Hydraulic Sluicing on the Gladstone Tinfield, Tasmania

By KEITH PRESTON

Tin mining by hydraulic sluicing proceeded intermittently at Gladstone, Tasmania, for over a century following the initial discovery of alluvial deposits along the Ringarooma River floodplain in 1874. Gladstone is located towards the northern margin of a denuded granite batholith that extends up to 45km to the south of Gladstone and runs approximately 35km from east to west. The Ringarooma River drains the northwestern portion of the resistant upland area associated with the batholith, it being forced on a circuitous route around the eastern side of Mt. Cameron (rising to 550metres) and between it and Empress Hills (110m) to the east of Gladstone (Fig. 1). The tinfield extends across the Empress Hills to be bounded by the Musselroe River to the east, the foot slopes of Mt. Cameron to the west and extending to the north of the Ringarooma River where deep leads and river terraces are associated with Tertiary deposits of lower elevation (less than 60m). As the upland tin deposits on Empress Hills were generally of low grade, economical water supply schemes were essential for achieving sustainable working prior to 1890. These early schemes all obtained water from the only reliable source, the Ringarooma River, but after 1890 the State Government funded Mount Cameron Water Race [MCWR], providing an alternative supply for the eastern and northern parts of the Gladstone tinfield but demand generally exceeded the available supply.

When compared with other Tasmanian tin mining areas, Gladstone was a relatively dry field, with an average rainfall of 925mm (range of 585-1210mm) calculated for the period 1915-39, based on the records kept for the intake of the MCWR, located 19km south of Gladstone.[1] Races cut from the Ringarooma River initially supplied water for ground sluicing of the river terrace deposits but workings were disrupted by elevated winter flows. In contrast, tin deposits associated with the greisenised *crust* of the granite forming the Empress Hills could only be sluiced during the winter months, when sufficient water was captured by dams constructed on intermittently flowing creeks. By 1880 mining was severely hampered by water shortages, leading to various schemes being proposed by mining companies seeking to work their leases but also to contain expenditure. This paper outlines the methods adopted to enable hydraulic sluicing to proceed prior to the commencement of the MCWR in 1890, and the impact of an engineered water supply from the Government water race on mining operations throughout much of the 20th century.

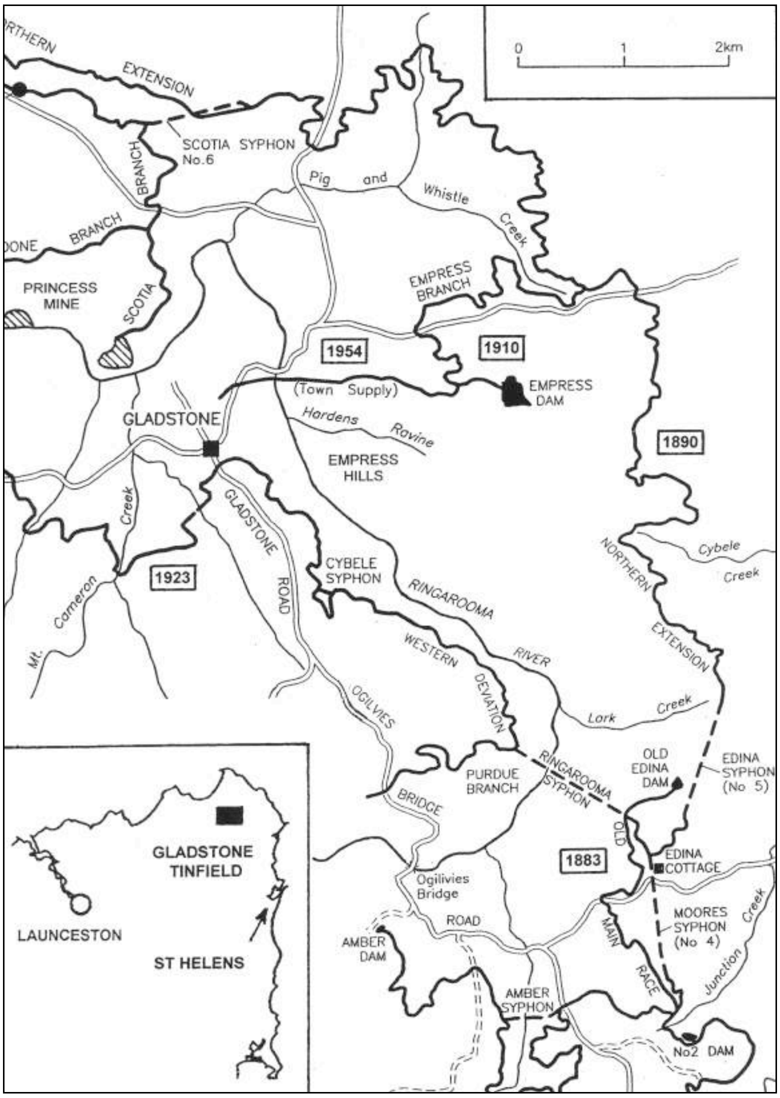
Early Developments

Following George Renison Bell's first discovery of payable alluvial tin deposits along tributaries of the Musselroe River to the northeast of Gladstone in March 1874, tin prospecting proceeded at a rapid pace.[2] By June 1876, numerous claims were being worked on the northern foot slopes of Mt Cameron, including the Clifton TM [Tin

Mining] Co.'s section where the *Launceston Examiner* correspondent witnessed the first low pressure sluicing (hosing) operation in the area:

> A race half a mile[3] in length has been cut from a creek on the Mount to the claim, and the water is then carried another hundred yards on fluming raised on staging to a point 22 feet above the ground. A wooden box, 11in. by 12in. inside measurement, lined with canvas, and 18 feet in length, comes down nearly perpendicular from the end of the flume, and a hose 6 inches in diameter, narrowing to a 3-inch hose, is fixed to the lower end of the box. There is about 20 feet of hose, and to it a brass pipe is affixed with a nozzle only a ½ inch in diameter. A paddock 2 feet in depth has been opened, very fine tin being found top to bottom.[4]

Figure 1: *Gladstone Tinfield showing part of the Mount Cameron Water Race network with completion dates given for each section.*



Source: Mineral Resources Tasmania, Report 1992/21, from compilation of figures.

Prospecting on the western slopes of Empress Hills towards the end of 1875 encouraged Joseph Kennedy to take up a 32ha section, and Thomas Moore to register four sections totalling 104 hectares along Harden's Ravine where greisenised granite outcropped (Fig. 2).[5] While Kennedy financed his own operation, the Eureka TM Co. was formed by a group of Launceston investors that included Moore, to raise the initial working capital of £3,250. In order for ground sluicing or hosing to proceed, the construction of storage dams was required. Kennedy had completed a dam on Tamar Creek together with a 460m long supply race by June 1876, at which time the Eureka Co had engaged 20-30 men to construct a large 45ML dam towards the head of Harden's Ravine. By the beginning of August two-thirds of the 905m long supply race had been cut.[6] Mining was underway in January but production was limited by a shortage of water, resulting in an operating loss of £237 for the previous six months. By August 1879 tribute working was proceeding to reduce operating costs, the dry summers the cause of 'the dam never having been full once'. Production during the following half-year of 17.5t [tonnes] barely covered operating expenses.[7]

