Power to the People

The built heritage of Scotland's hydroelectric power

HISTORIC SCOTLAND

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Edited by Dawn McDowell

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Glossary
A glossary of building and architectural terms is included in ***Scotland's Listed Buildings: What Listing Means to Owners and Occupiers*** (2009). A glossary of hydroelectric power terms are included at the end of this publication.

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Foreword

***Power to the People* celebrates the massive achievements made by Scots to generate electricity from a renewable source. The result was conceived and built before the idea of global warming had gained recognition. The utility is now at the forefront of national and international government initiatives for green energy and makes a key contribution to sustainable growth in Scotland.**

The sector combines a number of Scotland's strengths. It not only shows considerable technological and architectural innovation, but also an appreciation of its unique landscape. The many power stations and dams were carefully designed to make a positive contribution to the rural scenery. The provision of HEP showed a far-sighted political vision optimising technology to make Scotland a better, more competitive, wealthier and environmentally attractive place. We can now appreciate the significance of these endeavours. Hydro is a key contributor to our status as a net exporter of energy and allows Scotland to play a key role in developing projects such as a North Sea Supergrid.

The great achievement of the sector is enhanced by the drama and beauty of the landscape given a helping hand by our famous weather. HEP in Scotland demonstrates excellence in architecture, engineering, technology and a responsible vision. It is a truly Scottish success story which is celebrated not only in this publication but each and every time you switch on a light.

Fiona Hyslop MSP
Minister for Culture and External Affairs

Introduction

The significant and early development of hydroelectric power in Scotland results not least from its combination of topography and weather. But this potential would not have been realised without the pioneering vision of a handful of architects, engineers and politicians whose personal energy and skills meant that Scotland has led the world in the development of this green energy source at various times in its history.

The vision and skill of these architects and engineers was backed up by a productive and resilient workforce capable of achieving world records during the frenzied construction of schemes across Highland Scotland. This massive potential began to be realised over 100 years ago. Initially in private developments and later under state control, Scotland had developed an internationally significant hydroelectric power sector by the late 1960s.

The legacy of this pioneering development is a vibrant hydro sector which contributes to Scotland's status as a net exporter of power to the rest of the UK. Scottish hydroelectric schemes are of national significance to the UK energy sector, generating around 12% of the gross power consumed in the UK in 2008.

This is a spectacular Scottish success story. The hydroelectric power movement has led to the creation of many internationally important buildings and structures, demonstrating architectural as well as engineering achievement.

This book traces the development of the industry through some of these key figures, from its roots in the aluminium industry through to hollow mountains with the capability to provide emergency power for whole of the UK. In addition to the numerous pioneering technical achievements realised by Scottish engineers the contribution of a number of distinguished pre- and post-war architects are discussed.

The gazetteer section explores the vision outlined in the book's

earlier chapters, giving a comprehensive overview of the existing infrastructure in Scotland. It underlines the contribution made by this most intriguing cast of characters and provides a clear view of the schemes which are so crucial in providing power to homes and business across Britain.

Malcolm Cooper
Chief Inspector
Historic Scotland's Inspectorate

OPPOSITE: **Laggan Dam, 1934, Lochaber smelter and hydroelectric power scheme.**

The Pioneers

'Suddenly Kinlochleven was transformed, from a remote crofting settlement, to a centre of industry with people from all walks of life and many nationalities in the village,' explains Avril Watt, a local historian in Kinlochleven, with a passion for its people and landscape. The powerful transformative force was the development of the pioneering Kinlochleven hydroelectric power system and aluminium smelter, completed in 1909 by the British Aluminium Company and at the time one of the largest and most sophisticated smelters in the world.

'What people don't appreciate,' continues Avril, 'is that although the scheme was technically pioneering it was built by hand – hard, dangerous work in which a number of men died and are buried in a graveyard overlooking the dam. A whole community of people sprang up at the dam, some living in bunk houses and others in small huts they constructed for themselves, cooking on an open fire sometimes over the back of a shovel. There were many types of men up there, not just travelling labourers, but lawyers and doctors who had fallen on hard times, and a surprising number of women acting as matrons, cooks and cleaners to some of the huts where men would pay pennies for washing and a meal in the evening.'

The extensive hydro scheme is still in operation by Rio Tinto Alcan, although part of the site has diversified as the community has matured, with mixed-use development and an ice-climbing centre in the former carbon silos. The legacy of the smelter remains at the heart of this remote Highland community.

Chapter 1

The Pioneers

Two pioneers, with a large cast of supporting characters, revolutionised hydropower in Scotland from the eccentric folly of a retired colonel to a dynamic modern industry with the potential to power the country sustainably and regenerate the Highlands. The success, or otherwise, of such a commanding utopian vision would rest on the shoulders of others – engineers, architects, politicians and landowners. It all began, though, with ambitious developments in industrial generation for aluminium smelting, which through the work of William Murray Morrison (1873–1948) and later Sir John Snell (1869–1938) opened up the possibility of using hydropower for mass electrical consumption.

Hydroelectric power is now a large worldwide industry: it already supplies around 19%[1] of world power, and is set to expand as the need to develop renewable energy sources in response to climate change grows ever more pressing. The roots of the industry lie remarkably close to home, with Scotland a pioneering force in the development of the technology and of hydropower resources for public supply. In an international context, one of the earliest uses for hydroelectric power generation was in 1882 when, at the electrical technology exhibition in Munich, an experiment on the transmission of power along high-voltage cables used energy generated from an experimental hydroelectric station. The pattern of development in the Alpine and Nordic nations was continued as they exploited the steep topography as a source of power in the absence of the rich coal reserves found in Britain. Hydropower first came to Britain soon after the Munich exhibition with the development of a scheme to power the Northumberland home of Sir William Armstrong (1810–1900) at Cragside. Armstrong, who was a friend of the

PREVIOUS PAGE
Avril Watt at Blackwater dam, 1905-1909, Kinlochleven smelter and hydroelectric scheme.

Kinlochleven power house, interior and exterior, 1905-1909, Kinlochleven smelter and hydroelectric scheme.

1.1 Cragside House, 1863 (hydroelectric power scheme in operation from 1878). © NTPL/Simon Fraser

inventor of the light bulb, Joseph Swan, showcased his technical achievement in his house, which in contrast to the ubiquitous smoky paraffin lamps was lit by bright, clean hydroelectric-powered light bulbs. [1.1]

The earliest developments in hydropower in Scotland were small scale and privately funded, mirroring Armstrong's work at Cragside and providing power to a small local community or even a single building. An early triumph by Colonel Blunt, the husband of the Countess of Cromarty, near Dingwall in 1903 was used to light the front of the Raven's Rock Hotel in Strathpeffer, much to the amazement of visiting tourists to the small spa town. In nearby Fort Augustus the monks of the abbey developed a small 18-kilowatt scheme in 1891 to power their electric organ and the local village, legend suggesting poetically that when the monks played the organ the lights in the village went dim. Whilst these developments and others like them proved that the technology worked, they were restricted by the fact that power could not be transmitted to a sufficiently wide area. Added to this, the market for power was so small that the available returns limited the scale of future development. For example, Colonel Blunt's development at Raven's Rock was to be dogged by financial difficulties, and even went bankrupt, before eventually being incorporated into a larger scheme in the 1920s. [1.2]

For hydropower to be economically viable and developed on a nationally significant scale, sufficient demand was required to allow the financing of a

1.2 **Fort Augustus Monastery, 1729-42.**

large scheme along with the essential development of civil and technical engineering. Without a national grid and a large energy market, this was unlikely to come from domestic or small-scale commercial supply in the late 19th century. The breakthrough came with the development of the Hall-Heroult smelting process for aluminium. [1.3] Using an electrical furnace, the process lowered the cost of production of the metal by some 75%. However, the lower production costs relied heavily on the provision of cheap electricity combined with easy access for the transport of bulk products, such as aluminium oxide, to supply the plant. Hydroelectric power was the obvious source for generating the required DC current at the lowest possible cost, and aluminium smelting quickly emerged as the economic spark necessary for the large-scale development of hydroelectric power.

The British and Colonial rights to the smelting process were purchased by a newly formed company in 1894. The British Aluminium Company (BAC) considered a number of locations across Britain for sites to establish production facilities, but they finally settled on the Highlands of Scotland because of the great potential for the production of cheap electricity from abundant water power, which was so crucial to the success of the infant technology. Having recognised the potential of the Highlands, BAC went about pioneering the development of large-scale hydroelectric power generation in Scotland with the construction of three large industrial generating schemes at Falls of Foyers, Kinlochleven and Lochaber over the course of the next 40 years. In the development of the first scheme at Foyers, BAC purchased the complete water catchment required, obviating the requirement for a parliamentary bill and allowing the rapid development of the scheme.

1.3 Aluminium smelting using the Hall-Heroult process, Lochaber smelter and hydroelectric scheme, c.1935. © Glasgow University Archives

Just a year after the company was founded it was joined by a newly qualified engineer, William Murray Morrison (1873-1948), who had taken his degree at the University of Edinburgh and then subsequently trained under Lord Kelvin at the Royal Technical College in Glasgow. [1.4] Morrison, who later went on to become BAC vice-chairman, was present at the birth of the hydropower industry in Scotland with designs for the first plant at Foyers underway when he joined the company. It had acquired Foyers estate and water rights over a large area of land on the south-east shores of Loch Ness, with the ideal topography for hydropower and access for bulk transport from the Caledonian Canal. Morrison was reunited with his former tutor, Lord Kelvin, for the design of the scheme, which was amongst the earliest in Europe to combine hydropower and aluminium production. Similar ventures in Norway, although on a very large scale, were not developed until the beginning of the 20th century, in particular with the Rjukan waterfall scheme from 1902 onwards.

1.4 **Sir William Murray Morrison (1873–1948).**
© Glasgow University Archives

The development at Foyers set the precedent for later schemes by attracting opposition from those who believed it would have a detrimental effect on what was considered Scotland's premier waterfall and a regular stop-off during the MacBrayne's steamboat excursions on Loch Ness.[2] [1.5] The company responded by outlining the employment which the development would bring to the area. An article in the *Northern Chronicle* of 1895 suggested that 'the founding in the Highlands of manufacturing or other industries calculated to develop local resources and to provide employment and increase a resident population is deserving of warmest encouragement and support'.[3] Although effusive in its praise, the report was justified as the development at Foyers grew from merely a factory into a settlement with a church and school, and as the number of employees expanded from 70 to 250.

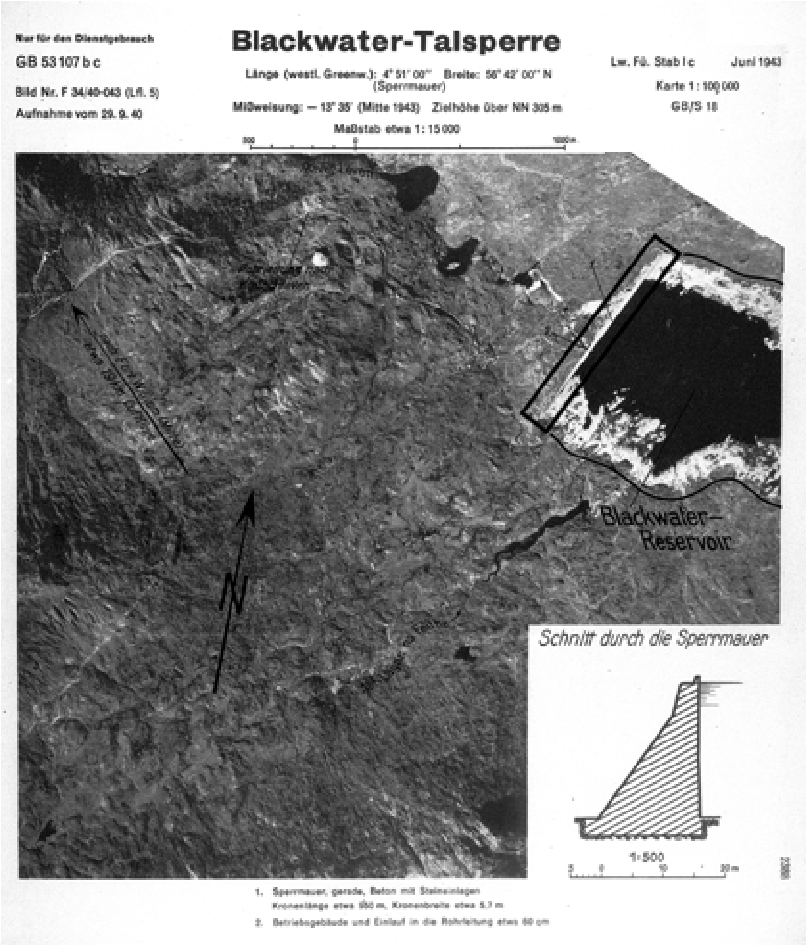
The Foyers scheme was undoubtedly pioneering and innovative, the first industrial-scale use of the Hall-Heroult process and the first use of hydroelectric power on this scale in the UK. It was also highly influential, as the five Girard turbines and Oerlikon generators proved the viability of producing electricity from water-powered turbines, something which had consequences well beyond industrial generation for the aluminium industry. They also showed that hydro power could be successfully applied to industrial processes. By 1900 the scheme was producing over 5% of the worldwide production of aluminium. The proven success of the technology, together with an aggressively expanding market with a range of domestic and industrial

1.5 The Falls of Foyers Waterfall (oil on canvas) by Alfred de Breanski (1852–1928). © The Drambuie Collection, Edinburgh, Scotland / The Bridgeman Art Library

products utilising the new lightweight metal, provided the impetus for further development. A bill for the development of the Loch Leven catchment was presented to Parliament and approved in 1904, paving the way for an engineering achievement of international significance in what had previously been a rural backwater in Argyll.

Whilst the Foyers scheme was pioneering but understandably cautious in scale, the BAC development at Kinlochleven was a step into the unknown. The increased confidence was mirrored by the growing skill and leadership of William Morrison, and such was his influence over the design and engineering of the scheme that he was promoted to general manager in 1908, just a year before it was completed. The damming of the river Blackwater created a 13-kilometre-long reservoir with a catchment area of some 150 square kilometres. The project was a large undertaking, and took four years to complete.

The Blackwater dam for the Kinlochleven scheme was a gravity dam,



1.6 **Blackwater dam, Kinlochleven smelter and hydroelectric scheme. Luftwaffe vertical air photograph of reservoir and dam with sketch section drawing of dam, 1943. The smelter was a key military asset with World War 2 significantly increasing demand for aluminium.** Crown Copyright: RCAHMS. Licensor www.scran.ac.uk

26 metres high and over 800 metres in length with a breadth of 19 metres at the base, and the largest in Scotland in terms of cubic metres of concrete until 1950. [1.6] Water was conveyed from the outlet over five and a half kilometres in a sealed reinforced concrete aqueduct, before entering six parallel steel pipes (which were imported from Germany) dropping 285 metres to the six Pelton turbines and three auxiliary sets in the powerhouse. Initially the production capacity at Kinlochleven outweighed demand for the product, nearly causing the collapse of BAC. However, the First World War hugely increased demand for aluminium, which was found to be perfectly adapted to a range of military requirements. Initially extensions were made at Kinlochleven with an aqueduct bringing in additional water from Loch Eilde Mor, and plans (eventually abandoned) were considered for a second powerhouse. The abortive scheme for a second powerhouse would have used water from Lochs Laggan and Treig, and this idea provided the basis for BAC's most audacious undertaking in developing a third smelter at Lochaber in Fort William.

The Kinlochleven scheme was a significant advance in scale over the first development at Foyers and represented a highly important civil engineering achievement, recognised internationally, on its completion in 1909. The smelter was one of the largest in the world at this time, and its capacity, combined with Foyers, meant that the west Highlands produced nearly one third of the worldwide total for aluminium.[4] [1.7]

Having been witness to the successful early development of the technology for hydropower at Foyers and an integral part of the expansion of the technology for the development at Kinlochleven, Morrison, in his role as general manager for BAC, went on to put his knowledge and skill as a pioneer of the industry into the most audacious and large-scale developments to date by BAC – those at Lochaber, begun in 1929. The development utilised a massive catchment, including three major reservoirs, with run off including parts of Ben Nevis. Lochs Laggan and Treig were joined by a three-and-a-half-kilometre tunnel. Water from these two lochs was later supplemented by the damming of the River Spey and its diversion into Loch Laggan to satisfy increased demand during the Second World War. Perhaps the most significant part of the scheme, however, was the 24-kilometre pressure tunnel bored through solid rock under Ben Nevis to connect Treig Dam with a steel pipeline dropping 180 metres to the powerhouse just outside Fort William. [1.8]

By the completion of the expanded stage of the Lochaber scheme in 1943, BAC's Highland aluminium smelters were a significant component of worldwide production of aluminium. The long-term investment and innovation of the company had transformed the use of hydroelectric power in Scotland, from small-scale local operations into a sector capable of generating power on an industrial scale. The investment in design experimentation for civil and mechanical components of the scheme, such as the pioneering use of rockfill technology in Treig Dam, was only possible because of the profits available from the association of power generation with aluminium production and the constant emphasis on larger and more efficient schemes. The development of the technology to such a degree had an important impact on the design of schemes for public supply, which began to develop on a large scale from 1928 onwards with the Grampian hydropower scheme. The environmental benefits of generating energy through hydropower, which are a key concern of the modern-day industry, were perhaps perceived at this time but were not central to the development of the industry during this period.

The development of schemes for public supply was dogged throughout

1.7 Kinlochleven power house and penstocks, 1905-1909, Kinlochleven smelter and hydroelectric power scheme.

by difficulties in funding and by local opposition in ways which had not affected the BAC schemes. One of the largest problems was raising capital to finance the massive civil engineering elements. This was one of the primary reasons why the public supply developments were reliant upon importing the technology pioneered by BAC schemes with their reliable returns. Local and national power transmission systems were still in their infancy, and most early schemes for public supply also faced problems in reconciling the fact that the power was produced in large sparsely populated areas, whilst demand was located far away in the densely populated central belt.

Despite the gap between the areas most suited to production and the most viable markets and concerns over scenic amenity (the visual impact of the schemes on the landscape), another pioneer with similar vision to Morrison was convinced of the viability of hydropower for public supply as early as 1920. In 1918 the Board of Trade established a committee to investigate Britain's water power resources, no doubt partially in response to the success of the two existing BAC schemes. The committee was chaired by Sir John Snell, a civil engineer by training who also had experience of government service. He saw in hydropower an opportunity to begin to shape a modern and forward-looking power sector which would revolutionise the way people lived in Britain. Snell's report was suitably expansive on the potential for hydropower to make a significant contribution to UK resources. The perceived acknowledgement by the government of the value of hydropower began to make the sector more appealing to financiers and opened up revenue streams for the funding of new schemes.

