Beam Pumping Engines in Victoria

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This is the second in a two-part study on mining heritage in Victoria. Here a case study is presented in which one class of mining machinery, beam pumping engines, is analysed utilising the database described in the first article. The number and distribution of beam pumping engines during the nineteenth century is discussed, the locations of surviving plant surveyed, and the heritage significance of that plant considered.

The beam pumping engine with its large vertical cylinder, massive rocking beam and well-oiled and polished valve gear was for the nineteenth century what a piece of high technology, such as a very fast train, a supersonic airliner, or a large power station would be in this century. Such engines were a later development of the atmospheric pumping engines of Newcomen, Smeaton and Watt. In all these early engines the motive power was provided by the pressure of the air acting on the exposed surface of a piston which moved in a long vertical cylinder. This arrangement was especially configured to suit the available reciprocating pump technology. As the power of these engines increased in proportion to the square of the cylinder diameter, and as steam pressures were limited both by James Watt and by prevailing boiler technology to be rarely much above that of the atmosphere (for example, no more than 5 pounds per square inch by 1775), they were built in ever increasing sizes to perform very heavy pumping work. Cylinders 72 inches in diameter were not unusual by the latter half of the eighteenth century, as 80, 90 and even 100 inch cylinder engines were in the nineteenth century. With the lapse of the Watt patents in 1800, and under Trevithick's influence, steam pressures of up to 50 pounds per square inch were substituted for air pressure, but to achieve adequate economy of operation these engines were worked expansively with early cut-off, so that the mean effective cylinder pressure remained low and cylinder diameters correspondingly large.

If Connell could discover some 50 beam engines in South Australia, how many such engines might there have been in Victoria?[1] The answer could be either more or less: more because mining in Victoria was much more extensive than in South Australia during the nineteenth century; less because Victorian mining, which was the major user of steam power throughout most of the nineteenth century, developed after that of South Australia, and at a time when the beam engine was being superseded by other forms of steam engine. McCarthy and Davis are of the latter view, identifying no more than ten beam engines in use in Victoria.[2] They argued that this was because the majority of Victorian mines used a simpler and less expensive above-ground installation, consisting of a horizontal rotative steam engine driving a crank arm through reduction gears, with a large balance bob set in a pit beside the shaft collar. In this paper the contrary proposition is argued, and the data bases described elsewhere in this volume are used both to raise the standard of debate about this issue, and to discuss the cultural significance of extant beam engine sites.

THE NUMBER OF BEAM ENGINES IN VICTORIA

An examination of the reports of the mining surveyors and mining registrars for the Department of Mines in Victoria for the period from May 1859 to December 1889, taken together with a number of additional departmental reports and selected newspaper and journal articles makes it possible to construct a list of some 38 beam engine installations.[3] These are summarised in Table 1. They range in size from a 6 horsepower one at Specimen Hill in 1859 to Australia's largest, the 80 inch by 120 inch-engine erected at Chinamans Flat in 1873, and they span almost the entire first period of active mining operations in Victoria, from 1859 to 1905.[4] What is particularly noticeable is that confirmed beam engine usage appears to be confined to a relatively small number of centres: Ballarat (including Sebastopol and Buninyong) (17), Berry and Timor deep leads (8), Castlemaine-Fryers Creek (5), Ballarat region (4), Daylesford (including Hepburn and Yandoit) (3), and Maldon (1).

In addition, there were seven other installations which, by virtue of the size of engine used, were possibly also beam engines. Before 1880 in Victoria, it was quite rare to have an engine with a cylinder diameter greater than 25 inches. It seems likely, therefore, that the 30 inch by 60 inch engine erected in June 1860 at Maldon was a beam engine. If the reference to a 26 inch by 50 inch engine in April 1862 for the same company is not the same engine then this was also likely to be a beam engine, as it had a vertical cylinder. One or other of these engines was acquired from the Great Eastern Company at Ballarat, an area where a number of beam engines were subsequently installed. Both the Cumberland, Durham and Cornish, and the Doma Mungi engines were large for their time and so may also have been beam engines. Finally, there is a reference to the Lady Barkly Company having obtained a Sebastopol drainage engine. As Sebastopol was an area where beam engines were in use, it is possible that this was a reference to a beam engine which was sold and removed to Castlemaine where such engines were also in use.

Even without any of these possible installations, it is already evident that the number of beam engines in Victoria was at least comparable with that for South Australia. It is questionable, though, whether this accurately estimates the actual number once in use. In the *Ballarat Times* for 5 May 1857, R. Towns and Company (1857–1873), Melbourne machinery agents and importers, were advertising beam engines for sale in cylinder sizes up to 30 inches in diameter, and obviously thought that the Ballarat mines would be a suitable market. Several years later, in the *Ballarat Star* for 28 July 1860, Alexander MacFarlane and Company (1857–1909), Melbourne machinery agents and importers, were advertising both horizontal and beam engines for sale, ranging from 4 to 60 horsepower, as well as 30 inch pumping engines manufactured by Harvey and Company, of Hayle, Cornwall. The Harvey engines were almost certainly beam engines, based on cylinder size. Although there is no evidence from the surviving business records of Harvey and Company that any of their larger engines were specifically imported into Victoria, at least one Harvey beam engine was installed by the Great North West Company at Ballarat in 1866.[5] It is also possible that one or other of the 80 inch engines installed by the Winter's Freehold and Great North West companies, in 1868 and 1870 respectively, was a Harvey engine, as the Harvey records show that an 80 inch engine was exported to Australia in 1868.[6] The 80 inch by 120 inch engine exported to Australia in 1872 may very well have been the engine installed at the Duke and Timor mine at Chinaman's Flat a year later.[7]

Table 1. Beam engine installations in Victoria

Date	Installation location: size, type, (function) [remains] {notes}
Confirmed mine installations (38)	
07.1859	Brown and Harper, Gordon: 18 horsepower ex Glasgow, rotative/pedestal (crushing)
05.1859	Union Mining Association/Eaglehawk Association/Eaglehawk Union Company, Eaglehawk Reef, Maldon: 16 inch by 48 inch, 35 horsepower, ?rotative (pumping and crushing)
06.1859	Gibbs, Pringle and Company, Specimen Hill, Fryers Creek: six horsepower, rotative (crushing)
11.1859	Prince of Wales Gold Mining Company, Cobblers Lead, No.4 Division, Ballarat, 10 inch by 24 inch, ?rotative (winding)
?1860	Donnybrook Company, No.3 Division, Ballarat, 25 horsepower {previously with the Prince of Wales Gold Mining Company}
?1860	Eldorado Company, Specimen Hill, Fryers Creek: 65 horsepower vertical (pumping) [fragment of rubble masonry beam wall]
04.1861	Band of Hope Company, No.1 shaft, Golden Point Lead, No. 1 Division, Ballarat: 30 inch by 108 inch, 70 horsepower (pumping)
03.1862	Old Specimen Hill Gully Quartz Mining Association, Specimen Gully, Barker's Creek, Castlemaine: 22 inch by 42 inch, 40 horsepower (pumping and crushing)
05.1862	Nelson and Wellington Gold Mining Company, Frenchman's Lead, Sebastopol, Ballarat: rotative (winding)
05.1862	Criterion Company, Hoggett's Reef, Yandoit: {previously with the Donnybrook Company}
07.1862	Perseverance Company/New Perseverance Quartz Mining Company, White Horse Reef, No.5 Division, Ballarat: Phoenix Foundry 18.5 inch by 35 inch (crushing)
09.1862	Ballarat Mill Gold Mining Company, Mill Lead, Wendouree Swamp, No.1 Division, Ballarat: 14 inch by 30 inch rotative (winding, pumping and puddling)
08.1863	Specimen Hill Quartz Mining Company, Specimen Hill, Hepburn: 14.5 inch by 30 inch (pumping and crushing) {previously with the Criterion Company}
03.1864	Great North West Company, No.1 Division, Ballarat: 32 inch by 48 inch, 100 horsepower (pumping)
08.1865	Havelock Quartz Mining Company, Daylesford: 12 horsepower (crushing)
08.1865	Leigh Consols Gold Mining Company: 14 inch by 30 inch rotative (winding)
12.1865	Stanley Gold Mining Company, Pitfield Plains, No.4 Division, Ballarat: 30 inch by *** inch, 70 horsepower (pumping) [shaft site and mullock]
05.1866	Amelia Reef Quartz Mining Company/New Amelia Reef Company, Blue Mountain North: 12 inch by *** inch (crushing)
05.1866	Great North West Company, No.1 Division, Ballarat: Harvey 40 inch by 108 inch (pumping)
09.1866	United Extended Band of Hope Company/United Hand-in-Hand and Band of Hope Company, Golden Point/Inkermann Lead, No.1 Division, Ballarat: 50 inch by *** inch, 90 horsepower (pumping)
12.1866	United Extended Band of Hope Company/United Hand-in-Hand and Band of Hope Company, No.4 shaft, Golden Point/Inkermann Lead, No.1 Division, Ballarat: 50 inch by *** inch, 90 horsepower (pumping) {previously with Great North West Company}
12.1868	Winter's Freehold Gold Mining Company, Winter's Paddocks, Sebastopol, Central: 80 inch by *** inch (pumping)
03.1869	Duke of Cornwall/Australian United Gold Mining Company, Cattle's Reef, Fryers Creek: 25 inch by 108 inch, 70 horsepower, rotative (pumping and crushing) [coursed rubble masonry engine house and brick and masonry chimney]
02.1870	Great North West Company, No.1 Division, Ballarat: 80 inch by *** inch Bull (pumping)
12.1870	Anglo-Australian Company/English-Australian Gold Mining Company, Heron's Reef, Fryers Creek: 70 horsepower rotative (pumping, winding and crushing) [coursed rubble masonry foundations, boiler setting, wheel pit and bob pit]
09.1873	Duke and Timor Company/Grand Duke Company, Timor Lead, Chinaman's Flat, Maryborough: 80 inch by 120 inch (pumping) [massive coursed granite block beam wall and engine foundation]
09.1873	Durham Company/City of Ballarat Company, Swamp/Suburban Lead, No.1 Division, Ballarat: 40 inch by *** inch (pumping) {rebuilt as 54 inch cylinder engine}
03.1881	New Holland Gold Mining Company/Melbourne and Avoca Company/Golden Stream Company, Avoca: 50 inch by *** inch (pumping) {previously with the United Extended Band of Hope Company ?}
09.1884	Berry No.1 Company, Smeaton, Creswick: Union Foundry 70 inch by 108 inch (pumping) {first large local engine} [red brick engine house essentially intact up to beam level]
03.1885	Mount Rowan Company, Central: 12 inch by *** inch rotative (puddling)
06.1885	Hepburn Estate Leasehold Company, Smeaton, Creswick: Union Foundry 70 inch by 108 inch (pumping) [red brick beam wall]
12.1887	Chalk's No.1 Company, Carisbrook, Maryborough: 80 inch by *** inch (pumping) {formerly with the Winter's Freehold Gold Mining Company} [red brick beam wall]