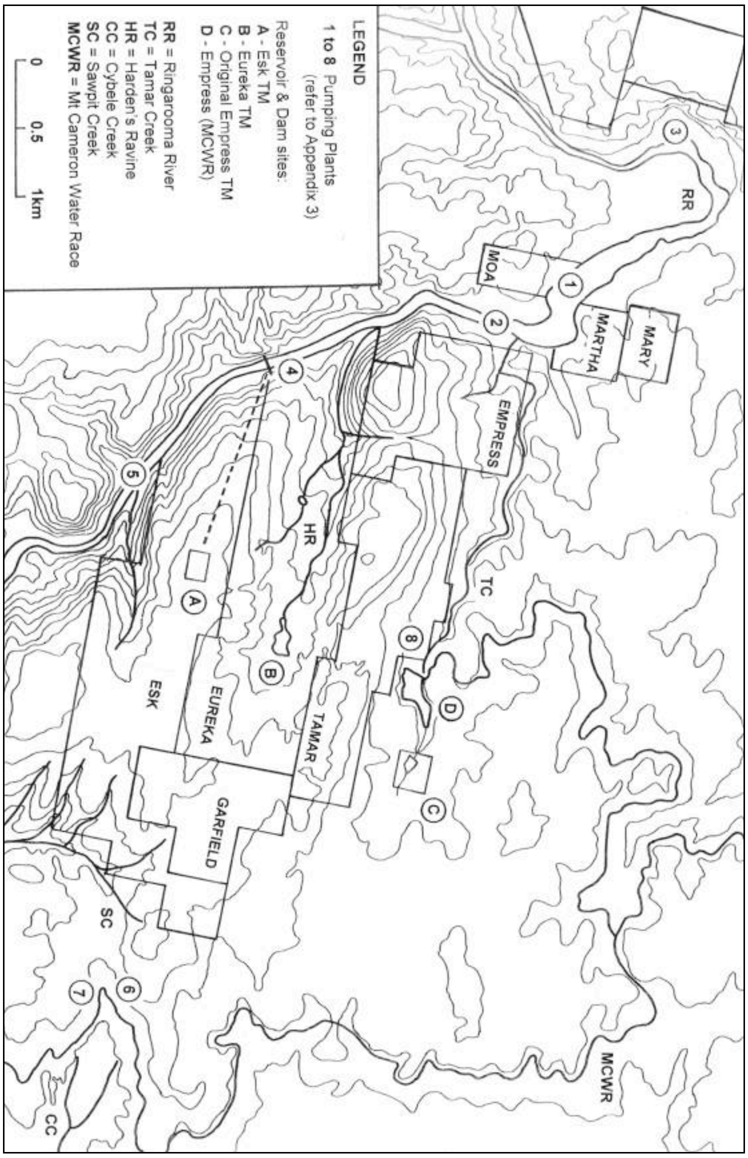
A 50 per cent increase in the tin price to £54 a ton between 1878 and 1881 provided renewed impetus, leading to formation of six public companies to work claims in the immediate vicinity of Gladstone between March 1881 and December 1882. All share offerings were fully subscribed, five floated in Launceston having a combined capital of £99,500 (refer to Appendix 1).[8] Mining leases on the Empress Hills were consolidated into four companies: the Empress that remained privately owned; the Tamar TM Co. that acquired the lease holdings of the Richards family; the Esk TM & Hydraulic Sluicing Co. that accumulated the largest holding of 219ha including the former Eureka TM Co. sections; and the Garfield TM Co. to the east (see Fig. 2). On the western bank of the Ringarooma River the Moa TM Co. acquired two 8ha sections directly east of the Empress lease. The Scotia TM & Water Supply Co.'s leases were widely dispersed but included an area on the north bank of the Ringarooma River that was to form the nucleus of their principle operation. Finally, the Princess TM Co. leased an area along the northern bank of the Ringarooma River some 3km to the west of Gladstone (Fig. 1).[9] All of these companies now had to address the supply of water to enable hydraulic sluicing to proceed unhindered by seasonal fluctuations. Water races of considerable length were not feasible due to the high cost to be borne by individual companies and the associated delays from a protracted construction period, hence pumping was the only practical solution.

Pumping by steam or water power?

A desire to commence production quickly determined the Moa operators to adopt steam power, while the Tamar & Scotia companies also selected steam pumping plants because they assessed the costs of constructing a supply race and waterwheel to be too high. To avoid lengthy shipping delays, steam pumping plant was supplied to the Moa Co. from stock held by the Melbourne agent W.B. Jones (established 1876) of Tangye Bros of Birmingham, England, with a requirement that it would raise water to a height of 21.5m (Appendix 2).[10] The plant arrived in Tasmania in April 1881 and the first pump was operational at the beginning of July. Hoses were used initially but seven months later they had 'commenced to use an hydraulic', thereby becoming a prime contender for the first such application within Tasmania.[11] Government Geologist

Gustav Thureau was actively promoting hydraulic sluicing at this time, leading to at least six operations commencing towards the end of 1882[12] - but the Moa 's first pump proved to be underpowered, leading to the mine being let on tribute in August for a royalty of £19 per ton (approximately 30 per cent). A larger pump arrived in Melbourne seven months later and was operational by November 1882, by which time £12,000 had been expended for minimal return. Tribute working continued but forfeiture of the leases in July 1885 suggests that it was not profitable.[13]

Figure 2: *Initial lease holdings of mines to the east of Gladstone supplied from the Esk reservoir, alignment of the Esk pipe column (No. 22W) from the Ringarooma weir, winter storage dams for the Eureka and Empress mines and locations of water pumping plants. (See Appendix 3 for pumping station details, 10m contour intervals).*



Source: TASMAP 1:25,000 Gladstone Sheet, 1981, with additions from Mineral Resources Tasmania, Mineral Chart 171d, December 1885.

Because of the increased lift height of 85m, larger capacity plant required for the Tamar mine had to be ordered direct from Tangye Bros in England. The boiler, pump and first consignment of iron pipes were landed at the Boobyalla port in June 1882, and the plant was trialled six months later by mine manager Robert Clarke. A long pipe column that extended across the Empress lease from the Ringarooma River was required to supply a small dam on the eastern knoll of Empress Hills (Section 2041).[14] Sufficient water was raised to supply two hoses operating for eight hours per day, although this was reported to be only 50 per cent of the design capacity. Any output went unreported, results merely being described as 'very unsatisfactory'. With water supply inadequate for increased production, the leases were forfeited after only nine months production.[15]

Following registration in October 1881, the directors of the Scotia TM Co. took five months to assess the machinery requirements before ordering a 52kW horizontal pumping engine from Hathorn, Davey & Co. of Leeds (England). This was to be powered by two large (1.2m diameter by 9.75m) boilers fabricated at Knight's Launceston foundry. Water rights were secured to 26 sluice-heads from the Ringarooma River and the pumping plant was designed to deliver 295kL/hr to a height of 42.5m.[16] The pumping plant arrived at Launceston in February 1883 and was operational six months later. Directors Peter Barrett and Charles McGregor, both with some engineering expertise, supervised the mine development and overcame deficiencies in the strength of locally manufactured iron piping that was prone to bursting under load. Hydraulic sluicing appears to have been introduced from the beginning to utilise 'the pressure obtained from reservoir to tank at end of flume [of] 70ft'.[17] Despite a development cost of £6,000, half of the projected water supply had been sold to the neighbouring New Imperial mine by the time of the July shareholders meeting that occurred some two months prior to the commencement of sluicing. This suggests that concerns had been raised about available grades and reserves. Although tribute working by Chinese miners was introduced, a call on shareholders was made in February 1885, further suggesting unprofitable working. Despite this, operations continued for another two years, when the pumping plant was sold to the Colossus TM Co. located on the Ringarooma River to the south of Mt Cameron.[18]

According to Government Geologist Gustav Thureau, the first ventures using steam pumping 'have been found too expensive to work, and the quantity of water raised too limited for economical mining purposes'. An operating cost of £3 per sluice head was claimed for the Scotia, causing miner John McKenzie to write to *The Mercury*, to claim the cost at the Tamar was 'at least £10 per head per week' due to the long pipe column and high hydraulic head (see Appendix 2 & 3). From November 1883 both of these operations had been undercut when the Esk TM & Hydraulic Sluicing Co. commenced supplying water at £1 per head per week, their pumping plant being water-powered.[19]

