Water Power in a Dry Continent: The Transfer of Watermill Technology from Britain to Australia in the Nineteenth Century

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This paper presents the results of research for a Doctorate undertaken from 1991 to 1995, in the Department of Archaeology and Palaeoanthropology at the University of New England, Armidale, NSW. The aim of the research was to construct a model for the transfer and adaptation of industrial technology from Britain to Australia in the nineteenth century. The paper considers what factors were important for the process of international technology transfer. This leads to hypotheses about how it should have been adapted as a result of its transfer. These are then tested by a comparison of the physical remains of the technology preserved in both countries. A generalised model for the transfer and adaption of industrial technology from Britain to Australia in the nineteenth century is then put forward.

In order to construct a model for the transfer and adpation of industrial archaeology between Britain and Australia in the nineteenth century, published research on international technology-transfer, which may be defined as the movement between countries of technological knowledge and/or hardware, was used to identify and define the most important economic, environmental, industrial, human and cultural factors influencing the process. These factors were then used as starting points for a comparison of the two countries, Australia and Britain, between which a given technology, that of watermills, was transferred. From this comparison it was possible to hypothesise about how the technology should have been adapted as a result of its transfer. These hypotheses were tested by a comparison of the physical remains of watermill technology preserved in the West Midlands of England, Tasmania and the New England Tablelands of New South Wales. From this, a generalised model for explaining the adaptation of industrial technology introduced into nineteenth-century Australia was put forward. This emphasises production inputs and resource endowments in the recipient country as the most influential selection pressures, and defines the relationships of these with other factors, including 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.

BACKGROUND

In seeking to define the aims and objectives of Australian historical archaeology as a discipline, Murray (1985:121) stated that, '...Australian historical archaeologists should build theory that takes into account the peculiar nature of the database here...'. Pre-empting this statement, one such major research theme to which Australian historical archaeology could make a major contribution was recognised as early as 1978 when Allen (1978:145) asserted that, 'By virtue of its late colonisation, Australia provides an excellent area for examining problems of colonialism which seem likely to be universal to all periods, historic and prehistoric'. One such problem was elucidated by Jack (1981:164) when he stated that, 'The whole question of industrial revolution technology transported to a hostile environment is challenging and exciting...', and pointed to the need for a '...more systematic appraisal of British influences on colonial technology, and colonial adaptations of overseas techniques'. Pearson (1984a:27–8) outlined this problem in more detail,

> Australia is one of the few areas of the world where isolated post-industrial revolution settlement occurred. In many fields this isolation resulted in the modification of European technology, or the improvisation of a local technology, with European roots, to cope with local conditions, both environmental and social. Many of these technological developments went unrecorded in the contemporary literature, and the 'hardware' of these developments seldom finds its way into our museums, and when it does it is often unidentified, presented out of context, or inadequately understood. In many cases archaeological techniques may be the only way to recover worthwhile evidence of these developments.

Thus, the unique database of Australian historical archaeology puts the discipline in an important position for formulating and testing ideas on technology importation and adaptation themes. However, taking the Journal of the Australasian Society for Historical Archaeology as an indicator of the research orientation of historical archaeologists in Australia, of the 115 papers appearing in that publication in the period 1983 to 1993, only 21 have comprised or contained studies of the material remains of some form of industrial technology.

Godwin (1983) describes the technology of a nineteenth-century, steam-powered flourmill at Uralla, New South Wales, while Bignell (1988) describes that of a water-powered flourmill at Bothwell, in Tasmania and Stenning (1993) discusses the technology of early textile mills in New South Wales. Pearson makes various contributions on the technology of the whaling industry (1983), wool scouring, at Tibooburra, in far western New South Wales (1984b), the lime industry in New South Wales (1990) and the eucalyptus distilling industry in Australia (1993). The technology of the whaling industry in Western Australia has also been dealt with by McIlroy (1986), while the technology of the wool industry at sites in Geelong, Victoria, has also been dealt with by Cummins (1989). Rogers (1984; 1988; 1990; 1991) makes a series of contributions on the technology of salt manufacture at various sites in eastern Australia. Research on mining and ore-processing technology featured heavily, with research on the technology of gold mining in Victoria by Davey (1986), hydraulic coal handling technology in New South Wales by Bairstow (1986), and the technology of tin mining in eastern Australia by Kerr (1989), copper smelting at Bolla Bollana in South Australia by Bannear (1988) and copper mining and smelting in New Zealand, which were closely related to these industries in Australia, by Clough (1989; 1991). Clough (1989) also examines the technology of the clay industry in New Zealand, while Stuart (1989) describes brickmaking technology in Melbourne, Victoria.

In all of these studies, explicit theoretical approaches and general statements arising from study of the physical evidence are at a premium. While most of the above-mentioned studies discuss the observed technology in terms of adaptation to the context in which it occurs, this has almost universally taken the form of the invocation of 'economic' factors as the forces producing technological adaptation, as in the case of Bairstow (1986), Clough (1989), Cummins (1989), Godwin (1983), Kerr (1989), Pearson (1983), Rogers (1984; 1991), and Stuart (1989). Some researchers have, however, sought to identify other factors acting to produce technological adaptation, such as climate or physical environment in terms of resource distribution (Pearson 1984b; 1990), political factors (Clough 1989; Cummins 1989), social factors (Clough 1989), industrial context, in terms of supportive and associated industries (Clough 1991) and human factors, in terms of the skilled operators (Rogers 1990; Stuart 1989) associated with the technologies. Only Stuart (1989), in his treatment of measures of 'adaptive fitness' in relation to the Victorian brickmaking industry, has explicitly discussed any theoretical approach to the study of technological adaptation or appropriate methodology by which such an approach may be undertaken, although it is not actually applied. A second limitation of much of this research is that many of the above studies adopt site specific and particularist approaches, usually only dealing with one site, or the 'first' or 'biggest' example of the technology.

It is clear that important theoretical and methodological issues remain to be addressed in the study of technology importation and adaptation in Australian historical archaeology. These are: the need for studies incorporating large samples of sites from geographic regions or from industries, the need for some theoretical and methodological framework by which observed variation in technologies may be linked to the various factors which researchers have postulated as causes for adaptation, and the need for a workable model describing the roles and interrelationships of all of these factors in the transfer and adaptation process.

RESEARCH DESIGN AND METHODOLOGY

Trigger (1989:21–23) outlines three levels of theory in archaeology. Firstly, there is what Klejn (1977) has termed low-level theory, or generalisations concerning regularities of space, time and form in the archaeological data. Secondly, middle-level theory is defined by Raab & Goodyear (1984) as generalisations that attempt to account for regularities that occur between two or more sets of variables in two or more sets of archaeological data. Most often these regularities are accounted for with the use of middle range theory (eg. Binford 1981), which seeks to establish and define relationships between archaeologically observable phenomena and archaeologically unobservable human behaviour. Thirdly, high-level theory is defined as the general rules that explain the relationships among middle-level theoretical propositions relating to major categories of cultural phenomena (Clarke 1979:25–30; Harris 1979:26–7). Binford (1981) draws attention to the external origin of most high-level theory used in archaeology, while allowing an internal origin for some middle and all low-level theory.

An inability to progress beyond the use of low-level theory in technological adaptation studies in Australian historical archaeology may perhaps be interpreted as a result of the fact that there does not appear to have been a clear understanding of what the concept of adaptation actually involves. With the exception of Stuart (1989) there seems to have been little awareness or reference to a huge body of high level theory, evolutionary ecology, which deals with adaptation as a process. Drawing on evolutionary ecology theory, Mithen (1989:486; cf. Kirch 1982:103) makes a distinction between adaptation as a study of end products (ie. the artefacts which reflect adaptive behaviour) and adaptation as a study of the process itself; a distinction which seems to have been largely overlooked by historical archaeologists in Australia.

Within evolutionary ecology theory, adaptation is seen as a process of change or modification so as to achieve a better fit between organism and environment. According to Kirch (1982:103), one of the basic tenets of this processual relationship is a specific environment, the stability and heterogeneity of which is of utmost importance in determining selection pressures on adaptation. In human terms, culture, or socially transmitted rules for behaviour (Deetz 1977:24), is the primary means by which the human organism adapts to its environment. Material culture, or those aspects of our physical environment that humans modify through culturally-determined behaviour (Deetz 1977:24), is what is left behind as the archaeological record of the adaptive process.

According to Binford (1964:426), if archaeologists are to profitably study the process of adaptation from its material remains then they, '...must be able to isolate cultural systems and study them in their adaptive milieu conceived in terms of physical, biological and social dimensions'. In other words, if we are to profitably study the process of adaptation of nineteenth-century watermill technology as a result of its transfer from Britain to Australia for example, the various dimensions against which the process takes place must be isolated and defined, and the influence and importance of each in the adaptive process treated in turn. The task thus becomes, '...the isolation of variables initiating directional change in the internal structuring of ... systems' (Binford 1968:323). Kirch (1982:15) puts it more simply by stating that one of the major issues confronting the archaeological study of adaptation is that of, '...relating observed variation to probable selection pressures in the environment...' and goes on to say that, 'As a matter of research strategy, the identification of possible constraints with regard to [adaptation in] a particular environment ... would seem to be a mandatory task' (Kirch 1982:124).

