6. List of Illustrations consulted for this paper -

a) Birkdale Old Mill - Painting by W.G.Herdman undated. Housed in the Botanic Gardens Museum, Churchtown.

b) also see ref.4 another Herdman picture.

c) Slides shown by D.Peterson at S.P.A.B. Windmill meeting 1981.

d) Everyday scene beside Birkdale Mill by E.Vernon

e) Photograph of Birkdale Mill taken about 1860.

f) Birkdale Mill - watercolour painted about 1850 (shows tailpole at front of mill!)

7. "Windmill Land" by A.Clarke pub. J.M.Dent and Sons Ltd. 1916. Photographs of Hamble Mill facing pp. 262 and 263 show it to be very similar to Birkdale Mill.

8. "Victorian and Edwardian Windmills and Watermills from old photographs" J.K.Major and M.Watts pub. Batsford Ltd. 1977. Photograph 4 shows Warton (misnamed Freckleton) Mill and photograph 136 the mill at Warton in decay, showing the lantern wallower.

FROM MILL TO MEGAWATT

The first half-century of hydroelectricity

By Gordon Tucker

1. Introduction

Electricity began to come into general use around 1880 with the availability of the recently-invented incandescent filament lamps of Swan and Edison in addition to the existing range of arc-lamps and other electrical equipment. The filament lamps could be worked in parallel across an electrical supply main, and made central generating stations possible. Public supply started towards the end of 1881, and legislation controlled it from 1882. Although the steam engine had been the most important source of power for almost a century, and internal combustion engines had started to come into use, yet there was still a deep-seated preference to use water power and its presumed economies wherever it was available. It was therefore natural that water power should be used for electricity generation as much as possible, and many mills were adapted to drive dynamos for both private and public supply of electricity. It was nearly a decade before purpose-built hydroelectric generating stations were built, except in one or two special cases.

At this introductory stage it will be useful to consider the potential of water power in different parts of the world. Table 1 sets out a summary. From this it will be seen that water can produce a very great deal of the world's demand for electricity - but not very much of Britain's. The total British water-power potential only equals the output of a really large modern thermal power station. So it will be misleading to discuss hydroelectric developments in Britain without putting them in context with the rest of the world. This paper will attempt to do this.

TABLE 1

Estimated World Hydroelectric Potential

Total between 0.5 and 1 m MW distributed roughly thus:-

Africa	41%
Asia	23%
N.America	13%
S.America	10%
Europe	10%
Oceania	3%
(Britain	0.2%)

Actual development was about 10% of total in 1960 but most of this was in N.America and Europe.

We look first, rather briefly, at the hydroelectric developments in Britain during the first decade or two after 1880, and then in more detail at the public supply schemes in the Midlands, both those actually built and those proposed but not built. The Midlands included the largest water-powered public-supply scheme in Britain during this early period, but we go on to describe two industrial systems of greater interest - one of them of much greater size, and both in the North. We then consider the early development of hydroelectricity in the world outside Britain, particularly on the continent of Europe, and at Niagara Falls and at Shawinigan Falls in North America. Finally we consider British developments in the first third of the 20th century, culminating in the highly successful Galloway scheme which produced a power of 102 megawatts.

2. Early hydroelectricity in Britain: the first decade or two.

The early use of water power for public electricity supply has received a good deal of attention in recent years, [1-6] and it is not necessary to go into much detail here. Table 2 lists all those sytems known to the author which came into operation up to 1900. The first two were experimental and short-lived. Wickwar, Blockley and Okehampton were based on existing industrial premises (loosely describable as "mills"), and only the last-mentioned used a turbine rather than a water-wheel; even that produced only about 8 kW of electrical power. Keswick and Lynmouth had specially-built premises, and produced 30 kW and 75 kW respectively; the former had supplementary steam drive, and the latter was notable in developing a system of pumped storage (probably the first in the world) by which surplus water power during the day could be used to pump river water to a great elevation in order to recover extra power at night when the demand for electricity was greatest. The Worcester station was by far the largest, with about 400 kW water-generated output, and is descibed in more detail in the next section. The water-generated supply survived half-a-century or more at Keswick, Lynmouth, Chagford, Worcester and Monmouth (at least), although not always with the original equipment.

Many hydroelectric schemes were proposed but, in the event, not built, and those known to the author are listed in Table 3 for the years 1881-94. Information about these schemes has been gleaned by assiduous searching of weekly reports in the electrical press of the time, mainly"The Electrician" and "Electrical Engineer". Anything approaching complete data regarding hydroelectric installations in private premises is very difficult to come by, but Tables 4 and 5 give some data on this matter.

TABLE 2

Hydroelectric Stations for Public Supply in Britain 1881-1900 - actually built

1881 Goldalming, Surrey.
1885 Greenock, Renfrewshire.
1888 Wickwar, Gloucestershire.
1888 Blockley, Gloucestershire.
1889 Okehampton, Devon.

1890 Keswick, Cumbria.
1890 Lynmouth, Devon.
1891 Chagford, Devon.
1894 Worcester.
1894 Milngavie, Dunbarton.
1896 Fort William.
1898 Salisbury, Wiltshire.
1899 Monmouth.
1900 Fladbury, Worcester.
1900 Ingleton, Yorkshire.

TABLE 3

Hydroelectric Stations for Publie Supply in Britain 1881-1894 - Proposed but not built.

