opposite direction. A 'breastshot' wheel is powered by a fall of water amounting

to less than the diameter of the wheel. That is, the water enters the wheel at some point between its apex and base. Again, power is generated by the weight of the water descending in the buckets of the wheel. An 'undershot' wheel receives water at its base and generates power through the impact of the flow on its paddles. This flow of water may either be in the form of a moving stream, or in rare cases, impounded tidal water released onto the wheel. Overshot and breastshot wheels can transfer approximately 75 and 60 percent respectively of the water power at any given site to the machinery of a mill, while undershot wheels can transfer approximately 30 per cent of the power available (the water power available at a site is a product of the available fall and rate of flow). Sites with a high fall are thus more optimal for power generation, even where the flow is relatively small, than sites with little or no fall. After the economic context in which a mill is situated, the geography of the mill site is the next most important factor in determining the technology employed in a watermill.

4 Collins 1798 vol. 1:428.

5 *Hobart Town Gazette* 20 Mar., 1816.

6 HRA, Series 1, vol. 4:468; HRNSW vol. 3:301-2.

7 Dimensions are given in imperial units to preserve their historical meaning. See text and scales on Figs 2 - 5 for conversion to metric.

8 Caley n.d.; *Sydney Gazette* 6 Nov., 1803.

9 HRA, Series 1, vol. 4:468.

10 Caley n.d.; HRA Series 1, vol. 5:11.

11 Governor King, *Dispatches*, 20 December, 1804, quoted in Campbell 1927:363.

12 Quoted in Russell 1978:50.

13 Wentworth 1819:121.

14 *Australian* 25 July, 1828.

15 *Sydney Gazette* 30 Sept., 1820.

16 Jack 1986:26.

17 Linge 1979:108-9.

18 Jack 1978.

19 *Sydney Gazette* 3 June, 1815.

20 HRNSW vol. 3:137; HRNSW vol. 4:898.

21 HRNSW vol. 4. :368.

22 *Sydney Gazette* 23 June, 1805.

23 See illustration and description in Jack 1983.

24 Collins 1798 vol. 1:316-17.

25 Collins 1798 vol. 1:366.

26 Collins 1798 vol. 1:359.

27 Linge 1979:47.

28 Linge 1979:143.

29 Davis 1988:21; Harrison 1979:23.

30 Hartwell 1954:148; Linge 1979:127-29.

31 Connah 1988:129-30.

32 Jack 1983:28.

33 Lea *et al.* 1977.

34 *New South Wales Legislative Council Votes & Proceedings* 1842:393-97.

35 J. Everett, 23 Feb., 1845, University of New England Archives.

36 *Tenterfield Independent* 7 Jan., 1880.

37 *Armidale Express* 29 May, 1858.

38 *Armidale Express* 24 April, 1858.

39 *Armidale Express* 23 Jan., 1859.

40 Walker 1966b:66.

41 *Statistical Register of New South Wales* 1849/58-1900.

42 *Armidale Express* 15 Sept, 1866.

43 *Armidale Express* 2 July, 1870.

44 Godwin 1983; Walker 1966b.

45 Gardiner 1854 vol. 2:78-9.

46 *Armidale Express* 29 Jan., 1858.

47 Walker 1966a:25; 1966b:3.

48 o'clock positions on water wheels are noted from the power take-off side of the wheel.

49 Reynolds 1983.

50 Gardiner 1854 vol. 1:101.

51 Jones 1969.

52 Gardiner 1854 vol 2:78-9.

53 *Sydney Morning Herald* 29 Jan., 1850.

54 *Armidale Express* 4 April, 1858.

55 Hartmann 1979.

56 Gardiner 1854 vol. 2:78-9.

57 Hartmann 1979:36.

58 Walker 1966b:4.

59 Halliday 1988:49.

60 Halliday 1988.

61 *Armidale Express* 30 Oct., 1858; Hartmann 1979:36.

62 Reynolds 1983 contains a discussion of the relative efficiencies of the various types of water wheels.

63 Renwick 1830 and Vince 1987 both quote a figure of approximately three to four horsepower as being sufficient to drive a single pair of millstones.

64 Handwritten note on the reverse of the 1868 photograph.

65 Gardiner 1854 vol. 2:78-9.

66 Walker 1963:1-2.

67 Walker 1963:2-4.

68 *Sydney Morning Herald* 8 June, 1874.

69 *Sydney Mail* 27 Jan., 1877. Goddard was later owner of the Phoenix Foundry at Uralla, which is still in operation today.

70 *Glen Innes Examiner* 7 April, 1934; Walker 1963:4.

71 *Glen Innes Examiner* 28 Mar., 1877.

72 *New South Wales Government Gazette* 1879, vol. 4:4910.

73 *Armidale Express* 9 Sept., 1871; 2 Aug., 1873; 14 May, 1875; 17 Sept., 1875.

74 R. Streeter pers. comm.

75 *Glen Innes Examiner* 7 April, 1934.

76 Reynolds 1983:180.

77 *Glen Innes Examiner* 7 April, 1934.

78 Craik 1877.

79 Connah 1980; 1983; 1994.

80 e.g. Pearson 1997.

81 See Pearson 1997.

82 Pearson 1997.

83 Walker 1966b:6-8.

84 Gardiner 1854 vol. 1:276.

85 Walker 1966b.

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