Snell was not only convinced of the general potential of hydropower, but laid out a far-reaching and highly influential personal vision of how the sector should be developed – something which went on to have a significant impact not only on the schemes developed immediately afterwards, but also on nationalised developments by the North of Scotland Hydro Electric Board (NoSHEB) from 1943 onwards. Snell's vision was for the development of individual catchments with dams and power stations rather than the mass movement of water

1.8 Treig dam, 1921-1929. Crown Copyright: RCAHMS

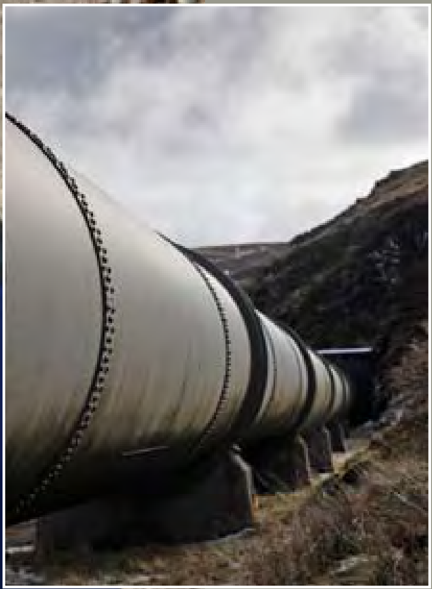
between catchments to single large power stations. This proved very influential, with the vast majority of schemes in Scotland consisting of a number of smaller stations using water resources from their own catchment and grouped together into a wider scheme. This also had a practical impact, providing flexibility in the generation pattern which could be achieved by putting individual stations in or out of production and thus regulating capacity more effectively. Snell also had a social vision for the use of hydropower which chimed with that of the early rhetoric surrounding the BAC development at Foyers. He saw the additional opportunity for the development of Scottish hydroelectric resources to regenerate the Highlands, as long as they were accompanied by the stipulation that developments should benefit the catchment in which they were located. Consequently later schemes developed at the Falls of Clyde, Tummel and in Galloway all paid particular attention to the scenic amenity of the areas in which they were located, in addition to providing power to local communities. Although this thinking would have had a considerable impact over the schemes which followed the report, it was in the post-1943 NoSHEB schemes that this almost socialist vision was perhaps most evident.

In a period characterised by an increasing focus on policy-led social agendas and coinciding with the advent of mass social housing, a commitment to social welfare was an ongoing theme throughout the development of hydropower. In general, a vision for a better life resulted in strategic planning amongst policy makers, architects and engineers, with a number of large projects throughout Scotland. The two pioneers, Morrison and Snell, perhaps both had a vision for the development of a vibrant and modern industry on an unprecedented scale. Despite being a pioneer of the technology behind hydropower, it was the common good that Morrison was most proud of, noting sentimentally in a letter, to Dr Lachlan Grant on 1 January 1935: 'It is a most pleasing recollection in my career that I have been able to do some practical and lasting good to my beloved Highlands.'[5]


berghaus

The Engineers

'I'll always remember looking around me [when working on a project in Lesotho] and seeing all the different nationalities, and knowing that we were developing a scheme to provide power where it had not been available before.' This reflects the great satisfaction James Arthur found in his international career as a civil engineer and former partner with James Williamson & Partners (latterly global multi-disciplinary consultancy Mott MacDonald), who were responsible for some of the defining engineering for hydro schemes in Scotland and worldwide.



James recalls that when he joined the practice in 1974 the original vision of its founder, James Williamson (who died in 1953), remained a central philosophy of the company. Hydro schemes were not just pieces of engineering, but were part of the social fabric of a place. Interpreting the landscape and requirements of a local community was the only way to produce the highest-quality designs for hydro schemes in a diverse range of locations.

James not only developed his civil engineering skills working at 'Williamsons'; he also embraced the social conscience which he could see demonstrated in so many of the projects across Scotland. This philosophy has been espoused by him and a small group of his colleagues and disseminated across the world in their later work, helping to develop successful projects in countries as far-flung as Iceland and Pakistan. James reflects that 'although Scotland does not necessarily have the largest hydro sector in the world, the role of engineers bred in Scotland, who learnt from Williamsons much more than just how to engineer a hydro scheme, has been very significant indeed.'

Chapter 2

The Engineers

In responding to the challenge laid down by Sir John Snell for further development during the course of a number of interwar projects at Tummel, Clyde and in Galloway, a breed of specialist engineers emerged whose work not only overcame the technical problems associated with using hydropower for public supply, but went on to shape the post-war development of hydro under the North of Scotland Hydro Electric Board (NoSHEB).

Snell's pioneering vision instigated the development of hydroelectric power schemes for public supply. The perception amongst financiers and other officials that the development of such schemes had government and public approval opened access to credit and allowed this area of the hydro sector to begin to catch up with the great strides made by the British Aluminium Company (BAC) in the provision of hydropower for their Highland aluminium smelters. Although developments by BAC had proved that the technology could work on a very large scale, the technical challenges associated with public supply were different and demanded equally innovative solutions.

Foremost amongst the engineers involved in shaping the industry in this way were Edward (later Sir) MacColl (1882–1951) [2.1] and James T Williamson (1881–1953). [2.2] Both had completed apprenticeships before the First World War and cut their teeth on projects ranging from explosives and munitions to tramways. MacColl was appointed Chief Technical Engineer for the Clyde Valley Electrical Power Company, following his work on the electrification of the Glasgow tram network. The Clyde Valley company

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James Arthur at Ben Lawers dam, Killin, Breadalbane hydroelectric scheme.

Ben Lawers dam and penstock, Killin, 1951-1956, Breadalbane hydroelectric scheme.

2.1 Sir Edward MacColl (1882–1951) pictured centre. © Am Baile. Courtesy of the Ramsay Collection, Skye and Lochalsh Archive.

2.2 James T Williamson (1881–1953). Reproduced courtesy of Mott MacDonald Ltd.

was the largest supplier of electricity in Scotland at the time MacColl was appointed. Having abandoned plans in 1909 to develop the Falls of Clyde for hydropower, the company had gone on to construct a number of thermal stations. Their attention returned to the potential of the Falls of Clyde following MacColl's appointment and the financial backing of the Power and Traction Finance Company. [2.3]

The capacity of the Falls of Clyde to provide water power on an unprecedented scale in Scotland had of course been recognised by David Dale in the late 18th century in the development at New Lanark, of pioneering of water powered mills and an associated village. The location of the proposed scheme was therefore not only at one of central Scotland's most renowned sites for water power, but also at one of the region's most recognised beauty spots, and vociferous opposition was expected in advance of the proposal being put forward for parliamentary assent. The critics of the scheme were appeased more through technical and architectural achievement than through public relations. Thus the far-sighted drive to ensure that developments made a positive impact on their environment by contributing to their setting, and by good design and engineering, was a theme MacColl had picked up from Snell's report and that would prove influential over all of his future work and latterly that of NoSHEB.

One of the key factors in the design at the Falls of Clyde was accordingly to preserve the falls

2.3 Falls of Clyde promotional booklet, 1926.
Crown Copyright: RCAHMS. Licensor www.scran.ac.uk

as a spot of scenic beauty, and this was achieved by MacColl through an innovative adaptation of the technology for hydropower. He chose astutely to use a 'run-of-the-river'-type scheme, precluding the requirement for a reservoir and so preserving the appearance of the landscape. As well as removing the need for a reservoir, the design also ensured that sufficient compensation water was provided to the river (ensuring water still flowed over the famous falls) through the use of cleverly designed tilting weirs, unique at the time when they were constructed. The three gates could be lowered by their lower section pivoting on steel bearings. A counterweight acting on the weir gates was set to resist the pressure of water when the river was at the optimum height but would allow the gates to move down if water level (and pressure) rose. The mechanism was designed to maintain water level to within 15 centimetres of this optimum, providing water both to the power station and over the falls. The preservation of the landscape was also of wider concern in the design of the scheme, with a group of prominent architectural advisers, including Sir Robert Lorimer (1864-1929), who was on the amenity panel. [2.4]

2.4 Workers constructing the tunnel at Bonnington power station, 1926, Falls of Clyde hydroelectric scheme.
Crown Copyright: RCAHMS. Licensor www.scran.ac.uk

Despite being disparagingly nicknamed 'MacColl's Folly'[1] by the coal lobby, the scheme managed to site two power stations and associated penstocks and weirs in an area of outstanding natural beauty. The primacy of the engineer's role which MacColl achieved on the Clyde project went on to become the accepted standard for hydro developments from this point onwards and had a major impact on the work of NoSHEB. Notwithstanding his success on the Clyde scheme, MacColl recognised the limitations of the sector at this time. A major obstacle which the BAC schemes had not needed to overcome was the transmission of power from generation to end user, a problem made particularly acute by the often remote rural location of many of the prime sites for hydropower resources to be developed.

The lack of national infrastructure for the transmission of power had already had an impact on the early work in the hydro sector of another key figure, James Williamson. Williamson was working as chief engineer to Alexander Gibb & Partners of Glasgow in 1923 when he was approached by two Kirkcudbrightshire residents, Wellwood Maxwell and Scott Elliott, to investigate the potential of the area for hydropower. Williamson found that the potential far exceeded his expectations. However, all developments were rendered uneconomic because of the sparse and predominantly agrarian character of the area's population, which would not provide a sufficient income to outweigh the significant costs involved in developing the scheme.

In a precursor to their later partnership for NoSHEB, it was MacColl who provided an answer to Williamson's problem. He was appointed to the Central Electricity Board (CEB) in 1927 and immediately began to work on solutions to the problem of long-distance transmission of power – a vital step to allow the accelerated development of the hydro sector in Scotland. MacColl's invention of the 'MacColl Protective System' was the crucial technological breakthrough that provided the basis internationally for long-distance power transmission. By 1933 the Scottish national grid had been created.

The work of MacColl on the development of the national grid had a direct impact on Williamson's prospects for the Galloway scheme. With the problem of transmitting the power resolved, it could now be exported to the central belt and north-west England, providing vital access to larger urban markets which made the development financially viable. The scheme, which spanned from Loch Doon in Ayrshire to Tongland on the Kirkcudbrightshire coast, was also amended to provide vital peak-load capacity for the new electricity network which was founded almost wholly on thermal stations capable of providing only base-load supply.

Despite the advantages offered by the development of the grid, large obstacles still remained for Williamson to overcome. The topography of the area chosen allowed Williamson to use the 60 kilometres from Loch Doon to Tongland as a cascade system, reusing the water for generation multiple times as it passed through the power stations and also, most notably, the nine separate dams that were constructed. The total fall over the 60 kilometres was a mere 210 metres, but Williamson's cascade design proved a highly innovative solution to the technical problems which this relatively low head of water created.

Having overcome the immediate technical difficulties, parliamentary assent was required to allow construction of the scheme to go ahead. It was carefully piloted through Parliament, but successful adoption by the House of Commons required the insertion of a number of clauses, one of which in particular proved highly influential not only over the work of Williamson

on the Galloway scheme but also on all subsequent developments in the sector:

> *In the construction of the works all reasonable regard shall be paid to the preservation, as well for the public as for private owners, of the beauty of the scenery of the districts in which the said works are situated. For the purpose of securing the observance of the foregoing provisions and of aiding the Company it shall be lawful for the Secretary of State, after consultation with the Company, to appoint a Committee. The Committee may make to the Company such recommendations as they may think reasonable and proper for the preservation of the beauty of the scenery.*[2]

The existence of this 'amenity' clause influenced the quality of engineering and design on this and all other schemes. It necessitated a carefully developed approach to the engineering of the schemes to ensure that they represented the minimum possible intervention necessary, thus preserving the integrity of the landscape, and that each feature made a positive contribution to its setting. The legal obligation to be mindful of natural setting made the skill and innovation of the engineer of paramount importance to the success of the Galloway scheme – not only would all the technical considerations need to be satisfied, but the appearance and impact of each intervention would be closely monitored.

Williamson rose to the challenge in his first major hydro commission, designing nine dams and developing a pioneering approach to their design which went on to characterise all of his later work. Williamson retained a constant focus not only on the visual appearance of the dams, but also on the opportunities to save on expensive materials and contract time. A number of the dams he designed were of composite type with central arched sections abutted by concrete gravity wings. The use of the arched central section saved a significant amount of concrete in comparison to a conventional gravity section, whilst the mass gravity wings compensated for the fact that the natural abutments were insufficiently strong or steep.[3]

A number of the dams on the Galloway scheme incorporated innovative fish passes, including an octagonal tower at Loch Doon dam containing a continuous spiral cascade of linked pools. However, it is perhaps Clatteringshaws, the largest dam on the scheme, which best illustrates the central role of the engineer in this phase of design. [2.5] The dam provides water storage capacity for Glenlee Power Station through a tunnel. Its unadorned modern appearance clearly ties it

stylistically and functionally to Glenlee, with the use of a striking Modernist design a key theme in both dams and power stations throughout the Galloway scheme. Constructed from the upstream face using a series of steam cranes on a track, with concrete mixed on site at the east end of the dam, Clatteringshaws skilfully combines engineering excellence with the use of arch and gravity sections, all on a curved profile with a heightened awareness of the natural setting. Taking into account both functional and aesthetic concerns, it is placed in a large valley, the steep sides of which flank the dam and screen it

2.5 Clatteringshaws dam, 1932-1934, Galloway hydroelectric scheme.

2.6 Tongland power station, 1934, Galloway hydroelectric scheme.

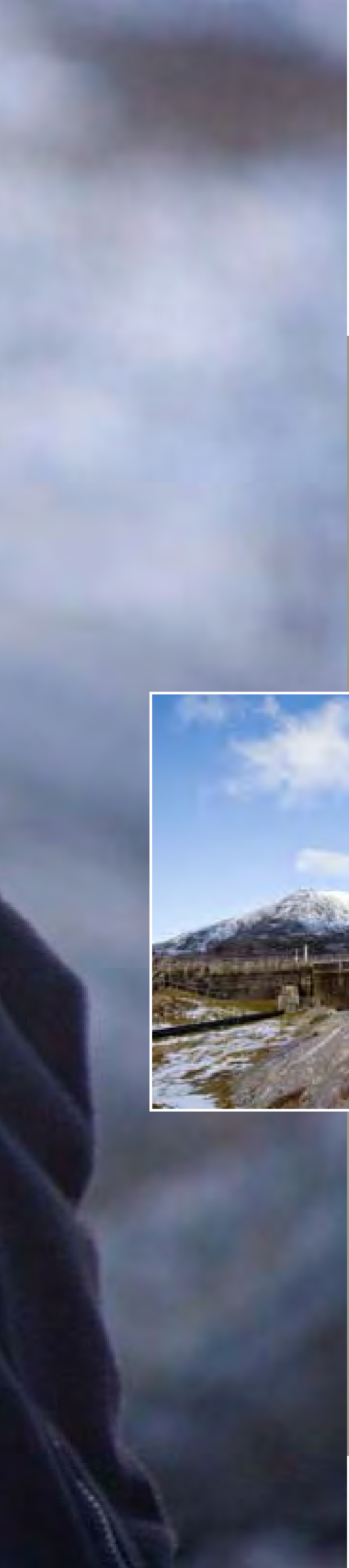
from view. The curved profile also adds a sinuous form in the landscape when viewed from a distance, melding the industrial structure into the curving hills.

The detailing of Tongland Power Station, with its stark roofline and rhythmic articulation of the façade, characterises the modern, dynamic attitude with which hydroelectricity was viewed in this period and the positive impact it could have. [2.6] The open rolling landscape of the Galloway Hills where the scheme was located provided a particular challenge for the design of the scheme, with long open vistas ensuring that any large civil engineering interventions could potentially have a significant impact on the character of the area. Williamson pioneered a dual solution to the design of power stations on the Galloway scheme which came from his engineering background, where he was accustomed to combining alternate systems into a single cohesive device, similar to his use of both gravity and arch elements in his dam designs. Whilst a clear focus is retained on the integration of the buildings and dams with their landscape when viewed from a distance (as at Clatteringshaws), this is coupled with a high-quality design for all features on the scheme. This recognises the fact that, when viewed from close by, such large features cannot be hidden in the landscape (although this became a theme that NoSHEB would later develop through the use of local stone cladding and underground stations), but conversely they could make a striking and positive impact with an outstanding Classical Modernist design and the use of high-quality materials, all while maintaining the necessary engineering requirements of a large commercial power station. [2.7]

The zeal with which both MacColl and Williamson approached work on hydropower projects during this period is characteristic of the drive and ambition of a young industry given boundless new horizons by the development of a national grid. The desire to innovate constantly and use high-quality design was a central principle for both men, whose commitment to applying these principles shaped the future development of the hydro sector in Scotland. The heights which the Galloway scheme reached in terms of design and the essential strategic role which it played in satisfying peak demand for power in the new national supply network for Scotland made it increasingly hard for central government to ignore the potential of the sector on a national scale. Williamson and MacColl's successes laid the foundations for the nationalisation of the industry. They had transformed the use of hydropower for public supply from the eccentric brainchild of Highland estate owners to a modern and dynamic industry confident to make a strategic and aesthetic contribution to Scotland.

2.7 Earlstoun power station, 1936, Galloway hydroelectric scheme.


Cape Breton
HEAD



The Visionaries

David Wake (inset) came to North Harris from Lancashire on holiday in 2004, and when he finally decided to give up the 'rat race' a year later he moved to the island permanently. Before too long, he was able to turn his business experience to working as the Energy Development Officer with the newly founded North Harris Trust (NHT).

A non-commercial body whose principle objectives are to enable this Hebridean island community to grow and prosper sustainably, mainly by providing housing and creating jobs, the Trust acquired the North Harris Estate in a right-to-buy agreement in 2003. Since then, they have been eager to capitalise on the great potential that renewable energy provide in terms of direct economic benefit.

Kenny MacKay (right) and Calum MacLennan (left), natives of North Harris, were both involved in the construction of the first large scheme on the island located at Chilostair in 1960. Calum provided his vans and trucks on loan to the Hydro Board and Kenny worked on building the pipeline for the scheme. They recall some 80 men working and living on site for over a year. The advent of the relatively small schemes at Chilostair and the other at Gisla, built shortly after in 1960, brought not only clean electricity to remote Hebridean townships (removing the reliance on diesel generators), but also new opportunities for the reinvigoration of the community. Similar themes are at the heart of NHT's plans for development on North Harris with the helpful involvement of Community Energy Scotland, and with Kenny still playing a key role as a trustee.

Chapter 3
The Visionaries

The pioneering developments of the British Aluminium Company schemes and the technical and aesthetic issues addressed by Edward MacColl and James Williamson had clearly illustrated the viability and strategic importance of hydro technology to Scotland's future energy needs. However, the continued development of the sector was not to prove so easy. Despite the success of the Clyde and Galloway schemes, there was increasing opposition from powerful landowners and a large coal lobby who supported the development of thermal stations which represented a significant market for coal. Consequently the industry needed a new champion to secure its future development against opposition.

PREVIOUS PAGE

INSET: David Wake, Energy Development Officer, North Harris Trust

MAIN: Calum MacLennan and Kenny MacKay, residents of North Harris who worked on the Chilostair hydroelectric scheme.