1881 Aberystwyth, Durham.
1882 Exeter.
1886 Lanark
1887 Cockermouth.
1888 Otley, St.Albans.
1889 Ayr, Burton-on-Trent, Penrhyn, Windsor.
1890 Llangollen.
1891 Egremont, Elgin, Helston, Hexham, Inverness, Matlock Bath, Plymouth, Richmond (Surrey), Shipley.
1892 Barnard Castle, Bridgend, Chester, Guildford, Moffat, Queensferry, Reading, Rochdale, Tutbury, Willesden.
1893 Bewdley, Cardiff, Crieff, Glynceiriog, Hawick, Llandrindod Wells, Montrose, Tiverton, Workington.
1894 Baslow, Bromsgrove, Conway, Newby Bridge, Ulverston.

TABLE 4

Some Hydroelectric Installations for Industry in Britain, 1882-1894

1882-3 Cone Paper Mill, Woolaston, Gloucestershire.
1886 Flour Mill, Boroughbridge, Yorkshire.
1886 Industrial premises in Okehampton, Devon.
1887 Flour Mill, Knottingley, Yorkshire.
1887 Paper Mill, Hope, Cefn-y-Bedd, N.Wales.
1888 Flour Mills, Buckingham.
1890 Greenside Lead Mines, Westmorland.
1893 Yeo Mill, Chagford, Devon.
1894 Paper Mills, Watchet, Somerset.
1894 Parndon Mills, Hertfordshire.

TABLE 5

Some Hydroelectric Installations in Private Houses and Estates in Britain, 1880-1889

1880 Cragside, Northumberland.
1881 Alnwick Castle, Northumberland.
1882 Carsaig, Mull.
1883 Dunphail House, Morayshire.
1884 Linden Park, Roxburghshire.
1885 Arborfield Hall, Berkshire.
1885 Bremore House, Scotland.
1885 Rothiemurcus House, Scotland.
1886 Hatfield House, Hertfordshire.
1886 Impney House, Worcester.
1887 Dovedale House, Blockley.
1887 Staghills, Bury, Lancashire.
1889 Scatwell, Inverness.
1889 Ancrum House, Roxburghshire.
1889 Ardwell House, Wigtownshire.
1889 Clapham, Yorkshire.

3. Hydroelectricity for public supply in the Midlands.

The Midlands had their fair share of hydroelectric development [7] in the early decades, with three small systems at Wickwar, Blockley and Fladbury, and what was for its time a large one at Worcester.

3.1 Wickwar, Blockley and Fladbury.

The public lighting of the little town of Wickwar in Gloucestershire was only an offshoot of a private installation started during the winter of 1887-88 by Arnold, Perret & Co.Ltd. at their brewery. It was a large brewery and had about 100 incandescent lamps. The overshot water wheel of 36 ft. diameter gave surplus power, and the town gladly accepted the offer of a public-lighting system eventually extending to 20 lamps over a mile of road, for which the town paid £15 p.a.

On the same sort of basis, some public supply was given from a mill at Blockley, also in Gloucestershire but once in Worcestershire, in 1888. The hydroelectric system at Fladbury, Worcestershire, was also based on a mill, but was a definite commercial operation with a limited company, and offered a D.C. supply to private consumers. It used two Armfield turbines. It was taken over by the Shropshire, Worcestershire and Staffordshire Electric Power Co. in 1927. A full description has been published by Mr. J.A.Crabtree in No. 5 of this journal.