John Lewis's 'very ingenious' pumping plant

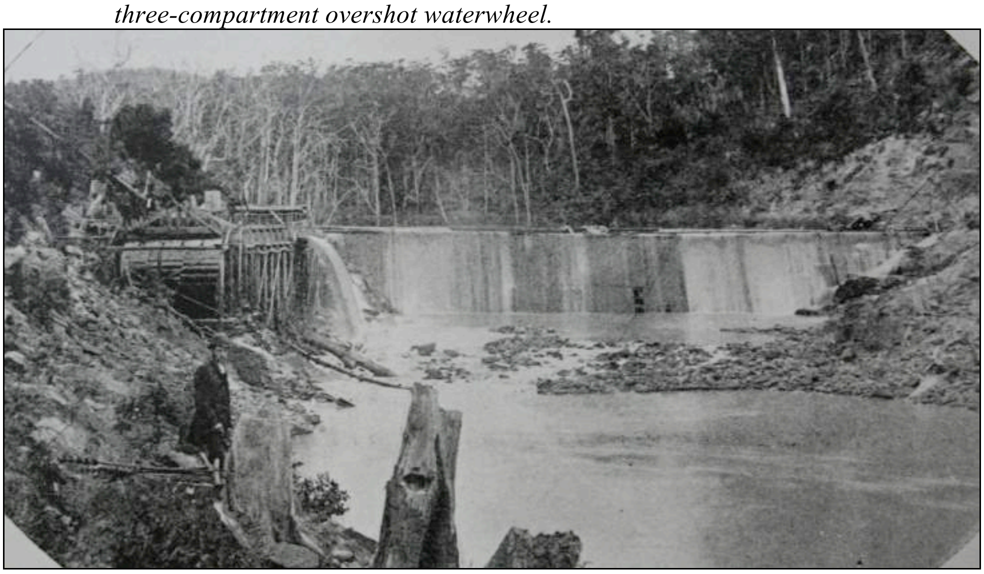
Prior to the prospectus of the Esk TM & Hydraulic Sluicing Co. being issued in December 1881, Victorian mining engineer John Lewis had been approached to assess the feasibility of a pumping scheme to supply a large reservoir on the highest point of Empress Hills. His design brief was quite specific, 'to obtain the necessary power ...

from the [Ringarooma] river itself by damming same at the most advantageous spot'. He reported that a dam 7.6m in height and almost 50m in length along the crest would be required to enable 9.8ML to be pumped per day to a height of 91.5m.[20] This dam was to be constructed:

> with two rows of timber cribs or crates filled in with large granite boulders and debris, having a row of sand bags in between. The timber would be bolted to the rock and faced with tongues and grooved planking let into a trench cut into the rock and cemented. The top and back of the dam should be covered with squared timber, spiked or trenailed to the cribs for the flow of water over the top ... the river is rock-bound on one side and over the whole of the bottom, and no great quantity of excavation will be required on the opposite bank before the rock is laid bare, thus forming an exceptional foundation for the embankment.[21]

The dam was designed to be overtopped along its entire length when the river was in flood, the only spillway, of limited capacity, was that of the fluming onto a waterwheel, and as such, the structure should be described as a crib-weir (Fig. 3). This design was employed on the Californian goldfields, being referred to in contemporary literature as the 'American crib-weir'. The spillway of the Malmsbury Dam in Victoria completed in 1870 has been identified by Chanson as the earliest application within Australia.[22] References to crib-weirs in the Australian press are sparse before the 1880s mining boom, whereas in New Zealand the crib-weir had been introduced by the early-1860s. Notable examples are the Opawa Dam at Blenheim completed in 1863, and cofferdam at Quartz Reef Point on the Clutha River that was constructed for gold mining purposes between October 1864 - December 1865.[23]

Figure 3: *Esk Co.* **c***rib-weir and pumping plant on the Ringarooma River driven by a three-compartment overshot waterwheel.*



Source: Mineral Resources Tasmania.

Lewis was an enthusiastic proponent of the waterwheel for mining applications, his rationale for adopting this in preference to pressure engines or turbines at Gladstone was that the amount of suspended sediment carried by the Ringarooma River would lead to excessive wear in the latter devices. Immediately following the release of the

Esk prospectus a rival scheme, the Gladstone Water Supply & TM Co., was being promoted by George Renison Bell to supply water to claims on the west side of the Ringarooma River where he had a vested interest in supplying his own leases. Instead of damming the Ringarooma River, a site for a water race sufficient to drive a large diameter waterwheel had been identified, the river falling 8.8m in 2.4km. The remaining details were similar to the Esk Co.'s proposals, incorporating a high-level storage reservoir. Despite an impressive list of technical advisers, including Alexander Clerke (civil engineer), Henry O. Christopherson (hydraulic engineer), John Pye and John Clark (foundry owners in Melbourne and Hobart respectively), the scheme did not proceed beyond a public meeting.[24]

Supervision of the crib-weir construction that commenced on 20th February was entrusted to Frederick McGregor (a major shareholder) and Andrew Young. The partly-erected weir remained unscathed after being submerged by the 'highest flood on record in the Ringarooma' in mid-July, but an even higher flood event three weeks later resulted in a 'greater portion [of the weir being] swept away', leading to a suspension of work until mid-December, when the river level had fallen sufficiently.[25] Meanwhile McCall, Anderson & Co. of Melbourne had completed fabricating the iron overshot waterwheel of 6.1m diameter, 5.5m width and almost 60t total weight, in mid-November (Fig. 3). A wrought iron shaft for this impressive waterwheel of 275mm diameter, 7.6m long, and weighing 4t, arrived in Launceston in mid-December.[26] The pumping plant produced at the Union Foundry in Ballarat, was landed in Launceston the following month and had been assembled by September. It consisted of:

> three tiers of pipes, laying horizontally. The lower, the suction pipe, is laid down in a trench cut out in the solid rock, six feet deep midway, the pump barrels being securely bolted on bed logs ... [which] lead into the discharge pipe above. On to the shaft is attached an enormous crank from three to four tons in weight ... to the crank is joined the main connecting rod, from 27ft to 28ft in length, in connection with cross-heads, to which are attached the side-rods supported in guides, as is also the main connecting rod. The rods are constructed of Oregon pine, strongly bolted and strapped with iron ... as one ram forces the water the other sucks from the lower column, and thus forming the principle of the double force pump. The stroke of this formidable thrust is 8ft ... the inlet and discharge valves are of the butterfly form, and weigh 45cwt each ... on top of the discharge pipe is an enormous air chamber, in shape resembling an elongated spheroid, in weight three tons.[27]

A balance-bob was fitted to the pumping plant 'for overcoming the dead point in the revolution of the crank working the plungers', being described as 'very ingenious' by Government Geologist Alexander Montgomery. It commenced working two months later after a two-year construction period, water being conveyed to the reservoir through a 940m long iron pipe column of 460mm diameter.[28] The total construction cost was variously reported to be in the range £14-18,000, with itemised costs in March 1890 perhaps being the most reliable figures: crib-weir £7,000, pumping plant £5,000, pipeline £2,475, waterwheel £1,200 (total £15,675). At the time of Thureau's visit in October 1884, 16 nozzles were supplied and production had risen to 12-15t per month of tin oxide. This may well represent the peak production level, as the company was working eight nozzles by February 1889, and a further three on tribute produced 4t per month.[29]

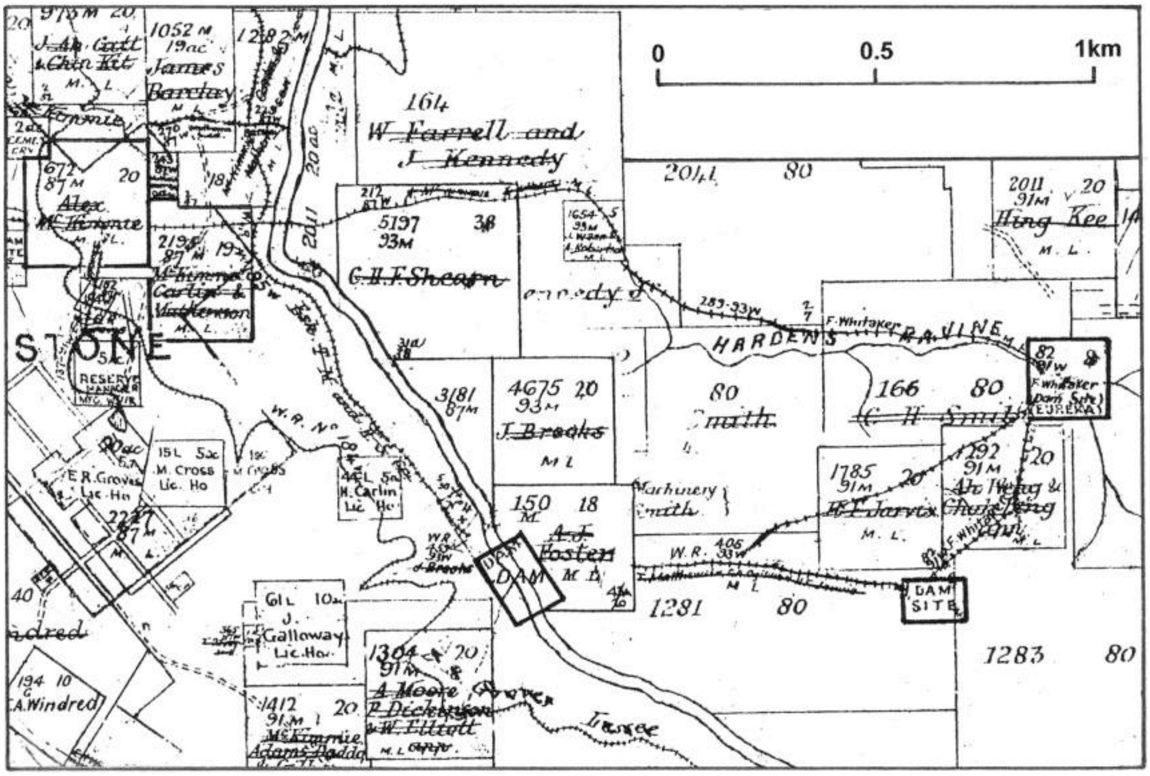
Although a water right (WR Ref. No. 22W) to 60 sluice-heads had been granted in May 1882, the maximum supply rate was found to be 10 sluice-heads, or approximately 9.1ML in 24 hours. This achieved Lewis's design capacity, representing an outstanding achievement by the design engineer, participating foundries and construction personnel. As water from the Empress Hills reservoir was supplied only for a single dayshift working of eight hours, 30 sluice-heads were effectively available for sluicing.[30] The Princess mine became the first customer for five sluice-heads as it had no other means of securing a water supply other than financing its own pumping scheme. A water race (WR 185W on Fig. 4) was constructed and financed by the Esk Co. from their dam along the western bank of the Ringarooma to a point below the Moa lease, while the Princess Co. was responsible for the remaining section of race westwards along the opposite bank. A river crossing was involved but no details of this have been found.[31]