It is not enough to argue that evolutionary ecology theory should be proposed as a high level theoretical approach to the study of technological adaptation without offering some form of middle-level, or middle range, theory by means of which it may be linked to low-level theory derived from study of the archaeological record. It is at this point that recourse to research in the field of international technology-transfer theory becomes useful. In examining conditions which either promote or retard successful international technology-transfer (see Stapleton 1975, 1987 for useful summaries), this body of literature may be used to identify and study the interaction of a variety of variables operating in the process of adaptation, thereby allowing generalised statements to be made which could lead to models of the technology transfer and adaptation process itself. Technology transfer theory therefore provides a way of linking observations on introduced technologies to variables influencing the process, thus providing a framework within which observed adaptations of introduced technologies can be linked to higher level theory to help explain the reasons for them. Such a use of technology-transfer theory as middle-level theory is consistent with the requirement that a logically-coherent relationship should exist between high, middle and low levels of theory in archaeological research design (Trigger 1989:21), insofar as both evolutionary ecology theory and technology-transfer theory allow the user to conceptualise adaptation as a process whereby an organism or technology changes in response to changes in its environmental setting.

This research therefore aims to construct a model for technology-transfer and adaptation between Britain and Australia in the nineteenth century. This is done via the testing of hypotheses on a case study. A body of theory on international technology-transfer is used to identify and define the most important conditions influencing adaptation of technology as a result of its transfer. A comparison of these conditions in two countries between which a given technology was transferred, based on both primary and secondary documentary sources, will allow for the formulation of hypotheses about how and why the chosen technology should have been adapted as a result of its transfer. A comparison of samples of the physical remains of the technology preserved in both countries, will allow the hypotheses to be tested. Once the hypotheses have been tested and modified where necessary, a generalised model for the adaptation of technology transferred from Britain to Australia in the nineteenth century can be advanced.

The use of documentary and archaeological sources, '...such that each body of data is used to inform the other in such a way as to arrive at a conclusion that neither data set could provide alone' (Deetz 1988:363), is what, according to Deetz, constitutes the distinctive methodology of historical archaeological research. According to Lydon (1993:34) historical archaeology's capability of gaining simultaneous access to the past through multiple, independent categories of evidence is its great strength (cf. Deagan 1988). Exactly how to do this has been the puzzle (Leone 1992). Leone proposed a method conceptually analogous to Binford's Middle Range Theory (Leone 1989; Leone & Potter 1988; Binford 1977). Substituting documentary evidence for the ethnographic record used in Binford's model, he suggests that by assigning the archaeological and documentary evidence different epistemological status we may be able to see them as 'independent and unidentical phenomena' (Leone 1989:33; Birmingham 1990:14–15). Such an approach is broadly followed by this research.

DATABASE

A large amount of research of widely varying kinds has been published on watermill technology. General surveys of the history of watermills are now available, a history of the vertical water wheel, *Stronger Than a Hundred Men*, by Terry Reynolds (1983) being the most detailed and comprehensive. Other historical surveys target more specific parts of the world, where water wheels formed an important industrial power source, such as Britain (Reynolds, J. 1970; Starmer 1975; Syson 1980), Scotland (Shaw 1984), New Zealand (Thornton 1982), the United States (Hunter 1979), and South Africa (Walton 1974). Industry-specific surveys of watermills in Britain have also been conducted on flourmills (Jones 1969; Watts 1983), textile mills (Giles & Goodall 1992), paper mills (Shorter 1957), metalworking mills (Crossley 1989), and water wheels used in mining (Woodall 1975).

Very little of this research however has been directed towards examining general questions or wider issues relating to the technology. Considering the prominent industrial, economic and social role water-power played in both pre and post-industrial revolution Western societies, this lack is somewhat surprising. Rare examples include Reynolds, T. (1979; 1983:ch. 4) and Gordon (1985), who examine the role of the water wheel in the development of the science of fluid dynamics; Gordon (1983), who examines the role of the cost and availability of water-power in promoting industrialisation in Britain and America; Hasse (1984), who examines the role of the small-scale watermill in maintaining quasi-premodern local rural cultures well into the twentieth century in parts of southern United States; Langhorne (1976), who examines the influence of different types of watermills on settlement patterns at a regional level in New York State; and Schreuder (1988:34), who uses watermill technology in South Africa as an example of the adaptation process to a new environment by a colonising people. It is noteworthy, that most of this research has been done in America, where, in contrast to the situation in Australia, there has been considerably more higher level theoretical development in historical archaeology (see for example papers in Schuyler 1978). In attempting to use higher level theory from outside the discipline (ie. geography) to model an historical cultural process such as settlement patterns, Langhorne's research in New York State is a case in point.

Research on water wheels and watermills in Australia has been extensive, with most of the early colonies and states being represented by historical surveys of water-power introduction and development. Victoria is represented by a survey by Mackay (1936-1937) of the first flourmills of Port Phillip and statewide by a survey of flourmills by Jones & Jones (1990). New South Wales is represented by several studies of the first mills of Sydney, including those by Selfe (1900) and Abbott & Nairn (1969). Tasmania is represented by a study of water-power in Tasmanian history by Dallas (1959) and regional studies of early watermills in Hobart and Launceston by Rayner (1988) and Morris-Nunn & Tassell (1982), respectively. Western Australia is represented by a survey of the early mills of Perth by Hasluck and Bray (1930). South Australia is represented by a survey of water-powered flourmills in that state by Jones (1981–1982). Queensland is represented by a single site-specific study of a water-powered sawmill (King 1994). On a larger scale, Jack (1983) gives an Australia-wide discussion of the technology and history of nineteenth-century water-powered flourmills and Linge (1979) discusses the geographic distribution of watermills of various industrial applications in his historical geography of early Australian industry.

While none of these surveys deal explicitly with the technology of the mills discussed, they nevertheless provide a good insight into the nature, distribution and economic context of early Australian industries which relied on water-power. The prominence of the flourmilling industry in the literature reflects more a higher visibility in the historical and archaeological record and consequent interest among researchers than the dominance of this industry among those which relied upon water-power. Other colonial industries which relied heavily upon water wheels included gold-mining, non-ferrous ore processing, and sawmilling (Birmingham 1979; Dallas 1959; Drew & Connell 1993:80; Milner 1989; Whitham 1980). Textile and gunpowder industries also made some early use of water-power (Jack 1980; Rowland 1944; Jones & Jones 1990:32).

In addition to these secondary sources, there are a number of important primary sources which hold information relating to watermill technology in nineteenth-century Britain and Australia. The first is in the form of *Statistical Returns* produced by the administrations of the various Australian colonies. These contain the numbers and location of watermills employed in various industries in each of the colonies throughout the greater part of the nineteenth century (cf. Institute of Engineers 1988). For the flourmilling industry, numbers of mills powered by steam, wind and animals are sometimes also available for comparison. A second source of primary information is in the form of collections of contemporary photographs of watermills held in the various State Libraries and the National Library of Australia. These often allow some assessment of the technology of design and construction of actual mills. While regrettably, few such comprehensive statistics on watermill use in nineteenth-century British industry are available for comparison with the Australian statistics, a similar contemporary pictorial record of nineteenth-century British watermill technology is available for study (eg. Major & Watts 1977). A variety of nineteenth-century British millwrighting treatises, such as Fairbairn

(1849, 1878) and Gray (1804) also provide detailed information on watermill design and technology of the period.

In excess of 2000 watermill sites in Britain, concentrated in England and Wales, have been recorded. These have been entered on a National Watermill Index (Jones 1966) compiled by the British arm of the International Molinological Society. Of these, some 150–180 mills remain in various stages of working order (S.P.A.B. 1991). This provides an extensive database for the physical study of nineteenth-century water wheel and watermill technology in Britain.

Obviously it was neither possible nor necessary to examine every watermill site available for study in Britain. In selecting a representative sample for detailed comparative physical analysis, watermill sites were sought where the technology of the water-supply, water wheel, power-take-off, power transmission gear to the machinery, the machinery and the mill building were largely intact and of eighteenth- to nineteenth-century vintage. The large number of preserved and restored mills in Britain allowed ample latitude for the selection of such a sample. The sample for this was drawn from the west Midlands area of England (Fig. 1), as this area had a high concentration of preserved watermills available for study. It also included both agricultural areas and some of the most heavily industrialised and populated areas of nineteenth-century Britain, such as Birmingham and Manchester. The region would thus have provided a varied sample of technology for transfer to the colonies. All of the mills surveyed had either been in constant production up to the present, or had been faithfully restored to working condition.

In Australia, the situation is very different. Very few watermills remain substantially intact and there was no latitude for selecting a representative sample from these. The sample was essentially limited to those remaining and was almost entirely restricted to a single part of the country, Tasmania. This sample comprises five nineteenth-century watermills in Tasmania (Fig. 2), with Anderson's mill from central Victoria included, and ranges from small-scale, rural flourmills to a large-scale flour factory, ranging in construction date from 1824 to 1861. These mills represent most of those known to be preserved in a reasonably intact or restored condition and available for study in Australia. The high concentration of relatively intact watermills was not the only consideration in the choice of Tasmania as a study area. A second reason was that Tasmania represented an optimal physical environment for water wheel technology in Australia, and thereby offered scope for comparison of the technology with that from more marginal physical environments in other parts of Australia. This is an important first step in considering the adaptive influence of the physical environment on an introduced technology, particularly one which is as sensitive to its environment as watermill technology.