Table 1. continued

Date	Installation location: size, type, (function) [remains] {notes}
Confirmed mine installations (38)	
03.1888	Duke No.1 Company, Timor Lead, Chinaman's Flat, Maryborough: (pumping) {engine house masonry numbered, suggesting relocation from another site} [bluestone block beam wall]
06.1893	Egerton Company Limited, Egerton: 54 inch by *** inch (pumping)
1895	Band of Hope and Albion Consols, No.9 shaft, Golden Point Lead, No.1 division, Ballarat: 60 inch by *** inch (pumping) [beam wall fragment in polychrome bricks]
04.1896	Star of the East Company, No.2 shaft, Sebastopol, Central: Phoenix Foundry 75 inch by 120 inch 270 horsepower (pumping)
12.1896	Chalk No.3 Consolidated Gold Mining Company, No.2 shaft, Carisbrook, Maryborough: 75 inch by 120 inch [several large red brick fragments, brick-lined bob pit, lattice bob beam]
1905	Loddon Valley Goldfields Company, Moolort, Maldon: 70 inch by 108 inch 270 horsepower (pumping) {formerly with Berry 1 or Hepburn Estate Company} [concrete beam wall]
Other confirmed installations (5)	
06.1854	Gray's flour mill, Corio: 20 horsepower Broomhill Iron Works
1862	Anderson's flour mill, Smeaton: 60 horsepower
02.1870	Hayes's flour mill, Ballarat: 65 horsepower {formerly the Eldorado Company, Specimen Hill}
1873	Ballarat Woollen Mills, Ballarat: *** inch by 30 inch vertical
1883	Laird, Ballarat: 10 inch by *** inch
Possible mine installations (7)	
06.1857	Great Eastern, Ballarat
12.1858	Cumberland, Durham and Cornish, Ballarat: Tennant 70 horsepower rotative
11.1859	Beehive, Maldon: 30 inch by 60 inch 60 horsepower
?1859	Wilding, Specimen Hill, Fryers Creek: 5 horsepower vertical
04.1862	Beehive, Maldon: 26 inch by 50 inch 50 horsepower vertical
03.1864	Lady Barkly, Castlemaine: {Sebastopol drainage engine}
03.1869	Doma Mungi, Chiltern: 90 horsepower
Other possible installations (2)	
pre-1864	Melbourne Gas, Melbourne: 32 inch by 48 inch {later Great North West Company, Ballarat}
pre-1865	The Argus, Melbourne: 14 inch by 30 inch {later Leigh Consols, Buninyong}

Finally, R. S. Gibbs had specifically advertised Cornish engines for sale in the *Ballarat Star* for 5 November 1860. All this suggests a greater importation of beam engines into Victoria, especially in the smaller sizes, than the evidence provided by the Mines Department reports would indicate.

When local engineering manufacturers became established they too either offered to make beam engines or to act as local agents for imported engines. Thus in the *Ballarat Star* for 1860 Richard Carter and Company's Phoenix Foundry (1855–1906) advertised both beam and horizontal steam engines for sale in sizes from 10 to 76 horsepower, although the only beam engine known to have been made by the company at this time was a small one for the New Perseverance Company, in 1862.[8] Furthermore, in the *Ballarat Star* for 1 October 1861, Hunt and Opie's Victoria Foundry (1856–1869) offered to make steam engines from 10 to 100 horsepower, both beam or horizontal, high pressure or condensing.

All this further suggests that there were many more beam engines available for use and almost certainly installed on Victorian mines than is suggested by the entries in Table 1.[9] Unfortunately, contemporary accounts rarely provide sufficient information about the machinery installed to make it possible to determine just how widely beam engines were used. This lack of information might be interpreted in either way: that such engines were so commonplace as to need no special mention, or that they were, indeed, extremely rare.

An upper limit on the number of beam engines used in Victorian mining can be estimated in this fashion. By 1870, or about 15 years after steam engines were first introduced onto the Victorian goldfields, there were about 1 100 engines installed.[10] If, as seems reasonable, very few engines were scrapped during this period[11] then this would have represented the total number of engines both made in and imported into Victoria for mining purposes up to that time.[12] Up to the end of 1870, when reports of mining machinery were most frequent, references to 1 319 steam engines have been found, exclusive of those which are clearly identified as beam engines.[13] Allowing for a certain amount of unavoidable duplication in the entries, due chiefly to the reporting of the same engine firstly by horsepower and then by cylinder size and to the development of a second-hand market for machinery, it would appear that most of the steam engines in use in the period have been accounted for. Of that total only 155, or 11.75 per cent, are specifically identified as horizontal engines.[14] For the same period only 24 beam engines have been identified. This suggests that horizontal engines outnumbered beam engines by about six to one. If that proportion were maintained amongst the very much larger number of unspecified engines then there ought to have been 182 beam engines installed on Victorian mines up to the end of 1870.[15]

DISTRIBUTION

It is questionable whether there could ever have been quite as many beam engines in Victoria as this simple calculation would suggest, because it assumes a uniformity of distribution throughout the state which is at variance with the available evidence of where beam engines were installed. This is primarily for two reasons. Firstly, the effective operation of such engines depended upon maintaining an exhaust pressure below that of the atmosphere by means of a separate condenser. Such apparatus could soon become fouled and require regular maintenance if the boiler feedwater and/or cooling water were of an indifferent quality. As the result condensing engines were only ever used by the more heavily capitalised companies[16] and did not gain anything like wide acceptance in Victorian mining until the end of the nineteenth century.[17] Secondly, because of their higher initial cost beam engines came to be preferred for heavy duty applications where their superior operating efficiencies over all other types of prime mover were considered to be important, and this tended to restrict their use to deep alluvial mines after 1863.[18]

EXTANT SITES

Very little now remains of the early beam engine installations on Victoria mines, chiefly because many of the early engines, prior to 1864, were small ones which may very well have been in-house, pedestal or entablature engines. These engines could so easily be removed without leaving any trace whatsoever. There are just 12 sites where extant remains can be examined. No beam engine has survived, but there is a broken and twisted lattice pump bob beam at the Chalk's No. 3 site, No. 2 shaft. The oldest extant remains occur at the Eldorado site, Specimen Hill, Chewton, where there is a fragment of the rubble masonry wall of the engine house, traces of the shaft collar and, about 40 metres east north east, the entrance to the main adit. The best preserved engine house, constructed generally in rubble masonry with brick details, is that at the Australian United Gold Mining Company's Duke of Cornwall mine, Fryerstown. The engine here operated pumps in Duke's shaft, about 50 metres away, by means of flat rods, as well as a stamp battery. Unfortunately, the ground in the vicinity of the engine house has been so disturbed that it is not yet possible to see just how and where all the machinery was arranged. A much more readily interpreted site is provided by the rubble masonry foundations of the engine house at the Anglo-Australian mine, Golden Gully, Fryerstown, a short distance away to the north. A copy of the general arrangement drawing for this site has also survived, so that it is possible to identify exactly where the engine was located, where the battery and chimney were, in what way the structure was modified by the later installation of machinery and, as the shaft opening and bob pit are nearby, how the pumping and winding gear were driven.

At both these early sites rotative (or whim) engines were used; the last such engines installed in Victoria. All other extant sites are for non-rotative beam engines used exclusively for pumping. The most intact of these is at the Berry No. 1 site, Smeaton, where most of the engine house still stands at the edge of the shaft. At all the other sites nothing more than portions of the beam wall survive. Probably the most impressive of these belonged to the Duke and Timor Company. The beam wall is 5 feet 9 inches thick and 32 feet 5 inches from the base of the arch to the base of the beam gudgeon bearings. The wall is made from dressed granite blocks, nominally 6 feet by 3 feet square, and the brick supporting walls are 3 feet 6 inches thick.

The Duke engine house was one of only three post-1870 extant engine houses not built wholly of brick. The other two were at the Duke No. 1 and Loddon Goldfields sites. At the first of these sites the beam wall was made of numbered bluestone blocks, suggesting that this engine house had been re-erected here after having been removed from some other site, possibly Ballarat. At the second site, the last beam engine installation on the Victorian goldfields, the beam wall was made of concrete. It is possible that the other three walls of these last two engine houses were made of brick, but these have been removed for other purposes.

Several of the wholly brick engine houses have not survived at all well. That at Chalk No. 3, No. 2 shaft appears to have been blown apart, whilst that at the Band of Hope and Albion Consols mine, No. 9 shaft, has been demolished until only a small portion of the beam wall remains. This is the last surviving fragment of at least 17 beam engines and their houses which were once installed in and around Ballarat. It stands on what appears to be vacant land adjoining a lane way at the rear of some houses in Leith Street, Ballarat.

INTERNATIONAL CONTEXT AND SUITABILITY

However many beam engines there were once in Victoria, what now remains has been regarded, both by McCarthy and Davis and also by Davey as yet further evidence of the use of obsolete technology by overly conservative mining companies and a major cause of their failure to succeed.[19] Each of these claims needs to be considered in some detail if a fair assessment of the significance of the sites is to be achieved.

At the beginning of the nineteenth century the beam engine was almost the only form of steam power technology available for mining and manufacture. Further development of this form of engine in the first half of that century, with the use of higher pressure steam, the introduction of the Cornish cycle, developments in valve gear, careful attention to details, and eventually compounding, made it, by 1838, when the first Cornish beam pumping engine was introduced into the London waterworks, several times more economical than any Watt engine and at least twenty times as efficient as the first Newcomen engines.

Beam engines continued to be used throughout the nineteenth century but from 1850 onwards many of their duties were taken over by the horizontal steam engine so that, despite some singularly spectacular installations in the latter half of the nineteenth century, they became increasing confined to heavy pumping duties.[20] A horizontal engine was used for the first time by John Fitch (1743–1798) to drive a 12-oared skiff on the Delaware River in 1787. In 1801, William Symington fitted a 22 inch by 48 inch horizontal engine in the paddle steamer *Charlotte Dundas*. Three years later Richard Trevithick built an 0-4-0 geared locomotive with a single horizontal 8.25 inch by 54 inch cylinder for the Penydaren tramway. The first stationary application of the horizontal engine was by Oliver Evans who erected a 20 inch by 60 inch pumping engine at Fairmount, Philadelphia, in 1817. By 1825 horizontal engines were introduced into London factories by Taylor and Martineau. These engines were gradually adopted more universally in the smaller sizes and for lighter duties, so that by 1873, despite compounding, whim engines used in manufacturing were obsolete. From this point onwards, except in Cornwall, beam engines were used exclusively for pumping purposes.