The Esk Co. call for Tenders for 15 sluice-heads of surplus water in February 1885 was taken up by the Empress and neighbouring Mary & Martha leases (Fig. 2), and supplied by a pipeline from the Esk reservoir. These mines continued to be supplied until at least the end of 1888, producing a regular annual income of £750 to offset the maintenance costs of the pumping plant. In September 1887, MHA member David Scott claimed that the Esk Co.'s production for one calendar year had been 416t, representing an income of over £18,000, but this cannot be confirmed as published production data for the Gladstone field is limited.[32]

Alexander McKimmie's lease located upslope of the former Moa lease on the western bank of the river was supplied by the Esk plant from mid-1889. In order to obtain an adequate water pressure for sluicing, a circuitous route was devised from the Esk reservoir, consisting of a water race and pipeline (WR 212-87W) to the Ringarooma River. This involved a river crossing by a 'syphon 7in. galvanized iron, 20 and 32 gauge, simply telescoped' supported by 'a rough suspension bridge'. With a capacity of 3.5 sluice-heads, all of the claims near the Gladstone township were supplied at a cost of 18 shillings per sluice-head by 1891.[33] From 1892 when mining disrupted the race alignment from the Esk reservoir, the route became even longer, proceeding via a 360m long race (WR 82-91W) to the old Eureka reservoir and a newly constructed water race (WR 289-93W) along the northern side of Harden's Ravine, to re-join McKimmie's race that had been cut between the two knolls of the Empress Hills (Fig. 4).[34]

Although a technical success, maintenance of the waterwheel proved to be a financial drain as replacement parts were sourced from Melbourne and not from local foundries. The first significant test that took place in June 1884 when the river peaked 7.3m above the summer level, only 0.6m below the top of the waterwheel, resulted in minimal damage to both the pumping plant and crib-weir. In January 1887 the wrought iron shaft fractured and it took two months for a replacement of increased diameter, and weighing 5-6t, to be produced in Melbourne. Dry summers in both 1887 and 1888 resulted in reduced water availability for sluicing operations dependent on the Esk pumping plant.[35] Another breakdown in May 1889 caused by a failed clack box on the pump, resulted in a replacement casting being conveyed from Melbourne by manager Michael Carlin. The highest summer flood peak 10.7m above summer level in December 1889 led to a further two month shut down for repairs.[36] Following the sale of the pumping plant to Carlin in August 1893, the waterwheel shaft again fractured twelve months later, 'near the collar'. In order to avoid the estimated £800 replacement cost, the old shaft was re-used but reduced in length, thereby also reducing the width of the waterwheel. Further unspecified damage to the waterwheel in June 1895 proved terminal and the plant was advertised for disposal 20 months later. A portion of the iron pipe column was sold locally but the remaining ironwork totalling 60t was 'consigned to the Salisbury Foundry Co.' in Launceston to be re-cycled as scrap.[37]

Figure 4: *Details of* **w***ater supply lines from the Esk Reservoir to the Eureka Dam, then along Harden's Ravine and between the Empress knolls to a syphon across the Ringarooma River, and on to Section 672-87M.*



Source: Mineral Resources Tasmania, Mineral Chart 171e, October 1890.

Mt Cameron Water Race

Early attempts to construct a water race through the challenging upland topography to the south of Gladstone between the deeply incised Ringarooma River to the west and the broad, flat-lying Great Musselroe River valley to the east, had been largely unsuccessful, and costly. The earliest scheme by the Edina TM Co. to construct a 10.3km long race of three sluice-heads capacity from Old Chum Creek (a tributary of the Great Musselroe River) to their leases at Edina Flat was completed by contractor

William T. Pearce in November 1881 for the modest sum of £550. This was, however, a *low level* race that avoided much of the difficult topography by contouring along the side of the Musselroe valley.[38] A *high level* scheme was promoted by a Melbourne company, the Mount Cameron Hydraulic TM Co., formed with a nominal capital of £30,000 to construct a larger race of up to 68 sluice-heads, to enable their 100ha lease holdings to be sluiced efficiently by maximising available water pressures. This required a longer 20km supply race from the Musselroe Creek, together with an additional 14.5km of distribution races within their leases. This work was completed by August 1883 but with a reduced capacity of 15 sluice-heads. The working capital of some £12,000 had been expended, while the income generated from tin sales was inadequate to fund extensions toward Gladstone.[39]

An offer to the State Government in 1884 'either to buy the works as they stand, or to subsidise their company as the works progress towards completion up to £10,000' was initially rejected. Protracted negotiations, a Parliamentary Select Committee and three readings of the Bill (finally passed on 20th December 1887) were required before the purchase of the water race for £4,750 could proceed. Construction of the extensions, originally prepared by the Mt Cameron Co's engineer James Brown using survey data provided by civil engineer Alexander Clerke, now proceeded. A 9.5km extension south to the Great Musselroe River improved inflows and a 25km *Northern Extension* to the east of Empress Hills that turned westwards (Fig. 1), enabled the mines to the north of the Ringarooma River to be supplied.[40]

When handed over to the Mt Cameron Water Race Board on 21st August 1890, refurbishment of the original race had cost £8,200 and construction of the new extensions totalling 34.5km was £18,500, or a hefty average cost of £525 per kilometre (£840 per mile). A maximum race capacity of 50 sluice-heads was now available enabling an average of ten claims a week to be supplied during the first year of operation, generating revenue of £1,751. Rates for the supply of water were linked to the price of metallic tin on the London Metal Market, being, for day water (8am-4pm) 10s when tin was less than £60 per ton, 12s 6d when £60-£80, 15s when £80-£100, 20s when £100-£120; for night water - 10s, 11s 8d, 13s 4d, 15s for the same tin price ranges. During the first decade of operation, the metallic tin price increased from £98 to £138 in 1900, and as such the rates were comparable with those of the Esk Co. for day water after the turn of the century. Would Government intervention now stimulate renewed mining activity in the vicinity of Gladstone?[41]

Scotia lease re-worked

Following the failure of the Scotia TM Co.'s steam pumping plant, tribute working was introduced in September 1890 in response to the completion of the Northern Extension of the MCWR that included a 2km long branch to the Scotia leases. This proved to be profitable, as 139.5t of oxide were produced valued at £6,650, enabling regular dividends totalling £2,170 to be paid through to early 1894. Scotsman James G. Galloway acquired the leases in 1897 and persevered in sluicing the earlier workings. The Scotia output of 36t of oxide for twelve months to June 1902 formed almost half of that from the Gladstone field, 83 per cent of this produced using water from the MCWR, thus justifying the Government expenditure.[42] Mining of the alluvial gravels was restricted by the eroded surface of the Silurian sandstone bedrock, described as 'very flat' by Government Geologist Alexander Montgomery. Galloway's solution was to drive a 340m tailings tunnel from the Ringarooma River at a grade of 1 in 40 up to the base of a vertical shaft, the collar located in a sump close to the working face. This was completed by September 1902 at a cost of £1,000, enabling the height of working faces to be increased to about 21m.[43]