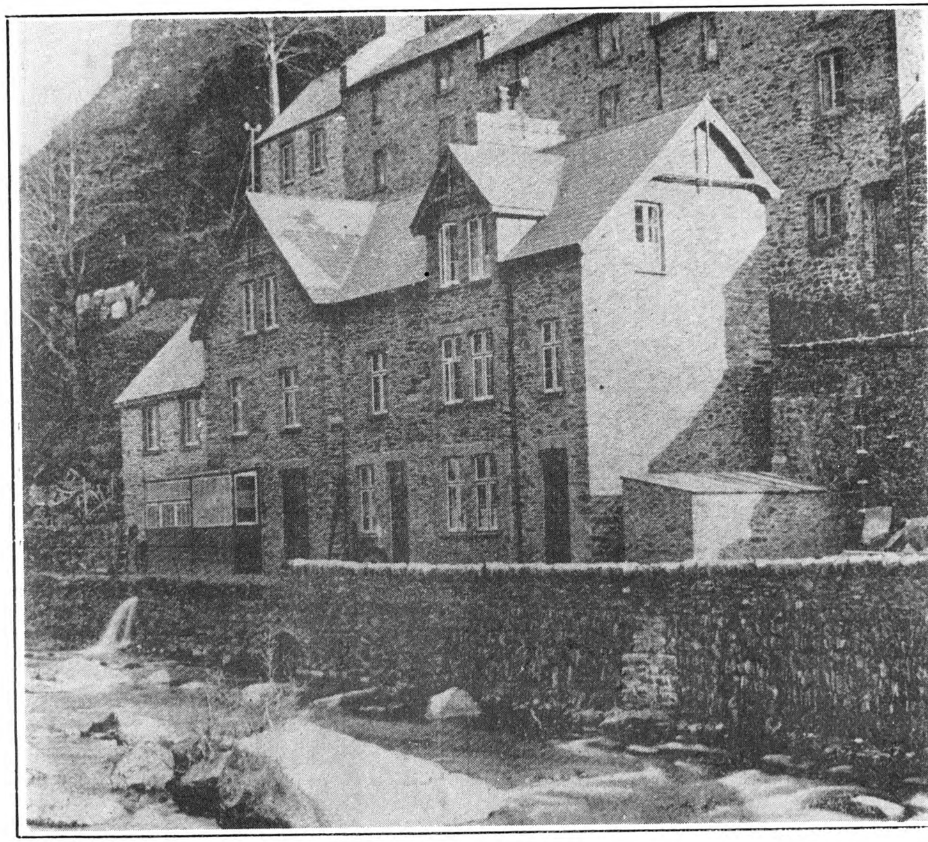


Plate 9. The hydroelectric generating station at Lynmouth, Devon. (From "Electrical Engineer", 1899.) This was opened in March 1890, and within a few years was using a pumped-storage system with a head of 760ft. and a reservoir capacity of nearly 200,000 gallons to help with peak loads. The power came from the East Lyn river, and about 75KW could be generated directly, with another 75KW when required from the water pumped to the high reservoir at times of low load. The station remained in use until destroyed by the great floods of 1952. By this time it had internal combustion engines to supplement the water power. (See Section 2 of article)

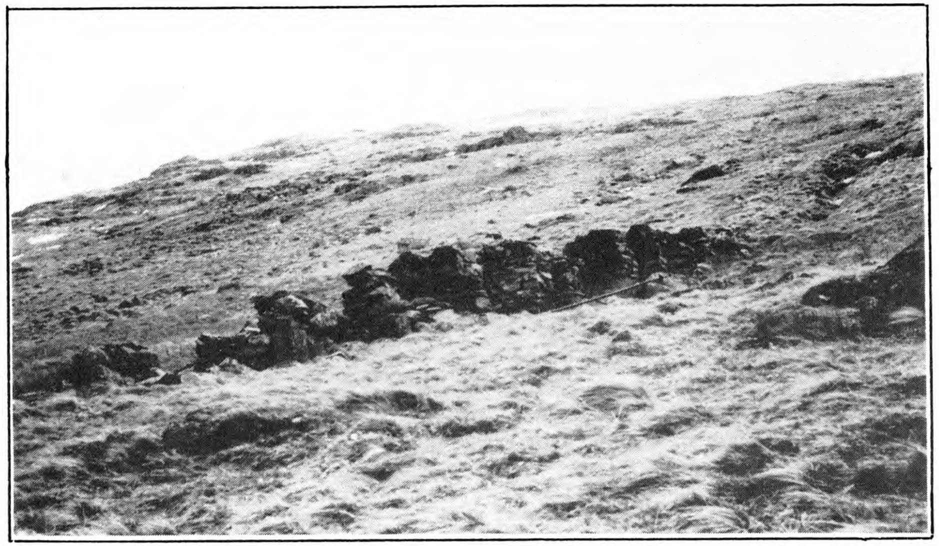


Plate 10. The remains of stone piers which supported the 15 inch iron headrace pipe which fed water at a head of about 400ft. to the hydroelectric generating station of the Greenside Lead Mines from 1890. (See Section 5.1 of article.)

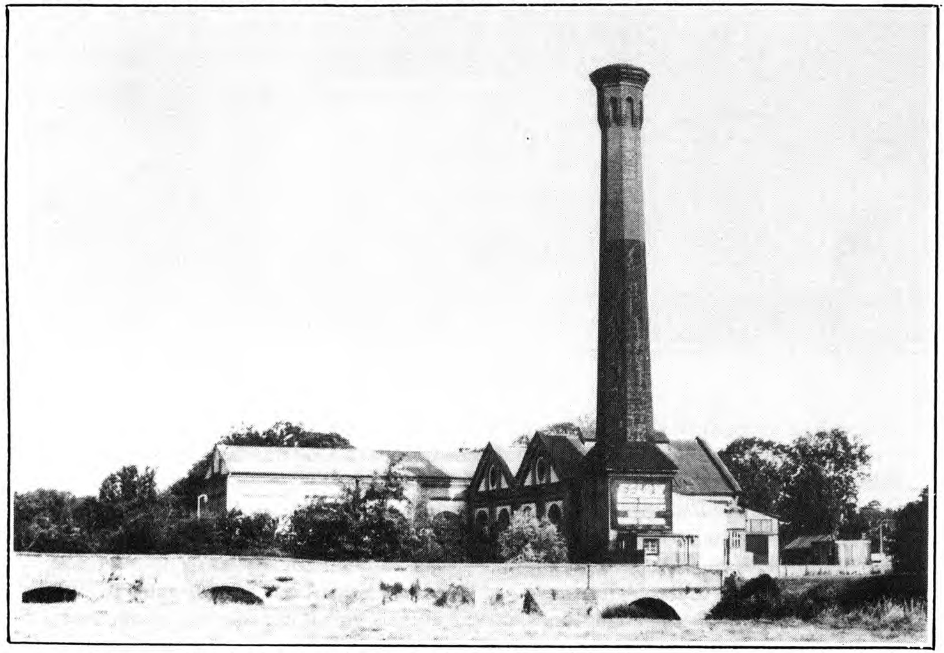


Plate 11. The hydroelectric generating station of the Worcester Corporation had steam auxiliary plant from its opening in 1894 until 1902. The boiler room, shown at the front in this photograph, was then let for commercial use. (See Section 3.2 of article)