The supremacy of the beam pumping engine was eventually challenged in three areas by four different forms of steam engine: for low-pressure and high-discharge applications by the high speed steam engine direct-coupled to centrifugal pumps; for high-pressure and low-discharge pumping applications by the horizontal direct-acting engine; and for moderate-pressure and moderate-discharge applications either by the horizontal engine coupled to reciprocating pumps by a crankshaft or by the compound and triple expansion marine engine in both the horizontal and inverted-vertical forms.

Centrifugal Pumps for Low-Pressure High-Discharge Applications

Although the idea of a centrifugal pump in which water was flung from the casing rather than pushed from a cylinder was first considered by le Dumour in 1732 it was not until the London Exhibition of 1851 that J. G. Appold exhibited such a pump with a practical efficiency.[21] Chiefly as the result of tests undertaken at Chatham Dockyard in 1866 this pump was found to be unsuitable for lifting water any distance, and one developed by John Gwynne came to be preferred.[22] From 1869 onwards steam engine driven centrifugal pumps began to be used in low-pressure applications: for land drainage, irrigation and dockyards, and also for marine condenser cooling water pumps where their compactness was also a decided advantage. By 1880 pump efficiencies were approaching 60 per cent, and by using them with the higher speed marine engines then in use water could be delivered at up to 30 feet at this efficiency. This began to make them directly competitive with beam pumping engines for certain applications, so that when the 1849 beam pumping engine, *van Lijnden*, which had been draining the Haarlemermeer at Leeghwater, Holland, was replaced in 1895, it was with two compound engines each direct-coupled to a centrifugal pump.[23] The transformation for low-pressure applications was completed by 1904 when the East London water works, one of the leading water companies in London and until 1889 an exclusive user of beam pumping engines, constructed the Angel Road station with three inverted-vertical compound engines each direct-coupled to centrifugal pumps.[24]

Horizontal Direct-Acting Pumps for High-Pressure Low-Discharge Applications

In 1845 Henry R. Worthington established a workshop in New York to make non-rotative direct-acting pumping engines in which the valve gear which controlled the motion of the piston in the steam cylinder was actuated by the motion of the piston itself.[25] Although these first engines were small, non-condensing and did not use the expansive properties of steam, and were therefore not particularly efficient, they were cheap to make and by the 1870s they were used in their thousands for such high pressure low discharge applications as boiler feed pumps and fire engines. Had these engines remained so, they would have presented no challenge at all, but Worthington went on to develop a twin cylinder or duplex pumping engine which provided an almost continuous flow of fluid, could be worked expansively, and in which the valve gear for one cylinder was activated by the movement of the piston in the other. He built these in larger sizes, and installed them in American waterworks. The first notable installation was at Newark[26] in 1870 where, for the first time, a horizontal pumping engine developed more than 100 water horsepower.[27] Both the introduction of hydraulic machinery[28] and the discovery of oil in America and also in Russia, in the 1880s, also stimulated the development of this type of pumping engine and in 1885 Worthington erected four of what were then the largest direct-acting pumping engines for transporting oil from the Philadelphia field to New York.[29] By 1886 Worthington pumps were in use in more than 40 per cent of American waterworks, and this was probably instrumental in persuading James Simpson and Company, Pimlico, who had erected their first Woolf compound beam engines in the London waterworks in 1866, to begin manufacturing Worthington pumping engines in Britain under licence.[30] The 330 horsepower Worthington pumping engine which they installed in 1888 at Hampton for the West Middlesex Water Works Company, when independently tested by Professor W. C. Unwin, demonstrated not only that such pumps could be built in sizes to equal those of beam pumping engines, but also that they could be just as fuel efficient.[31]

That British waterworks did not suddenly convert to this new form of pumping engine as many of their American counterparts had done, and even persisted with the construction of more beam pumping engines was because, as distinct from most American and some European waterworks, many British companies derived their supplies from wells.[32] In the horizontal direct-acting pumping engine the steam cylinder has to be at the same level as the water cylinder, and this must be within 30 feet of the water if the pump is not to suck air. As most wells were over a hundred feet deep this would have required the pumping engine to be located underground, most probably without a condenser, and for the steam to be supplied to it down the shaft from a surface boiler with an attendant increase in condensation and a considerable drop in operating efficiency. Such considerations, however, did not trouble British collieries who had unsaleable slack coal to burn and from before 1870 several British companies began supplying them with these horizontal direct-acting pumping engines.[33] Such considerations did, however, affect Cornish mine owners, and this is one of the reasons why they persisted with beam pumping engines long after others had abandoned them altogether.

Pumping Engines for Medium-Pressure and Medium-Discharge Applications

The disadvantage for horizontal direct-acting pumping engines of underground installation could be avoided if the engine were erected on the surface and connected to the conventional Cornish pit work by flat rods, angle cranks and tee bobs. Whilst such engines were constrained in size both in diameter and stroke by considerations of excessive wear, their capacity was limited. The pump stroke could be increased by the introduction of reduction gearing, so that for a given cylinder size and pumping rate the engine operated faster and therefore supplied more power. But all the reports in the British technical literature, for the period between 1870 and 1887, are for engines capable of developing considerably less than one hundred horsepower, during a period when beam pumping engines developed well in excess of that figure. Indeed, beam engines totally dominated large power installations until at least 1876, when that position was challenged firstly by several horizontal compound pumping engines and then by inverted-vertical pumping engines, based on marine engine practice. In 1876 Hathorn, Davis, Campbell and Davey of Leeds had erected a 34 inch by 64 inch by 90 inch horizontal tandem-compound non-rotative pumping engine[34] at East Hetton colliery, Durham.[35] During trials this engine indicated 254 horsepower and returned a duty of 100.8 millions.[36] This made it comparable with the best beam pumping engines at the time. Nevertheless, it was not the horizontal stationary engine but the inverted-vertical triple-expansion marine engine which finally made the beam pumping engine totally obsolete.[37] In 1889 T. Richardson and Sons, Hartlepool, built and erected an 18 inch by 30.5 inch by 51 inch by 36 inch 160 indicated horsepower inverted-vertical triple-expansion pumping engine at Waltham Abbey pumping station for the East London Water Works Company.[38] This was the first such engine in the London water works.[39] During trials the engine returned a specific steam consumption of 13.53 pounds per indicated horsepower hour and demonstrated that the inverted-vertical engine, based on marine engine practice, was comparable for economy with any other type yet built.[40] Although a few beam pumping engines were built for water works after this the inverted-vertical triple-expansion pumping engine soon became dominant.

Beam engines provided the most efficient form of large pumping engine for much of the nineteenth century. That position began to be challenged from 1870 onwards, firstly by horizontal direct-acting pumping engines which could either be installed underground or close to a source of water, then by centrifugal pumps for low-pressure high-discharge applications and finally and directly by the inverted-vertical triple-expansion pumping engine.[41] Only in Cornwall did they continue to be used well into the twentieth century, in part because coal for fuel remained a costly imported commodity.[42] Although few examples now survive, these engines remain, along with the railway locomotive and the trans-Atlantic steamer, one of the major achievements in mechanical engineering in the nineteenth century.

THE LOCAL EXPERIENCE

In Australia engineers and engineering manufacturers did not slavishly follow any particular traditional engineering practices, Cornish or otherwise. They rather demonstrated considerable responsiveness to, and understanding of, the changes in steam technology occurring in all other countries. They abandoned the use of whim engines by 1870 at the latest, although such engines continued to be built in Cornwall until 1887.

Centrifugal pumps were introduced to the Ballarat goldfields towards the end of 1865. By March 1866 the Llanberis Quartz Mining Company, Gum Tree Flat, Ballarat, had installed two small Gwynne centrifugal tailings pumps operating at 640 revolutions per minute and belt driven by a steam engine.[43] Whilst this enabled them to clear some 400 to 500 tons per week they reported that such pumps were little improvement over ordinary plunger pumps for power consumption.[44] Several other companies on Ballarat and Clunes began to use centrifugal pumps[45] and local engineering manufacturers began to make them,[46] but there were no bigger installations until 1889 when large scale hydraulic sluicing began. In that year the Gillespie Gold Mining Company at Stanghorn Flat, Yackandandah, constructed a suction cutter dredge of New Zealand design which made use of a twin 12 inch by 12 inch engine and a 60 inch centrifugal pump of special design.[47] Other companies followed[48] and Thompsons at Castlemaine, which was one of the centres for sluicing in Victoria, began making pumps for sluicing plant. Between 1902 and 1917[49] they made 242 pumps not only for Victorian mines but also for mines in the other Australian states and abroad, exporting them to New Zealand, the Federated Malay States, South Africa, and even Cornwall.[50] The one and only large mine installation was by the Duke and Main Leads Consols Company, Timor, which installed two 18 inch plunger pumps and a 3 000 horsepower electrically-driven centrifugal pump in 1901, whilst they sank their shaft.[51] Most large centrifugal pumps were not built for the mines, however, but for irrigation purposes. The first of these were at Mildura in 1888–1889. Their installation is particularly important as the first application of the marine inverted-vertical triple-expansion engine directly coupled to a centrifugal pump. They were, in fact, respectively, the fifth, sixth and seventh land-based triple-expansion pumping engines to be built and as two of them have survived (one in almost working order) they are the oldest extant engines of their class in the world.