Operating costs for 1904-05 further highlight the dependence on the MCWR, with Scotia production for 1904 of 80t seeing weekly operating costs of £80, with the water bill accounting for 50 per cent of that sum. A seasonal variation of water during the following year was reported, as 20 sluice-heads were available in the winter months enabling two-shift working at a cost of £12 per week, while a reduced supply of only four sluice-heads in summer limited working to a single shift. Operations were disrupted during the early part of 1907 by a break in the No. 5 Syphon of the MCWR, which continued to limit mining a year later. The syphon collapsed in December 1908 and although replacement pipes had been ordered, difficulties in transport to the isolated site hindered the repair work.[44]

Cybele fiasco

Leases along Cybele Creek downslope of the MCWR on the eastern side of Empress Hills (Fig. 2) had been taken up by a local syndicate in mid-1904, and included a 16ha section (4219-93M) immediately east of the MCWR, previously purchased from Joseph W. Torley for £3,000. A year later, having accrued considerable debts from sluicing operations, the syndicate was bought out by the Melbourne-registered Cybele Tin Mines NL, which had also acquired much of the former Esk, Tamar and Garfield lease holdings to the west. The results of prospecting undertaken by consulting engineer Lawrence W. Grayson MAIME were summarised in a report that also detailed the previous mining activities on each lease. This was reproduced in full in the *Launceston Examiner* in August, perhaps to prime potential investors for the release of the prospectus four months later.[45] This prospectus included the results of 161 hand auger bores supervised by mine manager Arthur Thomas AMICE (London), together with plans showing the locations of the bores and cross-sections of the orebody to highlight the interpreted extent of the deposit. Reserves of 28.9 million cubic metres grading 0.375kg/m^3 tin oxide was predicted, all from previously worked leases. Of the projected £120,000 capital to be raised in £10 shares, it was intended to provide 50 per cent of the shares, '£3,000 out of first profits', together with £4,500 cash, to the Launceston syndicate and the Melbourne promoters. Working capital for the venture consisted of £25,000 raised from the public float of 5,000 shares, paid up to $5 per share.[46]

Proposed expenditure of £46,000 detailed in the prospectus included the construction of three bucket dredges costing £36,000, and provision of an 'independent water supply' for £9,000. The latter involved a pumped supply from the old Esk dam to be used for working the western section of the property, supplementing rights to 12 sluice-heads from the MCWR that consultant Francis Payne (from Dunedin) considered adequate for dredging.[47] This ill-conceived concept appears to have been influenced by Grayson's involvement in promoting three dredging ventures on the Ringarooma River at that time, leases to practically all of the river flats downstream of the Esk dam having been secured for the first of these, the Gladstone Tin Development Co., by May 1905.[48] Less than three months later a change of plan eventuated as Thompson & Co. of Castlemaine were contracted to supply a pontoon-mounted 255mm Kershaw centrifugal gravel pump, and a 305mm nozzle pump for sluicing (that is, a suction dredge plant) of the eastern leases instead of using the bucket dredges. This was the first of Thompson's 'suction dredging plants' to be utilised in Tasmania, based on a successful design supplied to mining ventures throughout Australia and south-east Asia over a 30 year period. The dredging plant was expected to treat 9,055m^3 per month for 12t of tin oxide, at a grade of 0.77kg/m^3.[49]

A further change in plan led to the steam pumping plant being sited 1,200m upstream of the Esk dam in order to reduce the length of twin 510mm rising mains to approximately 450m (Fig. 5). To supply the considerable power required, twin 450kPa Allen & Co. triple expansion engines and a Babcock & Wilcox 930kPa boiler were to be obtained from England at a cost of £3,150.[50] The right to 45 sluice-heads (WR 365W) was granted on the 1st June, giving a design supply rate of 1850kL/hr, over 4.5 times that of the Esk waterwheel (see Appendix 2). The question was, could this be achieved?[51] The gravel pump commissioned in December 1906 enabled a working face to be formed, and consequently, the first seven weeks sluicing of 10,500m^3 yielded 6.25t oxide, equivalent to 45 per cent of the expected grade (0.35kg/m^3). This was not to last, as at the beginning of February the water supply was disrupted by a break in the No. 5 Syphon of the MCWR. Water supplies remained inadequate for continuous operation at the beginning of April and sluicing was suspended, this at a time when the tin price had more than doubled from the £80 recorded in 1905.[52]

With the pumping plant nearly completed, including installation of the engines and boilers, erection of the 36.5m high steel chimney stack, completion of the rising mains and raising the embankment of the old Esk reservoir, the working capital was exhausted and all operations were suspended at the end of April. Grayson's plan to generate income from the suction dredge prior to the pumping plant commencing had been thwarted, and Thomas, fearing that he would be made a scapegoat because of the indifferent ore grades, resigned the day before a stormy shareholders meeting was convened in Melbourne. Why had the expected ore grades not eventuated? The answer was provided in the Secretary of Mines report of September 1905, for the company had relied upon spurious results from unlined auger bores for prospecting, rather than accepting earlier test results obtained from Government bores that had indicated a much more conservative estimate of grades and reserves.[53]

A review of the operation undertaken by James B. Lewis (manager of the Anchor tin mine) concluded that 'considerable skill and economy will be required to work [the low grade deposit] profitably'. As a further £7,000 was required to commence production and the shareholders would only to commit to £3,500, a deputation to the Tasmanian Premier in September sought a grant of £4,500, which was not forthcoming.

What was claimed to be the 'largest pumping plant in Australia' remained unproven, and Lewis's estimate of £2-10s per sluicehead per week for steam pumping was not significantly different from that of the first steam pumping schemes 20 years earlier.[54]

Tenders were called for the mining plant the following January, the pumping plant snapped up by the nearby South Mt Cameron TM Co. for £1,800, and a saving of £2,400 when freight to the site was taken into account. The dredging plant remained unsold at auctions held the following May and a year later, but was eventually acquired by the Arba TM Co. in March 1910 for an unspecified amount. Thus the liquidator would have recovered a minimal return for distribution to the shareholders for plant valued at £15,000.[55]

Empress Hills: inter-war period

Before another five years passed, Walter Higgs and Louis Kerrison took up leases, and an unspecified water right (WR 1475W) was granted in December 1913 to the MCWR where it crossed the Cybele Creek on the eastern side of Empress Hills (Fig. 2). This short-lived venture utilised a 15kW portable steam engine to raise water about 15m into a 805m long head race, but below average rainfall and a 25 per cent fall in the tin price due to the outbreak of WW1, prematurely curtailed work.[56] In order to stimulate a post-war revival, a Parliamentary Standing Committee recommended in August 1921 that £7,700 be provided to construct a *Western Deviation* of the MCWR from the Edina Flats across to the western side of the Ringarooma River (Fig. 1). To reduce costs, the pipework forming the No. 5 Syphon was dismantled and reconditioned, thus cutting the water supply to the Northern Extension when construction commenced six months later.[57]

In response to a request from the Ringarooma Municipal Council, Government Geologist Percival D. Nye reported in April 1926 on the potential benefits of supplying hydro-electric power to the mining industry in the northeastern part of the state.[58] Although this did not eventuate for another 20 years, a commitment to restore the connection to the Northern Extension of the MCWR was obtained, encouraging plans for further mining on the Empress Hills to proceed. A small Tasmanian syndicate had acquired a consolidated lease 10302M of 216ha, largely the holdings of the former Cybele Co., and proceeded to register the re-incarnated Garfield TM Co. NL later in April. The syndicate included prospector Michael Curtin, who had worked the Empress mine 38 years earlier, and he attracted investors, thus enabling an initial fund raising of £5,000 to proceed. Three months later it was resolved to increase capital to £20,000 in a public float, of which £5,000 was to be paid to the original syndicate and £4,000 allocated for mine development. Prospecting in Harden's Ravine was underway in July and development plans had been finalised the following month when applications were made for tailraces that discharged into Tamar Creek to the west (WR 2442W), and Saw Pit Creek to the southeast (WR 2443W).[59]