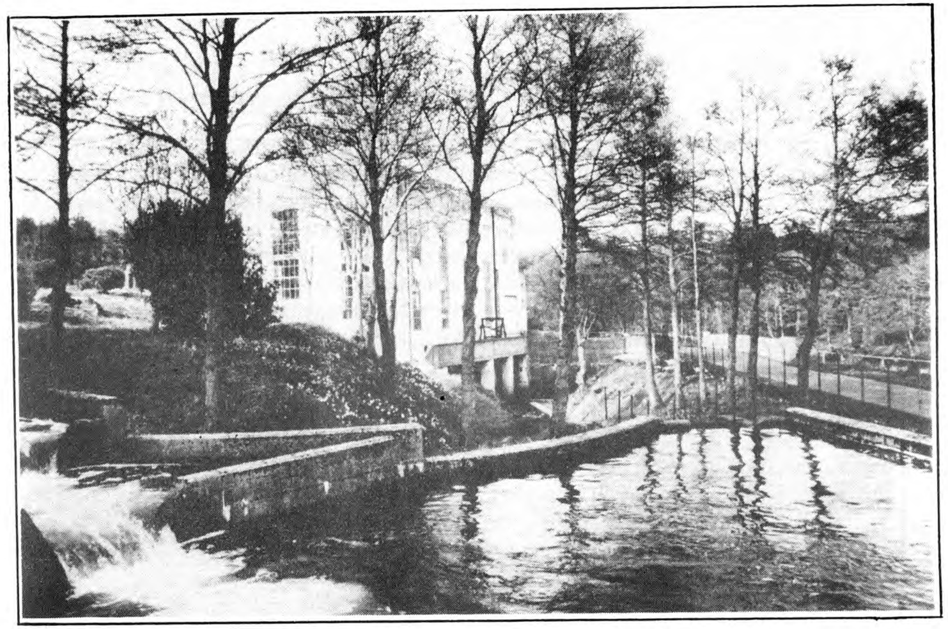
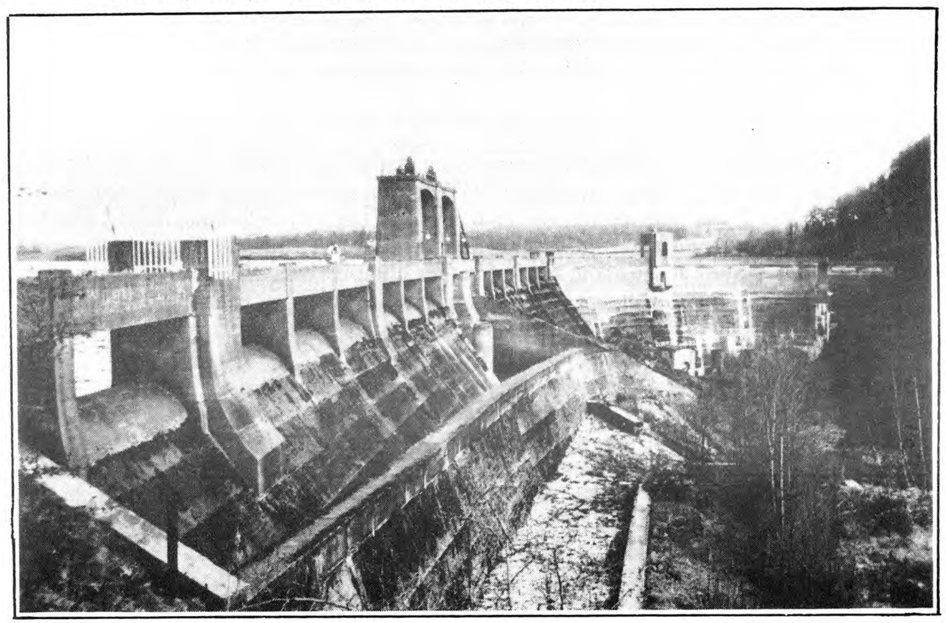


Plate 12.(above) The Earlstoun generating station of the Galloway hydroelectric power scheme of the 1930s. (See Section 7.1 of article.)

Plate 13.(below) The dam of the Galloway scheme.