The problem of the sample of Australian mills being much smaller and less representative in some respects than that from Britain was overcome by the inclusion of a second sample of mills from the New England Tablelands of New South Wales for comparison with the British sample (Fig. 3). While the mills from this study area do not physically preserve as much of their buildings or machinery, they are nevertheless reasonably well documented as a group, allowing some reconstruction of their technology.

The New England Tablelands is a region very similar in size to both the West Midlands of Britain and Tasmania. The sample comprises small-scale, rural flourmills, ranging in construction date from the 1840s to the 1870s. The inclusion of the New England Tableland Region as the third study area in this research program had two advantages. Firstly, the relatively high concentration of nineteenth-century watermill sites it contained allowed for the total number of mills in the Australian sample to be equivalent to the British sample. Secondly, and most importantly, it allowed the sampling of sites across the entire range of physical environments in which the technology was used in colonial Australia. The New England Tablelands may be considered a more marginal area for the use of watermill technology, in terms of its climate, when compared to other parts of Australia, such as Tasmania.

As with the written record, the bias towards flourmills in the physical record is unfortunate, but inescapable. These mills

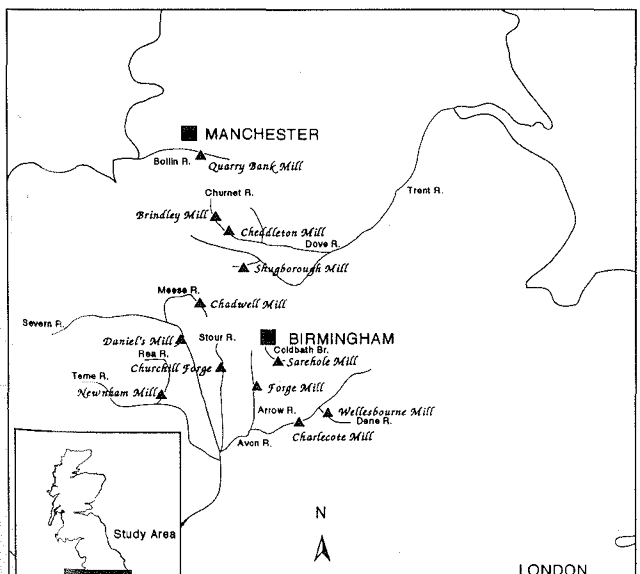

Fig. 1: Location of watermills studied in the West Midlands of Britain. All were either built in the eighteenth–nineteenth century, or were last rebuilt at that time, and preserve their machinery intact, and in most cases in working order. With the exception of Forge Mill (needle-making), Churchill Forge (ironworking), Cheddleton Mill (flint-grinding) and Quarry Bank Mill (cotton textile manufacture) all are flourmills.

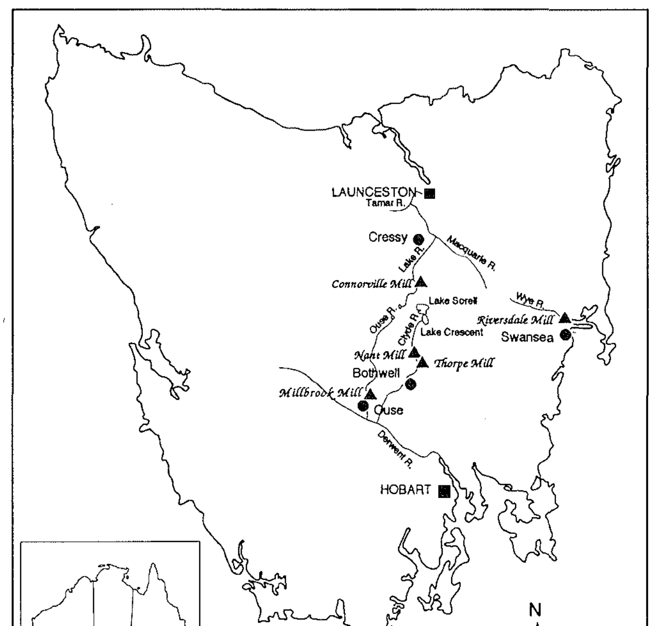

Fig. 2: Location of watermills studied in Tasmania. Construction dates range from the 1820s to the 1840s, with all preserving their machinery largely intact. All are flourmills. Anderson's Mill, a large flour factory built in 1861 at Smeaton in Victoria, was also included in this sample.

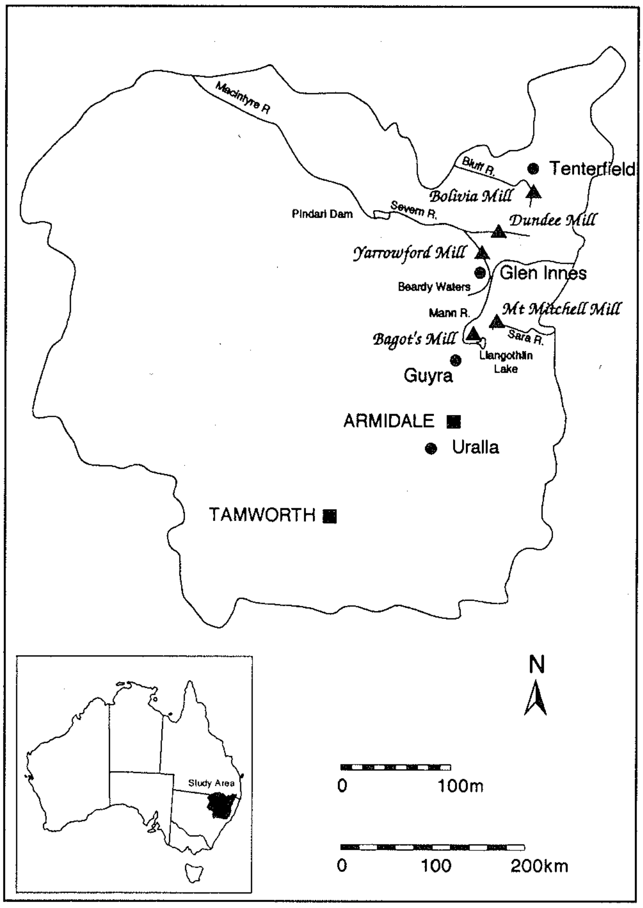

Fig. 3: Location of watermills studied on the New England Tablelands of New South Wales. All were flourmills, with construction dates ranging from the 1850s to the 1870s.

tend to have been of more permanent construction and have remained in use longer than watermills serving other industries such as sawmilling and mining, and so more have survived intact for study.

After recording the mills, the archaeological data was summarised and tabulated by study area for the purposes of analysis. The analysis consists of the comparison of the Australian and British samples of watermills for the presence of hypothesised changes in technological attributes considered diagnostic of important adaptive pressures identified in various contexts, including: economic, environmental, human, industrial and sociocultural. If these technological attributes were seen to have changed in the way it was hypothesised that they should have as a result of the differences in the various contexts between the two countries, then the hypotheses were supported, with the reverse applying also. Once the veracity of the hypotheses about adaptation as a result of transfer of the technology had been assessed, and they had been refined where necessary, they could then be used for the construction of a generalised model describing the interrelationships and importance of the various contextual factors in the transfer and adaptation process.

RESULTS

Economic conditions

The seminal contribution on the importance of the role of economic conditions in international technology-transfer was made by Nathan Rosenberg (1970, 1972b). Basic to Rosenberg's work was the idea that the successful transfer of technology is heavily dependent on selection and adaptation of technology to accommodate the production inputs of the recipient country (Rosenberg 1970:183, 185; cf. Rosenberg 1972b:203).

> Since countries differ, sometimes drastically, in the availability of the factors of production...techniques which are efficient (i.e. minimise costs for a given volume of output) in one environment may not be efficient in another. Therefore, between two countries differently endowed...we should expect the borrowing country to borrow in a highly selective fashion; i.e., to borrow some techniques rapidly, others more slowly, and perhaps yet others not at all. Underlying the selective nature of the transfer and diffusion, then, is an economic mechanism, based upon factor proportions and factor prices, which determines the expected profitability of different techniques in a new environment. (Rosenberg 1972a:61)

Rosenberg argued that differing production inputs within the recipient country could explain the success or, failure or adaptation of a transferred technology. Transfer of those technologies which were most suited to the production inputs of the recipient country would be favoured with success. Jeremy (1981:ch. 3) demonstrated this in relation to the transfer of textile manufacturing technology from Britain to the United States in the nineteenth century. Those technologies which were most successful were among the simpler alternatives from the range of British technology, and were more labour efficient and less raw material efficient, reflecting the relative strengths and weaknesses of economic resources in the donor and recipient countries. In using expected profitability as a measure of the suitability of technology for transfer, Rosenberg also allows output markets an important role as an economic condition influencing transfer and adaptation. This stress upon specific factors relating to production inputs and output markets, forms a recurrent theme in the economic-history literature on technology-transfer. Uselding (1977:184–6) listed several studies of technology-transfer between Britain and the United States in the nineteenth century, including those of Coleman (1969) and Jeremy (1973:1981) on textile technology, that of Temin (1964) on the iron industry, and that of Robinson (1974) on steam engines, which emphasised the importance of these factors in shaping the transfer and adaptation process.