Chilostair dam and surrounding landscape, North Harris.

Six major hydro schemes were put before Parliament before 1940, all of which were defeated despite sound planning, economic and technical rationale. A well-organised and influential coal lobby was developed, and this effectively suppressed further advancement in hydropower. The situation reached an impasse, with no new schemes able to pass Parliament. At this point, prior to the Second World War, something had to change to allow for further hydro schemes to be developed, or else suspicious viewpoints from some elected officials would continue to disparage the potential loss of 'wooded shores, heather-clad hillsides, rocky gorges, tumbling waterfalls' to be replaced by 'huge white dams … wide stretches of rotting vegetation and slimy mud … . And here and there the blackened skeletons of trees … projecting above the ooze'![1]

The outbreak of World War in 1939 further limited consideration of the hydro question until Churchill re-formed his cabinet in February 1941, making Tom Johnston (1882–1965) Secretary of State for Scotland. Johnston was a keen proponent of hydropower, and saw its potential role in the reconstruction of post-war Scotland

3.1 Tom Johnston, Chairman of the North of Scotland Hydro Electric Board (1947-59) and Secretary of State for Scotland (1941-45).
Licensor www.scran.ac.uk

from early on. It would be his drive, ambition and political acumen which would see the transition of the industry from one in political gridlock and unable to realise the potential of the available resources to a nationalised industry with a development plan encompassing nearly 100 proposed schemes. [3.1]

Johnston quickly recognised the important role that the nationalised development of Scotland's resources for water power could play. Having established – as a subject of his appointment to the post – a council of state composed of former Secretaries of State for Scotland, one of the first things Johnston asked them to do was set up inquiries to look at Scotland's post-war problems. One of the earliest of these, under Lord Cooper, was established to look at the issue of Scotland's resources for water power. However, it seemed that the Cooper Committee did not share Johnston's utopian vision for the future development of hydropower. The Committee members felt there was little which they could add to the Snell report of 1921 and found that all of the potential schemes identified by Snell had already been developed by private interests.[2] Despite the initial concerns of the Committee, they mounted a thorough investigation of the sector, taking evidence from a wide variety of sources including those opposed to the development of Highland hydro resources, and in addition reviewed a number of third-party reports on the subject.

The Cooper Report was published on 15th December 1942 and it was soon easy to see that the Committee members had been converted to Johnston's vision for hydropower in Scotland. The opening statements were a damning indictment of the stagnation suffered by the industry since the completion of the Galloway schemes.

3.2 North of Scotland Hydro Electric Board coat of arms.
© Glasgow University Archives

It began 'all major issues of policy, both national and local have tended to become completely submerged in the conflict of contending sectional interests.'[3] The report clearly shared the frustrations of Johnston, Williamson, MacColl and others that the great potential for development had been so effectively thwarted by other interests, leading (in their view) to the economic decline of the Highlands. The Committee's report made much of the perceived signs of economic recovery in the Inverness and Easter Ross areas and noted that the provision of power to these developments, although essential to their success, was prohibitively expensive via conventional thermal stations. Thus came the official sanctioning of Johnston's sweeping vision that the power of Highland water would be turned to generation.

Such was Johnston's political influence, coupled with that of the prominent political figures who made up the Cooper Committee, that by 1943 their recommendations had become law with the passage through Parliament of the Hydro-Electric Development (Scotland) Act. [3.2] This act effectively nationalised the further development of Highland water resources, the task of which was to be managed by a newly founded body, the North of Scotland Hydro Electric Board (NoSHEB). It took all of Johnston's political skill and influence to ensure that the bill progressed through Parliament. Both the coal lobby and the coalition of landowning and sporting interests were still highly opposed to it. The battle was particularly savage in the press, with a letter to the New Statesman suggesting a member of the Cooper Committee should be taken to the shores of Loch Laggan 'where his nose could be held beneath the slime' until he reconsidered.[4] A surprising strand of opposition was also developed against a background of surging Scottish Nationalism, encouraged by the Scottish National Party (SNP) which had been founded in 1934. The nationalist interests objected to the sale of power generated in the Highlands to south of the border, despite the promise of profits as a result. However, Johnston continued to exercise his political will and by the time the bill came to the

3.3 M Joughin, Chairman of NoSHEB with school children from North Ronaldsay at the 1983 inauguration of the local hydro scheme. © North Ronaldsay Heritage Trust. Licensor www.scran.ac.uk

house he was confident that he had 'placed the bill outside partisan politics'.[5] In fact, such were the efforts of Johnston that the bill to found NoSHEB was supported by no less than eight cabinet ministers, including the Chancellor of the Exchequer. The newly founded board provided Johnston with the perfect vehicle to move forwards with his vision for hydro in Scotland, initially in a behind-the-scenes role supporting the first chairman, Lord Airlie, and latterly as the chairman himself from 1947 to 1959.

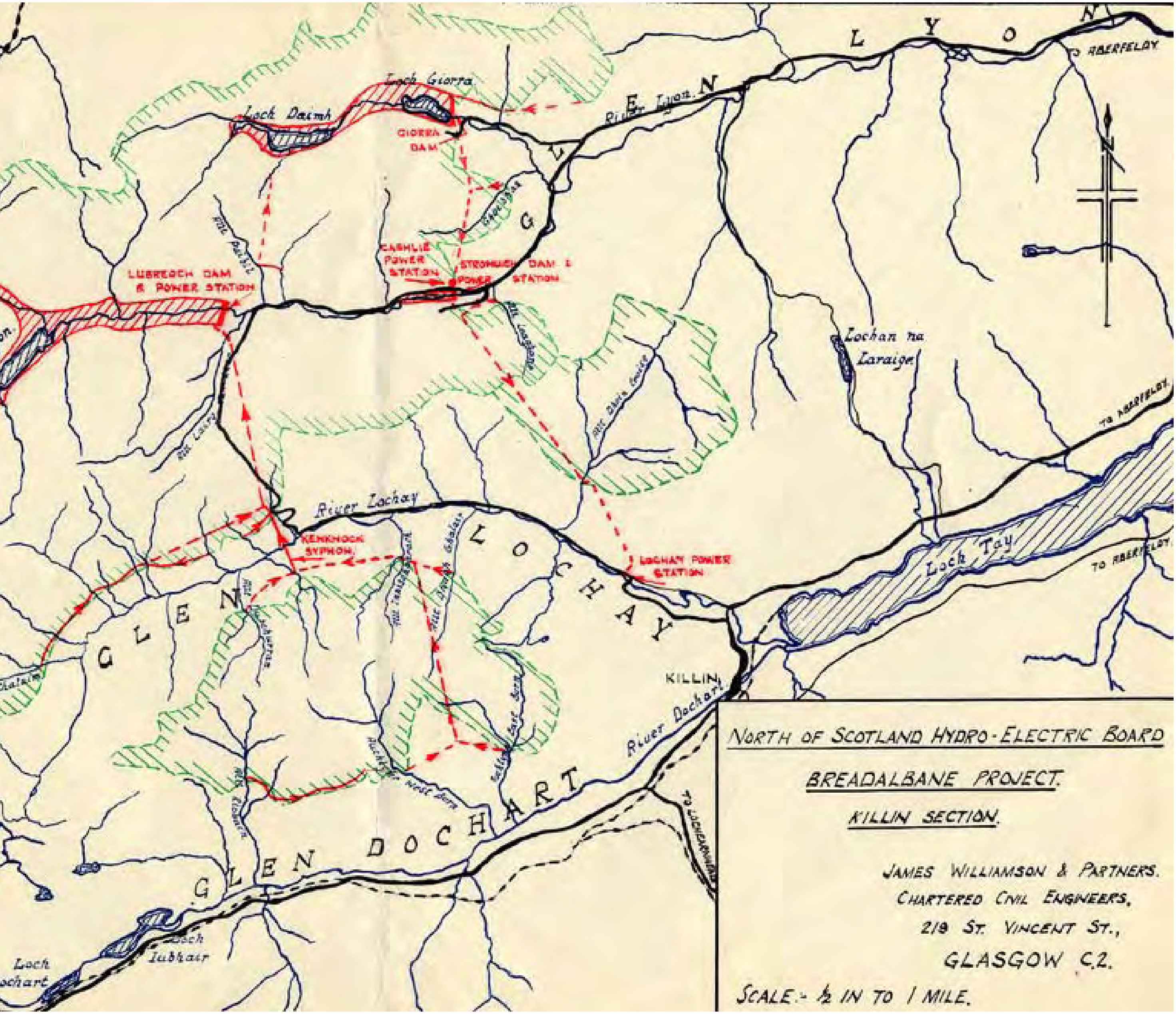
Social concerns dominated the agenda and rhetoric of NoSHEB and formed a major component of its founding principles, completely in line with Johnston's vision. The themes of economic regeneration and social invigoration were the main driving forces behind the creation of new hydropower schemes in the Highlands. The supply of cheap and reliable power, as had been proven by the British Aluminium Company, was to stimulate industrial development, with private connections to the grid provided for the homes of the workers who would be required for each new industrial venture. A key plank of this social policy was the assurance that provisions for workers and villagers would be made regardless of their economic viability, ensuring that even the remotest settlement would benefit from electricity. Crofters were even to be encouraged to dry hay and grain electrically, while the fishing industry could benefit from electrically powered refrigeration.[6] This social vision was to be financed through the export of power to the bulk markets of south and central Scotland. [3.3] The Hydro Act was at the core of Johnston's idealism and it was his strength of conviction that allowed a clause in the Act, which was branded as socialist by conservative politicians, to be carried into law. Subsection 3 of section 2 of the act stated that profits which were gained from the exportation of bulk supplies of power were to be used for 'the economic development and social improvement of the North of Scotland'.[7]

The focus by Johnston on social welfare was a result of his own deeply held conviction, but is also an important early example of the burgeoning movement for social and class equality which followed the end of the Second World War, and was later to manifest itself in the foundation of the National Health Service in 1948.

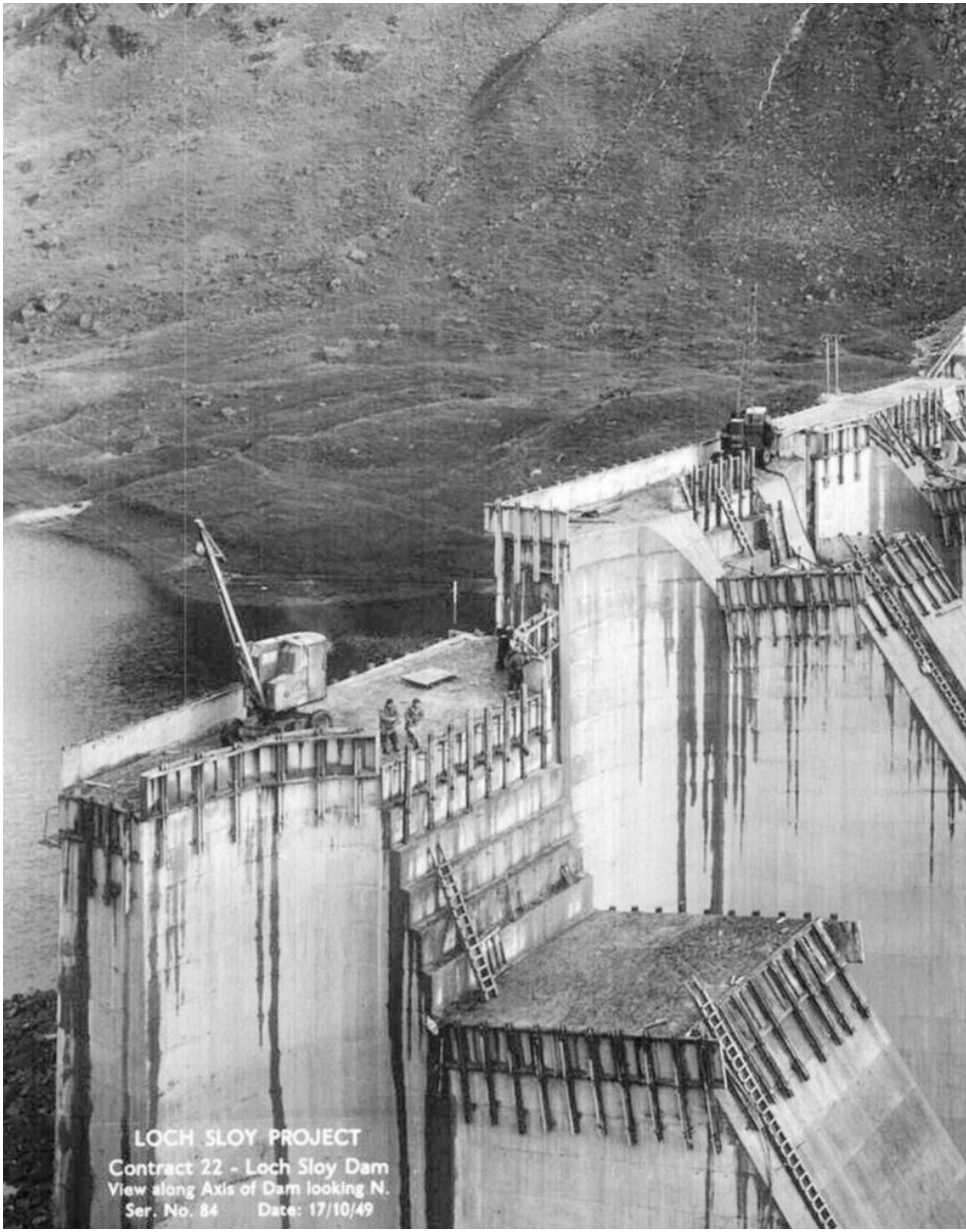
Johnston's concerns mirrored closely the contemporary issues in housing, and his plan to provide power to the Highlands went hand in hand with the recommendations of the Barlow Report of 1940 which advocated population dispersal and talked of the importance of relationships between landscape, population and employment. Johnston's vision, as set out in the Act, of new Highland communities centred on small industrial ventures, powered by cheap supplies of electricity and with jobs on hand was exactly the type of development that the Barlow Report had advocated.

Johnston was directly involved in commissioning Alan Reiach and Robert Hurd's publication of 1941 entitled *Building Scotland*. This polemical report recommended a modern Scottish vernacular injected with Scandinavian brightness and colour, and discussed wider social and political issues which went beyond the design of new housing, ultimately influencing Johnston's whole outlook, especially in his plans for hydro. Johnston took his cue from Norway, where hydropower was used as a tool for economic regeneration of predominantly rural areas throughout the country. From 1945 onwards the Norwegian state put in place a policy to reconstruct the internal economy and also to assist exports. Central to this policy was the provision of cheap power from hydroelectricity. This was coupled with mineral extraction to allow for massive growth in the chemical, refinery and aluminium industries.[8] The core role which hydropower played in the Norwegian post-war economic and social reconstruction was exactly the vision that Johnston shared for the Highlands. The economic stagnation which left those employed in the low-waged agrarian sector, and persuaded others to emigrate, could be transformed with a similar shift of labour and capital to a modern prosperous industrialised society along the Norwegian model, and hydropower was to be the spark. [3.4]

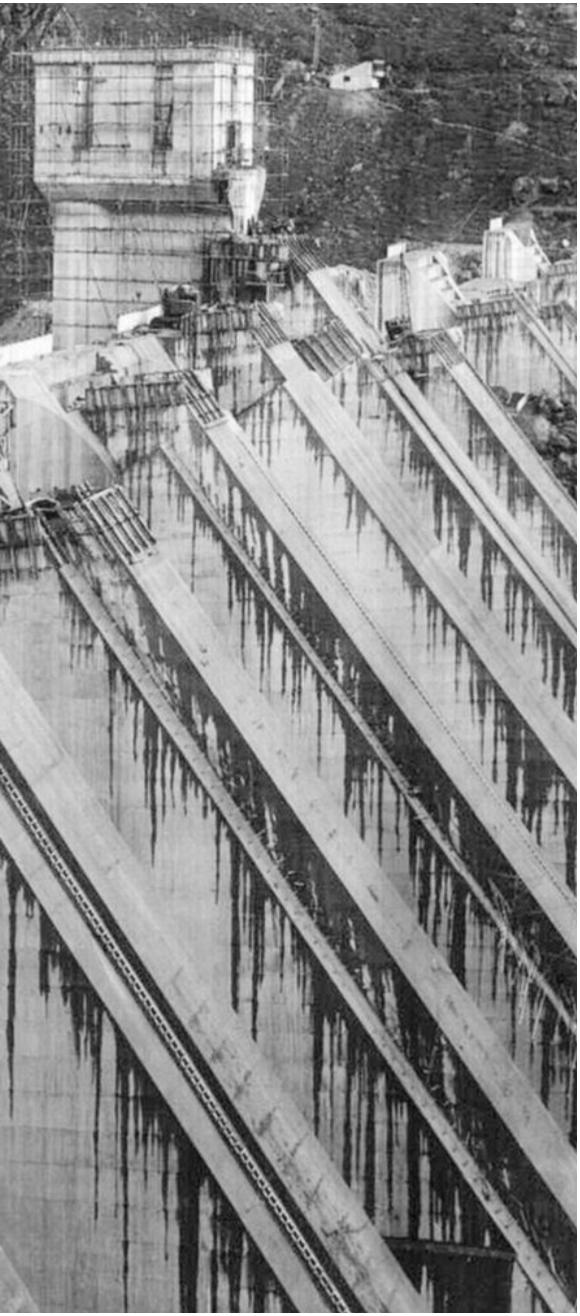
In order to move forward with plans for hydro and to deliver on promises, Johnston had not given any more thought to the need for design quality in hydro schemes as these considerations had led to much fruitless debate and stagnation before the Second World War. NoSHEB initially sidestepped the issue of



3.4 **Example of a section of the NoSHEB development plan showing a proposed scheme centred around Killin, c.1947.** © University of Dundee-Archive Services. Licensor www.scran.ac.uk scenic amenity by purchasing land as required from landowners according to a set scale of compensation. At the same time the Cooper Committee noted that 'it was sure the complaints which have been made and the fears which are entertained on the score of injury to amenity have been seriously exaggerated'.[9] This dismissive attitude to the question of scenic amenity, which had so concerned Williamson and MacColl, was a surprising stance on the part of NoSHEB and naively misjudged the serious impact that this issue was still to have. The Board justified their stance in two ways. The Committee cited the remoteness of the planned developments as a major contributory factor, noting that only 'a handful of deer-stalkers, salmon anglers, ghillies and gamekeepers and the adventurous spirits who have traversed these mountain districts on foot' would see anything.[10] What the Board failed to take into account was the influence that these deer stalkers, salmon anglers and adventurous spirits could bring to bear on their plans. The second point of justification by the Board was that the great benefits the developments would bring to the Highlands would effectively



3.5 Construction work at Sloy dam, 1943-50, Sloy hydroelectric scheme. © Scottish and Southern Energy



outweigh any of the negative impacts on scenic amenity. Just like Johnston, the Board felt that its social justification would conquer all and was sufficiently strong to give them the power to overcome previous difficulties.