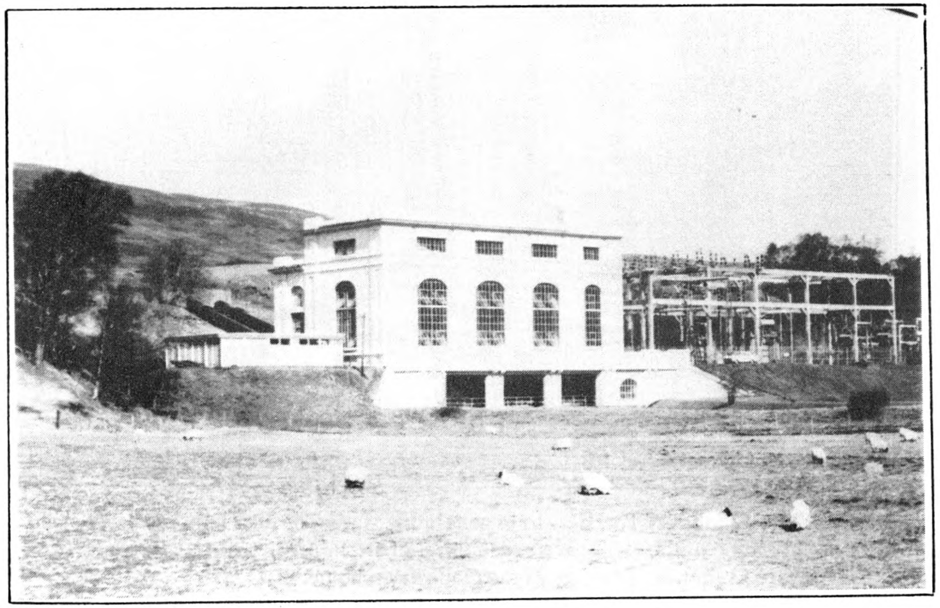


Plate 14. The hydroelectric generating station at Rannoch in the Highlands of Scotland, built in 1930 as part of the 42MW scheme of the Grampian Electricity Supply Company. It was planned by George Balfour, of the firm of Balfour Beatty, who had already developed the 20MW scheme at Kinlochleven for the British Aluminium Company. (See Table 6 of the article.) In the Grampian case the electricity had no local market and was dependent on long transmission lines to enable it to supply the industrialised Forth-Clyde belt of Scotland. Another hydroelectric station in the same scheme was opened at Tummel in 1933.

3.2 Worcester.

The Midlands had the honour for many years of having the largest hydroelectric generating station in Britain used for public supply. The City of Worcester was the first municipality in Britain to build and operate on a long-term basis its own hydroelectric station. It was opened in 1894, and had a water-generated power of up to about 400 kW. It operated from the River Teme at Powick, two miles to the south-west of the city centre, on a site where several old mills had stood. (Map ref. SO835525). It continued to generate electricity for well over half a century, and the main part of the buildings still stand on the site, used for another purpose.

As a result of several companies notifying their intention to apply for a Provisional (Parliamentary) Order to enable them to supply electricity in Worcester, the City Council decided in 1889 to apply for an Order to generate and supply electricity themselves. They duly obtained the Order and, after some delay, made plans in consultation with the Brush Co. and W.H.Preece, F.R.S. The use of water power was proposed, using the Diglis weir on the River Severn. Preece thought that the saving due to the use of water power justified quite a large cost for works at the weir. There was argument as to whether AC or DC should be used. Then in October 1892 it became evident that the Severn Conservators would not allow the use of the Diglis weir for electricity generation. However, negotiations for the use of the Powick site on the smaller River Teme were successful, and as this was some two miles from the city, the choice of AC for supply was sensible. It was estimated that up to 1500 hp of water power was available, and turbines of 600 hp were to be installed. Work started in late Autumn 1893 and the station opened on 11 October 1894. The electricity supply was taken to the city by oil-filled cables at 2200 V, and then transformed down to a suitable voltage for the consumers. The load at the opening was supplied entirely by water power.

The only water storage available was that in the headrace itself, there was sometimes a shortage of water in the river, and sometimes the Severn flooded up from its confluence a mile or two below so reducing the head; thus it was essential to have steam engines in reserve. The arrangement installed provided a great deal of flexibility; there were four 125 kW alternators in a row. The two middle ones could be driven by 160 hp water turbines or by 286 hp Brush compound vertical steam engines or by both. One of the other alternators was coupled only to a steam engine, and the remaining one only to turbines; a 60 hp turbine or a 100 hp one or both. The turbines were of mixed-flow type with a cylinder gate.

The electricity undertaking was in profit for the first time by 1899, when over half a million units were sold. The use of water power does seem to have resulted in a cheaper electricity supply, for the Worcester charge was only 2.0d per unit by 1899, whereas at Bristol, where all electricity was generated from coal, albeit cheaper coal than was obtainable at Worcester, the charge was 2.5d.

The electrification of the tramways at Worcester led to a demand for more electricity, and moreover for DC. It was decided to build a new central coal-fired steam station at Hylton Road in the city, which was opened in December 1902. From that date the steam plant was removed from the Powick station, and it functioned as a purely hydroelectric station thereafter. The no-longer needed boiler room was let for other uses. In recent years the whole station was let as an industrial building.

4. Abortive hydroelectric schemes in the Midlands.

The list of early abortive schemes in Britain, given in Table 3, includes five which can be regarded as in the Midlands. These are Burton-on-Trent, Matlock Bath, Tutbury, Bewdley, and Bromsgrove. The first four had some possibility of being viable schemes, but Bromsgrove, with only the little Spadesbourne Brook available for power, was really a non-starter. In most of these cases there is little information available.

4.1. Burton-on Trent.

In 1889 the Town Council was discussing the matter of electric lighting. According to the "Electrical Engineer" of 23 August 1889, p.141, "the proprietor of a cotton-mill has offered to let the water power on lease for the purpose of generating eletricity for the electric lighting of Burton. The gas manager has been asked to report on the matter". His report was received a few weeks later, but its contents were not reported. When, in the middle of the next year, a Provisional Order had been obtained, and demand was being assessed, there was no mention of water power.

The site offered was probably Winshill Mill, for this was, according to Owen, [8] the only mill in Burton still producing a cotton product at that time; all the earlier cotton mills had closed by 1860. The proprietor would have been glad to lease his mill, for the business was failing. The location is SK263240. Burton used a lot of water power in earlier times, and many of the leats and weirs still exist.

4.2. Matlock Bath.

The "Electrical Engineer" of 13 Feb. 1891 stated the proposal to use water power for the electricity system here, but it does not seem to have been followed up.