Thus, the important economic factors for successful international technology-transfer and adaptation may be defined in terms of the specific combinations of production inputs, such as labour and capital, as well as output markets, particular to a given industry and which act as determinants of technology in use within that industry. A comparative discussion of the economic structures of the various industries served by watermills in both nineteenth-century Britain and Australia and how these determined the technology of watermills and the techniques of production used in them, will allow for the generation of hypotheses regarding how altered economic conditions within industries represented in both countries would have acted to produce differences in the use of the technology between countries, and what those differences should have been.

As would be expected in a comparison between a heavily industrialised nation and what still largely amounted to a colonial outpost, some economic contexts for the use of watermill technology did not exist in both countries. More basic economic conditions common to all industries were radically different between the two countries. While the available labour for industry in nineteenth-century Australia was small, an even smaller proportion of it could be considered to be skilled. Certainly the number could not match the available industrial labour pool in nineteenth-century Britain. Also, the trickle into Australia of immigrants with capital to invest in industry would have in no way matched that available for investment in Britain. Nor would there have been many opportunities for investment in building industrial establishments on such a scale as to provide attractive returns in the colonies. In addition there was the obvious constraint of a very small population spread over a vast area in Australia causing markets for products to be very dispersed. Finally nineteenth-century Australian economic conditions favoured primary industries over manufacturing industries, a reverse of the situation in nineteenth-century Britain.

From this comparison, a number of hypotheses may be made about adaptation of watermill technology as a result of its transfer from Britain to Australia. The economic situation of Australian watermills should generally be reflected by more widely dispersed mills operating on a smaller scale of production, and in a more restricted range of industrial applications than was the case in Britain. These should therefore also be characterised by the generation of power in smaller units.

As predicted, colonial watermills were found to be more widely dispersed in the landscape. While all three areas sampled for this study were approximately the same size geographically, the two areas in Australia supplied only a similar amount of mills for study to the single area in Britain. While this finding is necessarily based on mills which have survived for study, it is corroborated by nineteenth-century statistics of numbers of mills in operation in Australia and Britain. Jones (1969) conservatively estimates a total of 10 000 flourmills alone to have been in operation in England and Wales during the eighteenth to nineteenth centuries, to which Shaw (1984) adds a further 2 300 for Scotland and Jones & Bowie (1977) add 1 482 for Ireland. By comparison, statistics for the maximum number of watermills of all industrial applications known to have operated in all Australian colonies at any one time during the nineteenth century approximate only 860 (see *Statistical Returns* and *Statistical Registers* for the various colonies).

In addition to being more geographically dispersed, colonial mills also operated almost exclusively in primary or extractive industries, as predicted (Table 1). Although the bias towards flourmills is a product of those mills which happened to survive intact for study, only a handful of colonial watermills are known to have operated in industries outside flourmilling, sawmilling and mining, such as the manufacturing sector (e.g. Institute of Engineers 1988). In contrast to Britain, where water-powered textile manufacturing industries underpinned the British economy in the early nineteenth century (Reynolds, T. 1983:ch. 5), a total of only five water-powered textile mills are known to have operated in Australia (Dallas 1959; Stenning 1993; Rayner 1988).

To compare the scale of production and power output of British and Australian mills in all industries would be misleading, as the nineteenth-century British economy possessed a far larger water-powered manufacturing sector, with many water-powered factories operating at mass production levels, and powered by water wheels generating up to several hundred horsepower (Reynolds, T. 1983:ch. 5). However, in a comparison of watermills in a single industry represented in both countries, such as the flourmilling industry, colonial mills were found to have operated on a generally smaller scale of production (Table 2), and generated smaller units of power (Fig. 4) than their British counterparts, again as predicted. The sample of water-powered flourmills surveyed shows that, as measured by the number of millstones in each mill (Table 2), production capacity was well below that of their British counterparts. The greater number of auxiliary grain and flour processing machines in Australian mills (Table 2) is interpreted as a response to less labour being available to do these jobs than in Britain. The often greater scale of provision for storage and handling of products in colonial mills is interpreted as a response to the more dispersed markets of nineteenth-century Australia than Britain.

Table 1

ENGLISH MILLS	INDUSTRY
Shugborough	flourmill (farm machinery)
Chadwell	flourmill
Newnham	flourmill
Daniel's	flourmill
Charlecote	flourmill
Wellesbourne	flourmill
Brindley	flourmill (sawmill)
Sarehole	flourmill (blade grinding)
Cheddleton	flint mill
Churchill	ironworking forge
Forge	needle mill
Quarry Bank	cotton textile factory
TASMANIAN MILLS	
Connorville	flourmill (farm machinery)
Thorpe	flourmill (farm machinery)
Nant	flourmill (farm machinery)
Riversdale	flourmill
Millbrook	flourmill
Anderson's (Vic.)	flourmill
NEW ENGLAND MILLS	
Mount Mitchell	flourmill
Yarrowford	flourmill
Dundee	flourmill
Bolivia	flourmill (sawmill)
Bagot's	flourmill (sawmill)

Table 1: Industries served by watermills studied in each of the three sample areas. The fact that similar patterns of water power use in nineteenth-century industry emerge from comparisons of contemporary statistics, suggests that differences are not simply a result of sample bias.

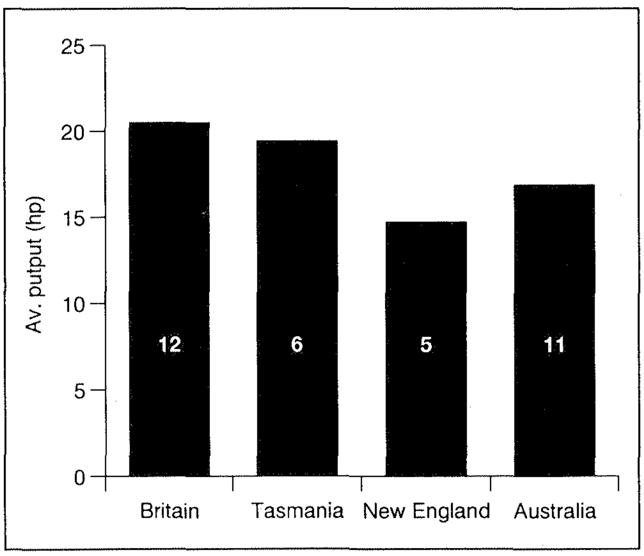

Fig. 4: Comparison of power output for water wheels studied in each of the three sample areas. Those in Britain have the highest output, followed by those in Tasmania and those in the New England Region of New South Wales. This is commensurate with other qualitative variables measuring productive capacity presented in Table 2.

Where economically-sensitive aspects of the technology departed most significantly from the British pattern such as on the New England Tablelands and at Anderson's Mill, in Victoria, the economic conditions had also departed most significantly from those in Britain. Early-to-mid nineteenth-century New England was characterised by extremely isolated, vast pastoral settlements each requiring its own small mill, such as that at Mount Mitchell (Fig. 5), while the boom of the Victorian goldrushes was the economic context for Anderson's Mill (Fig. 6), a huge flour factory. The case of Anderson's Mill also demonstrated that appropriate technology may need to be

Table 2				
ENGLISH MILLS	PAIRS OF STONES	No. AUX. MACHINES	STORAGE	HANDLING
Shugborough	2	1	bin floor	hoist
Chadwell	2		bin floor	hoist
Newnham	3	2	bin floor	hoist, elevator
Daniel's	3		bin floor	hoist
Charlecote	3	2	bin floor	2 hoists
Wellesbourne	2	1	bin floor	hoist
Brindley	3		bin floor	hoist
Sarehole	5	1	bin floor, barn	2 hoists
AVERAGE	2.9	0.9		
TASMANIAN MILLS				
Connorville	1	2	bin floor	hoist, elevator
Thorpe	2	2	bin floor, barn	hoist, elevator
Nant	2	1	bin floor, barn	hoist
Riversdale	2	1	bin floor, barn	hoist
Millbrook	2	3	bin floor	hoist
Anderson's (Vic.)	3+	10+	bin floor, barns	hoists, elevator
AVERAGE	1.8	1.8		
NEW ENGLAND MILLS				
Mount Mitchell	1		hopper	
Yarrowford	1		hopper	
Dundee	1		hopper	
Bolivia	~2	1	bin floor	hoist
Bagot's				
AVERAGE	1.25	0.25		

Table 2: Comparison of variables measuring the productive capacity of flourmills studied in the three sample areas. With some variation, those in Britain have the highest production capacity, followed by those in Tasmania and those in New England.