Johnston certainly saw problems coming in the early years of the Board and attempted to use his political skill and clout to effectively limit the potential difficulties. His influence was at its height in the appointment of Lord Airlie as the first chairman of NoSHEB. Airlie was a major Scottish landowner, Governor of the British Linen Bank and Director of Barclays Bank. Despite his status as a major Scottish landowner he had professed support for Johnston's plan, criticising the bill in Parliament because it did not go far enough.[11] The choice of Lord Airlie was an attempt by Johnston to neutralise the possible backlash from landowners against the powers of the Board to move forward with developments which they had previously been able to effectively oppose. Edward MacColl was also appointed as chief technical director, both for his skills as an engineer and also his experience in the promotion of controversial developments following his work on the Falls of Clyde where scenic amenity issues had been very skilfully sidestepped, ironically through high-quality design and engineering. [3.5 and 3.6]

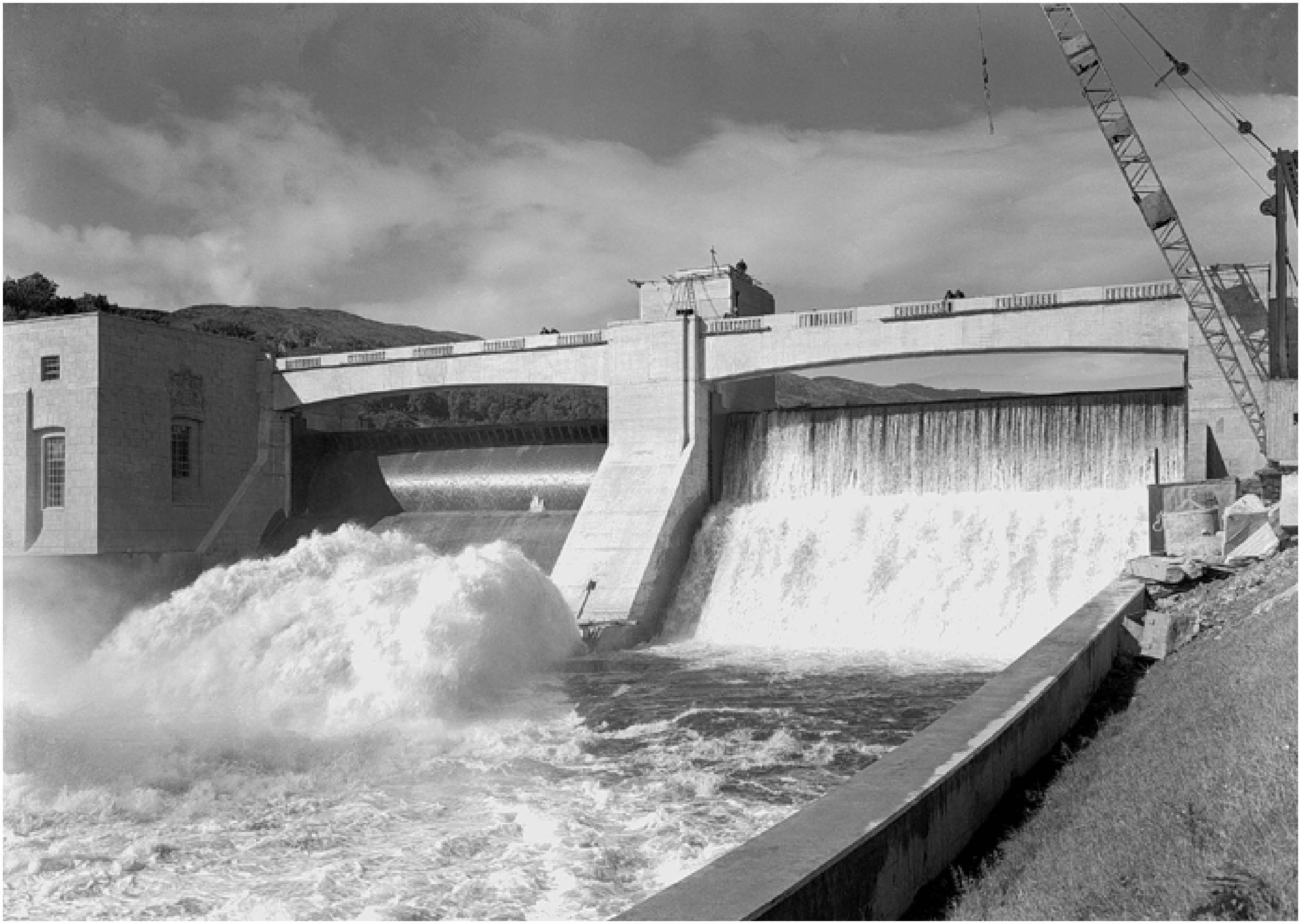
MacColl had been frustrated by the slow pace of development following his early work in the sector prior to the Second World War and shared Johnston's vision for the development of the Highlands. MacColl intended to drive ahead at full speed with the first duty of the Board to produce a development scheme, which in an illustration of MacColl's energy was produced within three months. Every possible site for development was listed and fully assessed, with MacColl ensuring that all possible schemes were considered, to prevent any problems later on. The plan consisted of a list and some basic maps with explanatory notes. It was a skeletal document, but it provided the basis for the future work of the Board and was the first true glimpse of the ambition of NoSHEB for development. The plan was approved by the electricity commissioners on 15th March 1944 and by the Secretary of State a week later.[12]

It seemed that Johnston had

3.6 Construction work on the tunnel at Sloy, 1943-50, Sloy hydroelectric scheme. © Scottish and Southern Energy

achieved his vision. NoSHEB had been created and had the power to enact a plan for development which would see hydropower rolled out across the Highlands as a precursor to major economic regeneration and social renewal. However, his vision was to stand a major test in the immediate aftermath of the euphoria following the completion of the development plan. Following various parliamentary considerations, proposals were advanced for a major overhaul of the national grid. Johnston argued against Lloyd George's ambition to see NoSHEB absorbed into a broader organisation incorporating the national grid, stressing the importance of its continued independence. He was 'quite satisfied that a central generating board of the kind suggested by your committee would not be able to command the confidence which the new Board has secured and that if it were to replace that Board on the generating side all the old controversies and difficulties would come to the surface once more.'[13]

The creation of the Board and the social vision which it had encapsulated were among Johnston's proudest achievements, and the prospect of its



3.7 Pitlochry power station, 1947-1951, Tummel Valley hydroelectric scheme. Crown Copyright: RCAHMS. Licensor www.scran.ac.uk

loss of independence before work had even begun would have been a devastating blow. Without the strength of his vision it may have been enough to fatally wound the board and end the fight for its independent status. However, Johnston was dogged and not prepared to give up so easily. He saw an opportunity to sidestep the political machinations by beginning to construct his great vision. Once the dams were underway the momentum of the great plan for the Highlands would become unstoppable, such was his conviction in the social and economic validity of his plan. Despite the threats, Johnston and those around him were still convinced of their all-encompassing initiative, neatly encapsulated by Lord Airlie in 1943: 'We had a great expectation of power all over the countryside … there are many things beside the production of electric power for industry. There is power for agriculture, forestry, fishery, tourist traffic, cheap transport and many other things. These are all bound up with the prosperity of our country.'[14] [3.7]

The Architects

'He used to light up a fresh pipe before taking a walk around the drawing office, peering over our shoulders whilst the sparks burnt little holes in our drawings,' recall architects Jim Armstrong and Marcus Johnston of their former boss James Shearer. The practice of Shearer & Annand was responsible for many iconic modern power station designs from the 1940s through to the 1960s.

Shearer's place on the amenity committee of the North of Scotland Hydro Electric Board ensured regular patronage by the Board. Both Jim Armstrong (left) and Marcus Johnston (right) later became partners in the Dunfermline-based firm, and both were instrumental in the design of seminal hydroelectric schemes throughout Scotland.

Early designs for Fasnakyle and Grudie Bridge, which both Jim and Marcus remember working on, were in the International Style. However, the designs quickly evolved, based on a reinterpretation of Scottish Pictish and Celtic sources that the two men recall were taken from 'great green bound volumes published by the Spalding Club'. Thus the large bas-relief Celtic panels came to characterise the power stations designed by the practice, including fine examples carved by Thomas Whalen for Fasnakyle, near Inverness.

The architects recall that designs came to the office from the engineers as little brick boxes, but Mr Shearer was convinced that for local communities to accept the hydro buildings they would have to build in stone to link them to their local area. Undoubtedly their efforts were successful, the architects proudly noting that when the International Congress of Large Dams visited Kilmorack power station they broke into spontaneous applause.

Chapter 4
The Architects

Statements to the effect that remote hydro schemes would only be seen by ghillies and hillwalkers indicated that the North of Scotland Hydro Electric Board held an attitude of indifference to the architectural design of the buildings, contrasting clearly with their concern for the technical and civil engineering of the schemes. However, the threat to the independence of the Board itself, represented by its potential absorption into a UK-wide body through the reorganisation of the national grid, proved useful in renewing interest in the design aspect. Focusing on the schemes' designs – technical, vernacular or even nationalistic – became an effective method of combating potential takeover, although the Board was keen to stress that this was not purely defensive but was intended to make a positive contribution to the Highland landscape. Their aims would be achieved through the use of visionary and thoughtful architects.

PREVIOUS PAGE
Marcus Johnston and Jim Armstrong, former partners with Shearer and Annand Architects.

Errochty power station, 1955, Tummel Valley hydroelectric scheme.

Beastie design for Grudie Bridge power station c.1950, Conon Valley hydroelectric scheme. Crown Copyright: RCAHMS. Licensor www.scran.ac.uk

The threat of a loss of corporate autonomy was thwarted by Johnston's plan to begin building the first of the schemes outlined in the development plan. This audacious plan tapped into a national feeling of hope and euphoria which characterised the immediate post-war years. It was with an excitement and faith in technology that post-war reconstruction commenced, and the first project of the board at Sloy was in the forefront of this wave of national pride, although perhaps with a Scottish rather than UK focus. An independent North of Scotland Hydro Electric Board (NoSHEB) was key to growing Scottish nationalism, with the Board a vital tool in developing a uniquely Scottish asset in hydropower. The public perception surrounding the start of work at Sloy, where the first sod was cut by dignitaries in a large bulldozer, contrasted strongly with the relatively perilous political position of the Board. Catapulted into this heady mix were the architects,

4.1 Sloy power station under construction, 1943, Sloy hydroelectric scheme © Scottish and Southern Energy

who had the vital role of turning large boxes containing turbines and pipes into buildings which could make a positive contribution to the landscape both physically and psychologically. [4.1] The story of the architects is moulded by these pervading issues, which in turn resulted in a range of high-quality and innovative designs, drawing on a shifting palette of design influences, but each time making a definite statement about the vision of the Board.

NoSHEB established a number of advisory panels at its inception, with the focus on the technical groups formed from the ranks of prominent engineers (including MacColl and Williamson). In addition to this, two other groups, one concerned with fisheries and the other with design, were established. Both of these panels shared the same rationale and were an attempt to engage any opposition by bringing them inside the Board. Whilst this was wholly the case with the fisheries advisory panel, there was a feeling that the architectural panel would also serve a valuable role in ensuring that the buildings made a

4.2 Deanie power station, 1963, tunnel access portal, Affric hydroelectric scheme.

positive contribution to the Highland landscape. This formed part of the Board's offensive strategy in attempting to retain its independence. The role of the Amenity Committee and the Fisheries Committee provided a higher level of protection for the natural landscape than had yet been seen in Europe and proved to the Board's opponents that their role in managing the Scottish landscape was a serious concern.

The panel of architectural advisers consisted of Reginald Fairlie (1883–1952), James Shearer (1881–1962) and Harold Ogle Tarbolton (1869–1947), all appointed in 1943. Initially their role was to adjudicate on competition entries for designs, but by 1947 they themselves had become the designers, with the competition model abandoned as time consuming and costly. There was a clear hierarchy of the various advisory panels, with the technical panel pre-eminent to the design panel. Although the Amenity and Fisheries committees could not make judgements on technical issues, they proved to be a powerful group and in a number of cases vetoed the use of above-ground power stations, forcing the technical panel to come up with innovative underground stations on various schemes. This was particularly the case on the Affric-Cannich scheme where there are a number of underground stations such as Deanie. This left the design panel with limited control over the functional form of the buildings, which was to be expected, but they did influence the appearance and the style of the designs. [4.2]

The first development by the Board was to be at Sloy on the banks of Loch Lomond. Perhaps not surprisingly given the location, there was vociferous opposition from both Local Authorities and private individuals, the

4.3 Sloy power station, 1943-50, Sloy hydroelectric scheme.

result of which was a public enquiry between Christmas 1943 and New Year 1944. The inquiry was chaired by John Cameron KC,[1] who after six days of deliberation approved the plan, but reminded the Board that it would have to be more prepared to argue its case in future. The inquiry dismissed concerns about the impact of the power station, but underlined the importance of the architectural design. [4.3] Cameron did not feel the existence of a powerhouse would be a problem:

> *[I] see no reason why a powerhouse per se should be a disfigurement of the landscape. It is not as though Loch Lomond and its banks were untouched by the hand of man: indeed in this very area the blank and undistinguished visage of the Inversnaid Hotel is a constant reminder of the needs of man and the means he has adopted to satisfy them.*[2]

The role of the architect was consequently to come more to the fore in shaping the appearance of stations, to fully satisfy the more stringent tests of the Board's plans which, Cameron warned, would come in the ensuing months and years.

Set against this uncertain backdrop it would have been easy for the Board to take refuge in designs based on predictable and uncontroversial vernacular themes. This was not to be the case. Johnston and the design panel saw the opportunity to make an authoritative mark. A completely new design vocabulary would not only emphasise the responsible approach of the Board as custodians of Highland scenery, but would also express its confidence as an independent organisation. The opportunity was ripe to develop a new architectural idiom for industrial buildings – not only to provide good architecture, but to create an impressive face for the Board in local landscapes and reinforce its position as a dynamic and modernising force in the Highlands. However, the concern with landscape also required, as had been hinted at by John Cameron, that solutions were inspired by their setting, and whilst high-quality modern design was important, it was vital that this also interpreted the history and culture of the landscape which surrounded it.

The Board turned first to Harold Ogle Tarbolton to undertake the task of reconciling the desire for a modern architectural design with the necessity to integrate buildings with their landscape. Tarbolton became involved in the design of hydroelectric infrastructure for NoSHEB late in his career, but he

4.4 Glenlee, power station, 1934, Galloway hydroelectric scheme.

4.5 Pitlochry power station under construction, 1950, Tummel Valley hydroelectric scheme. Crown Copyright: RCAHMS. Licensor www.scran.ac.uk had been a member of the Amenity Committee which considered the work carried out under the Galloway Water Power Act of 1929, acting as advisory architect for the Galloway schemes, and designing the associated housing schemes. He was the ideal candidate for NoSHEB to select, to produce a design which would emphasise the confidence of the Board (even if only demonstrated outwardly) and which would make a positive contribution to the setting of the proposed power station. Tarbolton's work on the Galloway schemes had been characterised by a confident fusion of Modernist and plain classical forms, which had fulfilled the aims. [4.4]

Tarbolton's design for Sloy power station, which is set prominently on rising ground and at an angle to the main A82 trunk road which passes directly in front of it, draws on similar themes to his work in Galloway. The design makes bold use of modern materials, particularly pre-cast concrete fascia panels with stone aggregate finishes. The general massing of the station also expressed the dynamism of the industry, with large primary volumes and stark rooflines set against the backdrop of crags and trees.

Tarbolton's design for Sloy was forthright and confident and was a conscious effort not only to assure the strength of the Board, but to shape the wider agenda. If the Board could crystallise their plan to bring prosperity to the Highlands and make a positive architectural contribution, they could prove critics wrong and emphasise to all the importance and success of their vision. The built expression of the industry in Modernist language also allowed the buildings to tap into a pervading enthusiasm for modern design as a facet of economic and social renewal. By adopting a number of the elements of the new language of design, namely Modernist design forms and the bold use of concrete as a decorative and constructional material, Tarbolton was clearly placing hydropower at the forefront of the post-war vision for reconstruction. Tarbolton sought to move the industry above the political machinations and wrangling over scenic amenity, to a modern monument of wonder to which the public would pay pilgrimage. The success, or otherwise, was potentially significant to the future of the Board.

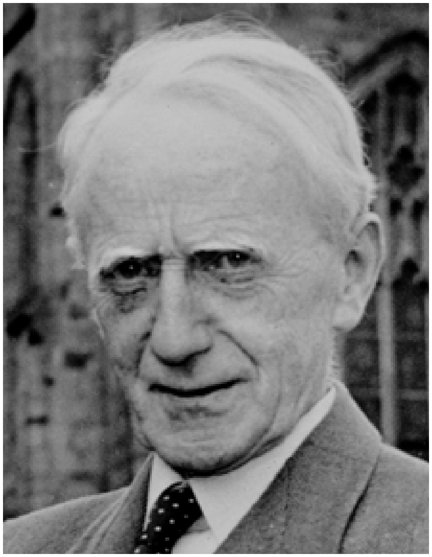
NoSHEB was to suffer further difficulties in the promotion of the next two schemes, one of which at Duntelchaig (near Loch Ness) had to be abandoned because of the level of opposition, with similar serious resistance to the Tummel scheme (which will be explored in more detail in the next chapter). This culminated in chairman Lord Airlie's resignation in 1946 and his replacement with Tom Johnston. The pressure on the Board at this point was extreme, and Johnston saw his role undoubtedly as that of a lightening conductor: his political skill and acumen were to be used to take the pressure away from the engineers and architects and allow work to continue. Just as had been his plan when the Board faced the threat of amalgamation with the national grid, Johnston felt that to keep building would be the best way to secure the Board's future.