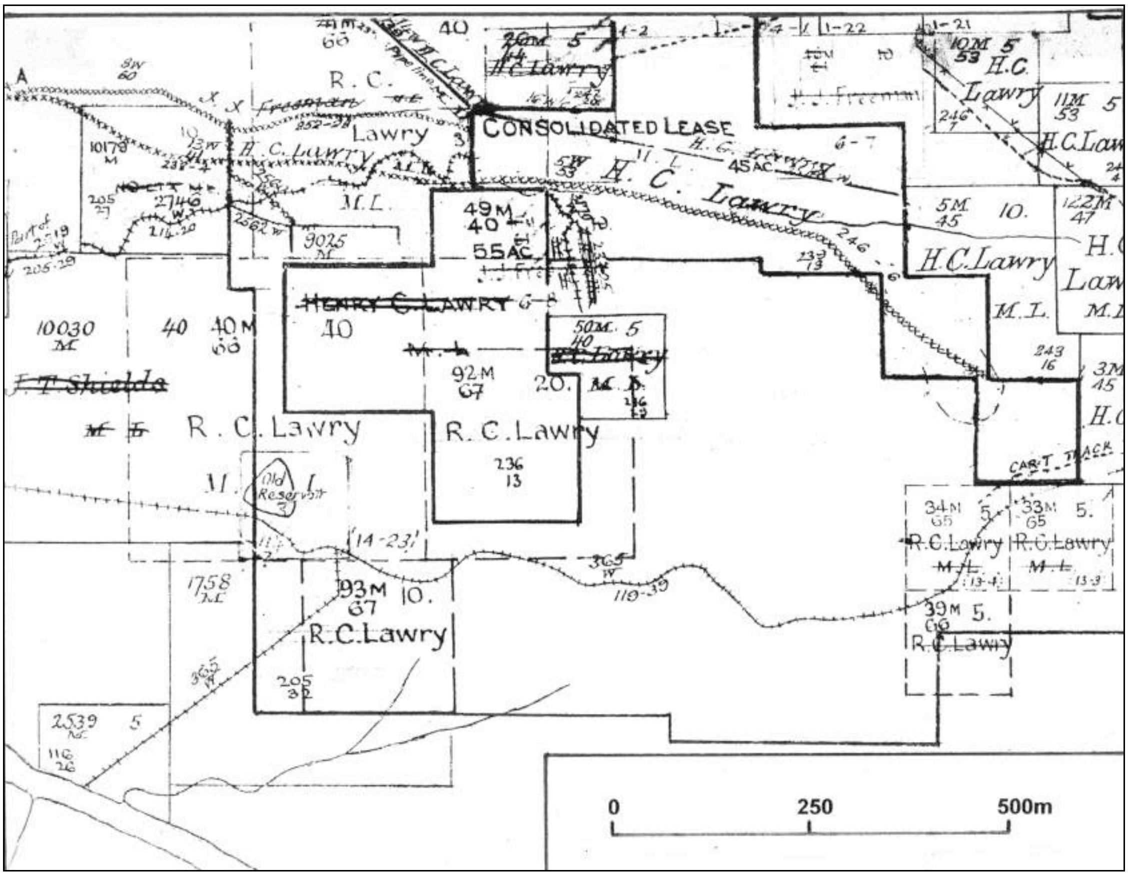
A 1.2ha machinery site (9837M) was secured at the *Cybele Bend* near to the site of Higgs & Kerrison's pumping plant (Fig. 2). Water from the MCWR was to be raised 31.5m by two 125mm Thompson two-stage pumps at the rate of 510kL per hour (approximately 12 sluice-heads) into a small dam, then along a 1,630m head race extending westwards towards the old Esk Co. reservoir (Fig. 5), necessitating 120m of timber fluming across Saw Pit Creek. Two 43kW Keighley crude oil engines were sourced from Melbourne by consultants R. Kennedy & Sons, each consuming 13.5L/hr fuel which comprised one part kerosene to five parts diesel.[60] Curtin proposed working a face in the vicinity of the old Eureka dam but a lease that was held by Aubrey Mallinson as WR 2274W prevented the tailings from being discharged into Harden's Ravine. Appeals to the Warden's Court and Mining Board in December 1926 for forfeiture of Mallinson's water right were unsuccessful, forcing Curtin to adopt a far less favourable option by directing the tailings towards Tamar Creek to the northwest.[61] The No. 5 Syphon had been re-instated by March 1927 at a cost of £2,518, utilising 1,255m of 455mm diameter concrete pipes supplied by the Humes Pipe Co., this the first such application on the MCWR. The pumping plant was operational two months later, enabling a 425m long channel up to 8m in depth to be cut through a 'cemented bar' to connect with the head of Tamar Creek. It was another three months before this work and construction of a 62m long sluice box was completed and production could commence.[62]

The results of the first sluicing went unreported and were most likely disappointing, as work had commenced on cutting a head race to enable 280mm and 380mm pipe columns to be erected at Saw Pit Creek in April. Mine manager Curtin had been replaced by October and the cutting deepened to 9m necessitating the length being doubled and the top opened out to a width of almost 13m. An output of 6.05t oxide for £1,012 at a grade of 0.11kg/m^3 was below expectations and work ceased soon after. Kennedy & Sons sought to recover £258 by court action the following February when the Shell Oil Co. was owed £693 and Salisbury's Foundry £109. Tenders were called in May for the purchase of the mineral leases and plant, ending another unprofitable operation on the Empress Hills.[63]

Final phase using hydro-electric power

The final phase of mining at Empress Hills commenced in 1939 when Henry C. Lawry's Star Hill Syndicate acquired leases to the same area mined intermittently for almost 60 years, but prospects were not good given the number of previous failed ventures. Lawry established a new machinery site (WR 14W-39) adjacent to the Empress dam (Fig. 2), one of the first established and connected by a 3.5km branch from the Northern Extension of the MCWR in about 1910. An application for 16 sluice-heads was registered in May and the Empress branch renovated.[64] Pumping was initially undertaken using steam plant, the water pumped 825m by pipeline to allow sluicing to proceed at the head of Harden's Ravine, which was used as a sludge channel for tailings disposal (Fig. 5).[65] Lobbying for the supply of power from the HEC was finally successful in 1952, allowing twin 93kW electric motors to power 200mm Thompson pumps, each able to supply 341kL/hr. A report produced by Government Geologist Nye in December 1952 claimed that tin worth £66,000 had been produced from the site, but the time frame is unclear. After Henry Lawry's retirement in 1958, work was continued by his son Ron until 1983, marking a century of mining on the Empress Hills and immediate vicinity of Gladstone.[66]

Figure 5: *Star Hill Syndicate workings supplied by a pipe column and head race from the Empress Dam (top centre), wash from working face (centre right) conveyed by tail races to the Harden's Ravine sludge channel (top left). Former Cybele pipe column and head race (No. 365W) also shown (bottom left).*



Source: Mineral Resources Tasmania, Mount Cameron No. 4 Mineral Chart (171n), May 1929 – December 1967.

Gladstone's domestic water supply was obtained from the Western Deviation of the MCWR from an undetermined date following construction in 1923, but ceased when this branch was de-commissioned in 1949.[67] Following the HEC power connection to the area, the residents of Gladstone instigated construction of a long-overdue reticulated water supply for the township. Fund raising was underway by October 1953, the state government providing a grant of £950 towards the total cost of £3,000. Water from the Empress Dam was conveyed by race and a piped syphon to the Bells Bridge crossing of the Ringarooma River, then on to a reservoir in the town. The scheme was officially commissioned on the 1st November 1954 as a lasting legacy of the mining industry.[68]

Conclusions

Difficult topography and low ore grades challenged the perseverance, resources and ingenuity of several generations of miners over a century of operation. Tributors and small syndicates with limited finance were generally successful, working within their means when sufficient water was available from high-level dams. Early attempts by publicly funded companies to provide a regular water supply failed to deliver returns to shareholders. All of the early steam powered pumping schemes proved uneconomic due to high operating costs. It was to take the genius of mining engineer John Lewis at the instigation of the Esk Co. directors, and skills of the Victorian foundry workers, to develop a water-powered pumping plant capable of delivering the required volume of water to the highest point on the Empress Hills, thereby enabling economic sluicing to proceed all year round. Although the low-grade deposits within their leases were spurned prematurely, the company continued to derive a sizeable financial return from water sales to neighbouring lease owners for over a decade.