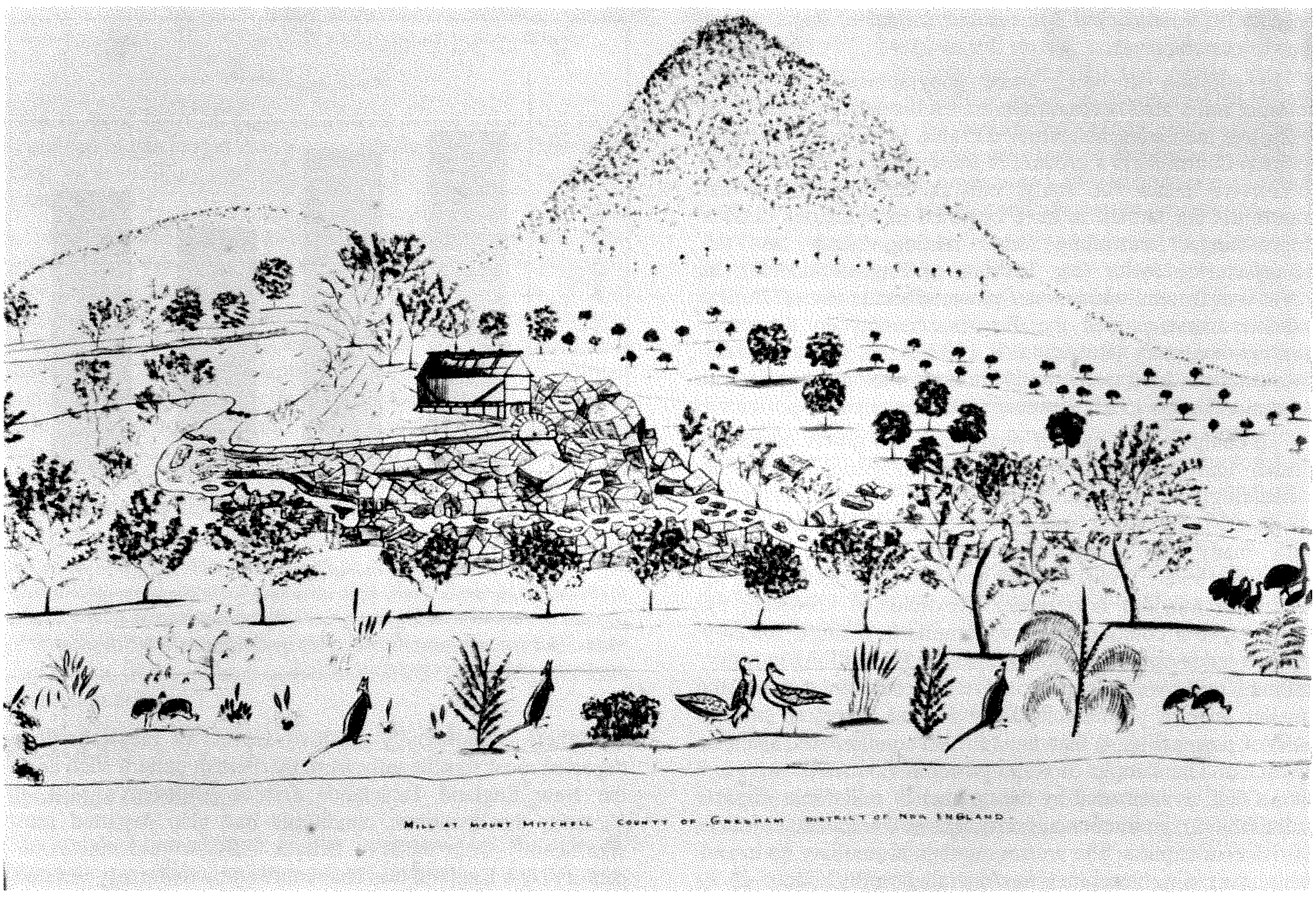

Fig. 5: Flourmill on Mount Mitchell Station, on the New England Tablelands of New South Wales (from a drawing in Gardiner 1854), an example of the smaller end of the economic spectrum for flourmills in nineteenth-century Australia. (Bicentennial Copying Project, State Library of New South Wales).

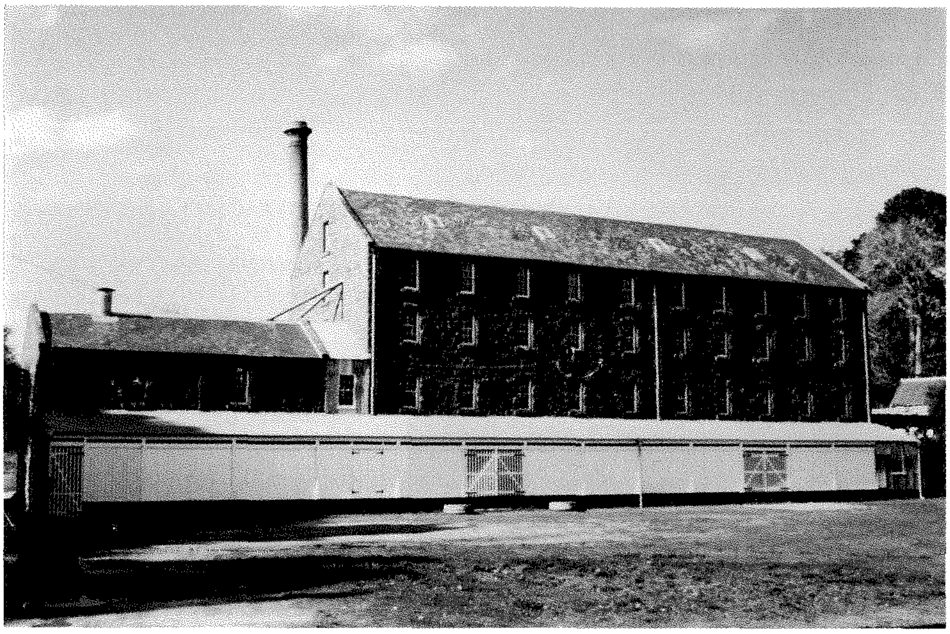

Fig. 6: Anderson's Mill at Smeaton, Victoria (photo. Pearson 1993), an example of the larger end of the economic spectrum for flourmills in nineteenth-century Australia.

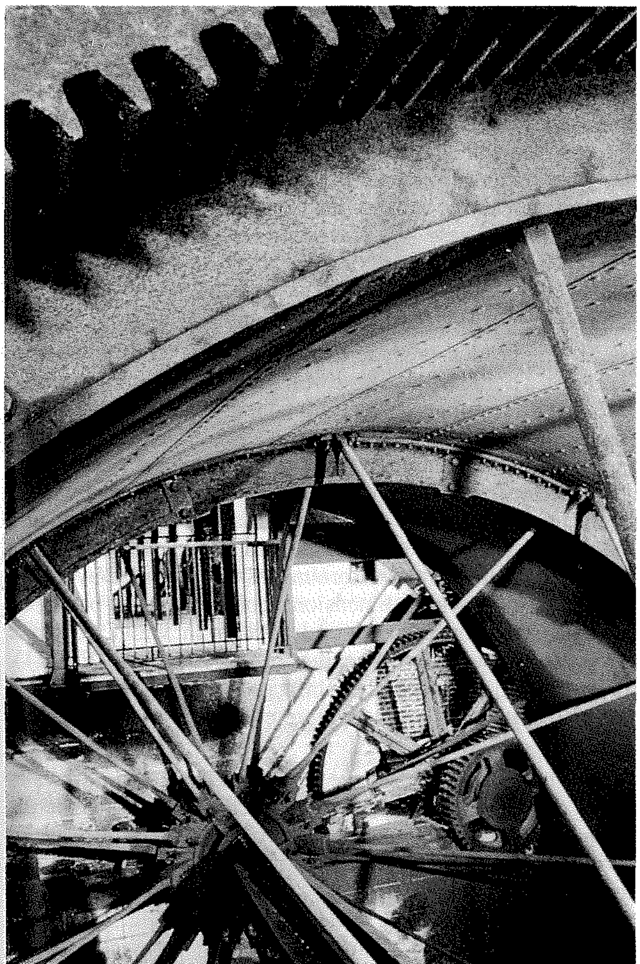

Fig. 7: Water wheel at Quarry Bank Cotton Mill, near Manchester (photo. Quarry Bank Mill Trust). The design and scale of this wheel is similar to that used at Anderson's Flourmill in Victoria.

borrowed from mills in other industries, where it is lacking in the corresponding industry in Britain. This is seen at Anderson's Mill in the use of advanced water wheel technology similar to that developed in the textile industry in Britain (Fig. 7), incorporating features such as rim gear power-take-off and the large, iron suspension wheel being held together by spokes acting in tension to reduce weight.

Environmental Conditions

In addition to outlining important economic factors for international technology-transfer and adaptation, Rosenberg also considered environmental factors important for the process. He stressed the idea that successful transfer of technology is heavily dependent on selection and adaptation of technology to accommodate the natural resources of the recipient country (Rosenberg 1970:183, 185; cf. Rosenberg 1972b:203). As conceived by Rosenberg, the natural resources of a country included such factors as climate, geology, and geography. Thus he found that, in analysing the transfer of water wheels and steam engines to nineteenth-century North America, the steam engine, even when solidly established in some parts of the country, could not displace water wheels in other parts well endowed with suitable rainfall and rivers (1972a:63–6). At a more detailed level, Temin, in his study of the early American iron industry, found that due to a local abundance of wood, American charcoal smelters were slow to be adapted to the new coke technology, which was rapidly replacing charcoal iron smelting technology in other countries where wood was in shorter supply, such as Britain (Temin 1964).