There was very serious opposition to the Tummel scheme because of concerns regarding the impact the development would have on the landscape, with large stations at Clunie and Pitlochry (that at Pitlochry integrated with a dam), and their ability to integrate with the local community

4.6 Pitlochry power station, 1947-1951, Tummel Valley hydroelectric scheme.

became of paramount importance. [4.5] Tarbolton was again the lead architect and in the design for Pitlochry produced arguably the best example of the bold Modernist phase of designs for NoSHEB. His design echoed that of Sloy (and his work at Clunie), with simple plain Modernist massing and abstracted classical detail such as the use of giant-order pilasters to articulate the bays of the turbine hall, with large multi-pane windows set between. This organisation of the main elevation was a signature device and one he had used in Galloway and at Sloy; the design itself became an exemplary model of the fusion of necessary engineering requirements of a large commercial power station and a striking architectural response to the brief. The stark roofline and rhythmic articulation of the façade characterise the modern, dynamic attitude with which hydroelectricity was viewed in this period, all while representing the vision of NoSHEB, especially set against a backdrop of severe criticism. [4.6]

But even at Pitlochry and Clunie there had been hints of an evolving theoretical approach to how building design might communicate the ideals of NoSHEB. Under the chairmanship of Tom Johnston the troubles of the Board began to ease because of his canny ability to defer controversy. With less outward pressure on the Board there was a perceptible change of emphasis in the design of the schemes, and consequently a change in the location of major developments. The use of local sandstone aggregate for the fascia panels at Pitlochry indicated a desire to integrate the buildings in a more direct way with the landscape in which they were set, and this 'vernacular' theme would become increasingly dominant



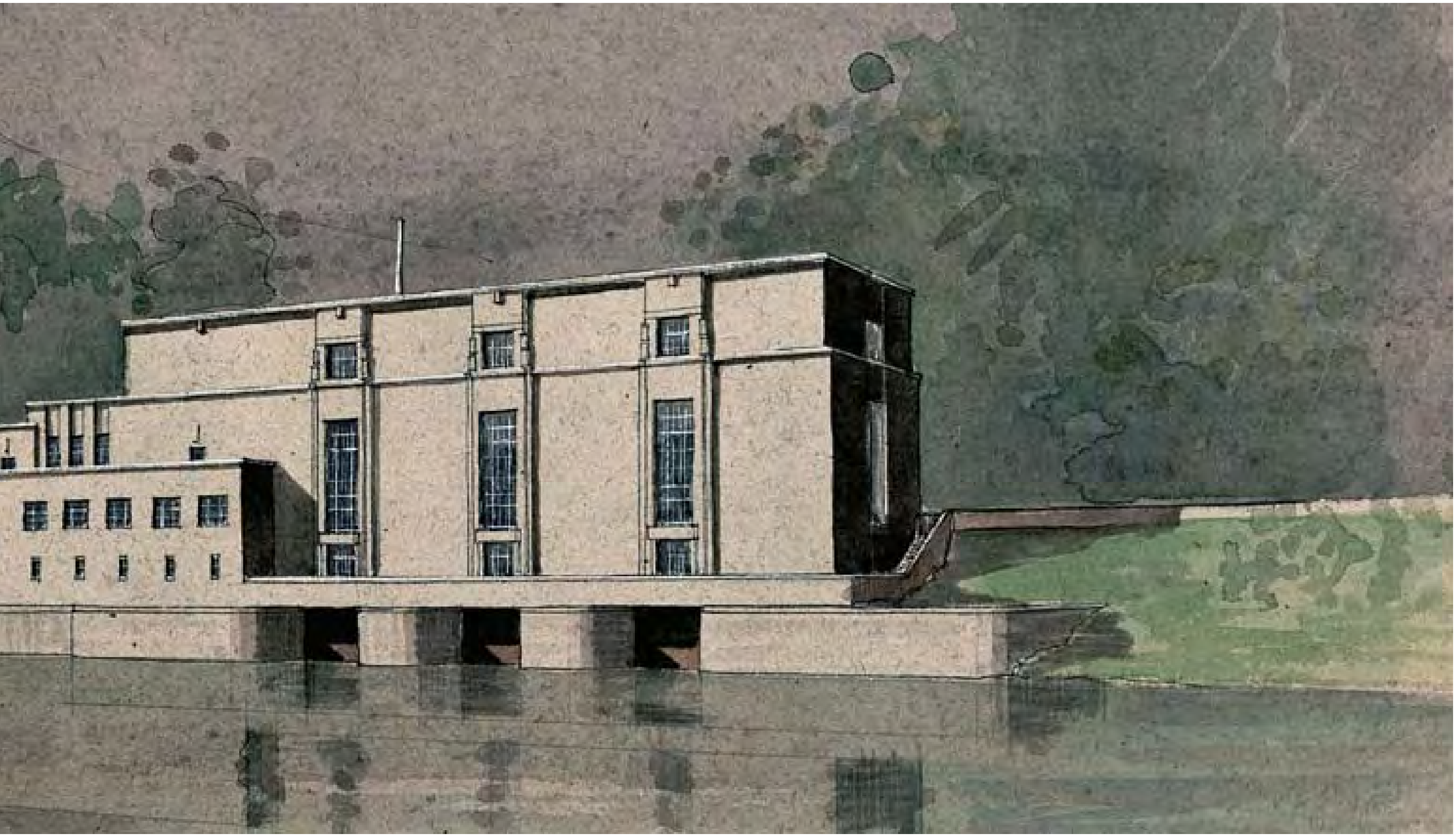
4.7 James Shearer (1881-1962). Crown Copyright: RCAHMS (Shearer and Annand Collection).

in future developments. Tarbolton and Fairlie both died (in 1947 and 1952 respectively) relatively early on in the work of the Board, leaving James Shearer to exert more control over the designs. In conjunction with this the Board entered a more settled period with fewer major threats to the development plan. As a result there was less of a desire to evoke the dynamism of the new industry through bold architectural statements. This positional shift coincided with a growing public perception of rural issues and an emerging democratisation of Scotland's natural heritage. The architectural idiom under Shearer was to reflect these growing trends. [4.7]

Shearer was the youngest member of the architectural panel and did not have the background in the sector of Tarbolton, nor had he inherited associations for the design ethos of hydro stations as bold Modernist boxes which previously characterised Tarbolton's work. Although the massive primary volumes were retained, as prescribed by the engineers, Shearer brought a new set of design ideals. He had a long-standing regard for landscape and was interested in marrying his designs to their location. Shearer was also interested in helping to facilitate access to the countryside, as seen in his work designing youth hostels in rural areas throughout Scotland. His design for a youth hostel at David Marshall Lodge, Aberfoyle (1958–60, now the Queen Elizabeth Forest Park Visitor Centre) illustrates the degree to which Shearer felt buildings could be integrated into a rural setting and picks up many of the themes which he applied to power station architecture. David Marshall Lodge is built from drystone rubble slate with large wings, pinned by a central tower, incorporating viewing galleries looking out across the landscape and

making a direct connection between the building and its setting.

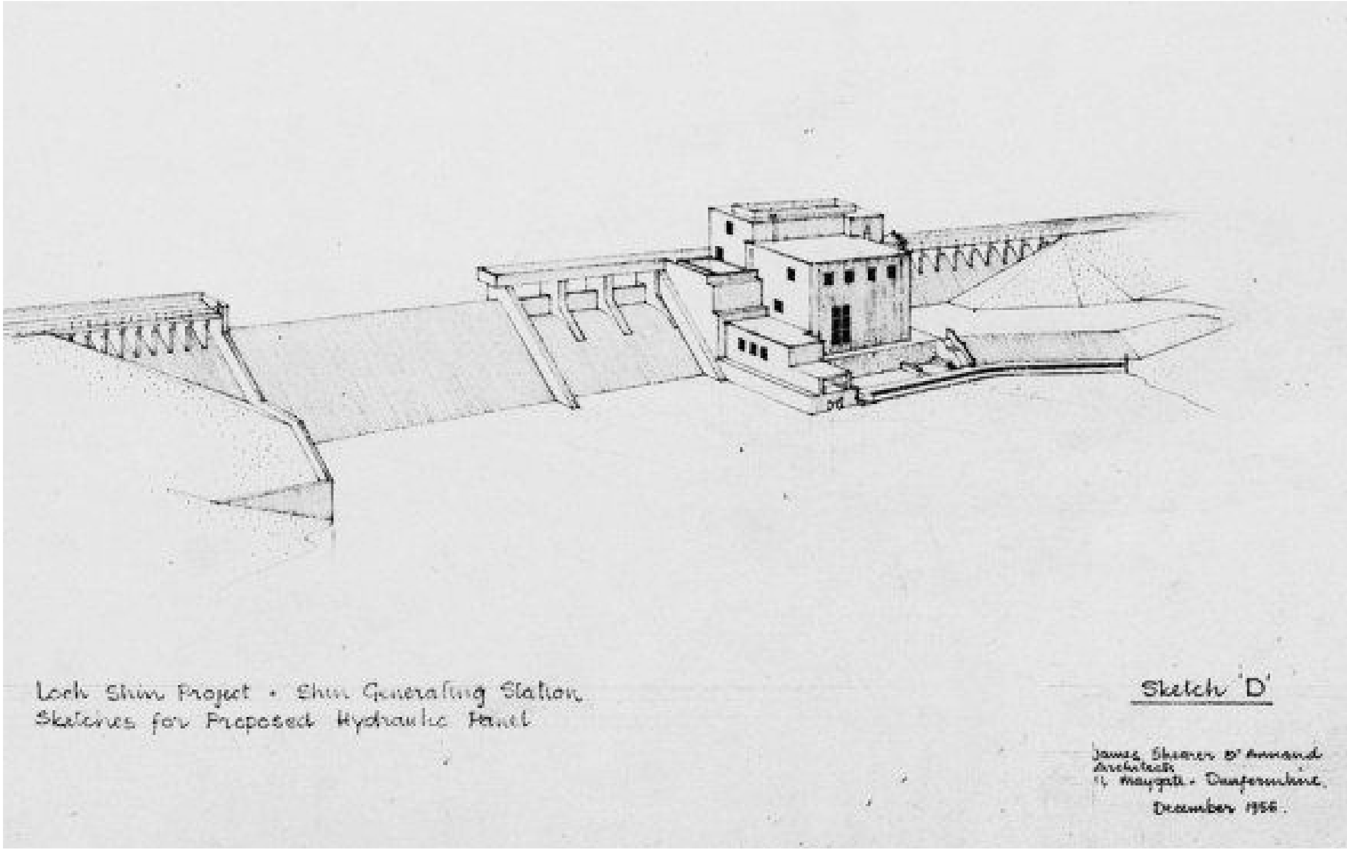
These are themes which Shearer had begun to develop almost a decade earlier in one of his most archetypal power station designs at Fasnakyle (1950), in addition to his work for the Scottish Youth Hostel Association from 1940. The design of this Highland power station is a fusion of the Modernist functional model, with the single large volume containing the turbine hall, and the vernacular and locally informed principals



4.8 **Fasnakyle power station, 1952, Affric hydroelectric scheme.** Crown Copyright: RCAHMS (Shearer and Annand Collection).

of design. In tune with Shearer's view of the landscape as a place of natural forms, the design roots the building deeply in its setting and melds the rhetorical form into the landscape when viewed from a distance. One of Shearer's primary design methods in achieving this aim, as seen on his design for David Marshall Lodge, is his use of compatible stone from Burghead in Moray to match the local bedrock. Shearer felt that using the correct stone at Fasnakyle would ensure the building matched the other colours in the landscape, allowing it to merge seamlessly into the backdrop when viewed from afar. Shearer's design also tied the building to its setting theoretically and historically through the application of sculptural bas-relief panels, carved by sculptor Hew Lorimer (1907–1993), depicting Celtic beasts and mythical figures. The combination of these two elements allowed the building to make both a physical and a spiritual connection with its landscape. [4.8]

As well as corresponding both



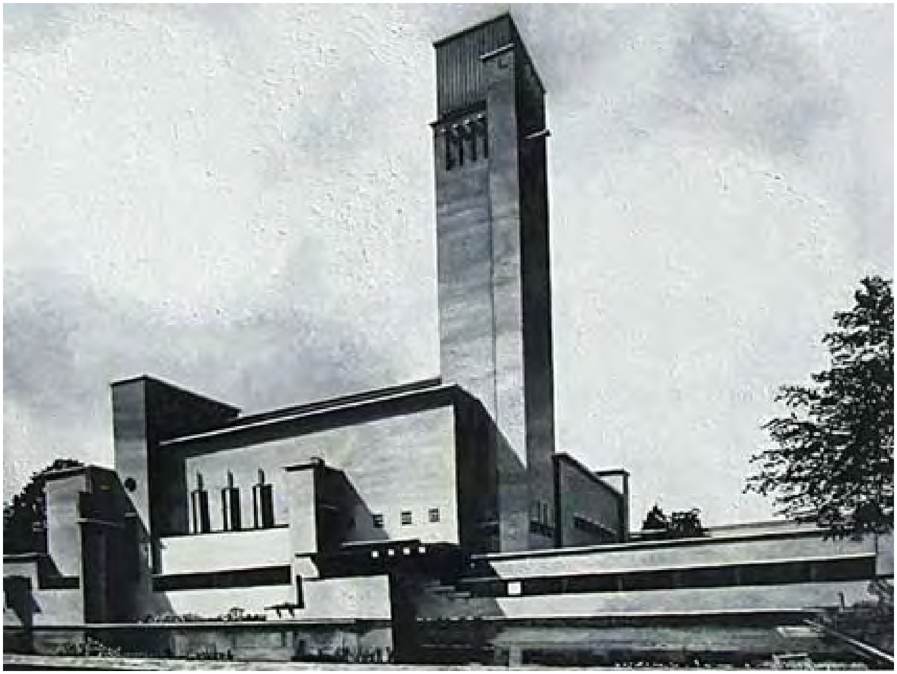
4.9 Lairg power station, 1960, Shin hydroelectric scheme. Crown Copyright: RCAHMS (Shearer and Annand Colelction).

with Shearer's own, and with wider public, attitudes to rural areas, the majority of the schemes for which Shearer designed were located in the North and West Highlands, in contrast to the relatively southerly locations of the schemes with which Tarbolton was engaged. A remarkable and apposite approach to the geographic location and function of each brief can be discerned. Whilst Tarbolton's designs had been for stations where power was to be exported to the grid for profit, and so a certain dislocation of meaning from the immediate local environment was mirrored in a functionalist architectural style, Shearer's stations were designed to provide local supply and consequently were ingrained in the vernacular and embedded within local communities. To emphasise the direct link in a number of the most remote schemes, Shearer also borrowed historical architectural motifs in addition to the use of local stone and whimsical carved panels. This is particularly evident in his design for

Lairg Power Station, where a Baronial stair tower was later incorporated into the design in which scenic amenity was of paramount importance as the dam and station directly overlook the village. This contrasts with Tarbolton's approach at Pitlochry where the architectural style remained uncompromisingly Modernist, in contrast to the local vernacular, but the station was integrated physically into the community by the inclusion of a public walkway above the dam. [4.9]

Although the success of Shearer's designs stemmed from the technical committee's brief, which had specific requirements, the same brief was interpreted differently by the architects involved in the design panel. Ian G Lindsay (1906–1966) interpreted it at Lussa Power Station and incorporated these spaces into a pitched roof structure with a more conventional vernacular form. [4.10] Shearer made the choice to retain the bold outlines and striking forms as a deliberate intention. This approach is likely to have been

4.10 Lussa power station, 1956, Lussa hydroelectric scheme.



4.11 Hilversum town hall, Willelm Marinus Dudock, 1924 (built 1928-31 Painted by Ben van Rooyen - oil on canvas). © Ben van Rooyen/ fineartamerica.com

influenced by Dutch architect Willem Marinus Dudok (1884–1974), whom Shearer visited on behalf of the Royal Scottish Academy in 1952. Dudok's most famous work, Hilversum Town Hall (1928–31), encapsulated a number of the design ideals Shearer incorporated in his approach to the NoSHEB power stations. [4.11] The dramatic massing of large single volumes harmonised with local rural and urban landscapes through the use of vernacular brickwork cladding was a defining characteristic of Dudok's work, and was clearly adapted by Shearer for his work on power stations. Dudok's intention for his design of Hilversum Town Hall chimes exactly with Shearer's ideals for his NoSHEB works, fusing the vernacular and the Modernist. As Kenneth Frampton and Yukio Futagawa later observed, 'Despite the asymmetric, neoplastically derived composition, the main representative elements were both traditional and monumental.'[3] Dudok's justification of the monumental form as 'the most pure expression of the human sense of harmony and order'[4] changed Shearer's view of the large single-volume forms which were dictated to him by the technical panel. Unlike Lindsay, he did not overlay the form with a vernacular pitched-roofed shell, but viewed the primary forms as themselves in harmony with nature and entirely appropriately clad in local stone. The form and the cladding were integrated, in Shearer's view, as a harmonious spiritual response to the purity of the surrounding landscape, which focused on the essential as an act of integration with nature.

The evolving architectural design of the power stations over the 1950s and 1960s reflected both changing attitudes to the development of hydropower in Scotland's rural areas and the increasing confidence of NoSHEB. Early on in the roll-out of the development plan, and against a background of political uncertainty and repeated attack from high-profile opponents, the Board reacted by producing bold and confident designs which encapsulated a wider social vision and tapped into a prevailing view of the 'white heat of technology'. It is easy to misinterpret the change in direction under Shearer as a move away from iconic and pure designs, in which the Board sold out to its critics and opted for a compliant policy on design. However, this misses a deeper subtlety in the work of Shearer, who after all was responsible for the vast majority of designs for the Board. Shearer responded to what he perhaps saw as an outmoded approach for architecture in rural areas, where the use of Classical Modernism was no longer justifiable. He sought to go beyond the architecture itself to ensure that the building became a part of its environment by a synthesis of natural forms (as bold primary massing was identified by Dudok) and used appropriate stone. The view that Shearer's designs were much more than simply attempts to hide power stations was shared as early as 1944 by the NoSHEB Amenity Committee, who noted when considering a scheme in Gairloch: 'the power station should be so designed as to harmonise generally with the West Highland scenery on the understanding that good design was of the greatest importance, attempts to hide power stations were to be deprecated.'[5]

The Campaigners

Alastair Riddell was brought up in Glenlyon, his family's home for the last 150 years. Alastair remembers as a boy the two small Gilkes turbines in the powerhouse that ran electricity down to the estate buildings and, before the national grid was set up, to the nearby village of Fortingall, in the heart of Perthshire.

Alastair recalls the awesome switchgear and dials in the powerhouse which he used to love to monitor as a pastime. His heart was in it at an early age and he was always eager to help the estate forester – whose job it was to look after the small hydro scheme – even when it meant being dragged out of bed to clear the intake screens up the hill in the middle of a blizzard!

Alastair spent many years away from Perthshire in his career in the armed forces and in the mining industry, which took him all over the world, but has since returned to Glenlyon with a firm commitment to being a responsible steward of the land. Since his return 11 years ago, he has worked to integrate a network of small schemes locally which share the infrastructure costs of grid connection. He is now managing director of Green Highland, and is at the forefront of organising a network of micro hydroelectric schemes in the sincere hope that – with communities, landowners and regulators all working together – an economically viable, environmentally sound, renewable resource can assist towards providing a sustainable and long-term benefit to all those living and working in rural Scotland.

The story of micro hydro has come full circle for Alastair, whose private firm still operates the small scheme at Glenlyon but with new underground piping and a state-of-the-art Pelton turbine able to provide one megawatt of power to the grid, which can provide sufficient energy for thousands of local homes.

Chapter 5
The Campaigners

The designers of the North of Scotland Hydro Electric Board schemes were determined, with the Board's blessing, that the schemes' major components would not be hidden in the landscape, but would make a positive contribution towards it. Consequently the visibility of the developments was always likely to be highly controversial. In addition, the creation of new reservoirs involved the drowning of a vast area of estate land. The Board brokered a defined scale of compensation to gain control over land holdings; but this did not avoid significant battles with landowners, especially over the scheme at Tummel in Perthshire. The task of convincing landowners and local communities of the merits of hydropower continued long after the construction traffic left and the turbines began ticking over, but the positive impact of the industry in the long term has gradually led to a revolution in which many of the very same estates which opposed the coming of hydropower sixty years ago have developed in their own right a new wave of micro hydro plants.