4.3. Tutbury

The proposal to provide this little Staffordshire town with electric light using water power appeared in the "Electrical Engineer" for 29 Jan. 1892. The source was Staton's Mill. This was an alabaster mill at SK213293, supplied with water power by a long leat from the River Dove. It seemed a reasonable proposal, but came to nothing.

4.4. Bewdley

As this small town is on the River Severn, there was undoubtedly sufficient water power available, although it might have proved expensive to harness it. The Town Council discussed a scheme early in January 1893, and appointed a committee to look further into the matter. According to the "Electrical Engineer" of 5 May 1893, the scheme was considered too risky, and was dropped.

4.5 Bromsgrove.

This sizeable Worcestershire town lies on the diminutive Spadesbourne Brook, which later, with other streams, becomes the River Salwarpe. Admittedly there were many mills on this brook [9] but at no site was more than a few horse-power available. Yet when an electricity scheme was proposed for Bromsgrove ("Electrician", 31 August 1894, p.529), it was stated that "It was proposed to use both steam and water power, the latter being utilised as much as possible". This proposal shows very clearly how often the promoters of electricity schemes failed to appreciate the enormous rate of growth of demand there would be for electricity. Fortunately this proposal fell through.

5. Major industrial hydroelectric schemes in Britain in the 1890s

Although the Worcester hydroelectric scheme was by far the largest in Britain for public supply before 1900, yet there were at least two industrial schemes of comparable size and much greater interest in this period; namely the electrification of the Greenside lead mines in Westmorland and the development of aluminium smelting at the Falls of Foyers in the north of Scotland.

5.1 The Greenside lead mines

The Greenside Silver-Lead Mining and Smelting Co. had been operating on the slopes of the mountain Helvellyn in the English Lake District for over 50 years and had made extensive use of water power when it was decided in 1890 to install a hydroelectric system as a more convenient means of transmitting and utilising water power in the mines [10]. The consequent economies are thought to have accounted for the survival of the company as a going concern until 1962. The electricity provided lighting, pumping, winding, and locomotive haulage underground. The initial installation comprised one 100 hp Vortex reaction turbine, but later a 100 hp Pelton wheel was added, and by 1911 the total turbine power was at least 300 hp and may have been 400 hp. Electrical distribution was by bare overhead wire, outside the mine, and insulated cable inside.

The mines were to the west of Glenridding at around NY365174. The generating station was on the wild mountainside at NY358168. Watercourses were built (and still remain) to bring the water of Keppelcove Tarn, Red Tarn, Brown Cove, and the Red Tarn and Glenridding Becks to a suitable point on the 1750 ft. contour, giving a head of about 400 ft. at the generating station. A 15-inch pipe, partly supported on stone piers, some of which remain, carried the water down to the station. The site is still detectable by some of the foundations. It was a wild spot, and one feels for the lone station attendant on a winter's night.

The underground electric railway was one of the more interesting features of the system. It was about 1.5 miles long, in the Lucy level of the mine, and of about 2ft.

gauge. It had one locomotive of 14 hp, weighing 2.5 tons, collecting its electric supply by two pairs of contact pulleys running on two bare phosphor-bronze conductors attached to the roof of the tunnel. The voltage was 250 and the situation was damp, but no accidents appear to have been reported. The locomotive was still in existence, and probably running, in 1921. It is supposed to have hauled a train of 12 wagons (about 18 tons) over the route in about 20 minutes.

5.2 Aluminium Smelting at Foyers

In the Herault process, aluminium ore (bauxite), which is aluminium oxide, is reduced to metallic aluminium by melting in an electric furnace in which electricity is passed through the molten ore from carbon electrodes [11]. The carbon combines with the oxygen in the oxide, leaving aluminium. The economics of the process depend on a very cheap supply of electricity. Hence the development of smelters near the sources of hydroelectricity.

The British Aluminium Co. was formed in 1894 to exploit the Falls of Foyers in Inverness-shire, where the River Foyers runs out of Stratherrick, giving a fall of over 350 ft. into Loch Ness [12]. The bauxite was mined in Ireland, concentrated at Larne, and then shipped to Foyers. The smelter went into operation in 1896. There were a tunnel and pipes to bring the water to the generating station, and initially there were five large Escher-Wyss turbines each directly coupled to a dynamo giving 7.5 kA at 64V; so the total power generated was about 2,500 kW. The installation was roughly doubled in capacity by 1905, and remained in use until 1967.

There were smelters in other countries too, and in Britain the industry expanded so that by 1909 the B.A.Co. had another big hydroelectric smelter at Kinlochleven, with an electrical capacity of about 12,000 kW, and another company, the Aluminium Corporation, had one in North Wales, at Dolgarrog, using a head of over 1000 ft. and with an electrical capacity of about 4,000 kW. It was at Dolgarrog that the dam burst in 1925, killing 16 people.

The B.A.Co. expanded still further in the 1920s, with the big Lochaber scheme at Ben Nevis, the smelter being at Fort William, and the electrical capacity being around 60,000 kW.

Before the reader is unduly impressed by the magnitude of these figures, it should be pointed out that the total aluminium production in Britain in 1921 was only 5.35% of the world's production, that it fell to 2.95% by 1945, and to only 0.75% in 1960. The largest producer of aluminium has long been the U.S.A. However, when the Foyers scheme was opened in 1896, it was one of the very few in the world, and rated as a large one.