The first reported use of a direct-acting pumping engine was by the Clunes Quartz Mining Company, in 1862. They used a small donkey engine to supply feedwater to a boiler.[52] Similar engines for similar purposes were soon reported as in use at Daylesford (1865), Inglewood (1865), Ballarat (1866) and Maldon (1868), but no such engines in larger sizes were made, even though a 16 inch by 32 inch by 48 inch horizontal rotative direct-acting pumping engine was designed by Norman Selfe and made by Mort's Dock and Engineering Company in 1877 for the Sydney water works;[53] Roberts at Bendigo had begun making relatively large direct-acting air compressors by 1886;[54] and Austral Otis had secured the Worthington agency by 1888[55] and in 1892 had made a 9 inch by 12 inch by 21 inch by 15 inch triple-expansion direct-acting pumping engine of their own design, capable of delivering 625 000 gallons per day to 450 feet (59.2 water horsepower), for the Stephens Creek pumping station of the Broken Hill water supply system.[56] The chief reason for this is that for much of the nineteenth century mining companies in Victoria had to use wood for fuel,[57] and in the vicinity of the major centres like Ballarat and Bendigo this was in short supply by 1865, so that fuel efficiency was of considerable importance for the managers of any large mine.[58] As the Belmont engine of 1873 demonstrated, and as the four 300 horsepower Worthington inverted-vertical triple-expansion direct-acting pumping engines built and erected by Thompsons between 1893 and 1897 at Spotswood for the Melbourne and Metropolitan Board of Works locally confirmed, such direct-acting engines were unable to perform as economically as other types of large pumping engine then available.[59]

As in Britain, beam engines were used for all the heavy pumping applications until the introduction of horizontal compound and triple expansion pumping engines after 1888.[60] In 1889 Lonie, Dingle and Company, Ballarat, had compounded a horizontal simple pumping engine for the Berry Consols Extended Company at Smeaton.[61] This was the first compound pumping engine built in Victoria. In 1892 Thompsons at Castlemaine built a 16 inch by 28 inch by 48 inch 280 horsepower horizontal cross-compound pumping engine for Chalk No. 3 Consolidated Gold Mining Company,[62] and in 1894 the Phoenix Foundry, Ballarat, built a 270 horsepower horizontal cross-compound pumping engine for the North Prentice Company, Rutherglen.[63] Such engines were now comparable in power and probably as economical as the smaller beam pumping engines then in use.[64] Three more beam pumping engines were built in 1895–1896, but these were the last. In 1895 an 11.5 inch by 18 inch by 30 inch by 60 inch 350 horsepower horizontal triple-expansion geared pumping engine was designed by George Richards for the Duke United Gold Mining Company at Timor.[65] This was followed in 1896 by an 11.5 inch by 16 inch by 30 inch by 60 inch 370 horsepower horizontal tandem-twin triple-expansion geared pumping engine designed by James Gibson for the Spring Hill and Central Leads Company, Smeaton,[66] and in 1897 by a 13.5 inch by 20 inch by 30 inch by 60 inch 400 horsepower horizontal geared triple-expansion pumping engine for the Southern and Prentice United Company, Rutherglen.[67] All these engines were built by the Phoenix Foundry, Ballarat, and in the Duke and Spring Hill engines at least, variable expansion gear had been fitted to ensure economical operation in sizes which were now quite comparable with those of the largest beam pumping engines in use, and from this point onwards such horizontal pumping engines became dominant.

Simplicity

McCarthy and Davis argued that horizontal engines were more frequently used for pumping because they were simpler and cheaper.[68] What constituted simplicity was undefined, but if the major sub-assemblies of beam, whim and horizontal pumping engine installations are compared, then it is evident that beam pumping installations had no more than two-thirds the number of major sub-assemblies that horizontal engines had and, on this account alone, may be judged the simpler arrangement.[69] Between the whim and horizontal pumping engine installation there are fewer differences: the beam and parallel motion in the former and a gear pair in the latter. These differences were probably not essential, and what seems to have brought the horizontal engine into favour was the relative ease by which this class of engine could be installed without the need for an expensive engine house; in particular a massive masonry wall by which to support the beam, if that is what these whim engines would have required.

Adaptability

In deep lead mining, where beam pumping engines dominated, pumping duties rarely remained constant. They varied with the depth of sinking, the position of the shaft in the strata, the time of year, and the extent of drainage from adjoining workings.[70] The application of the cataract governor to the beam engine made it possible for a more or less lengthy dwell period to be inserted between each working stroke so that the pumping rates could be varied continuously and easily between zero and some maximum level, usually between 12 and 15 strokes per minute.[71] In a horizontal pumping engine in which the motion of the piston rod was transferred to the pump rod by a crank no such dwell period was possible. These engines had to operate continuously, utilising a flywheel to maintain motion through the dead centres at the end of each stroke, and to prevent stalling. Variations in engine speed, and hence pumping rate, could only be achieved within a narrow range by alterations in the governor settings, and generally at the expense of throttling the steam supply, as few of these early horizontal engines appear to have been fitted with any form of variable expansion valve gear. To obtain a wider variation in pumping rates involved either an alteration in the crank position, so altering the pump stroke, or, less frequently, an alteration in the gear ratio. In neither of these cases could these changes be made, if allowed by the pumps and gearing employed, whilst the installation was operational. The beam engine installation was always easier to control whenever the pumping duty varied considerably.

Cost

The costs associated with any installation consisted of a fixed cost associated with the manufacture, transport and erection of the engine on site; a cost for fuel which varied more or less proportionately with the water horsepower; and a cost for general maintenance and repair. Although there are some data available about the overall cost of mining installations, it is not easy to identify the costs associated with particular pieces of machinery, except in selected instances. Such data as do exist suggest, however, that the installation costs per horsepower for beam engines were substantially lower than for horizontal engines until at least 1880, despite the fact that the engine houses themselves represented a substantial capital outlay.[72] Even though a beam engine might cost more initially, the subsequent working of such engines was generally far more economical than for horizontal engines at least until 1890.[73] Horizontal engines on Victoria mines were often high pressure/non-condensing engines so that the specific fuel consumption was always higher than for beam engines in which the steam was exhausted to a condenser. Although it is true that companies often had considerable difficulties in the operation of their beam engines: broken gudgeon pins, cracked beams, and fractured castings; there is some evidence to suggest that the gear specifically associated with horizontal pumping engines was not particularly reliable either. Of 292 breakages to mining machinery which were reported in the literature between 1859 and 1918 almost 40 per cent related to pumps; and of these pump failures 10 per cent were failures in the gear pairs which connected the engines to the pump rods.[74] What all this cost in lost production is unknown, but it appears to have been a fault which persisted for some time, at least from 1863 to 1869, when such accidents were regularly reported.

Mine Failures

The suggestion by Davey that the high cost of beam pumping engine installations was partly responsible for the failure of some of the deep lead mining companies ignores that fact that no cheaper machinery of comparable power was available at the time these companies were in operation.[75] The Berry No. 1 and Hepburn Estate beam engines each developed 270 horsepower when installed in 1884 and 1885 respectively. The largest horizontal steam engine installed in Victoria up to that time only developed 100 horsepower. Horizontal engines more powerful than the largest beam engines were not built before 1895, when the Phoenix Foundry at Ballarat supplied a 350 horsepower horizontal triple-expansion pumping engine to the Duke United mine, north of Maryborough. But even a year later, in 1896, when the Chalk's No. 3 Company, at Carisbrook, came to consider a new pumping engine for their No. 2 shaft, they gave serious consideration to one proposal for a horizontal triple-expansion pumping engine and to another for a beam engine, and despite already having a horizontal compound pumping engine installed at the No. 1 shaft, which might have made them predisposed to engines of this type, they chose the beam engine. To blame the failure of mining companies upon their choice of pumping engine ignores the fact that they were mining in a notoriously wet part of the lead system and it was only to be expected that operations there were going to be expensive. As the records of those companies which worked on the Berry leads north of Creswick show, very few of those who installed horizontal pumping engines fared any better than the two which installed beam engines.[76]

Innovation

Finally, it has been suggested that the horizontal steam engine and the associated pumping gear was a Victorian invention. This may be more than just wishful thinking, although some of the elements in this arrangement had clearly been used before. Flat rods, for instance, were used to connect the pump rods to a whim engine at the Wherry mine, Penzance, Cornwall, at some time before 1790. The remainder of the apparatus: a simple horizontal steam engine, a gear pair, and interconnecting cranks and rods, was illustrated in a catalogue from William's Perran Foundry, circa 1875.[77] The accompanying description indicated that such installations were sent abroad for the operation of small mines. It might therefore appear that Victorian miners, many of them Cornishmen, were simply following accepted Cornish mining practice. Nevertheless there are references to horizontal geared pumping engines in use at Clunes as early as 1859, Bendigo in 1860 and Ballarat from 1862 onwards.[78] As references overseas to geared pumping engines do not appear until 1870, this may well be a case of local innovation, although the available evidence is by no means conclusive.

The general impression is that the engineers and engineering manufacturers in Victoria in the latter half of the nineteenth century were no fools. Although the first stage of mine mechanisation had, perforce, to be with readily available imported machinery, they soon began to adapt this to their own needs, encouraged in this firstly by the newly formed Science Board and then by the Department of Mines. By 1859, more than a decade before they were reported in Europe, they were installing horizontal geared pumping engines; by 1862, and apparently before their introduction into Britain, they were using small horizontal direct-acting pumping engines; and by 1865, a year before the Chatham trials, they were also using centrifugal pumps. By 1870 horizontal engines had displaced whim engines for general duties, as was then happening in Britain and Europe, and for moderate pumping duties horizontal engines were considered to be preferable to beam engines. They were cheaper to install, even if more expensive to operate, and they were, as the records show, the choice of companies wanting to minimise their initial expenditure. For heavy pumping duties however, where the engine was to be used solely for this purpose, beam engines remained the first choice. Although they might cost more to install, they were generally cheaper to operate and far easier to control. This advantage was not seriously challenged until the introduction of horizontal triple-expansion pumping engines, the first of which was installed in 1895. Until this time horizontal pumping engines complemented rather than competed with beam pumping engines. What eventually brought about the demise of the beam engine was the great increase in pumping power brought about by compounding. This first occurred in Victoria in 1889, at the same time as the first marine triple-expansion engine was installed in the London water works, but whereas in Britain it was the inverted-vertical form which was successful, in Victoria it was the horizontal one which was adopted because this left the shaft opening relatively uncluttered for other essential machinery.

Beam pumping engines in Victoria were therefore not antiquated machinery tolerated in some technologically backward corner of the world, but were, for their time, a carefully considered and wholly appropriate engineering response to the problems confronted by local mining companies. Such sites as now remain therefore need to be considered fairly on their merits unhindered by unwarranted preconceptions.

SIGNIFICANCE

Although only twelve beam engine sites now survive they are nevertheless representative of the range of sites once active, from almost the first to the last, and from relatively small whim installations to the largest pumping ones; and they are able to document the gradual sophistication of engineering manufacture in Victoria in the latter half of the nineteenth century.[79] All the very earliest engines appear to have been imported, as might be expected. The only beam engine known to have been made locally, prior to 1884, was by the Phoenix Foundry at Ballarat for the New Perseverance Company in 1862. All trace of this site has long since disappeared.

The first of the larger engines, with a 40 inch cylinder and installed by the Great North West Company at Ballarat in 1866, was an imported Harvey engine. Local engineering establishments at that time almost certainly lacked the experience, the patterns and the productive capacity needed to make this and the larger engines which were installed on Ballarat up to 1870. In the next decade, however, they made good all these deficiencies.