PREVIOUS PAGE
Alastair Riddell, managing director of Green Highland Ltd.

The hydro power scheme at Glenlyon.

The Public Local Inquiry which had considered the Board's plans for development at Sloy had warned that future opposition may be stronger and examinations under Local Inquiry much more exhaustive. This was to prove the case on the very next scheme which the Board developed, almost contemporary to Sloy, from 1945 onwards at Tummel in the southern Highlands. [see 4.1 and 4.3] The scheme was built on a pre-existing development of two power stations at Tummel Bridge and Loch Rannoch, both of which dated from before the existence of the North of Scotland Hydro Electric Board (NoSHEB). [5.1 and 5.2] At a capacity of 150,000 kilowatts,[1] the scheme formed a vital component of the Board's wider plans to provide power for export to the Central Electricity Board and to the city of Aberdeen. The revenue which this would bring in to the Board was vital in financing the schemes in the northern Highlands and in fulfilling social aspirations to bring power to the region. The development of the scheme involved a dam in the upper tributaries of the River Garry and on Loch Errochty via a dam at Glen Errochty. This water was then used by a power station (Errochty) at the head of Loch Tummel. A further dam was then placed across the River Tummel to impound the river as well as some small tributaries and Loch Tummel itself, raising the level of the loch by five metres and restricting the flow of water over the falls of Tummel. Downstream of this the River Tummel was dammed at Pitlochry with a power station incorporated into the dam. The reservoir this dam created had a vital role to play as a balancing reservoir to even out the fluctuations in flow downstream of Clunie Power Station.

In contrast to Sloy, the proposed developments at Tummel were not in a remote location, but in the heart of the historic Perthshire countryside, with the station at Pitlochry on the fringes of one of the most popular tourist towns in the southern Highlands. The Board was

5.1 Tummel Bridge power station, 1931-3, Tummel and Rannoch hydroelectric scheme.

5.2 Rannoch valve house, 1931-3, Tummel and Rannoch hydroelectric scheme.

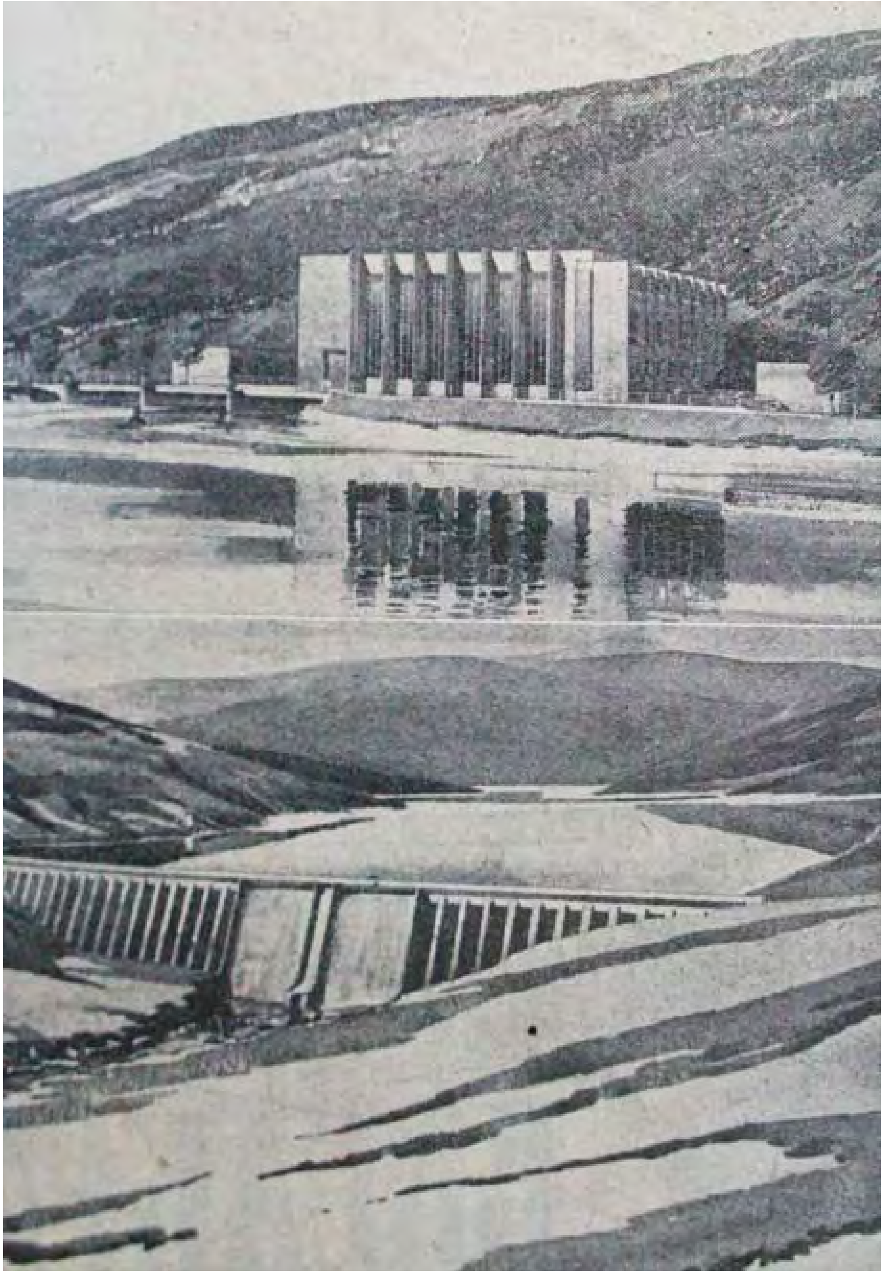
5.3 Postcard from Loch Rannoch Hotel, Kinloch Rannoch, 1905. © Scottish Life Archive. Licensor www.scran.ac.uk

aware from early on that the scheme was likely to generate concerted opposition given its prominent location and, in the aftermath of the debate over Sloy, discussed whether they should still proceed. However, such was the importance of the revenue which the finished scheme would generate that it was decided to push ahead.[2] There was a feeling amongst some members of the Board, notably MacColl, that success in a high-profile battle over the Tummel scheme would also provide a solid platform for the Board and reduce any negative reaction to future schemes. [5.3]

The opposition to the Tummel scheme was led by the Lord Provost of Perth, G T McGlashan, with the Perth and Kinross County Council expressing its unanimous opposition in March 1945. The Council formed a powerful coalition with a number of high-profile local landowners who were all determined to oppose the scheme. The group were highly critical of the Board, and slammed what they felt was a lack of transparency, with Lord Mansfield referring to the 'miserable policy of secrecy'.[3] The Board also faced internal opposition from the Amenity and Fisheries Committees within NoSHEB. The Amenity Committee recommended the omission of the Pitlochry dam because of the perceived impact on the village, whilst the Fisheries Committee noted that the Board should not divert the headwaters of the River Garry as it would damage salmon fishing interests. The strength of these two committees offered an unprecedented level of protection for the scenic and natural environment, with the power to veto developments, and the Amenity Committee recommended power stations to be moved underground in a number of cases.

Following the publication of the scheme, more than 25 formal objections were lodged. Tom Johnston went on to note 'many newspapers … opened their columns to strings of vituperation from the letters-to-the-editors brigade; fantastic and ridiculous imaginations from beauty lovers, some of whom saw in their visions the Highlands being converted into an amalgam of the Black County, a rubbish heap and a desolation; commercial salmon interest, anglers and hoteliers, whose business they foretold would be ruined, all cried aloud in protest.'[4] [5.4]

The inevitable conclusion to such vociferous opposition was the appointment by Johnston of a tribunal



5.4 Watercolour drawing of proposed designs for Clunie and Pitlochry power stations on the Tummel Valley scheme. © Perthshire Advertiser

5.5 Landscape of the Tummel valley prior to development, 1949. © National Museums Scotland

to hear the two sides. John Cameron KC was again in the chair (as he had been for Sloy), with assistance from Sir Robert Bryce Walker and Major G H M Brown Lindsay for the inquiry which began on 25th May 1945 and lasted ten days.[5] The familiar issues of harm to scenic amenity and fishing interests were to be at the core of the debate. The Dean of Faculty sought to deflect some of the criticism in his opening address by underlining the importance of the scheme to the whole of the NoSHEB plan and emphasising the duty of the Board to promote schemes which were firmly in the public interest.

Despite a strident opening statement in defence of the scheme,

members of the Board who appeared as witnesses were subjected to hostile cross-questioning. The chairman of the Board, Lord Airlie was especially unsettled by his cross-examination, which followed months of harsh criticism. Airlie was particularly exposed by the controversy over the Tummel development, because he was himself a major landowner and many of his landed contemporaries viewed him as a traitor. The key line of cross-examination was that the Board could just as successfully develop the Great Glen scheme (a later phase of the development plan) if it left the glens of Perthshire untouched. Furthermore, Airlie was portrayed as following the whims of the Central Electricity Board who wished him to provide power to England at the expense of Pitlochry.[6] Such was Airlie's discomfort that he was persuaded to disclose the statement where he noted that 'personally I do not like these things being done any more than you do; I am a lover of the countryside, but I believe this to the advantage of the public as a whole and therefore I am bound to support it.'[7] By the following day Airlie was more composed when countering questioning, being able to sustain the Board's argument and describing how the scheme would allow for benefits to be rolled out for people across the Highlands and Islands: 'If you offer them some of the amenities that their brothers and sisters have in the towns you will find that their country instincts will lead them to the desire to stay where they are, but if you do not give them water, transport, housing and power, I do not think they will.'[8]

Airlie was followed into the stand by technical engineers who stressed that the construction of the Tummel scheme would alleviate an imminent shortage of power in Scotland's central belt. The secretary of the Board, Tom Lawrie, was called in the absence of MacColl and he addressed head-on the criticism that the development would harm tourism in the area. He cited parallels with the Tennessee Valley Authority in the United States, which drew in some two million tourists a year,[9] and he saw no reason why this would not also be the case with the Pitlochry development.

Lawrie was followed by one of the chief engineers to the scheme, J Guthrie Brown, who illustrated the economics with a mass of statistics. He was followed in turn by a number of painters, biologists and piscatorialists who all professed that the scheme would have little impact, and that the Board had designed suitable mitigation measures for the landscape interests. The Board's argument therefore hinged on the strategic importance of the scheme to contribute to their wider social vision and on their assurance that the plan would not have a negative impact upon the scenic or natural amenity of the area.

On the inquiry's sixth day, the views of the opponents to the scheme were considered. The objectors were once again marshalled by McGlashan as they had been prior to the inquiry. Rather than focusing on scenic amenity or the damage to the tourist industry, McGlashan's argument directly addressed the strategic importance which the Board placed on the scheme. He argued that the scheme would account for only 0.79% of national generating capacity,[10] and he questioned at length if it was worth sacrificing the Perthshire countryside for such a small gain, given that the area already contributed to the grid via the Grampian scheme of the 1930s. McGlashan was followed to the stand by a number of environmentalists, local hoteliers and artists. All testified to the damage which the scheme would cause to the scenery of the area, known as one of the most beautiful in Scotland, and consequently to the tourist trade. [5.5]

A significant component of the opposition's evidence related to information on salmon fisheries, and this issue was to shape many subsequent controversies surrounding developments elsewhere in the Highlands. Such was the mass of contradictory evidence on this matter that the final report of the inquiry was forced to conclude: 'as regards the effect upon fisheries, the tribunal found that the extent of the damage to be apprehended was the subject of acute divergence of expert evidence … no attempt was made in the witness box to quantify any of the apprehended loss. In a matter so uncertain as the prospects of salmon fishing we think it was wise to refrain from the attempt.'[11]

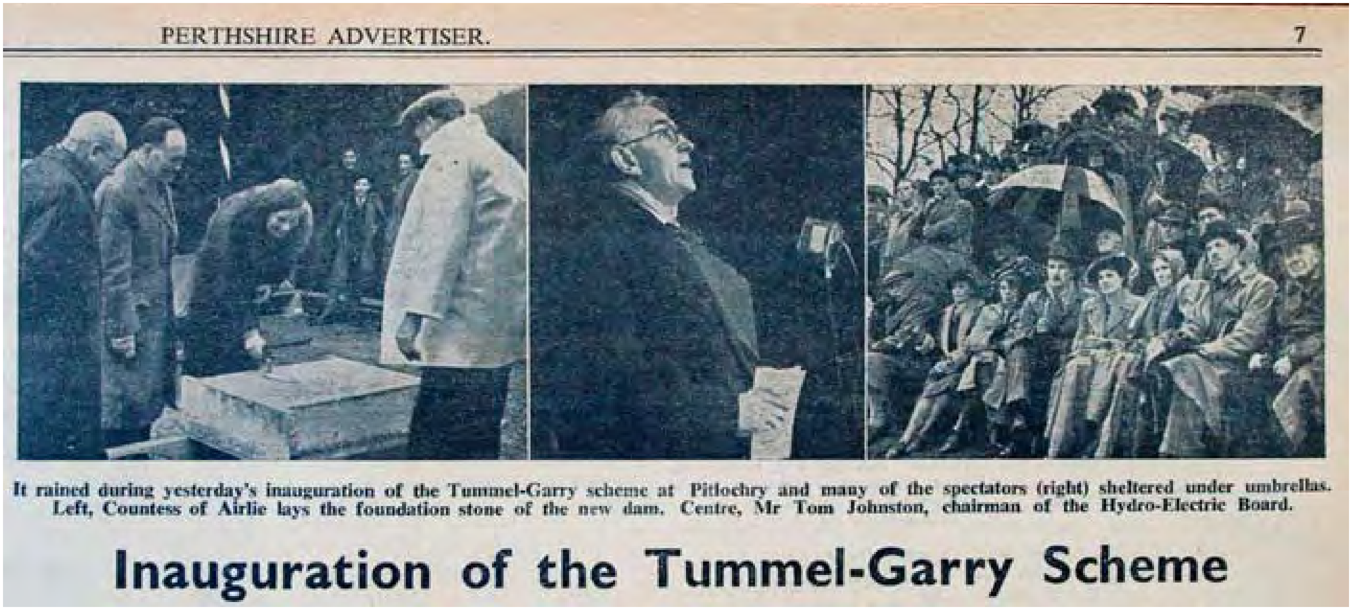
Influential local landowners also sought to make their opposition known; however, their approach was not through straightforward representation to the inquiry. It was revealed, shortly before the conclusion of the inquiry, that a number of landowners had gifted sections of their estates to the National Trust for Scotland, including the Falls of Tummel. Their intention had been to put the land beyond the reach of the Board and prevent development. The opposition of the KC for the National Trust was particularly vicious. He noted his disgust with NoSHEB for pedalling power and electric cookers to remote West Highland glens and the development of Pitlochry in what he described as a Prussian manner, with 'a seat every fifty yards and a police notice every hundred'.[12] He was also not above personal attack, tacking two additional lines onto a verse describing the 'other' [17]'45 Jacobite rebellion:

Cam' ye by Atholl, lad with the philabeg,
Doon by the Tummel and banks of the Garry,
Saw ye lads with their bonnets and white cockades,
Leaving their land to follow Prince Cherlie.

Saw ye lads with their cusecs and kilowatts,
Leaving the rivers defaced by Lord Airlie[13]

With the bruising cross-examination, the blackballing of his son from the Perthshire hunt and his own exile from society, Lord Airlie found the experience too much and resigned the chairmanship in 1946 to be replaced by the former Secretary of State for Scotland, Tom Johnston.

Both sides had made extremely closely argued cases and were equally convinced of their own position. When the inquiry closed it was clear that there was an extremely difficult decision to


PERTHSHIRE ADVERTISER. 7

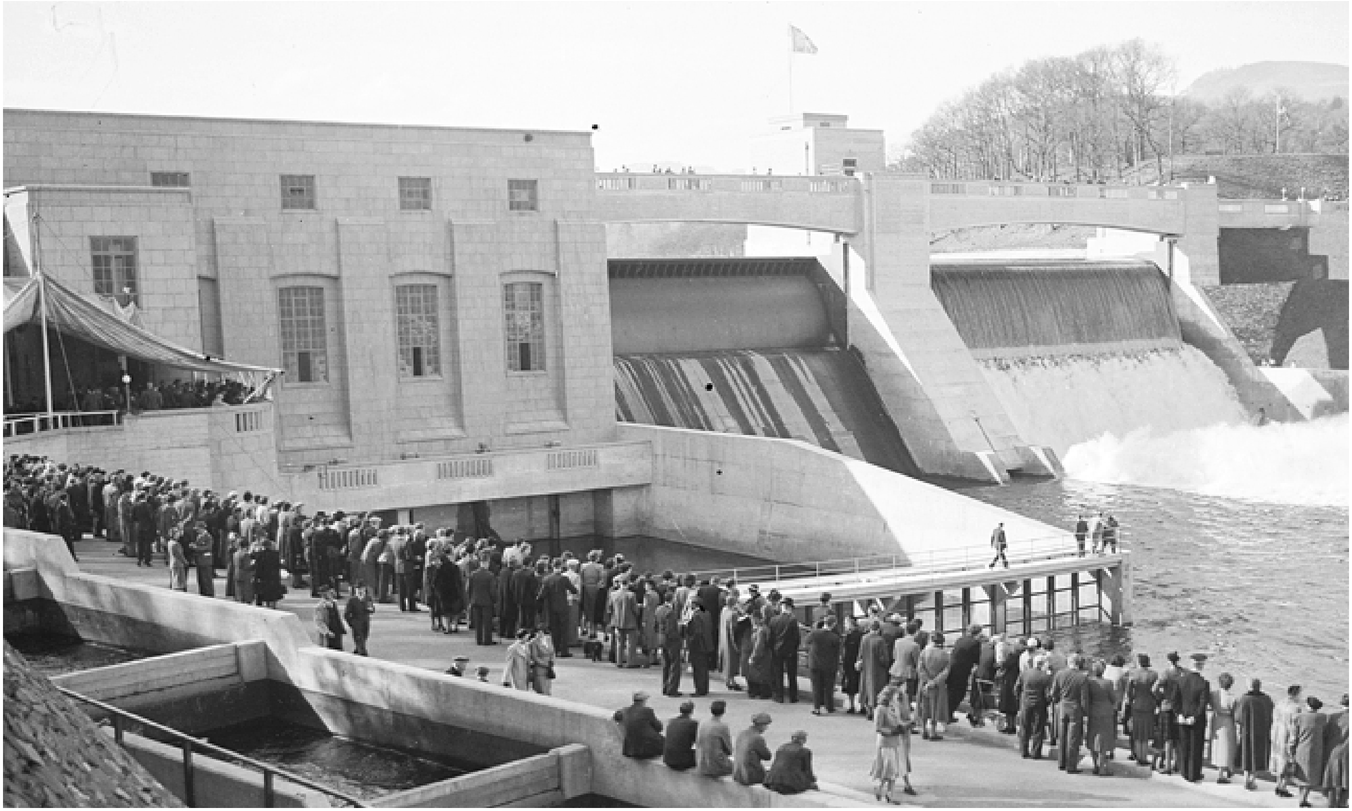
It rained during yesterday's inauguration of the Tummel-Garry scheme at Pitlochry and many of the spectators (right) sheltered under umbrellas. Left, Countess of Airlie lays the foundation stone of the new dam. Centre, Mr Tom Johnston, chairman of the Hydro-Electric Board.