Intervention by the State Government in funding construction and maintenance of a network of water supply races was instrumental in providing a cheap, reliable and efficient source of power following the demise of the Esk pumping plant. This assisted in minimising the duration of downturns when tin prices fell, thereby prolonging the life of the tinfield. Attempts at large scale production, most notably the Cybele venture, failed spectacularly due to the high cost of installing large capacity pumping plant. Although a small-scale producer when assessed in terms of the overall State output, mining of the Gladstone field was essential for stimulating the local economy throughout much of the twentieth century. Government Geologist Nye determined in 1932 that the MCWR enabled 2,765t tin to be produced over a 40-year period.[69] Although this formed only two per cent of the total state production, it represented a healthy investment return, highlighting the benefits of timely Government intervention in ensuring construction of essential infrastructure, combined with stable management that extended until the completion of mining in the early 1980s.

Acknowledgements
The assistance of AMHA member Greg Dickens with drawing searches and provision of additional information, and the supply of plan copies by Mineral Resources Tasmania is gratefully acknowledged.

Endnotes

[1] Rainfall data from the annual reports of the Mt. Cameron Water Race Board attached to the Secretary for Mines Reports in the *Journals of the House of Representatives, Tasmania* [hereafter *TPP*].

[2] J. Beswick, *Brothers' Home, the story of Derby, Tasmania*, Launceston, 2004, pp. 5-10, *Launceston Examiner,* 17 June 1876, p. 2; *ibid.,* 22 June 1876, p. 2; *Chemical Engineering & Mining Review*, vol. 19, December 1926, p. 111.

[3] The following conversion units can be used to convert: measurements used in this paper: 1 inch = 2.54cm; 1 foot = 0.3048metres; 1 yard = 0.9144metres; 1 mile = 1.609344km; 1 acre = 0.404686 hectares; 1 ton = 0.90718474 tonnes.

[4] *Launceston Examiner,* 20 June 1876, p. 2.

[5] 'Plan of mineral sections, Mount Cameron', Mineral Resources Tasmania [hereafter *MRT*], Plan 171d, 3 December 1885; W.H. Twelvetrees, 'The Gladstone Mineral District', *Geological Survey Bulletin,* no. 25, August 1916, p. 21, *MRT*.

[6] *Launceston Examiner,* 4 April 1876, p.1; *ibid.,* 22 June 1876, p. 2, *ibid.,* 1 August 1876, p. 3.

[7] *Cornwall Chronicle*, 31 January 1877, p. 3; *ibid.,* 31 January 1880, p. 2; *Launceston Examiner*, 2 August 1879, p. 2.

[8] For registration details see *Launceston Examiner,* 30 March 1881, p. 3; *ibid.,* 4 October 1881, p. 3; *ibid.,* 24 October 1881, p. 3; *ibid.,* 13 April 1882, p. 4; *The Argus*, 20 December 1882, p. 3.

[9] For prospectuses see *Launceston Examiner,* 15 March 1881, p. 3; *ibid.,* 1 August 1881, p. 4; *ibid.,* 13 September 1881, p. 3; *ibid.,* 24 December 1881, supplement, p. 1; *ibid.,* 26 August 1882, p. 4; *ibid.,* 14 December 1882, p. 3.

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[10] *The Mercury*, 25 July 1881, p. 3; *Launceston Examiner,* 12 July 1882, p. 3; *ibid.,* 21 July 1882, p. 3; for W.B. Jones the Melbourne agent for Tangye Bros see N. Ridgway & R. Lamb, 'Tangye in Australia and New Zealand', *Proceedings 16th Engineering Heritage Conference, Hobart, November 2011*, p.14.

[11] *Launceston Examiner,* 20 April 1881, p.3; *The Mercury,* 5 July 1881, p. 3; *ibid*., 30 January 1882, p. 3.

[12] G. Thureau, 'Report on West Coast Mines: No.1 Pieman River Goldfield', OS026, 1 July 1881, p. 9, *MRT*; hydraulic sluicing commenced on the Mt Cameron tinfield by the Mt Cameron Hydraulic & TM Co. See *The Mercury,* 2 September 1882, p. 2; on 'Derry TM', *Launceston Examiner,* 14 December 1882, p. 3; on the Derby tinfield by the Australian Alluvial TM, *The Mercury*, 29 November 1882, p. 3; for St. Leonard's TM, *Launceston Examiner,* 17 January 1883, p. 2; and the Blue Tier by the Leopold TM, *Launceston Examiner,* 16 October 1882, p. 3; on the Marie Louise TM, *Launceston Examiner,* 15 January 1883, p. 3.

[13] *Launceston Examiner,* 27 April 1882, p. 3; *ibid.,* 1 November 1882, p. 3; *ibid.,* 9 July 1885, p. 3.

[14] *Ibid*., 13 May 1882, p. 1; *ibid.,* 13 June 1882, p. 3; *ibid.,* 12 January 1883, p. 3; *The Mercury,* 12 December 1882 supplement, p. 1; A. Montgomery, 'Report on the general geological structure and tin-bearing gravels of the Gladstone District', OS086, July 1891 p. 14, *MRT*.

[15] *Ibid*., 29 November 1883, p. 4; *The Mercury,* 12 December 1882, supplement p. 1, 22 January 1883, p. 3; *ibid.,* 13 July 1883, p. 3.

[16] *The Engineer*, 25 June 1880, p. xiii for details of Davey's patented *compound differential* horizontal engine; *Launceston Examiner,* 12 August 1882, p. 3; *The Mercury,* 10 April 1882, p. 3; *ibid.,* 27 January 1883, p. 3.

[17] *Launceston Examiner,* 5 February 1883, p. 3; ; *ibid.,* 26 September 1883, p. 2; *ibid.,* 14 November 1883, p. 3.

[18] *Ibid*., 31 July 1883, p. 3; *ibid.,* 13 October 1883, supplement p. 1, 2 February 1885, p. 3; *ibid.,* 1 November 1888, p. 3; *The Mercury,* 25 September 1885, p. 4.

[19] *The Mercury,* 2 November 1883, p. 3; *ibid.,* 31 August 1885, p. 3; *ibid.,* 15 September 1885, p. 3; G. Thureau, 'Report on the proposed water scheme for supplying the North-Eastern Tin Mining Districts', *TPP*, vol. 3, no. 151, October 1884, p. 6.

[20] *Launceston Examiner,* 24 December 1881, supplement, p. 1.

[21] *Ibid.*

[22] H. Chanson, *A short history of stepped cascades in Australia*, ANCOLD Bulletin No. 106, August 1997, p. 104; H. Chanson, *Hydraulic design of stepped cascades, weirs and spillways*, Pergamon, 1994, pp. 181-82; *The Argus*, 7 July 1877, p. 4.

[23] *Nelson Examiner & New Zealand Chronicle*, 11 July 1863, p. 3; see also Lloyd Carpenter, 'The Clutha's first dam: the Nil Desperandum Project at Quartz Reef Point 1864-66', *International Journal for the History of Engineering & Technology,* vol. 83, no. 2, July 2013, pp. 253-73.

[24] *Launceston Examiner,* 24 December 1881, p. 1; *The Mercury,* 13 January 1882, p. 3; see G. Russell, *Water for Gold - the fight to quench Central Victoria's Goldfields*, Australian Scholarly Publishing, 2009, p. 135 for Henry Oscar Christopherson who served as Superintending Engineer for the Coliban water supply project in central Victoria from December 1864.

[25] *The Mercury,* 19 July 1882, p. 3, 12 December 1882, supplement p. 1; *Launceston Examiner,* 31 October 1882, p. 3; *ibid.,* 7 November 1882, p. 3, 24 September 1883, p. 3.

[26] *Daily Telegraph*, 15 November 1882, p. 3; *ibid.,* 8 December 1882, p. 3.

[27] *Launceston Examiner,* 24 September 1883, p. 3.

[28] *The Mercury,* 2 November 1883, p. 3; *Launceston Examiner*, 12 February 1897, p. 8; *MRT*, OS086, July 1891, p. 14.

[29] *TPP*, vol. 3, no. 151, October 1884, p. 6; *Daily Telegraph*, 3 November 1884, p. 3; *Tasmanian Mail*, 9 February 1889, p. 14; *Launceston Examiner*, 11 March 1890, supplement, p. 1.