6. The early years of hydroelectricity in Europe, North America, & elsewhere

As would be expected, the much greater availability of water power in convenient places in most of the other countries of Europe, in much of North America

and in other countries such as Australia, New Zealand, India etc., led to much more widespread development of hydroelectricity in most such places. One or two examples will give the idea. In France, for instance, a very useful list of electricity generating stations, mostly for public supply, was given, complete with capacity and date and source of power, in the French journal "L'industrie electrique" for 10 June 1892. A total of 104 hydroelectric stations was listed, roughly half the total number of generating stations. Capacity was given in horse-power of the turbines; 10 hp would have corresponded roughly to about 6 kW electrical output. The largest station was of 1280 hp; there were another 16 between 100 and 1000 hp; the remaining 87 were under 100 hp. This is a very different picture from that for Britain.

Over the years 1880-1894, even the British electrical journals reported, according to my recording, about 160 hydroelectric stations on the Continent and over 50 in the rest of the world. The largest noted in Europe had an electrical capacity of the order of 5,000 kW.

As to North America, "The Electrician" for 10 September 1886 reported that up to mid 1886, it had been estimated that not less than 14,000 hp. (say 10,000 kW electrical power) was derived from water power in the U.S.A. and Canada in the form of electricity, mostly for arc lighting. By the 1890s, the giant Niagara hydroelectric scheme was under way; we shall discuss this later.

One of the most important influences in all this was the development of long-distance electrical power transmission. So much of the water power available was in the wrong places, remote from the centres of population and industry. Occasionally it was possible to set up a new industry where the power was, as at Foyers for aluminium smelting; but the real need was to get the power from the source to the place where it was needed. There were, in the 19th century, many examples of very long leats, or power canals, to carry water power over many miles, in the Welsh lead mines, for example. In Switzerland [13] there were interesting examples of wire-rope and high-pressure hydraulic power transmission; the former at Schaffhausen on the River Rhine, where from about 1874 some 1500 hp from the great waterfalls was transmitted to the factories by wire ropes; and the latter at Geneva where the lake flows out into the River Rhone and from 1886 afforded about 6000 hp, converted by turbines and pumps into the supply for a hydraulic piped power distribution system. But the development of electrical power distribution revolutionised all this.

The most important experimental electrical long-distance system was that between Lauffen and Frankfurt in Germany in 1892. It was 105 miles long, three-phase AC, operating at 40,000 V, transmitting about 150 kW. It was real pioneering, and it was successful. It was seen at once as the answer to the water-power problem, and was applied in numerous cases, although rarely involving such great distances. By 1895, "Cassier's Magazine" was able to tabulate some 25 examples, totalling over 44,000 hp, or say, well over 30,000 kW electrical power. Clearly, hydroelectricity could now develop rapidly, and outside Britain it did.

6.1 Some major European schemes of the 1890s

Even before the influence of long-distance electrical transmission was felt, there were some notable installations in Europe, much larger than the 400 kW scheme at Worcester. At Neuhausen [14], on the Rhine in Switzerland, an aluminium smelter using the same process as later used at Foyers in Scotland was established as early as 1888, generating about 2000 kW of electrical power. A few miles above it, the old wire-rope system at Schaffhausen was supplemented in 1890-91 by a 400 kW electrical system. In 1892, an earlier small system at Tivoli [15], about 20 miles from Rome, was replaced by a large system generating about 2,700 kW which was fed by single-phase line to Rome. Then, around 1896, the great hydraulic-power system at Geneva, previously described, was supplemented by a much greater electrical system of about 13,000 kW, using two-phase transmission over the four miles from the station to the town.

6.2 The Niagara Falls scheme [16]

The Niagara River is only about 30 miles long, flowing between Lakes Erie and Ontario, and separating Canada and the U.S.A. The main falls have a head of 165 ft. and above them is a half-mile stretch of rapids with a fall of 55 ft. The ordinary flow is about 275,000 cu.ft. per second, giving a maximum generating capacity of about 5 million kW or, 5,000 MW. The water power was used for minor industrial purposes from 1725, but in 1861 a major development was opened, with a mile-long power canal, 35 ft. wide by 8 ft. deep, bringing water from above the rapids to a basin 214 ft. above the lower river. Many mills were built to use this power, and although the head was not fully utilised, the flow in the canal was; about 10,000 hp was obtained; not much more than one-thousandth of the power of the falls.

In 1886, Thomas Evershed put forward a plan with a view to attracting industry to Niagara. To preserve the environment of the falls, he proposed the industrial area should be a mile above the falls, turbine-powered, with the tail water taken through a long tunnel to an inconspicuous point well below the falls. This scheme would provide 100,000 hp on the American side. If required, a further 250,000 hp could later be provided on the Canadian side. Financial support was forthcoming, and the Niagara Company was formed in 1889. They went ahead with the provision of huge turbines (5,000 hp each), ultimately to number 20, made by Faesch and Piccard of Geneva, placed 140 ft. below the surface, transmitting power to the surface by shaft.

An international panel of consultants, under Lord Kelvin, considered further developments, and decided on electrical generation and transmission. They thought industry would develop at Buffalo, only 20 miles away, and planned a two-phase system. But industry developed mainly on the spot at Niagara.

The power was first used in 1895 by an aluminium smelter at Niagara. The transmission line to Buffalo was opened as a three-phase system in 1896. Already the scheme had the world's largest generators and transformers. Electric lighting and an electric tramway were provided at Niagara, and many other industries moved there to

use the cheap power. So Niagara was a great success. By the 1960s, over 4,000 MW were generated there.