Important environmental factors for successful international technology-transfer may thus be broadly conceived of in terms of the climate and natural resources of the countries involved in the transfer process. The specific environment for watermill technology may be further defined firstly in terms of climatic variables such as average annual rainfall and rainfall variability, and secondly in terms of physical geography, or topography. A comparative discussion of the environments for watermill technology in Britain and Australia, in terms of climate and geography and how they act to influence the nature and use of watermill technology, should thus allow for the generation of hypotheses about how and why the different environments of the two countries should have acted to produce adaptation of the technology.

Different types of water wheels are suited to different conditions. Overshot wheels require only the weight of a small volume of water over a high fall to generate power. Breastshot wheels are adapted to lower available falls by being wider to accommodate a larger volume of water in their buckets. Undershot wheels use the impact of fast-flowing water on paddles to generate power where no fall is available. As the weight of falling water can be more efficiently harnessed by water wheels, than its velocity of flow (Reynolds, T. 1983:ch. 3),

Fig. 8: The water race to Thorpe Mill, at Bothwell in Tasmania (photo. Pearson 1993), is an example of the trend for watermills in Australia to be fed water via long races, rather than directly from dams, as was the case in Britain.

Table 3

ENGLISH MILLS	WATER SUPPLY	RACE LENGTHS (yds)
Shugborough	dam	
Chadwell	dam	
Newnham	weir & race	100
Daniel's	dam	
Charlecote	dam	
Wellesbourne	dam	
Brindley	weir	
Sarehole	dam	
Cheddleton	weir	
Churchill	dam	
Forge	dam	
Quarry Bank	weir & race	250
AVERAGE		175
TASMANIAN MILLS		
Connorville	dam & race	600
Thorpe	dam & race	400
Nant	weir & race	500
Riversdale	weir & race	1500
Millbrook	weir & race	800
Anderson's (Vic.)	weir, race & flume	900
AVERAGE		783
NEW ENGLAND MILLS		
Mount Mitchell	weir & race	40
Yarrowford	dam & race	50
Dundee	dam	
Bolivia	dam & race	120
Bagot's	dam & race	2500
AVERAGE		678

Table 3: Comparison of the water supply systems in use at the mills studied in the three sample areas. The trend from most mills being fed water directly from dams in Britain to most mills being fed water via long races in Australia is clear, and is a direct result of different conditions of rainfall and topography between the two countries.

overshot wheels represent the more efficient option. These are able to transfer 75 percent of the power of falling water to machinery, while breastshot wheels can transfer approximately 65 percent, and undershot wheels can transfer approximately 30 percent of the power of flowing water.

The generally lower volume and higher variability of rainfall in Australia, together with a topography of higher relief in those parts of the Australian colonies suitable for waterpower use, should thus have selected for an increased use of large, thin overshot wheels which require long headraces to get water to the top of the wheel, rather than smaller, wider breastshot wheels and undershot wheels fed directly by rivers or dams. The numeric distribution of these water wheel types and water supply systems would have been more even in Britain as a result of both lowland and highland areas receiving high rainfall. These changes would also have resulted in differences in the average efficiency and dimensions of water wheels between the two countries.

As predicted, colonial mills did indeed make increased use of long headraces at the expense of large dams and ponds (Table 3). Thorpe Mill at Bothwell in Tasmania is an example of this trend in colonial watermill construction (Fig. 8), while Shugborough Mill, near Stafford, illustrates the British pattern of mills fed directly from ponds (Fig. 9). This change is coupled with a relatively greater number of overshot wheels in the colonial mills at the expense of breastshot and undershot types (Fig. 10). The shift in dominant water wheel types in use between the two countries was attended by a shift in average water wheel dimensions, colonial wheels being, on average, larger in diameter and smaller in width, to make better use of the different conditions of water flow (Fig. 11). As a further result of the shift in wheel types, colonial watermills were, on average, more efficient power generators (Fig. 12).

The trends in water supply types, water wheel types, water wheel dimensions and water wheel efficiency noted in the comparisons of the samples above may not just be a result of environmental influences for adaptation of the technology, however. As noted earlier, the application of water wheel technology underwent a shift in basic economic conditions from including large-scale manufacturing industries in Britain to almost exclusively small-scale, rural and extractive industries in Australia as a result of its transfer. The rural location and dispersed nature of industries such as flourmilling, sawmilling and mining in Australia would have allowed more scope for adapting the technology to local conditions, and choice of optimally efficient technology, such as large, overshot wheels fed by long water races, than the constraints placed upon large-scale manufacturing industries in Britain by the need for concentration of supply and markets. Even in the small-scale, rural industries of Britain, the saturation of streams with mills in the nineteenth century (Reynolds, T. 1983:ch. 5) severely restricted technological

Fig. 9: The dominant method of water supply for mills in Britain was direct from large ponds, as seen here at Shugborough Mill, near Stafford (photo. Pearson 1992).

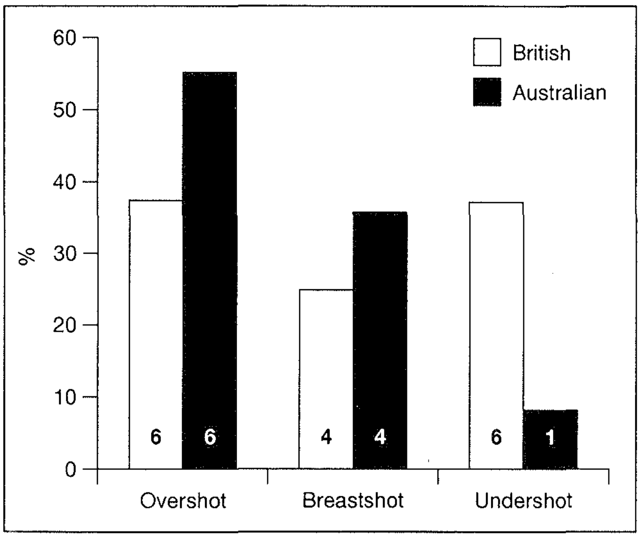

Fig. 10: Comparative analysis of the distribution of water wheel types in use at mills studied in the three sample areas. A relatively even distribution in Britain gives way to a dominance of overshot wheels at the expense of undershot wheels in Australia.

choices. Thus, while changes in environmental factors will have an adaptive influence on a technology, other economic and industrial factors may constrain this process.

Thus, while different environmental factors are a valid explanation for the technological changes noted between the survey samples above, this should be seen in a wider context, including other economic and industrial factors. For example, if we were to include a sample of water wheels used on the Victorian goldfields in the Australian sample, the resultant trend in technological change becomes even more accentuated. A survey of the technology of 66 water wheels used on the Victorian goldfields by Milner (1989) revealed that, where the wheel type was known, 93 percent were overshot wheels and, where dimensions were known, the diameter-to-width ratio was 8.2:1 (cf. Fig. 11). Such large, overshot wheels would have required the use of long races for water supply. The fact that more water wheels were used in mining than any other industry in nineteenth-century Australia (Statistical Returns and Registers) would further accentuate this trend of technological change as a result of transfer. Thus the importance of economic factors in addition to environmental factors in influencing technological change becomes clear.

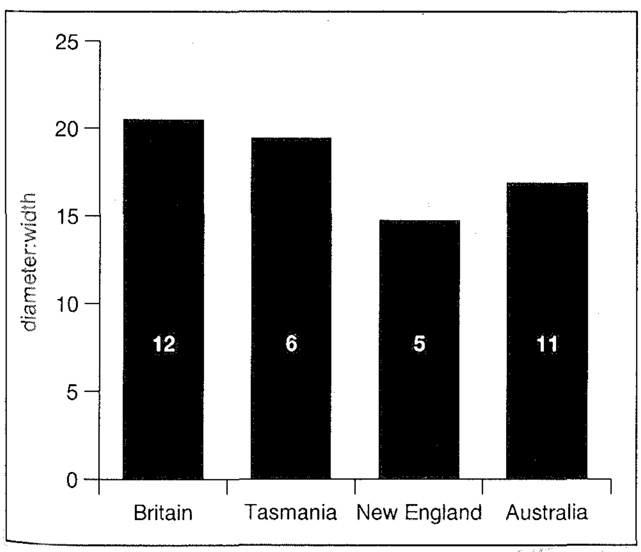

Fig. 11: Comparison of water wheel dimensions for mills studied in each of the three study areas. The trend for wheels to become taller and thinner as a result of the transfer of the technology from Britain to Australia is a direct result of conditions of water supply and topography.

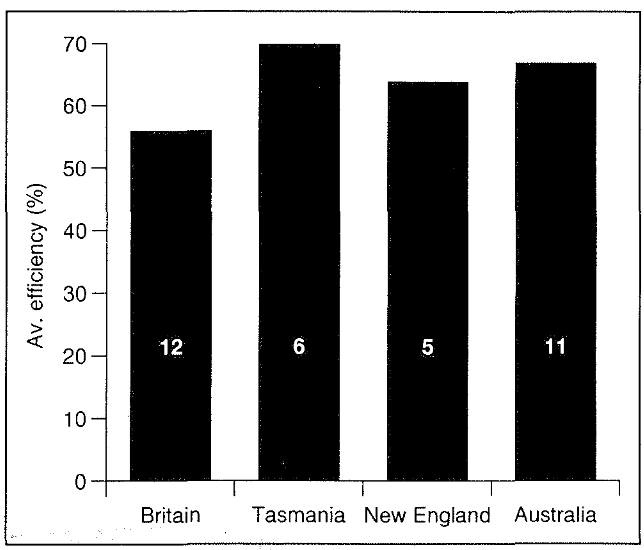

Fig. 12: Comparative efficiency of power generation for wheels at mills studied in each of the three sample areas. Those in Britain have a lower efficiency relative to those in Australia. This is related to different types of wheel being favoured by different environmental conditions in each country.