Inauguration of the Tummel-Garry Scheme

5.6 Article on the inaugauration of the Tummel Garry hydroelectric scheme, 26th April 1947. © Perthsire Advertiser

be made. When the report was finally published it proved to be a complete vindication of the work of the Board. It found that 'a case of sufficient urgency has been made to overcome the objections which have been maintained against the Constructional Scheme and that it is in the public interest … that the scheme should be confirmed.'[14] The central argument of the Board that the impact on the scenery of the area would be outweighed by the social improvements was wholly endorsed by the reporter: 'losses such as these would be a small price to pay for a project which will bring the amenities of life where few existed before, and inject new energy into the straths and glens of the Highlands.'[15]

However, the Board did not rest upon their laurels, even after the bill's complicated passage through Parliament for approval. The spotlight was on both Clunie and Pitlochry, and so the designs for the schemes came as a direct response to the now defeated opposition, and set the precedent for all future developments with high-quality design and materials. Thus both Clunie and Pitlochry were designed with utmost attention to their setting and to local amenity. Pitlochry is designed with an underground connection to the grid so that there are no transformer stations or overhead cables to clutter the appearance of the dam. The desire for clean lines was also carried into the design of the dam itself, which incorporates large automatic drum gates that are free of overhead gear and provide constant regulation to maintain the level of the dam. The architectural design is also of the highest quality, with a Classical Modernist scheme by Harold Ogle Tarbolton that, although rhetorical in form, is a welcome addition to its natural setting. The Board were also keen to ensure that the dam was accessible to the local community. At the insistence of MacColl the dam includes a public walkway, and the public viewing gallery



5.7 **Opening ceremony at Pitlochry Power Station, 1951, Tummel valley hydroelectric scheme.** © The Scotsman Publication Ltd. Licensor www.scran.ac.uk

at the fish ladder became a major tourist attraction. The public were also invited to name the loch created by the dam, with the community council naming it Loch Faskally after the estate on its banks.

The decision of the inquiry and the subsequent conciliatory measures which were implemented the Board during the Tummel scheme's construction were to prove highly influential not only on local opinion but also on the shape of and approach to future developments. At the foundation-laying ceremony for the scheme, McGlashan commented that 'we as a county council have established a most friendly relationship with the Board'.[16] [5.6 and 5.7]

Opposition of a similar scale was not seen on any of the subsequent developments by the Board over the period until the final scheme was created in 1969 at Ben Cruachan. The Affric–Cannich scheme, announced in 1946, was set to be in one of Scotland's most scenic areas, with the remnants of Caledonian pine forest making it a highly sensitive area to choose. Several houses were to be submerged as part of

5.8 Clunie dam, 1950, Tummel Valley hydroelectric scheme.

the plan, along with a large area of land, yet the scheme met with widespread approval. All that the Inverness Courier could note was that two thousand men would be employed on the scheme during construction.[17] This was a major turnaround from the situation at Tummel, and the pattern of general welcome for the new developments was to become the norm. [5.8]

The turnaround has become even more complete in recent years. A survey in 2009[18] found that there were some 2,033 micro hydro systems operating on estates around Scotland. The coming of the technology which was once perceived as bringing financial ruin to the tourist trade at Pitlochry is now a vital lifeline to many Highland estates, including a number of the very same estates which had not only objected to the developments in Tummel but also formed the parliamentary coalitions that had stifled developments in the run-up to the founding of NoSHEB. As Angus Robertson, the factor at Ardtornish estate in Argyll, noted in 2009 of their micro hydro scheme: 'It has revolutionised the financing of the estate … it is a good thing to be doing. We get a lot of rain here but it means that when it pours and life is tough and people are getting depressed, we have this wonderful thing that is doing well.'[19]


SCOTTISHPOWER

The Innovators

'You simply never get used to how special this is,' says Michael Mullen, assistant civil engineer with Scottish Power, surveying a snow-capped panorama across the top of Ben Cruachan Dam. 'I used to turn up every morning to work and then I'd be out onto the mountain' – he was known along with his colleague, Murdo MacLean, as one of the 'hillmen'.

Working at the ground-breaking Cruachan hydroelectric scheme for his entire 39-year career has inspired Michael to be equally innovative and committed in his own work, being responsible for the maintenance of the dam, penstocks and inlets and later serving as coordinator of the works projects in the turbine hall, hollowed out of the mountain, and known as the 'cavern'. He recalls a particularly poignant incident out in the hills following a fall when clearing an inlet. After an excruciating overnight stay in a bothy, Michael was evacuated by the local mountain rescue team. Such is his passion that he was soon back out on the hill.

Michael remembers both his own awe and that of the visitors, who were originally allowed to wander around the turbine hall floor. Now visitors are led to a viewing platform high above the hall where they can view four turbines which can provide up to 440 megawatts of power to satisfy peak demand on a UK-wide scale. Cruachan, designed by Shearer & Annand (1960-4), was the first major scheme in the UK to utilise pumped storage, and remains architecturally ambitious and a key strategic component of power supply to the national grid.

Chapter 6

The Innovators

In the 24 years between the aftermath of the public inquiry into the Tummel scheme and the completion of the final scheme to be built by the Board (1969-1975) at Foyers, some ten major schemes were constructed, with the provision of over fifty dams and a similar number of power stations. Power was supplied to homes throughout the Highlands, with an expanding grid of cables spreading across the map that made Scotland one of the foremost nations in the world for its use, per capita, of hydropower. The creation of a network of power stations which still produce today some 10% of the United Kingdom's national energy supply required an unprecedented level of technical innovation as – despite all consisting of a dam, pipeline and power station – no two schemes are the same. In certain notable instances, world and British firsts were achieved to make the schemes work successfully.

PREVIOUS PAGE
Michael Mullen, at Ben Cruachan dam.

Ben Cruachan dam and detail of power station, 1965, Sloy / Awe hydroelectric scheme.

The advancement which surrounded the sector is a story which begins long before the founding of the North of Scotland Hydro Electric Board (NoSHEB), in the development of the technology by the British Aluminium Company (BAC) and the work of James Williamson and Edward MacColl on pioneering electrical generation for public supply (see Chapters 1 and 2). A legacy of knowledge and experience culminated in one of the most significant feats of engineering in the 20th century in the UK, where all the lessons learnt from previous developments were drawn upon to create a pioneering type of power station buried deep in the flanks of a mighty ridge of mountains near Oban. The power station at Cruachan was indeed the culmination of all the research and, much like Dounreay Nuclear Power Station, would become an icon for the industry and for the

post-war period in Scotland.

Innovation on a nationally and internationally significant scale began on the Lochaber scheme developed by BAC. The scheme itself was one of the most significant civil engineering achievements of the first half of the 20th century and included a tunnel bored through the side of Ben Nevis to carry water from the Spey watershed through to the powerhouse on the banks of Loch Linnhe at Fort William.

One of the three dams on the scheme is at Loch Treig, where water is gathered in a large reservoir before entering the pipeline. The dam received international attention on its completion as an early example (and the first in Scotland) of a rock-filled dam. [6.1] This construction method represented a significant reduction of cost and time, saving in materials and labour over a mass concrete dam, and required the use of local materials for its construction.

6.1 Loch Treig dam, 1929, Lochaber smelter and hydroelectric power scheme.

The construction of this type of dam had not been attempted previously in Scotland as most rocks were unsuitable schists, and there was great scepticism that the construction of Treig would actually work. The dam includes an upstream diaphragm which ensures the structure is watertight, with the embankment to the downstream face also covered with a concrete skin to minimise erosion when the dam spills. Thus in all aspects of its design and construction the dam was a resounding success. The use of this innovative technology was partly down to the site, but cost and time implications were also major factors in pioneering new ways of building dams.

Balfour Beatty's contract for the civil engineering works at Lochaber included a number of bonuses if work could be completed to a demanding schedule. This was made more difficult by working with concrete where long periods of time were required to let each section 'go off' before the next could be poured, an issue compounded by the large number of days lost during the winter months when temperatures were too cold to allow the pouring of concrete. Rock-fill technology faced none of these problems, as once the waterproof membrane was constructed, work on the embankments could be ongoing even in wet and cold weather. Work on Treig proved to the sector that innovation could save both time and money, and it was a discovery that was to lead to a continued desire for innovation throughout both private and state development in the sector.

6.2 Downstream face of Sloy dam under construction, 1949, Sloy hydroelectric scheme.
© Scottish and Southern Energy

Much of the focus of the innovation in the sector was on dam construction, given the large expenditure on man-hours and materials which was involved in erecting these megastructures. At Loch Sloy dam (from 1946), the influence of American dam construction was further developed by James Williamson to produce the first major example of a buttress dam in the UK. [6.2] Williamson had toured the United States and is likely to have known of examples of buttress dams, such as that at Coolidge in Arizona where buttress technology was combined with a multiple-dome dam constructed in 1930. Williamson went on to adapt the technology for use in place of a mass gravity dam, and his work at Loch Sloy was his first opportunity to put theory into practice. He had outlined his design during a lecture in Chicago in 1936 and the design for Sloy was based almost entirely on the one he outlined. The

use of this technology represented a significant cost saving for the Board, with only 20,000 tons of concrete required for construction, in contrast to the 50,000 which would have been necessary for a conventional mass concrete dam. Williamson's work was pioneering on an international stage and helped to develop the modern form of the buttress dam as an alternative to the use of a mass gravity construction. The development at Sloy pre-dates the other major examples of this type by engineer André Coyne (1891–1960) – the dam at Grandval, France (1959) and the Daniel-Johnson Dam in Quebec, Canada (1961–8). Williamson's groundbreaking approach to design a solution specifically suited to its location was to typify all of his work for NoSHEB, and that of his company, James Williamson & Partners (later Mott MacDonald), which

6.3 Monar dam, 1963, Glen Affric hydroelectric scheme.

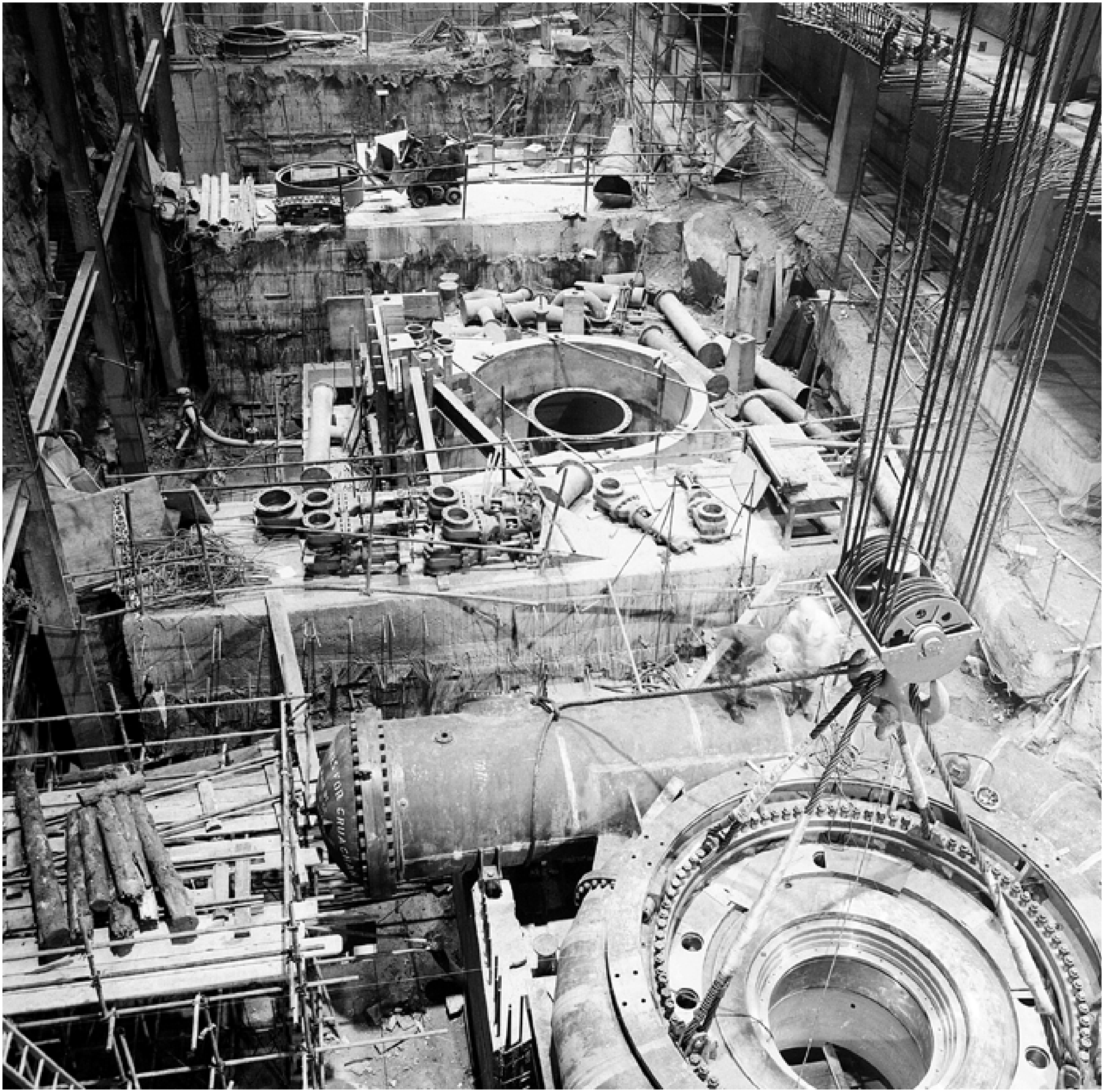
continued working for the Board after his death in 1953.

The Williamson practice was also involved in the pioneering use of a double-arch dam at Loch Monar on the Affric–Beauly scheme, begun in 1952. [6.3] The only example of its type in Britain, it pre-dated its widespread use, especially in the US, although admittedly on a smaller scale. Arch dams require specific conditions in order to be successful, necessitating a very solid abutment to either side (in the form of a gorge in this case) to withstand the force of the water behind. Single-arch concrete technology was first used in 1911 for the construction of the Roosevelt Dam in Arizona, and was also employed for the Hoover Dam in Colorado in 1931. However, experimentation with double-arch structures (arched in both planes) did not follow on a large scale in the US until the later 1960s.

The architectural design at Loch Monar is largely functional, with the elegant curves of the dam walls expressing their function and contrasting with the fractured rock of the gorge walls. The dam is composed of two continuous concrete arches which dissipate the thrust of the water against the sides of the valley: the particular site of the dam with available abutment into solid rock on the sides of the gorge allowed for a double-arch dam to be used in this location. The double-arch construction method represented a 9% saving in materials over a conventional gravity dam, with the dam wall a mere three-and-a-half metres thick in some places. The upstream face of the dam is arched in both horizontal and vertical planes asymmetrically to the more shallow doming of the front of the dam; the tension this creates is the key factor in counterbalancing the thrust of the water on the upstream face. The engineering of the stepped concrete abutment to the walls of the gorge on the downstream face at Loch Monar is to help prevent excessive erosion, which would threaten the structural integrity of the dam.

The culmination of the drive for groundbreaking technology is perhaps best expressed by the penultimate scheme developed by the Board at Ben Cruachan near Oban, between 1960 and 1965. The scheme included one of the earliest large-scale uses of pumped storage technology, with reversible turbines used both for generation and to pump water back up to the top reservoir. The turbines are contained within a 3,240-cubic-metre cavern, hollowed out entirely from the solid bedrock of Ben Cruachan ridge and is accessed by a 1-kilometre-long vehicular access tunnel. The housing of a power station of this scale wholly underground, in addition to secondary features such as transformers and pressure tunnels, was unprecedented, and allowed for the development of a facility which plays a nationally significant role in energy supply in an area renowned for scenic beauty, with very limited visual impact. [6.4]

During periods of cheap electricity, the turbines are run in reverse to pump water from Loch Awe back up into the reservoir, a process which provides 90% of the water used for generation by the station. Prior to the design of Cruachan, pumped storage facilities had required separate pumps and a separate pipe network to bring water back into reservoirs, making them much more expensive to build than conventional hydro systems. The use of reversible turbines at Cruachan was unprecedented and removed the costly requirement for separate



6.4 Ben Cruachan turbine hall floor under construction, 1965, Sloy / Awe hydroelectric scheme. © Scotsman Publications Ltd. Licensor www.scran.ac.uk

6.5 100 MW turbine, Ben Cruachan turbine hall floor, 1965, Sloy / Awe hydroelectric scheme.

pumping infrastructure. The reversible technology was first developed in the 1930s, but Cruachan was one of the first large-scale applications in Europe, with a capacity of over 440 megawatts. The Lünerseewerk station of 1958 in Austria pre-dates Cruachan, but has a smaller capacity of 232 megawatts. The technology became more widely used, in Britain and worldwide, from the later 1960s onwards with further schemes in Wales at Ffestiniog in 1963 with a 360-megawatt station. At Cruachan the turbine hall houses four turbines capable of a combined capacity of 440 megawatts, with two sets generating at 120 megawatts and the original two at 100 megawatts. Each set uses approximately 110 megawatts of power to pump water back up to the dam. The station can move from standstill to full generating output in under two minutes, compared to a time of several hours for a thermal power station. The station fulfils a key strategic requirement for the UK with the capability to produce enough power to restart essential services nationwide – a so called 'Black Start'. [6.5]

The development of hydroelectric power in Scotland is a story filled

6.6 **Ben Cruachan dam, 1959-1965, Sloy / Awe hydroelectric scheme.** © Scotsman Publications Ltd. Licensor www.scran.ac.uk

with innovation and achievement on an international scale. That infrastructure largely developed over the course of two decades from 1945 not only remains in active use but is still responsible for 85%[1] of the UK's hydropower resources is a testament to the success of architects, engineers and construction workers at all the sites.