By 1870 the Union Foundry at Ballarat had installed a large cupola capable of melting 20 tons of iron in three hours, as well as two overhead cranes traversing the entire length of the foundry and together capable of lifting 60 tons. It had also designed and specially made, at a cost of £800, a large engine lathe capable of machining objects up to 11 feet in diameter and up to 40 feet long. Shortly before this, on 26 September 1867, one of the side plates of the cast iron beam broke on the 32 inch engine belonging to the Great North West Company at Ballarat. The beam was 32 feet long, 5 feet 6 inches deep at the centre, and 2.5 inches thick. The Union Foundry delivered a new half-beam, requiring 12 tons of molten metal, within 12 days. This was the largest casting then poured in the colony. Early in 1874 the same foundry supplied a replacement 54 inch cylinder for the City of Ballarat Company when the flow of water became too great for its imported 40 inch engine. Finally, in October 1879, the foundry supplied two sets of 22 inch pumping gear for the Duke and Timor 80 inch engine. This was the heaviest lot of pumps and gear then made and assembled in Australia. By 1880, therefore, the Union Foundry had made and installed all the main components needed in a large pumping engine. All it wanted was the opportunity to put this experience together in a single installation.

In 1872 the Duke and Timor Company had invited tenders from local foundries for a 72 inch engine. They had hoped to get one for £3 000, but the only tender received, probably from the Union Foundry, was for £5 000. Langlands Foundry, Victoria's oldest engineering establishment, had been interested at first, but eventually decided that they would have had to import too much costly and special machinery. The Duke Company eventually imported an 80 inch by 120 inch engine from England at the somewhat depressed price of £2 738 (including transport). This was the last of the large beam engines to be imported.

At the next available opportunity, in 1884, the Union Foundry succeeded against international competition in securing a contract to supply a 70 inch by 108 inch engine for the Berry No. 1 Company at Smeaton, but only after entering into a bond for £1 000, or about one third of the cost of the engine, because critics thought the foundry was unable to make it. The 25 ton beam was cast in two main sections, 32 feet long by 6 feet 3 inches deep.[80] The cylinder weighed 10 tons, the bottom casting 5 tons, and the cylinder cover 4 tons. As it happened, the engine was ready well before the company bottomed their shaft, and when it was finally put to work, in September 1885, it went away without a hitch. It had an all-up weight of about 120 tons and developed 270 horsepower.

The Berry No. 1 engine was the largest beam engine made in Victoria up to that time. Whatever the design lacked in originality, it nevertheless marked a high point in the development of mechanical engineering manufacture in this country; signifying that in little more than forty years after the first foundry had been started in Melbourne with the simplest of equipment, some engineering establishments had gained sufficient experience and skills to manufacture economically what, at that time, were examples of high technology. Over the next thirty years that newly-won confidence was expressed with a certain exuberance in a series of pumping engine installations which were neither simple copies of imported machinery, nor merely the work of one highly specialised foundry. These developments made it possible for Victoria to be a net exporter of machinery throughout the period following the financial crisis of 1892–1893 and this undoubtedly assisted some local establishments to recover when there was a gradual decline in the local demand for mining machinery, and a reduction in the availability of investment capital.

Although the early engine houses which survive appear to be copied from Cornish examples,[81] the absence of local stone on Ballarat and the central leads, as the traditional building material, led to the application of other materials so that several of the later Victorian engine houses were constructed in ways which were not to be found in Cornwall. For example, there are no engine houses in Cornwall built wholly of brick,[82] there are none built in concrete, and none compares for monumentality with the massive granite beam wall at the Duke and Timor mine site.[83]

CONCLUSIONS

Victoria had almost as many confirmed beam engines installed as in South Australia, and although no engines have survived, the sites of twelve engine houses have. These span the period from 1859 to 1905, and complement those still extant in South Australia.

Throughout most of the nineteenth century non-rotative beam engines were a simple, effective and cost efficient way to pump large volumes of water. This position was not seriously challenged for moderate pressures and moderate discharges until the introduction of the triple-expansion steam pumping engine, based on marine engine practice, after 1889.

Quite apart from their own intrinsic significance as examples of the local use of what was then regarded as advanced technology, it is possible to read the Victorian sites in terms of the gradually increasing level of local engineering sophistication in the latter half of the nineteenth century. At a time when the engineering establishments involved in these developments have disappeared altogether, and the places they once occupied have often changed beyond all recognition, what remains of the sites where the engines they made and maintained once operated are a significant part of Victoria's engineering heritage, and a timely reminder of local enterprise.

Half a world away the surviving Victorian and South Australian beam engine sites complement and extend the range of those sites still to be found in Cornwall. Indeed they represent the most significant collection of engine houses outside Britain, providing striking evidence of the continuity of Cornish mining technology and mining practice, as well as local variations on those traditions. In view of renewed interest in the preservation of the surviving engine houses in Cornwall, it would appear appropriate if greater efforts were made to do something similar here, beginning by nominating the more significant of these sites for the Register of the National Estate and then for the World Heritage Register. For Victoria this should include these ten sites: Eldorado Company, Specimen Hill, Fryers Creek (1860), oldest extant site in Victoria; Duke of Cornwall/Australian United Gold Mining Company, Cattle's Reef, Fryers Creek (1869), most intact engine house; Anglo-Australian Company/English-Australian Gold Mining Company, Heron's Reef, Fryers Creek (1870), most intact whim engine site; Duke and Timor Company/Grand Duke Company, Timor Lead, Chinaman's Flat, Maryborough (1873), largest beam engine site in Australia; Berry No. 1 Company, Smeaton, Creswick (1884), site of first locally made beam engine; Hepburn Estate Leasehold Company, Smeaton, Creswick (1885), site of second locally made beam engine; Chalk's No. 1 Company, Carisbrook, Maryborough (1887), relocated site of largest beam engine on Ballarat; Duke No. 1 Company, Timor Lead, Chinamans Flat, Maryborough (1888), site of relocated Ballarat beam engine; Band of Hope and Albion Consols, No. 9 shaft, Golden Point Lead, No. 1 division, Ballarat (1895), only extant site on Ballarat; Loddon Valley Goldfields Company, Moolort, Maldon (1905), site of last beam engine used in Victoria.[84]

NOTES

1 Connell 1987.

2 McCarthy and Davis 1986; These were: Band of Hope, Ballarat; Great North West Company, Ballarat; Band and Albion No. 9, Sebastopol; Star of the East No. 2, Sebastopol; Duke of Cornwall, Fryerstown; Grand Duke, Timor; Duke Extension, Timor; Moolort Gold Estates, Moolort; Berry No. 1, Allendale; and Hepburn No. 1, Allendale. All these engines are included in Table 1, although the names of the companies with which they were associated differ in some instances.

3 Baragwanath 1903, 1923; Gregory 1906; Hunter 1903, 1909.

4 Imperial units are used throughout as almost all the machinery described here was made in those units. In specifying a beam engine, none of which were compounded, the first dimension is the diameter of the cylinder and the second is the maximum length of the working stroke. This also applies to other simple engines. For compound and triple expansion engines the first dimensions are the diameters of the cylinders (from high pressure to low pressure) and the last dimension is the stroke. Where dimensions are unknown these are designated by ***.

5 Barton 1969:279–281.

6 Barton 1969:281.

7 Barton 1969:281. The company had called tenders for the local manufacture of a 72 inch engine at a cost of £3 000, but had been disappointed that no one was prepared to supply such an engine at this figure. The 1872 engine is listed in Barton (1969:281) with a price of £2 350 delivered in London which is comparable with the price set by the company for local manufacture if transport costs for the imported engine are also included.

8 5 September and 1 November 1860, for example.

9 Advertisements for beam engines persist over several years, at least from 1857 until 1862.

10 Victoria, Department of Mines, Quarterly Reports of the Mining Registrars.

11 This also assumes that the data are reliable. Whilst the accuracy of the numbers recorded for any particular division depended crucially upon the energy, initiative and perseverance of the individual mining registrar, the accuracy of the aggregate would be less seriously affected by such individual differences.

12 Steam engines were used elsewhere, notably in flour milling and in manufacture, but at least for the period to 1880 the consumption of power in Victorian quartz mining was at least twice that for manufacturing and agriculture combined; without taking account of the power initially expended in alluvial mining. Power consumption in Victorian manufacturing did not achieve parity with that in quartz mining until 1884.

13 742 by horsepower and 577 by cylinder diameter.

14 41 by horsepower and 114 by cylinder diameter. There were also 36 portable engines (26 by horsepower and ten by cylinder size), 16 vertical engines (11 by horsepower and five by cylinder size) and seven other types of engine (oscillating, donkey and locomotive).

15 That is, 24 + (446 + 659)/7 = 182 (Milner 1988:7, and Tables 1 and 2).

16 The data need to be treated with a certain amount of caution as none of the companies which had large beam engines were recorded as having installed condensers; the Berry No. 1 Company, for example. But the sectional elevation of this engine, which was published in the Annual Report of the Department of Mines for 1884, clearly shows both the condenser and the air pump mounted between the beam wall and the shaft.

17 There are 71 references specifically to condensers for steam engines in the Department of Mines and associated reports. The first of these was one installed at the Port Phillip Gold Mining Company, Clunes, in 1859, but the majority of the references (47) are to installations after 1899, and there are only 11 references to installations prior to 1880. This would suggest either that the use of a condenser was not worth reporting or that most engines used on Victorian mines were non-condensing. The latter explanation is more likely as there are regular reports (34) for the period from 1863 to 1868 about companies cleaning boilers, and occasional reference in the same period to the corrosivity of the mine water which seems to have been in regular use.

18 In the conventional Cornish engine arrangement, where the beam load was supported by a massive masonry wall, this was chiefly associated with the building of a substantial engine house. For the 80 inch engine obtained by the Duke and Timor Company for £3 000 and installed at Chinaman's Flat, the beam wall was constructed from dressed granite blocks generally 3 feet square and 6 feet long and the engine house had cost £2 000.

19 This view has been chiefly promoted by Blainey's (1963) reading of Thureau (1877), Rickard (1890), and 'Victorian goldfields. Sandhurst', *Engineering*, 49, 3 January 1890, 15–18; 49, 17 January 1890, 53–56; 49, 312 January 1890, 105–108; 49, 14 February 1890, 160–162, supplement; 49, 21 February 188–192; 49, 7 March 289–292; and more recently supported by McCarthy and Davis (1986), and by Davey (1985).