Human Context

Another important characteristic of successful transfer and adaptation of technology, according to Rosenberg, is the presence of skilled operators in both countries. This means that it is almost inseparable from the transfer of skilled individuals. Rosenberg argues that much technical skill is uncodified and cannot be reduced to paper, and thus the men with the skills, such as craftsmen, technicians, engineers and mechanics, must be transferred also if the technology is to be successfully transferred (Rosenberg 1970:5–54; 1972a:18; 1972b:198–9).

The important role of the international movement of people for the successful transfer and adaptation of technology is well demonstrated in a study of the transatlantic diffusion of textile technologies between Britain and America from the 1790s to the 1830s, conducted by Jeremy (1981). In this he concluded that, '...for a new technology still partially understood or not yet reduced to verbal or mathematical forms, the experienced practitioner must be the most efficient agent of international diffusion' (Jeremy 1981:162). Stapleton (1987:14) summarises Jeremy's argument by asserting that even where people in the receiving country possessed the necessary skills to build and operate the new machines, but without the intimate knowledge and experience of the best and most appropriate designs, there could have been no successful transfer of the English textile factory revolution to the United States.

It should be noted that much of this technology-transfer literature relates to what may be called 'closed access' technologies. These are characterised as new or developmental technologies about which knowledge dissemination was deliberately restricted, through patents, monopolies and industrial secrecy, or as technologies which require a high degree of skill, experience or education on the part of potential users, such as ironworking and textile manufacturing technologies. In contrast 'open access' technologies are those such as agricultural and pastoral techniques, about which knowledge was readily disseminated to potential users, who need not be highly skilled or educated. It is argued here that watermill technology may best be characterised as a closed access technology, in the sense that it was largely a 'craft', embodied in the knowledge and skills of its practitioners, and that the millwrighting craft required a high degree of knowledge and experience on the part of its practitioners, which was chiefly communicated through the apprenticeship system. In this sense, it was not general knowledge. Further, where large industrial mills were designed by engineers, this knowledge was restricted to those with the requisite education.

The human context for successful transfer and adaptation of watermill technology may thus be defined in terms of the presence and activity of people having the required skills and knowledge for the design, construction and use of the technology, such as millwrights and engineers. A comparative discussion of this aspect of the human context for watermill technology in nineteenth-century Britain and Australia, and how these acted to influence the nature and use of watermill technology, will thus allow for the generation of hypotheses about how and why the different human contexts of the two countries should have acted to produce adaptation of the technology.

With regard to important human factors then, the simultaneous transfer of millwrights and engineers may be hypothesised to have been a vital agent in the successful transfer and adaptation of watermill technology to the recipient country. Further, it may be expected that evidence for the more scientific design input of engineers will be more visible in large-scale economic contexts where the productivity increases gained by the use of more sophisticated technology are more important. In general, such opportunities would have been scarcer in the nineteenth-century Australian economy than in Britain.

Evidence from the colonial mills surveyed attests to both the presence of millwrights as agents in the transfer of the technology and the importance of this role for the successful adaptation of the technology to Australian conditions. For example, inscriptions on the machinery of Connorville Mill in Tasmania preserve physical evidence of the work of the English millwright W.H. Knight, while Riversdale Mill, also in Tasmania, preserves the work of Scots millwright John Amos.

Anderson's Mill in Victoria is also known to have been constructed by an emigrant English millwright John Anderson (Department of Conservation and Environment 1990). Other early watermills in the colonies known to have been constructed by millwrights who had emigrated from Britain include the mills of the Singleton Brothers on the Hawkesbury River in New South Wales (Jack 1986), and John Dunn's Bridgewater Mill in South Australia (Department of the Environment 1980).

The importance of skilled millwrights for successful watermill construction was recognised from the very earliest years of settlement in the colonies. Their lack among the colonists at Port Jackson was keenly felt by colonial administrators endeavouring to feed the colony (HRA Series 1, 1:143) and contributed to long delays in the construction of the first mills in the colony. The first watermill at Parramatta was not completed until 1805 (HRA Series 1, 4:468). The experience of other colonies was similar. As late as 1833 an observer in Hobart commented that '...among a list of trades and employments to be encouraged to emigrate to Tasmania are included millers and millwrights' (Parker 1833:225). Even convicts who could demonstrate skills as millwrights and millers found favour with the colonial administration. One such was Robert Nash, who built the first successful watermill in the colonies, on Norfolk Island in 1795 (Collins 1798, 1:316–7), and the first watermill in Hobart by 1816 (*Hobart Town Gazette* 20 March 1816).

The hypothesis that the more sophisticated design and construction input of engineers was restricted to larger-scale industrial watermills in Britain, and would therefore have been required less in the colonies is not well supported. Evidence of input by engineers into the construction of small-scale flourmills, such as Brindley Mill in England (Copeland 1972) and Bagot's Mill in Australia (Connah 1980), indicates that they played a role across the entire range of economic contexts for the use of watermill technology, in both countries.

Industrial Context

The need for the receiving nation to have a sufficient industrial base to be able to use effectively the transferred technology has also come to the attention of researchers as an important factor for successful international technology-transfer. This industrial base may include the ability to provide both suitable materials and sufficient space for the local construction and use of that technology. While an oversupply of space for industrial expansion actually provided the impetus for the importation of railroad technology from Britain to America, Rosenberg (1970; cf. 1972b:199) cites the necessity for the development of a native American iron industry prior to the viable widespread use of railroad technology in that country. Again, regarding the provision of suitable materials for new technologies, Stapleton (1987:30), in discussing technology-transfer between Britain and the United States up to and including the first half of the nineteenth century, states that, 'America had a level of technical activity capable of supporting almost all the basic agriculturally-related craft technologies, but only a few of the industrial technologies'.

Important aspects of the industrial context for successful international technology-transfer may thus be defined in terms of the presence of supportive and associated industries necessary for the construction of an introduced technology. A comparative discussion of these aspects of the industrial environments for watermill technology in nineteenth-century Britain and Australia, and how these acted to influence the nature and use of watermill technology, should thus allow for the generation of hypotheses about how and why the different industrial environments of the two countries should have acted to produce adaptation of the technology.

A comparative lack of domestic iron production in Australia compared to Britain, and the widespread availability of wood, should have selected for an increased use of the latter in the construction of water wheels and mills, except in those few large-scale economic contexts where the cost of importing iron parts was not a concern. Recycling of iron parts may also have been a response to the scarcity of these in the colonies, especially in smaller-scale mills. It may also be hypothesised that the high cost and scarcity of other manufactured mill building materials, such as brick, would have caused many colonial mills to be constructed of alternatives such as stone and wood, and that the pioneering industrial context of many Australian mills would see a reduction in architectural elaboration, to more utilitarian construction methods and materials.

From the mills themselves, we find that, while some colonial water wheels relied heavily on wood, such as those at Thorpe and Riversdale Mills (Table 4), the predicted general shortage of iron for mill parts was not supported, at least in the more settled parts of the colonies, such as Tasmania and Victoria. Only in the more remote parts such as the New England Tablelands were iron parts in short supply. Little evidence for recycling, and no evidence for importing iron parts was found at any of the colonial mills surveyed. Rather, direct evidence that much of the iron in use for construction of Australian water wheel and mill parts was produced in local foundries was seen in the mills surveyed, in inscriptions on the wheel itself at Millbrook and Nant Mills, for example.

Table 4

ENGLISH MILLS	WATER SUPPLY	WATER WHEEL	MILL GEARING	MILL BUILDING
Shugborough	concrete	wood	iron	brick
Chadwell	earth	iron	iron	brick
Newnham	concrete	iron	iron	brick
Daniel's	earth	iron	iron	brick
Charlecote	stone	iron	iron	brick
Wellesbourne	earth	wood	wood	brick
Brindley	concrete	iron	iron	stone
Sarehole	earth	iron	iron	brick
Cheddleton	concrete	iron	iron	brick
Churchill	earth	iron	iron	brick
Forge	earth	iron	iron	brick
Quarry Bank	stone	iron	iron	brick
TASMANIAN MILLS				
Connorville	earth	iron	iron	brick
Thorp	earth	wood	iron	brick
Nant	earth	iron	iron	stone
Riversdale	earth	wood	wood	brick
Millbrook	earth	iron	iron	stone
Anderson's (Vic.)	stone	iron	iron	stone
NEW ENGLAND MILLS				
Mt Mitchell	stone	wood	wood	wood
Yarrowford	stone			
Dundee	earth			
Bolivia	earth			wood
Bagot's	earth	iron	iron	stone

Table 4: Summary of the construction materials used in various elements of the mills studied in the three sample areas. In each case the material listed is the dominant material, as most elements comprised a number of materials, for example most iron wheels had some wooden parts with the reverse also applying.