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[31] 'Plan of mineral sections, Mount Cameron', Plan 171d, 3 December 1885, *MRT*; *The Mercury,* 21 May 1883, p. 3; *ibid.,* 2 November 1883, p. 3; *ibid.,* 23 November 1883, p. 3; 'Register of applications for water rights on the East Coast', MIN 92/1/1, 13 January 1886, *TAHO*.

[32] *Launceston Examiner,* 23 February 1885, p. 1; *ibid.,* 13 October 1883, p. 3; *ibid.,* 28 September 1885, p. 3; *ibid.,* 1 November 1888, p. 3; *The Mercury,* 28 September 1887, p. 4.

[33] 'Registers of applications for water rights', MIN90/1/1, 24 September 1888, *TAHO*; *MRT*, OS086, July 1891, p. 14; 'Report of the Secretary of Mines', *TPP*, vol. 17, no. 81, July 1889, p. 9; *Launceston Examiner*, 11 April 1891, p. 2.

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[36] *Daily Telegraph*, 3 June 1889, p. 3; *ibid.,* 6 December 1889, p. 3; 'Report of the Secretary of Mines', *TPP*, vol. 20, no. 64, July 1890, p. 7.
[37] *Ibid*., 10 August 1894, p. 1; *ibid.,* 12 June 1895, p. 3; *Launceston Examiner*, 24 May 1889, p. 4; *ibid.,* 12 February 1897, p. 8; *ibid.,* 4 April 1898, p. 3.
[38] *Launceston Examiner,* 9 April 1881, p. 4; *ibid.,* 28 January 1882, p. 3; *The Mercury,* 9 November 1881, p. 2.
[39] *The Argus*, 20 September 1881, p. 8; *The Mercury,* 30 January 1882, p. 3; *Daily Telegraph*, 23 August 1883, p. 3; G.J. Burke, 'Great Mussel Roe water scheme', *TPP*, vol. 6, no. 105, June 1885, p. 3; Greg Dickens, 'The Mount Cameron Water Race – a century of operation', Report 1990/15, p. 1, *MRT*.
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[44] *Launceston Examiner,* 18 March 1905, p. 4; *ibid.,* 16 August 1905, p. 2; *ibid.,* 10 March 1908, p. 3; Greg Dickens, Report 1992/21, pp. 8-9, *MRT*.
[45] *Launceston Examiner,* 11 July 1904, p. 1; *ibid.,* 6 April, 1905, p. 2; *ibid.,* 24 August 1905, p. 2.
[46] *Ibid*., 9 December 1905, p. 10; Prospectus of the Cybele Tin Mines NL, State Library of Victoria, undated.
[47] Cybele Tin Mine NL, 'Directors' report to share holders', 06-009, 18 July 1906, *MRT*.
[48] *The Mercury*, 15 May 1905, p. 2; *Launceston Examiner,* 21 May 1906, p. 2.
[49] *Launceston Examiner,* 9 December 1905, p. 10; *ibid.,* 23 March 1906, p. 2; Thompson's Engineering & Pipe Co. Ltd, 'Dredging for Gold & Tin', 8th Edition, c1940, State Library of Victoria.
[50] *Ibid*., 25 July 1906, p. 2; *ibid.,* 28 January 1907, p. 2; P. Milner, 'Thompsons of Castlemaine', University of Melbourne, Dept of Mechanical Engineering, Report TR-90/8, 1990, p. 23 – as there is no reference to the Allen & Co. engines, the order was probably placed direct with the manufacturers.
[51] *TAHO*, MIN90/1/1, 21 July 1905.
[52] *Launceston Examiner,* 11 December 1906, p. 2; *ibid.,* 30 January 1907, p. 2; *ibid.,* 4 February 1907, p. 2; *ibid.,* 1 April 1907, p. 2; *The Mercury,* 12 February 1907, p. 3.
[53] *Ibid.,* 9 April 1907, p. 8; *ibid.,* 1 May 1907, p. 6; *Launceston Examiner,* 15 April 1907, p. 2; *The Argus*, 11 May 1907, p. 22; 'Report of the Secretary of Mines', *TPP*, vol. 53, no. 12, September 1905, p. 8.
[54] *Ibid*., 21 November 1906, p. 6; *Launceston Examiner,* 10 September 1907, p. 2; *ibid.,* 20 September 1907, p. 2.
[55] *Launceston Examiner,* 20 September 1907, p. 2; *ibid.,* 22 January 1908, p. 6; *ibid.,* 9 March 1910, p. 2; *ibid.,* 8 May 1908, p. 8; *The Mercury*, 14 March 1908, p. 8; *The Argus*, 8 May 1909, p. 3.
[56] *TAHO*, MIN 90/1/5, 26 February 1913; 'Report of the Secretary of Mines', *TPP*, vol. 71, no. 8, June 1914, p. 16; *ibid*., vol. 73, no. 11, June 1915, p. 17.
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[64] *Ibid.,* 2 March 1939, p. 3; 'Register of applications for water rights from the Derby Office', AC39/1/4, 26 May 1939, *TAHO*; Report of Mt. Cameron Water Race Board, *TPP*, vol. 123, no. 35, June 1940, p. 35.
[65] G. Wilson (Ed.), *As the River Flows*, Ringarooma Council, 1988, p. 165, for steam engine manufactured by Rudolf Wolf of Magdeburg-Buckau who specialised in producing semi-portable engines.
[66] H.G.W. Keid, 'Report on the tin fields of North Eastern Tasmania', *MRT*, UR1952, 23 December 1952, p. 140; Greg Dickens, Report 1990/15, p. 6, *MRT*.
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Appendix 1: *Summary of publicly listed mining companies adopting pumped water supply schemes*

Company	Registration Date	Nominal Capital (£)	Initial Working Capital (£)	Lease Holdings (ha)	Location
Moa	3/1881	12,000	800	10	West bank Ringarooma River
Tamar	10/1881	24,000	2,400	28	Empress Hills: north side
Scotia	10/1881	20,000	10,000	32	North bank Ringarooma River
Esk	4/1882	36,000	18,000	219	Empress Hills: south & centre
Garfield I	10/1882	7,500	750	40	Empress Hills: centre
Cybele	12/1905	120,000	25,000	379	Empress Hills: east side
Garfield II	4/1926	20,000	4,000	216	Empress Hills: east side

Appendix 2: *Summary of Pumping Supply Schemes*

Mine	Operating Period	Power Source[(1)]	Pump Capacity (kL/hr)	Lift Height (m)	Power Supply
Moa	7/1882 - 8/1883	S	59	18.3	Tangye engine
Tamar	12/1882 - 9/1883	S	91	85.5	Tangye engine
Scotia	9/1883 - 10/1888	S	273	42.5	52kW Davey compound horizontal
Esk	11/1883 - 6/1895	W	409	85[(2)]	112kW overshot waterwheel
Cybele	Not commissioned	S	1,887	85[(2)]	2 x 448kW Allen triple expansion
Garfield	9/1928 - 2/1929	D	509	31.5	2 x 43kW Keighley engines
Star Hill	1939 - 1952 1952 - 1982	S E	246	39.5	Wolf compound engine 2 x 93kW electric motors (HEC)

Notes:
(1) D = diesel engine, E = electric motor, S = steam engine, W = waterwheel
(2) Approximate values as contemporary accounts amended to allow for the height of the pumping plant above sea level.

Appendix 3: *Summary of Water Rights and Pumping Stations*

Mine	Water Right Ref. No.[(1)]	Ref. No. on Fig. 2[(2)]	Water Source[(3)]	Application Date	No. SH[(4)]	Pipe Column Length (m)	Head Race Length (m)
Moa	–	1	Ringarooma River	–	1.5	c300	?
Tamar	–	2		–	2	c1310	?
Scotia	–	3		–	26	c100	865
Esk	22W	4		1881	30	940	Various
Cybele	365W	5		21/7/1905	45	450	1,560
Higgs & Kerrison	1475W	6	MCWR: Cybele Bend	26/2/1913	?	c250	805
Garfield II	365W	7		4/1926	12	c250	1,630
Star Hill	14W-39	8	MCWR: Empress Branch	26/5/1939	16	825	550

Notes: (1) Mines Department registers of water race applications (TAHO MIN90) commencing January 1882 and TAHO AC39/1/4
(2) Numbered in order of application date.
(3) MCWR = Mount Cameron Water Race.
(4) SH = Sluice-head, equal to 0.68 cubic metres per minute or 41.1 kilolitres per hour.