20 For example, the three 84 inch by 144 inch by 132 inch annular compound beam pumping engines, *Leeghwater*, *Cruquis* and *van Lijnden* designed by Arthur Dean and Joseph Gibbs for the drainage of the Haarlemermeer, Holland, and built between 1845 and 1849 by Harvey and Company, Hayle, and by Williams' Perran Foundry, Perranarworthal. The eleven 63 inch by 120 inch pumps were arranged around the circular engine house and connected to the engine with lattice work beams cast in Holland. Two other engines (the *Cruquis* and *van Lijnden*), each with eight 84 inch by 132 inch pumps were built shortly afterwards. The 110 inch by 120 inch 1 600 horsepower rotative beam pumping engine, *The President*, with lattice-work beam and 75 ton flywheel made by Meyrick and Sons, Philadelphia, and erected in 1868 at the Friedenville zinc mine, Bethlehem. Four sets of 30 inch by 120 inch plunger pumps and four sets of 31.5 inch by 120 inch bucket pumps, boilers and fittings were made by I. P. Morris and Company, Philadelphia. The 130 inch by 156 inch Bull pumping engine erected at Sanita Barbe mine, Charleroi, Belgium, in 1873. This operated 24 inch pumps at 1 900 feet. It was the largest such engine ever built, with probably the deepest Cornish pitwork. Finally, the twin 40 inch by 120 inch 1 400 horsepower rotative beam engine with cast iron beams 27 feet long and 9 feet deep, a 30 foot flywheel weighing 56 tons mounted between the beams, built by George Corliss for the Centennial Exhibition, Philadelphia, where it operated all the machinery through line shafting. It weighed 700 tons and stood 40 feet above the exhibition floor.

21 'Centrifugal pumps'. *Engineering*, 1, 27 April 1866, 275–276; Barr 1902:335.

22 This was based on a design patented and used by Andrews in New York in 1846. John Gwynne purchased this patent, obtained a British patent for elements of this design ('Machinery for pumping, forcing and exhausting steam, fluid and gases; adoption of the same for producing motion, and to the saturation, separation and decomposition of substances.' British Patent no. 13 577, 31 March 1851) and began making centrifugal pumps in London. Additional British patents were granted to James Eglinton Anderson Gwynne ('Machinery for lifting, forcing and exhausting.' no. 2043, 22 September 1854, and 'Improvements in the construction of centrifugal pumps and in the application thereof, parts of which improvements are also applicable to other pumps.' no. 1248, 29 April 1862). The second of these patents disclosed the design of a centrifugal pump runner capable of lifting fluid to moderate heights, and it was probably this runner which was used in the tests of 1866.

23 Centrifugal pumps were used in sewage pumping stations at Canterbury (1881), Kingston (1888) and Dublin (1888) where only a low lift was required; 'The drainage of the Haarlem Meer', *Engineering*, 59, 8 March 1895, pp. 299–301.

24 'Pumping plant, East London water works', *The Engineer*, 98, 30 September 1904, pp. 328–329.

25 'The Worthington steam pump constructed at the Henry R. Worthington hydraulic works, New York', *Engineering*, 38, 14 November 1884, pp. 450–452, 454; 'The Worthington steam and brewery pumps', *The Engineer*, 54, 22 September 1882, p. 214. Worthington was soon followed by others whose pumps differed from his chiefly in the form of valve gear used (see Barr 1902:200–225 for details).

26 'The Worthington pumping engine', *Engineering*, 10, 23 September 1870, p. 224. This pumping engine delivered over 4 million gallons of water per day to 175 feet and developed 123.5 water horsepower.

27 Trials of a 29 inch by 50.25 inch by 50 inch Worthington twin (duplex) horizontal tandem-compound non-rotative pumping engine installed at Belmont, Philadelphia, in 1873, demonstrated that further developments in the direction of operating efficiency were still necessary. The engine returned a duty of only 44.68 millions when the contract had been for 67.969 millions ('Reports upon the tests of the Worthington pumping engines at Belmont', *Engineering*, 15, 6 June 1873, p. 411; 16, 4 July 1873, pp. 17–18).

28 As at the West Docks, Hull, in 1882 (780 pounds per square inch); the Windsor Slipway, Cardiff, in 1885 (1 000 pounds per square inch); Buenos Ayres docks in 1885; Pirnie colliery, Fifeshire, in 1886 (1 000 pounds per square inch); and the Eiffel Tower in 1889.

29 These were horizontal tandem-compound pumping engines with 41 inch and 82 inch cylinders for the National Transit Company. They were the largest direct-acting pumping engines in the world at the time and were capable of delivering 25 000 barrels of oil per day at a pressure of 1 500 pounds per square inch ('The transportation of petroleum', *Engineering*, 31 July 1885, pp. 108–109, supplement; 'Pumps for mineral oil', *The Engineer*, 68, 30 August 1889, p. 178). S. Owens and Company, London, had also supplied Blake pattern duplex direct-acting pumping engines for the oil fields in the Caucusus in 1882 ('Pumping petroleum', *Engineering*, 33, 27 January 1882, pp. 86, 88).

30 'The Worthington pumping engine', *The Engineer*, 61, 19 March 1886, pp. 232–233.

31 'The Worthington high duty pumping engine', *Engineering*, 46, 7 December 1888, pp. 565–567.

32 For example, in 1876 Farcot et ses Fils, St. Ouen, erected a 14.17 inch by 39.37 inch by 70.87 inch horizontal cross-compound rotative direct-acting engine in a pumping station at St. Maur which returned a very commendable specific coal consumption of 1.54 pounds per indicated horsepower hour. Direct-acting engines were subsequently installed at Potsdam (1878), Flensburg (1881), South Africa (1882), Remscheid (1883) and Yokohama (1886). Surprisingly, however, McNaughted compound beam pumping engines were designed by Otto Mueller and built and erected in 1882 by the Prager Maschinenbau Actiengesellschaft, Prague, at the two pumping stations at Ofen, to pump water from the Danube River up to service reservoirs at various heights between 175 and 933 feet to supply Pesth; conditions which would surely have suited the use of direct-acting pumping engines ('Pumping engines at Buda-Pesth', *Engineering*, 39, 8 May 1885, p. 528, supplement; 39, 22 May 1885, pp. 574, 578, supplement; 'Compound pumping engines for the Buda-Pesth water works', *Engineering*, 39, 5 June 1885, pp. 622–623).

33 Tangye Brothers, Birmingham, began supplying the American Cameron pattern horizontal direct-acting pumps to the Newcastle and Durham coalfield in 1870. They installed a 26 inch by 72 inch pumping engine developing 37.8 water horsepower, complete with its own boiler, in an underground chamber at the 1 040 foot level in the Adelaide colliery, Bishop Auckland, in 1871. They and others subsequently supplied such pumping engines to Stannier's colliery, Silverdale (540 feet underground in

1872); Newton Gap colliery (1873); Erin colliery, Westphalia (1876); Newent colliery (280 feet underground in 1880); Pildacre colliery, Ossett (1884); Hebburn colliery (1 100 feet underground in 1886); Petershaft, Michalkowitz (1887); Denby colliery, Derby (1887) and Dynevor colliery, Newton Abbey (1888).

34 This had steam jacketted cylinders, Davey differential valve gear and was coupled by an angle crank to two 24 inch bucket pumps in series and each lifting to 300 feet. With steam in the cylinder jackets and operating at 6.95 double strokes per minute with steam supplied at 63.6 pounds per square inch and exhausting to 12 pounds per square inch vacuum, a duty of between 75 and 83.3 millions was returned. With the stroke reduced to 86.25 inches, no steam in the cylinder jackets and operating at eight double strokes per minute with steam supplied at 62 pounds per square inch and exhausting to 11.75 pounds per square inch vacuum, the engine indicated 254.47 horsepower and returned a duty of between 90.72 and 100.8 million ('Direct acting pumping engines', *Engineering*, 22, 17 November 1876, pp. 421–425, supplement).

35 There were also three notable horizontal pumping engine installations at Staveley in 1873, 1876 and 1879. In the last of these the 45 inch by 72 inch by 120 inch horizontal tandem-compound pumping engine indicated 290 horsepower. This was the first engine to achieve a stroke similar to that in use in many large Cornish beam engine installations ('Compound horizontal pumping engine, Staveley', *The Engineer*, 50, 24 September 1880, pp. 229, 232; 'Pumping engines at Staveley — old and new. No. V', *The Engineer*, 50, 8 October 1880, pp. 262, 269. See also for comparisons Milner 1988:122).

36 Duty was a measure of the overall effectiveness of a pumping engine, expressed in terms of the number of million Imperial gallons of water raised 1 foot by a fixed measure of coal (84, 100 or 112 pounds). Such measures have to be treated with a certain caution as coal quality varied, the actual amount consumed was not always stated, United States rather than Imperial gallons were sometimes used, and the engine under test might have been specially prepared and operated with exceptional care.

37 By 1842 marine engines were being measured in thousands rather than hundreds of horsepower, and although their slow speed of operation (generally no more than 50 revolutions per minute) made them ponderous giants at the time, by 1877 the speed of smaller marine engines of a size suitable for waterworks and mine pumping duties exceeded 300 revolutions per minute, they had become relatively compact and, as the result of experience gained on long ocean voyages, had become remarkably reliable.

38 The company had acquired considerable experience in building marine engines at least since 1868 ('Expansion gear of the engines of the Colombian constructed by Messrs T. Richardson and Sons, engineers, Hartlepool, from the designs of Mr. Geoffrey W. Jaffrey', *Engineering*, 5, 17 April 1868, p. 359, supplement).

39 Two years earlier, in 1887, S. Moreland and Company, London, had erected a 32 inch by 52.65 inch by 84 inch inverted-vertical cross-compound pumping engine in the Hampton pumping station for the Southwark and Vauxhall waterworks, but although this was generally based on marine engine practice it was designed by the resident engineer, J. W. Restler, and built by a company with little experience in marine engine construction ('Double cylinder compound pumping engine — Southwark and Vauxhall waterworks, Hampton', *The Engineer*, 64, 1 July 1887, pp. 10, 13; 64, 8 July 1887, p. 30; 'Compound pumping engines — Southwark and Vauxhall Water Company', *The Engineer*, 64, 22 July 1887, pp. 65, 68, 69, supplement).

40 Comparable performance for Woolf compound beam pumping engines ranged from 14.43 (1878) to 18.09 (1882) pounds per indicated horsepower hour.

41 The key installations were Newark, United States of America (1870), with a Worthington horizontal non-rotative direct-acting pumping engine; East Hetton colliery, Durham (1876), with a Hathorn, Davis, Campbell and Davey horizontal tandem-compound non-rotative pumping engine; Hampton pumping station for the West Middlesex Water Works Company (1888) with a 330 horsepower Worthington pumping engine by James Simpson and Company, Pimlico; Waltham Abbey pumping station for the East London Water Works Company (1889) with a marine-based inverted-vertical triple-expansion pumping engine by Richardson and Sons, Hartlepool; and Leeghwater, Holland (1895) with the replacement of the annular-compound beam pumping engine by two compound engines, each direct coupled to a centrifugal pump.