In Tasmania, the first iron foundry capable of casting items of mill machinery, such as gearing, was in operation in Hobart by 1822 (*Hobart Town Gazette* 30 March 1822) and, according to Selfe (1900:23) Sydney possessed an iron foundry by 1823. By 1833, the Australian Foundry in Sydney was capable of producing castings up to four tons in weight (Selfe 1900:24). By 1834 Tasmanian foundries were capable of casting all iron parts for mills, including water wheels up to 40 feet 6 inches in diameter (*Hobart Town Courier* 19 Dec., 1834). By 1842 Sydney had five foundries in operation, but local supply in the early nineteenth century had not been able to completely meet demand, and it is known that in a few cases, such as that of John Terry in Tasmania in 1819 (*Hobart Town Gazette* 11 Dec., 1819), mill-owners did find it necessary to import iron mill parts from Britain. By the 1880s when the foundry of R. Kennedy & Sons, Hobart, cast the wheel for Nant Mill, locally-cast iron mill parts would have been in widespread supply.

Another case of the importing of iron parts for a watermill, including the 36 feet diameter water wheel, was that of John Dunn's Bridgewater Mill, built in 1860 in South Australia (Department of the Environment 1980). However, the local founding of the 27 feet (8.3 m) diameter, 25 tonne water wheel for Anderson's Mill, built in 1861 in Victoria, by Hunt & Opie of Ballarat (Department of Conservation and Environment 1990) indicates that iron founding technology for large-scale water wheels was available in the colonies by this time.

As predicted a greater proportion of Australian mill buildings were constructed of wood and stone than their British counterparts, at the expense of manufactured materials such as brick (Table 4). Construction of water-supply systems to colonial mills also shows less use than British mills of expensive, processed building materials, such as brick and iron. Further, while the vernacular architecture of British watermills was so well established and defined that individual architects could be identified on the basis of certain architectural stylistic features, such as the work of James Brindley at Brindley Mill (Copeland 1972), the Australian mills surveyed showed no such elaboration, reflecting instead a much more utilitarian approach to architecture, as seen at Bolivia Mill near Tenterfield on the New England Tablelands (Fig. 13).

Sociocultural Context

According to Rosenberg (1972a:31–9) the necessity for the receiving nation to have a social matrix which is receptive to the transfer of a given technology is also vital for its successful transfer. It is only within a receptive social and cultural environment, Rosenberg argues, that a transferred technology can become successful on a large scale. This is a point that Stapleton (1975:28, quoting Cairncross 1962:187) reiterates:

> Little consideration has been given ... to 'atmosphere', in the sense of social attitudes, customs and beliefs, as a factor in the transfer of technology. Yet no one doubts that this can be one of the most important factors governing technological progress.

The point has been appreciated by some researchers, such as Kenwood & Loughheed (1982) and Headrick (1988), who have dealt with technology-transfer in contexts of British imperialism and colonialism, in Africa and India respectively. Failures in some attempts to transfer technology in these contexts have made researchers realise that any technological object or process is deeply embedded in the culture or nation from which it came; it may not fit easily, or at all, into a widely differing one (Headrick 1988). Handlin (1952: 55–6, 90) also found that transfers which did not survive were encumbered with the preconceptions of the persons in the transmitting country about the receiving country. Handlin's primary point

Fig. 13: Flourmill on Bolivia Station, on the New England Tablelands of New South Wales. The construction materials and methods show the utilitarian approach to architecture in colonial watermills (Mitchell Library, State Library of New South Wales).

was that the survival and success of a transferred technology depended upon the ability to tear loose from the concepts attached to the technology or skill in the parent culture.

The sociocultural context for successful international technology-transfer may thus be defined as the society in which the technology is used and of which the technology forms a part of the material culture. In the case of this research, technology is not transferred between different societies, but within essentially the same nineteenth-century British society. This does not necessarily mean that the sociocultural context for the technology remained the same in nineteenth-century Britain and Australia, and had no influence on adaptation of the technology as a result of its transfer, however. Changes in other economic, industrial or environmental conditions may have acted to cause change to the sociocultural context between the two countries also, producing an adaptive, rather than a conservative cultural context. This may be measured by the survival of distinctive 'traditional' or regional patterns in the technology. Aspects of watermill technology relevant to testing such hypotheses may be conceived of in terms of recognisable patterns or distinctive groupings of technological features, such as particular configurations of mill design and architecture, and traditional methods of water-supply, water wheel, power-take-off and gearing design and construction.

Regional traditions in the technology of the nineteenth-century British flourmilling industry, for example, have been identified in the literature (Jones 1969; Jones & Bowie 1977), corresponding to the division of Britain into upland and lowland zones. It is hypothesised that the demonstrated high degree of adaptation required by other conditions for watermill technology in Australia, would have meant that, far from these traditions being identifiable in nineteenth-century Australian watermill technology, a distinctive hybrid colonial watermill pattern should have emerged.

The lowland tradition of British flourmills can be described as: being geared towards larger scale operations, requiring the use of storage floors and auxiliary grain and flour-processing machinery, often powered by undershot or breastshot wheels, fed directly from dams, and featuring extensive use of iron in machinery. In contrast the upland mills did not operate on such a large scale, requiring less storage capacity and auxiliary machinery, were powered by a greater proportion of overshot wheels fed by long races and featured less extensive use of iron parts for machinery. As has been demonstrated, conditions in Australia should have selected for a hybrid pattern combined from aspects of both these regional traditions from Britain. Economic conditions in Australia generally favoured the British upland tradition geared towards smaller scale production. However, less available labour and more dispersed markets in Australia then in Britain, required slightly more extensive use of auxiliary machinery and storage space, more characteristic of British lowland mills. Environmental conditions in Australia generally favoured the British upland mill powered by an overshot wheel fed by a long race. Industrial conditions in Australia selected for aspects of the lowland British traditions, in providing for a fairly extensive use of iron parts for machinery. The result of the transfer of the technology was thus a distinctive hybrid colonial flourmill pattern combining aspects of both major traditional British watermill technology traditions.

CONCLUSION

From the tests of the hypotheses above about how watermill technology should have been adapted as a result of its transfer from nineteenth-century Britain to Australia, a general model for the historic transfer and adaptation of industrial technology between the two countries may be proposed. This is that:

1. Economic factors are the most important selection pressure for adaptation of an introduced technology, insofar as they determine certain basic choices such as the product to be produced, the scale of production and the methods of production.
2. Where the economic context for a given technology in the recipient country differs significantly from that of the donor country, technology may be borrowed from other industries with a more suitable economic context in the donor country.
3. The degree to which aspects of an introduced technology that are in some way sensitive to, or dependent on, environmental factors will be adapted to accommodate changes in these, may be subject to other adaptive pressures, such as the industrial context for the technology.
4. Those having the requisite knowledge and skills will play an important part in the successful transfer of the technology, especially where it must be adapted to different environmental conditions. Further, in a strongly

adaptive context, innovative application of knowledge and skills may not be restricted to use of the technology in important or large-scale industrial contexts.

5. The industrial context for an introduced technology will exert significant adaptive pressures on the construction methods and materials of that technology. In a colonial industrial context, greater opportunistic use will be made of naturally-occurring materials at the expense of pre-processed, manufactured materials. However, production facilities for the most important parts of the technology requiring prefabrication will be quickly developed where necessary, and these will rapidly become widely available, even for use in small-scale economic contexts. Further, a utilitarian approach to construction will characterise the technology in a colonial industrial context.
6. Finally, sociocultural factors will also play a part in the adaptation process, although the extent to which this is important will be dependent on other influences on adaptation. Where a high degree of adaptation is required by economic, physical and industrial factors, such as in a colonial context, sociocultural values of tradition will quickly give way to those of innovation, and even long-established traditional technologies will not survive transfer.

For Australian historical archaeology, the results of this research make a significant contribution to both methodological and practical problems. In methodological terms, the contribution is twofold. Firstly, the research advances a generalised model for the process of technology-transfer and adaptation from Britain to Australia in the nineteenth century, which had previously been lacking. Secondly, and equally as importantly, the model was constructed using an explicitly articulated theoretical framework, and it was constructed in a logically developed and repeatable manner. While such an approach has long been identified as important for the development of Australian historical archaeology, examples have been slow in coming.

Perhaps the most significant methodological contribution of this research, however, is that having arrived at some generalisations about the transfer and adaptation of industrial technology from Britain to Australia in the nineteenth century, through the use of technology transfer theory as middle level theory, it is now practically possible to link the findings of this research to some form of higher level theory, such as evolutionary ecology, to explore the Australian historical archaeological record of human cultural processes in even more general terms. It is only this sort of approach, whereby low level generalisations derived from the archaeological record are set within a framework of middle level theory, that enables the final step to higher level theory to occur.

In practical terms, the main contribution of the research lies in the fact that its findings were based on the analysis of large, regional samples of archaeological sites. While this in itself represents a step toward maturity from site-specific approaches to data gathering, the sites chosen for this research also represent a major, previously untapped, contribution to the database of the discipline. This research represents the first largescale, systematic recording and analysis of the remains of water-powered industry from nineteenth-century Australia.

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