6.3 Early hydroelectric development in Quebec

The area of Quebec in Canada, to the east and north-east of Montreal, was, in the 1890s, a practically empty land with enormous water power potential. The development of the Shawinigan Water and Power Co., which began seriously in 1898, is an example of how the availability of what is seen to be cheap power can produce a new pattern of industry [17].

The territory of the company was the land around the St.Maurice River, a northern tributary of the St.Lawrence about halfway between Montreal and Quebec City. The main power location was Shawinigan Falls, and the nearest established city was Three Rivers. The electricity generated was transmitted eventually over 100 miles, even to Montreal, and also to the south and south-east. But as elsewhere, the first big load was an aluminium smelter which came to Shawinigan and purchased about 3,500 kW; then a pulp mill, then a carbide-manufacturing plant. Urban development went along with the industrial development, and lighting companies were being supplied.

This kind of story can no doubt be repeated for many other places.

7. British hydroelectric schemes in the first third of the 20th century.

We have already mentioned the expansion of aluminium smelting by hydroelectricity in Britain after 1900; this did indeed represent the greater part of hydroelectric development between 1900 and 1930, as the data in Table 6 shows [18]. During this period there were numerous small installations of purely local significance, but in the light of the very large schemes in other countries, it is only our larger ones that we should now consider. It will be seen from Table 6 that there was no large system built between 1908 and 1926. The reasons for this were many; environmental objections had been significant even in regard to Foyers; the coal industry saw hydroelectricty as a threat to its business; Wales saw developments in Scotland as a threat to the exploitation of its own potential. These matters are discussed by Hennessey [19]. After the First World War a Water Power Resources Committee was set up by Parliament, and reported in 1919 and 1921. It set out many possible schemes, and clearly one of its most important considerations was the creation of employment and the prevention of depopulation in the Highlands. Cost and the need for long transmission lines were not obstacles; the proposals seemed economically viable. It can be seen from Table 6 that a few schemes did develop. But the factor which led to the largest and most interesting scheme - the Galloway scheme [20] - was the development of the Electricity Grid in Britain. The Grid was authorised by an Act of Parliament in 1926, and opened for service in 1933. The Galloway scheme was originally conceived by the Galloway Water Power Co. as having a capacity of only 20 MW, but the availability of the grid to carry away its electricity to the industrial parts of South Scotland and North-west England (and elsewhere) caused the planned capacity to be raised to 102 MW. The scheme will now be considered in a little more detail.

TABLE 6

Principal British hydroelectric stations in 1930

Station	Date opened	Output (MW)	Purpose
Foyers, Inverness	1895	4.5	Aluminium Smelting
Cym Dyli, N.Wales	1906	4.5	Public Supply
Dolgarrog, N.Wales	1907	10	Aluminium & public supply
Kinlochleven, Argyll	1908	20	Aluminium
Falls of Clyde	1926	15.5	Public Supply (2 stations)
Maentwrog, N.Wales	1928	18	Public Supply
Lochaber	1929	75*	Aluminium
Grampian scheme	still under construction	42*	Public supply(4 stations)

(* when complete)

TABLE 7

The Galloway Hydroelectric Scheme (early 1930s)

Generating Station	Catchment Area(sq.mi.)	Ave.Net Head(ft.)	Total Gen. Cap.(MW)
Tongland	393	102	33
Glenlee	46	365	24
Kendoon	152	150	21
Earlstoun	193	65	12
Carsfad	171	64	12
			Total 102

7.1 The Galloway hydroelectric scheme

The Act of Parliament for this scheme was passed in 1929, and electricity was supplied from 1935. It had been largely the brainchild of William McLellan (of the famous firm of Merz & McLellan of Newcastle upon Tyne), but he died in 1934 and so did not see the completion of the scheme. The main particulars are shown in Table 7. The water of a very large area of Galloway, in South-west Scotland, was used, one or two existing lochs were enlarged and some new ones created, care was taken in the planning and it is probably now generally agreed that the already-high landscape value was enhanced. Three principal lengths of tunnel were built, of 3.6, 1.4 and 1.0 miles respectively. In spite of the high head at Glenlee generating station, which operated entirely on the water tunnelled down from the man-made Clatteringshaws Loch, all turbines used in the scheme were of reaction type with vertical shafts. Those at the relatively small and low-head stations at Earlstoun and Carsfad had skirtless runners. The angling interest in the rivers had to be taken into account, and fish-ladders were provided at Tongland, Earlstoun, and Carsfad.

The capital cost of the whole scheme was about £3 million. Over 50 years later, it is still working; evidently capital charges on the original investment have long since become negligible. Not only is it still working, but it has even been recently expanded by the addition of a small new generating station up in the mountains at Drumjohn.

8. Conclusions.

It will have been seen that long-distance electrical power transmission is the key to the long-term development of hydroelectricity, for the possibilities of full use at the generating site are limited. In Britain, the electricity grid has permitted a good use of the very limited supplies of water power available. The Galloway scheme, with which this paper finished, was effectively the beginning of the modern era of hydroelectricity in Britain.

Hydroelectricity uses an everlasting source of energy and gives no pollution. It is highly desirable on these counts, but does not necessarily give an economic advantage over rival systems. Its capital costs are very high. However, the life of an installation is also high compared with that of a thermal or nuclear plant, for it is not so liable to technical obsolescence.

The early hydroelectric stations were indeed conceived as a sort of mill development; by the time the output had risen to megawatts their technology had become all their own.

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