42 This was reason enough why Watt engines succeeded Newcomen atmospheric engines so swiftly in the eighteenth century.

43 This was just after the report on the comparative tests between the Appold and Gwynne pumps at Chatham docks had been published in the British technical journal *Engineering*, for 27 April 1866.

44 This confirms that such pumps were not yet particularly efficient, something the Americans found out several years later.

45 Notably, Phoenix Gold Mining Company, Avoca (October 1866 for water supply); Newington Gold Mining Company, Ballarat (January 1867 for water supply); Western Freehold Gold Mining Company, Haphazard Lead, Ballarat (January 1867 for water supply); United Sir William Don Gold Mining Company, Ballarat (February 1867 for water supply); Newington Freehold Gold Mining Company, Haphazard Lead, Ballarat (May 1867 for water supply); Latham and Watson, Hustler's Reef, Bendigo (December 1867 for water supply); New Don Gold Mining Company, Ballarat (May 1868 for water supply); and the Port Phillip Gold Mining Company, Clunes (December 1868 for tailings). The speed with which Ballarat companies in particular took up this new form of pump suggests that they were active in seeking any improvements to their operations.

46 Notably, the Phoenix Foundry at Ballarat. This company was responsible for supplying to the Newington Gold Mining Company three 6 inch 500 gallons per minute centrifugal pumps operating at 902 revolutions per minute to provide water for puddling (*Dicker's Mining Record*, 1 January 1867, p. 2). Their ability to manufacture these units locally may have encouraged other Ballarat mining companies to purchase these pumps. Wright and Edwards (1860–1900) began the manufacture of centrifugal pumps in Melbourne in 1870 (*The Age*, 1 January 1870) in sizes from 200 to 8 000 gallons per minute, but the majority of these appear to have been used in connection with their patent sheep washing plant (William Wright, 'The improvement of sheep washing (altered to) Improvements in the construction of sheep washing machinery.' Victorian Patent no. 1 200, 21 December 1868). They exhibited a

12 horsepower portable engine coupled to a 20 000 gallons per minute centrifugal pump at the Victorian Centennial Exhibition in 1888, and this appears to have been the largest size of pump which they made. Robison Brothers, South Melbourne (1858–1973), began centrifugal pump manufacture in 1874, but there is no evidence of the use of their pumps in Victorian mines before 1917. They did, however, supply several quite large units: a 50 000 gallons per minute centrifugal pump in 1878 for Wright and Orr's dry dock, South Melbourne (Woodley and Botterill 1985:43), and two 90 000 gallons per minute centrifugal pumps in 1904 for Duke and Orr's dry dock (Weickhardt 1984). The Atlas Company of Engineers, Melbourne and Carlton (1868–1919), advertised their centrifugal pumps in 1870 (*The Age*, 1 January 1870 and 10 March 1870) and John Walker and Company (later Hickman's Union Foundry), Ballarat (1865–1912) advertised their centrifugal pumps as general machinery in 1871 (*The Age*, 21 November 1871), but there is no evidence that any of these pumps were used in Victorian mines. If they were, then it was only in such small sizes that they escaped attention.

The original pumps for the Alfred Graving Dock, Williamstown, and Duke's dock, South Melbourne, were supplied by the Fulton Foundry Company in 1872 and 1874 respectively (contract nos. 654/71-72 and 1535/73-74, Victoria, Government Gazette, and Woodley and Botterill 1985:43), and were almost certainly steam engine driven reciprocating pumps, as there was no capability for the manufacture of large centrifugal pumps for this application in Melbourne at the time. In fact, this may well have prompted Robison Brothers to begin their manufacture in 1874. When the original Williamstown pumps were replaced in 1922 they were with two 11 inch by 19.5 inch by 9 inch 260 brake horsepower two-crank inverted-vertical cross-compound totally-enclosed high-speed stationary steam engines, each direct-coupled to a double-sided centrifugal pump.

47 Victoria, *Annual Report of the Secretary of Mines* (ARSM), 1889, p. 38.

48 Wallace's Rowdy Flat Company, Rowdy Flat, Yackandandah (1890); Wallace's Woolshed Valley Gold Mining Company, Woolshed Valley, Beechworth (1890); and the Yarrowee Creek Gold Dredging Company, Ballarat (1891).

49 This information has been extracted from the company's works order books held by the University of Melbourne Archives. Books for the years 1902 to 1917 inclusive were the only ones available, although it is evident from the rise and fall of orders that there was little activity prior to 1902, and not much immediately after 1917. It is not clear when Thompsons first made pumps for hydraulic sluicing plant, although they participated in trials of centrifugal pumps suitable for irrigation purposes at Kerang in 1886 (in which they were placed third out of three competitors), and they made the first of a number of centrifugal pumps for irrigation works to the Cohuna Irrigation Trust between 1889 and 1892.

50 The Thompson works order books for the period indicate that 10 inch and 12 inch gravel pumps and a 14 inch hydraulic pump were supplied to F. M. Lush, Goss Moor Tin Alluvials Limited, Cornwall, in 1909. Another 12 inch hydraulic pump was supplied in 1910.

51 Hunter 1909:82. 3 000 horsepower, if correctly reported, seems like overkill; but it was probably a reflection upon the difficulty which companies working the Berry lead system further to the south had experienced at least since 1883 in bottoming their shafts. The pump was first used as a sinking pump in accordance with accepted American mining practice. The electric motor was later used for the underground haulage system, but in 1906 a centrifugal pump had to be installed to augment the capacity of the 18 inch plunger pumps (Victoria, Annual Report of the Secretary for Mines and Water Supply, 1906, p. 106).

52 *Dicker's Mining Record*, October 1862, pp. 7–8.

53 This pumping engine was capable of discharging 2 million gallons every ten hours to 100 feet [101.01 water horsepower] ('Pumping engines for Sydney', *Engineering*, 24, 6 July 1877, p. 10, supplement). In 1886 a 12 inch by 20 inch by 36 inch horizontal cross-compound rotative direct-acting pumping engine with a 6-spoke flywheel mounted between 90 degree disc cranks, operating at 50 revolutions per minute, direct coupled by tail rods to 8.375 inch brass plunger pumps designed by Norman Selfe was built by the Atlas Company, Sydney, for the Botany water works. The plant was started on 28 June ('Steam pumping engines for Sydney water works', *Engineering*, 42, 3 December 1886, pp. 571, 574).

54 *The Bendigonian*, 6 February 1896.

55 Sutherland 1888:620, 'The Austral Otis Elevator and Engineering Company, Limited, Opening of Their New Works, South Melbourne', *The Australasian Ironmonger*, 1 March 1889, pp. 122–123.

56 'The water supply of Broken Hill, Australia', *The Engineer*, 73, 6 May 1892, pp. 381, 386.

57 Victoria's coal resources were not exploited until after 1880. In 1866, as the supply of firewood on Ballarat became critical, the United Extended Band of Hope Company United began experimenting with burning coal instead of wood in their boilers at No. 2 shaft. At this stage the yearly consumption of firewood was 9 000 tons at seven to eight shillings per ton, whereas coal from Newcastle via Geelong, delivered at the mine, cost £2/8/4 per ton (*Dicker's Mining Record*, 18 December 1866, p. 355). By January 1870 they had concluded that wood was still the cheaper fuel (*Dicker's Mining Record*, 7 January 1870, p. 154). In 1881, with the commencement of black coal mining in Victoria, further tests by the company showed coal to be a more economical fuel than wood (Victoria, Department of Mines, Reports of the Mining Registrars and Surveyors, Ballarat district, 1881, p. 328).

58 In August 1865 the Johnson's Reef Gold Mines, California Gully, Eaglehawk, started two new boilers and reduced their firewood consumption to no more than 40 tons per week (*Dicker's Mining Record*, 20 August 1865, pp. 84–85); in February 1867 the United Sir William Don Gold Mining Company, Ballarat, was reported to have reduced its firewood consumption from 150 to 85 tons per week by resetting its boilers to improve the draught (*Dicker's Mining Record*, 5 February 1867 p. 76); in June 1867 the Comet Gold Mining Company, Redan Reef, Bendigo, installed a new set of pumping gears and saved fuel as a consequence (*Dicker's Mining Record*, 11 June 1867, p. 260); in September 1867 the Specimen Hill Quartz Mining Company, Specimen Hill, Hepburn, rebored the cylinder of its beam engine and saved 30 tons of firewood a week (*Dicker's Mining Record*, 14 September 1867, p. 99); in March 1868 the Caledonia Company at Maldon were erecting a 50 horsepower condensing engine and expected to save 25 per cent in firewood (Victoria, Department of Mines, Reports of the Mining Registrars and Surveyors, Maldon Division, March

1868, p. 1041); by December 1869 the Catherine Reef United Claimholders Gold Mining Company, Peg Leg, Eaglehawk, had erected a condenser for their battery engine and were saving 25 per cent in fuel (Victoria, Department of Mines, Reports of the Mining Registrars and Surveyors, Sandhurst District, December 1869, p. 225; *Dicker's Mining Record*, March 1870, p. 198); in December 1885 the Hepburn Estate Company, Smeaton, hoped to save 30 per cent on firewood by winding with a wire rope in place of a manilla one (Engineer's Report, Hepburn Leasehold Company, 5 December 1885); and in 1908 the New Moon Gold Mining Company, Eaglehawk, had installed a Stirling water tube boiler and saved 90 tons of firewood per week (Victoria, Annual Report of the Secretary for Mines and Water Supply, 1908, p. 160).

59 See Note 30.

60 The only 100 horsepower engine erected on a Victorian mine before 1889 was the 10.25 inch by 36 inch twin cylinder horizontal simple engine which the Black Hill Company had erected to drive their stamp battery. This was never used for pumping. In November 1861 this was reported to be capable of developing 80 horsepower ('Mining Intelligence', *The Ballarat Star*, 7 November 1861), but in August 1862 this was reported to be 100 horsepower (*Dicker's Mining Record*, August 1862, p. 10). Most large beam engines were capable of developing upwards of 250 horsepower.

61 ARSM Victoria, 1891, p. 48.

62 ARSM Victoria, 1892, p. 51.

63 *The Ballarat Star*, 17 April 1894; ARSM Victoria, 1894, pp. 42–43.

64 That is, the two 70 by 108 inch engines at Smeaton.

65 This was reported to be one of the finest and most powerful pumping engines manufactured in the colony and was capable of lifting 157 980 gallons of water per hour. The high pressure and intermediate pressure cylinders were steam jacketted and all cylinders were lagged with felt and covered with varnished cedar secured by polished brass bands. The high pressure cylinder was fitted with a compound piston valve and operated independently by Allan straight link motion valve gear. The intermediate and low pressure cylinders were fitted with double ported slide valves and coupled Allan straight link motion gear. The flywheel was 17 feet in diameter and the pumping spur gear was 12 feet in diameter and weighed 12 tons. The engine was designed to operate with steam supplied at 150 pounds per square inch by three Cornish boilers, 6 feet 6 inches in diameter by 28 feet, each fitted with Galloway tubes and a water bridge. Each of the three cylinders were mounted side by side on separate cast iron bed plates for ease of transport and these were rigidly bolted together by two additional cast iron girders to ensure correct alignment of bearings and to ensure rapid erection. Special care had also been taken with the provision of efficient lubrication, relief valves and facilities for efficiently taking indicator diagrams (Victoria, Annual Report of the Secretary for Mines and Water Supply, 1895, 35, pp. 59–60; 'A modern pumping engine', *The Ballarat Courier*, 14 January 1896, p. 4).

66 This engine was designed to operate with steam supplied at 150 pounds per square inch. The high pressure and intermediate pressure cylinders were placed in tandem with the low pressure cylinder alongside, with 90 degree cranks. The high pressure cylinder was fitted with a compound piston valve, whilst the other cylinders were fitted with slide valves. All cylinders were fitted with Allan straight link motion valve gear. The flywheel was 17 feet in diameter and weighed 10 tons, and the pumping spur gear was 12 feet 6 inches in diameter and weighed over 14 tons (Victoria, Annual Report of the Secretary for Mines and Water Supply, 1896, p. 85; *The Ballarat Courier*, 11 April 1896, p. 5; *The Ballarat Courier*, 9 January 1897).

67 Victoria, Annual Report of the Secretary for Mines and Water Supply, 1897, p. 34; 1898, p. 55.

68 McCarthy and Davis 1986.

69 For the non-rotative beam engine there are eight: cylinder, beam, pump rods, pumps, balance bobs, parallel motion, valve gear and condenser. For the whim engine there are 13: cylinder, beam, sweep rod, flywheel, pump rods, pumps, balance bobs, angle crank, flat rods, parallel motion, crank, valve gear and condenser. For the horizontal engine there are 11: cylinder, sweep rod, flywheel, pump rods, pumps, balance bobs, angle crank, gears, flat rods, crank and valve gear. If the sub-assemblies common to each are eliminated (ie pump rods, pumps and balance bobs) then the numbers of sub-assemblies are five, ten and eight respectively.

70 This was particularly noticeable on Ballarat where companies had to sink through up to three leads in order to bottom on the richest one at the lowest level. At each lead the amount of water to be pumped could increase quite dramatically and this required a very flexible pumping arrangement if the mine were not to be hopelessly flooded.

71 In the Cornish beam engine there was always a dwell period between the downward working stroke and the upwards/indoor/return stroke (Stowers 1958:126–127), in order to allow the pumps to become filled with water. This was accomplished by the cataract governor which was a pivoting bucket attached by a lever to the valve gear. When empty the bucket was held in the upright position by the weight of the lever, but as it filled with water it overturned, actuating the gear and emptying the contents into a cistern. The frequency with which it did this depended upon the flow rate of water which, on regulation, altered the length of the dwell period and hence the rate at which the engine worked.

72 There are many more data for horizontal engines (22) than for beam engines (two). The costs per horsepower for horizontal engines range from between £25 and £195 in 1860 to £7 per horsepower in 1892, with all the other data points within these limits. This trend reflects the gradually increasing size of individual engines, the decline in imports, and the growth of local manufacture. For beam engines the cost per horsepower in 1866 was just under £20, or about half the average cost of a horizontal engine at that time. The cost per horsepower was the same in 1872 (the Duke and Timor engine and engine house), by which time the average cost for horizontal engines was roughly comparable. Although there are insufficient data to be able to draw any detailed conclusions, it would appear that the unit costs for beam engines were lower than for any horizontal engines prior to 1875.

73 This is based on the rather sparsely published data on stationary engine testing which appeared in the British technical literature during the nineteenth century. Little or no testing of the specific fuel consumption of engines installed on Victoria mines appears to have been undertaken. The better maintained beam engines were capable of returning a duty of 100 million by 1834. The best horizontal simple engines to 1887 returned a duty of no more than 60. In 1870 an 80 inch Cornish engine returned a specific steam consumption of 37 pounds per

indicated horsepower hour whilst a horizontal simple engine at the same time returned only 55.3 pounds. It is assumed for the purposes of this discussion that these British data are applicable.

74 The gear-cutting capabilities of early engineering workshops in Victoria have not been determined. Wright and Edwards, Melbourne, were reported to have installed the first milling machine in 1886 for the helical gears needed for Melbourne's cable tram system (*The Australasian Ironmonger*, 1 July 1886, p. 73). Before this gears may have been used as cast, and "ground in" during operations. This would only have been possible if they were operated at slow speed, and it might have led to some early failures.

75 Davey 1985.

76 Madam Berry took over two and a half years to bottom their shaft, using second hand equipment including a 25.5 inch by 48 inch horizontal engine and 15 inch pumps, but then they worked a particularly rich section of the lead which made the company a leading gold producer for a number of years. Lord Harry, adjoining this property to the east, used a 26 inch cylinder horizontal non-condensing engine with 18 inch pumps and took over three years (February 1885 to December 1888) to bottom their shaft for very modest returns. Berry Consols, adjoining Madam Berry to the north, were a little more successful. They used an 18 inch cylinder horizontal engine and 10 inch pumps and took four and a half years to bottom (June 1883 to December 1887), but spent £30 487 in sinking No. 1 shaft which was then abandoned. Further north Berry Consols Extended took over ten years to bottom (1883–1894), starting with 16 inch pumps and a 26 inch by 52 inch horizontal engine (compounded as a 14 inch by 26 inch by 52 inch engine in December 1889). Further along the lead to the north the Spring Hill and Central Leads Company erected an 11.5 inch by 16 inch by 30 inch horizontal tandem-twin triple-expansion condensing engine with two sets of 18 inch pumps early in 1896, plant which was regarded as amongst the best in the colony, but had no better fortune than to pump water. Many of the mines in this area were extremely wet, and whether they were eventually successful or not depended much more upon careful sampling of the lead and positioning of the shaft than upon the pumping machinery in use. The failure of the Hepburn Estate Company to make effective use of their beam pumping engine was the result of a poorly positioned shaft and not the inefficiency of the engine; and although the Berry No. 1 Company spent £120 000 with their beam engine their mine was exceptionally wet.

77 'Illustrated catalogue of pumping and winding engines, and other plant used for mining purposes, horizontal, fixed, and portable engines, Cornish and other boilers, general machinery, manufactured by Williams' Perran Foundry Company, Perranarworthal, Cornwall, and 1 & 2 Great Winchester Street Buildings, London, E. C.' Redruth, The Trevithick Society, 1974, p. 9.

78 The Victoria Quartz Mining Company at Clunes purchased an 18 inch by 34 inch 30 horsepower steam engine with 10 inch pumps, geared 3:1 in June 1859 (*Colonial Mining Journal*). This is the earliest reference to such an installation. In February 1860 the Long Gully and Back Creek Mining Company, Bendigo, erected a 15 inch by 30 inch steam engine with 8 inch pumps geared 2:1 (*Dicker's Mining Record*, 21 December 1861, p. 6), and there were subsequent reports of geared pumping installations for the Clunes Quartz Mining Company (September 1861); Cooper's Little Redan Company, Bendigo (September 1861); Albion Gold Mining Company, Ballarat (1861); Alston and Weardale, Ballarat (May 1862); Buninyong Freehold Gold Mining Company, Buninyong (by January 1864); Great North West Company, Ballarat (March 1864); Malakhoff Great Extended Quartz Mining Company, Steiglitz (June 1865); Cambrian Gold Mining Company, Taradale (November 1865); Ararat and Black Lead Gold Mining Company, Ararat (May 1866); P. I. Company, Buninyong (July 1866); Specimen Hill Quartz Mining Company, Hepburn (by January 1867); Argus Gold Mining Company, Castlemaine (June 1867); United Albion and Prince of Wales Gold Mining Company, Ballarat (by February 1868); Lord Harry Company, Allandale (by August 1883); Duke United Gold Mining Company, Timor (1895); Spring Hill and Central Leads Company, Smeaton (by April 1896); Glenfine South Gold Mining Company, Pitfield Plains (1899); Barambogie Gold Mining Company, Indigo (by 1902); Berry United Deep Leads Limited, Smeaton (1907); New Jubilee Company, Smythesdale (?1909); and Magpie Gully Gold Mining Company, Ballarat East (by 1916).

79 Just how much these engines depended upon the accumulation of basic skills and technological capabilities is evident from an account of the erection, between 1797 and 1800, of the first beam engine in the United States, for the pumping station on the Schuykill River, Philadelphia. This had a wooden beam, wooden flywheel, and a 38.25 (40) inch by 78 (72) inch cylinder which had to be cast in two halves because there was insufficient blast furnace capacity available. The two halves were joined together by a copper gasket and secured by a wide band of cast iron, weighing 1 200 pounds. 7 500 hundredweight (pounds?) of metal was used in the cylinder. The hard chilled inner surface had to be chipped by hand and bored to a depth of 0.75 inches using a water-wheel driving boring machine. This took over four months to complete. Steam was supplied by a fire tube boiler, 14 feet long and 9 feet square, made from 5 inch white pine planks reinforced on the outside by oak scantlings 10 inches square, with a central wrought iron flue and cast iron cross flues. The central flue was made from imported English plate as the locally made ones were all produced in different sizes with rough edges which had to be cut smooth by the purchaser. The contractor claimed to have spent the contract price twice over, the engine only returned a duty of 4.79 million, and was replaced by another before 1815 ('The history of the steam engine in America', *Engineering*, 3 November 1876, pp. 383–386; 'Underground pumping engines', *Engineering*, 43, 25 March 1887, pp. 276, 281). Engineering manufacture in Melbourne in 1842 had started in a similarly primitive fashion in the Flinders Street workshop of Langlands and Fulton (Weickhardt 1983:47–49).

80 These were similar proportions to those of the beam which the foundry repaired for the Great North West Company in 1867.

81 Duke of Cornwall, for example.

82 Bricks were only ever used for corners, arches and tops of chimneys.

83 The nearest examples are the engine house of the United Hills copper mine, Porthtowan (Williams n.d.:20), the Basset engine house constructed in 1854 (Ordish 1967:59) and Great Wheal Busy engine house and the East Pool whim engine house, Camborne (Barton 1970:13, 31).

84 More detailed information on all of these sites is given in Table 1.

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