Although the available natural resources in Scotland are smaller than elsewhere in Europe, the sector in this country is characterised by a sheer determination to innovate and develop schemes which use all available water to the best of its potential. The social aspect of the work of NoSHEB is another defining characteristic of their original concept, and although it did not prompt the renaissance of the Highlands in quite the way Johnston had outlined in his early utopian visions for the sector, the provision of a reliable and affordable power supply to what were some of the remotest settlements in Europe was a major achievement on an international scale. With the perspective of over 40 years since the last major work by NoSHEB, it is possible to realise how significant their achievement was. [6.6 and 6.7]

The success of the Board is often dominated by the debate about the difficulties they faced in realising the social vision enshrined in the Act which founded NoSHEB. Whilst their work did not prompt the industrialisation and re-population of the Highlands on the scale originally envisaged, it did perhaps halt a decline, providing jobs and a modern standard of life to people who otherwise may have left the Highlands altogether. A contemporary analysis of the post-war euphoria which saw the birth of the Board shows that this may well have been an unrealistic aim born of an optimistic response to the end of the Second World War. However, the same perspective provides a new

6.7 Orrin dam, 1961, Conon Valley hydroelectric scheme. Orrin dam provides the main water storage for Orrin power station and contains an innovative 4-level fish pass in the large central buttress.

version of the argument, put forward to justify the Board's demise in 1990, that it simply did not achieve its aims. The development of the sector in Scotland was still a massive achievement both in social provision and in architectural and engineering terms. Hydro is unlike virtually any other contemporary utility, with an infrastructure that is still far from defunct and where the issue is not one of developing a strategy of imaginative reuse for a redundant structure, but quite simply of imagining any other use. The Board succeeded in developing a robust infrastructure to provide power to Scotland, and managed to put in place secure foundations for the realisation of the broader social vision, something which has endured beyond their own existence.

Although the scale of the sector in Scotland is relatively small when compared to Norway or Central Europe, there are 34 dams constructed by the Board that are significant enough to feature in the World Register of Large Dams.[2] Many of them drew worldwide attention from engineering experts on their completion. NoSHEB schemes were visited not only by numerous heads of state on official tours, but also by engineering experts from both Russia and the United States.[3] Perhaps the most telling visit of all was from the Director of the Tennessee Valley Authority, the scheme which had provided so much of the inspiration behind Johnston's vision for what hydro could do in Scotland. The international focus on hydropower continues to be underlined today, with the very same infrastructure which was developed by NoSHEB still significant in a European context. None of the buildings or major pieces of engineering infrastructure is redundant, only turbine technology continues to develop. Scotland's huge potential as a renewable energy generator, much of which is down to hydro, has again put the sector at the centre of European attention. Plans for a North Sea supergrid, which will allow power generated by Scottish hydro schemes to provide light and heat to homes throughout Europe, underline the legacy of the sector on a truly international scale. Indeed, the achievement made by the Board was formally recognised in 2001 by Brian Wilson, the then Scottish Energy Minister, who noted: 'The expansion of hydro was one of the great acts of the post-war period.'[4]


Scottish and Southern Energy

The Managers

Neil Lannen is Senior Civil Engineer with Scottish and Southern Energy, and has been with the company since the late 1990s. He explains that his expertise is very simply related to the 'use of water'. When he first joined the privatised hydro sector he was responsible for keeping the existing infrastructure maintained and fit for purpose.

Neil's work at Fasnakyle Power Station, near Beauly, completed in 2003, marked a transition in his career, where he was first charged with providing a substantial extension to a category A-listed power station. His challenge was to adapt the building, whilst acknowledging its special architectural or historic interest and ensuring that it remained at the cutting edge of power generation. This major capital project incorporated a new compensation-set turbine, increasing the efficiency of the station as a whole. Neil was acutely aware of the need for a high-quality design when altering a building which is regarded by the company as one of their finest power stations.

It is only in the last few years that he has turned his focus to the identifying, planning and building of completely new schemes, as Hydro Development Manager – Glendoe being one of the largest new schemes since the completion of the Foyers pumped storage facility of 1969–1975. Neil's work can therefore be considered part of a continuing legacy of great industrial architecture of the 20th and now also the 21st century, and plays an important role in developing a healthier, wealthier, greener Scotland.

Chapter 7
The Managers

Hydropower in Scotland has brought a distinctive estate to our landscape and, as some other countries such as Norway are finding, it is playing a significant role in the current development of the sector. The sector's past achievements – which we recognise to have produced important and influential architectural and industrial heritage assets such as dams, powerhouses, plant and equipment – are now being re-evaluated in conjunction with recent European and national government initiatives, including the Renewables Obligation Certificate (ROC), for contemporary power production.

PREVIOUS PAGE
Neil Lannen, Senior Civil Engineer, Scottish and Southern Energy.

Details of Fasnakyle power station, 2003, Affric hydroelectric scheme.

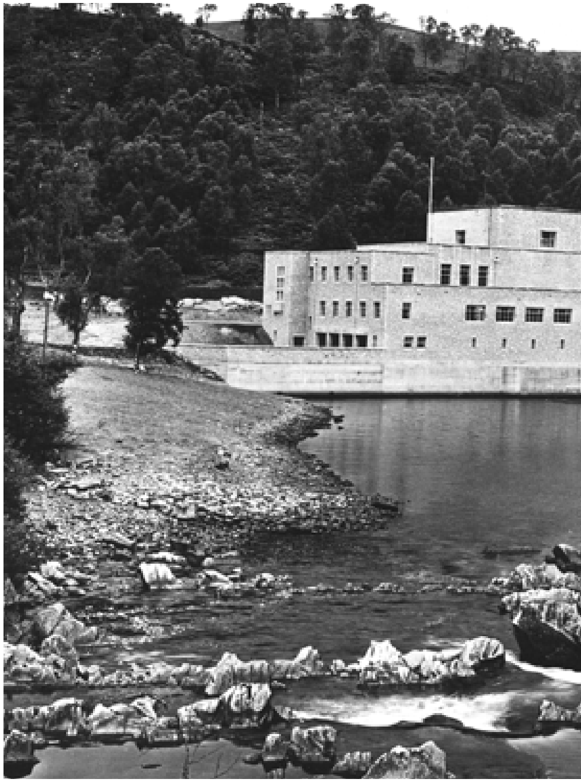
ROC came into force on 1st April 2002 and is the key means through which the Scottish Government is pursuing its renewable energy objectives, with a commitment to ensuring that 20% of primary energy demand is met from renewable resources.[1] The ROC initiative made it timely for Historic Scotland to assess, through a comprehensive listing survey, the cultural, historical and architectural significance of the hydroelectric industry in Scotland. This chapter will provide an overview of the statutory system of protection in the form of Listing and Listed Building Consent, and give advice from National Museums Scotland on the collecting and recording of the civil and technical infrastructure. Highlighting Historic Scotland's and the National Museum of Scotland's role will hopefully demonstrate how the management

of the heritage assets, as well as the collecting of the most significant components of the industry, are vital in promoting and celebrating the sector's remarkable heritage. [7.1 and 7.2]

Historic Scotland

The opportunity afforded by a thematic study to consider an industrial subject in its entirety ensures that designation accurately reflects the architectural, historic and technical interest for the building type, so that decisions on future designation can be made from an informed standpoint. Furthermore, the relative importance of component items within the type can be better understood. Listing of the best examples celebrates the watersheds, the technological innovation and design within the sector. It is important to stress, particularly in the context of

7.1 Bonnington power station, 1925-1927, Falls of Clyde hydroelectric scheme. Crown Copyright: RCAHMS. Licensor www.scran.ac.uk



LEFT TO RIGHT

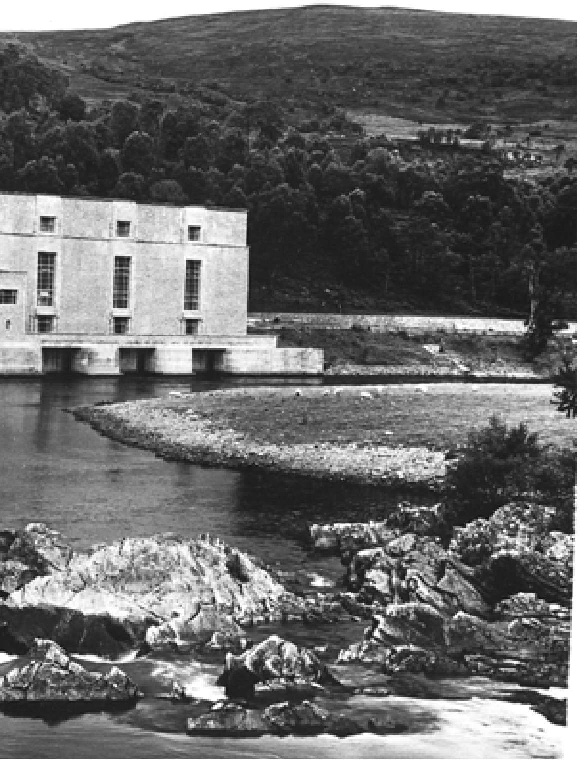
7.2 Tongland power station, 1934, Galloway hydroelectric scheme.

7.3 Fasnakyle power station, 1950, Affric hydroelectric scheme. © St Andrews University Library. Licensor www.scran.ac.uk

7.4 Fasnakyle compensation set turbine hall extension, 2003, Affric hydroelectric scheme.

such an active industry, that Listing is not intended to preserve buildings in aspic. Listing identifies why a building's character is significant. It allows flexibility to be able to adapt buildings and other civil infrastructure successfully to ongoing operational demands while ensuring their special interest continues through the change.

A balance between heritage value and corporate operational concerns was achieved by Scottish and Southern Energy at Fasnakyle Power Station, listed at category A and recognised as an archetypal example of the work of the pre-eminent architectural practice of Shearer & Annand. The building was extended successfully in 2003 to incorporate an additional bay on the end of James Shearer's four-bay block housing a compensation set. Early involvement of both Local Authority planning officers and Historic Scotland's casework teams allowed for the first-rate development of innovative and cost-effective plans for extension and redevelopment which enabled the building to remain flexible and responsive to the needs of a commercial power company. The work



at Fasnakyle provides just one example of a successful partnership which has been employed at a number of listed sites. Other examples include the renovation works by Rio Tinto Alcan to the interior of Kinlochleven Smelter, which was also subject to Scheduled Monument Consent. Works to Scottish Power's Tongland and Earlstoun power stations in Galloway were similarly the result of successful engagement. The clear identification of the interest in an item and the early involvement of all parties in the planning process has assisted these cases in the Listed

Building Consent process, adding value to the practice of change management of the sites in question, many of which are iconic features in Scotland's natural landscape. [7.3 and 7.4]

In drawing on the detailed research and source material from site visits which formed part of the thematic Listing survey, this publication celebrates and shares our understanding of the cultural, architectural and historic context of items in this sector. In addition to developing an awareness of the historic importance of a site, unravelling technical information on building materials and construction types is also a key part of achieving effective future management. This is particularly the case in post-war buildings where new materials like pre-cast concrete, glass and steel increasingly form vital components of the construction method. Significant work has been done in developing skills and knowledge for post-war conservation in the UK in recent years, revealing that the well-publicised difficulties and structural failings in buildings from this period are often overstated. Historic Scotland's Technical Conservation Group promotes a wide range of research in this area and provides a wealth of information and support so that the technical aspect of managing a site or preparing a plan for proposed change can be fully informed.

The hydro estate in Scotland includes important examples of machinery, plant and other equipment which can also be considered heritage assets – often as part of a listed building – and require similar effective management to balance their continued use or the acknowledgement of their value at the point of any proposed change or disposal. National Museums Scotland provide specialist advice in this area, helping to develop partnerships and guidance for managing these assets for the future.

National Museums Scotland

The North of Scotland Hydro Electric Board's (NoSHEB's) policy of placing orders with Scottish and English companies which were prepared to create new factories in the Highlands, or sub-contract to local engineering workshops,[2] led to a frenetic period of research, development and production in hydroelectric plant. Expertise in hydroelectric provision and light

7.5 Construction work during the building of the Tummel Dam, 1947, Tummel Valley hydroelectric scheme. © National Museums Scotland industry production were brought north for the first time and a number of partnerships were achieved. The American firm S Morgan Smith agreed a contract with Harland Engineering of Alloa to produce water turbines under licence, which constituted their first experience of manufacturing hydroelectric plant. The English Electric Company subcontracted to Harland & Wolff's factory in Scotstoun, and Boving & Co worked with John Brown's of Clydebank.[3] Factories developed by Radiation Ltd, Amalgamated Electrical Industries, the British Thomson-Houston Co and Ferranti's appeared in Inverness, Buckie, Peterhead and Auchterarder supplying lamps, electricity meters, transformers, cookers and power tools for hydroelectric schemes.[4] [7.5]

Significantly, the Board directly sponsored research into machine manufacture. They commissioned John Brown's to experiment with fuel supplies including pulverised peat and install an experimental wind-generator at Costa Head in Orkney. Although both of these experiments were ultimately unsuccessful, lessons were learned with application to the development of future renewable industries.[5]

In the stringency of the post-war environment when contracts and materials were in short supply, NoSHEB's ambitious hydroelectric scheme sustained a number of engineering firms and prompted them to develop new skills. Glenfield & Kennedy Ltd of Kilmarnock, specialists in water supply and control engineering who produced significant volumes of plant for schemes throughout the project, became one of the largest firms of its kind in the world, employing 2,400 men in 1953.

When in July 2001 the Scottish Executive announced that ROC support would be extended to older hydroelectric power stations up to 20 megawatts and include new-build stations of any size, major refurbishment programmes were instigated. As almost fifty years has elapsed since the peak hydro planning period, technology has moved on with turbines becoming more powerful and new materials developed. To name just a few examples, a new turbine has been supplied at Rannoch; the original cross-flow turbine was removed from Auchtertyre and replaced with a Francis machine; and Mott MacDonald uprated all four machines in Cruachan Power Station. In addition to their work at Fasnakyle, Scottish and Southern Energy have also submitted a planning application to extend the hydroelectric power plant at Sloy as part of a multi-million-pound redevelopment of their estate. These developments represent a new and exciting chapter in the evolution of hydroelectric power. It is crucial to record the necessity for change, the research and development that underpins each decision and, where possible, to preserve the original machinery. [7.6 and 7.7]

In 2001 National Museums Scotland's Acquisition and Disposal Policy identified a notable gap, namely 'equipment and materials representing the generation of power from hydro, wave and marine current, solar, wind and nuclear energy'. Work is currently being undertaken to redress this balance through a proactive collecting project designed to illustrate the story of Scotland's past, present and future energy production. In addition, it has formed the basis for a new approach to joint collecting initiatives. It is therefore an ideal time for National Museums Scotland to work with industrial and heritage partners to survey

7.6 Interior view of Fasnakyle power station, 1950, Affric hydroelectric scheme.

hydroelectric holdings and identify prospective acquisitions.

The current hydroelectric collections inadequately represent the significance of the industry. National Museums Scotland holds a number of turbine models, some sectioned, and many made in the museum workshop from blueprints supplied by manufacturers. However, there is no record of collecting during the NoSHEB era, nor is there any full-scale plant preserved. The key suppliers of hydroelectric plant – such as Glenfield & Kennedy, Gilbert Gilkes & Gordon, Bruce Peebles and Boving & Co – are also poorly represented in the collections.

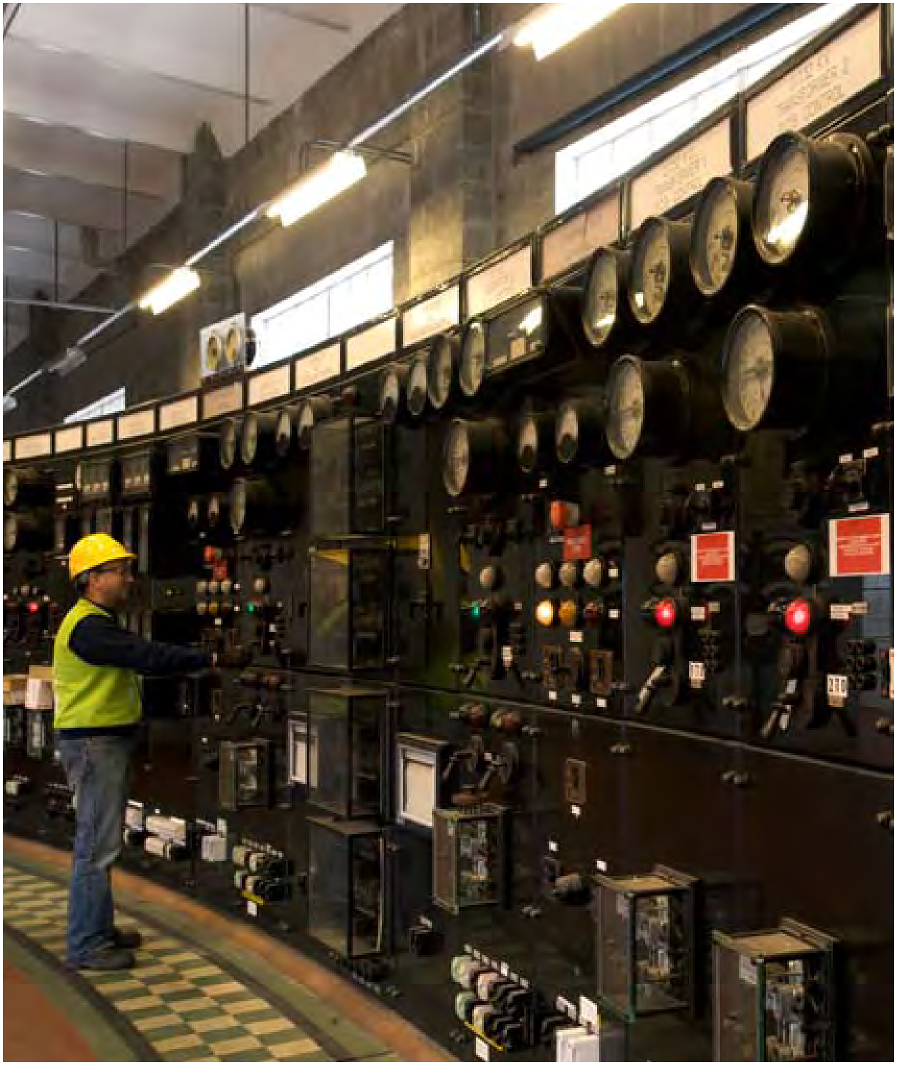
More recently, the most successful museum acquisitions are the consequence of evaluation, research and multiple-stakeholder participation. This is particularly applicable when recording or collecting a live industry, and there are several case studies which are testament to the merits of this approach. One of the most successful collecting and research partnerships of recent years is the Capturing the Energy Project. This initiative was established by a steering group composed of heritage bodies, academic partners and industrial and commercial bodies whose aim was to record the decommissioning process of the offshore oil and gas industry. Numerous outcomes have been achieved, including: the creation of a panel to assess the heritage merits facing disposal; the creation of a website; the indexing of commercial archives; and the formation of a vast oral history resource now deposited with the University of Aberdeen. The project has assisted commercial partners to understand the quality of their resource and capitalise on its assets, and it has enabled heritage and academic partners to plan strategically the stewardship of this internationally significant collection.

An innovative project that both National Museums Scotland and Historic Scotland are currently engaged in is the Dounreay Site Restoration Limited Heritage Strategy. Both agencies have collaborated with Dounreay's decommissioning staff providing advice from an international perspective to devise a strategy, which is currently the subject of public consultation. This is the first instance of a nuclear site being decommissioned in the UK where heritage bodies have been actively involved and this approach has enabled all agencies involved to plan for the large-scale acquisitions which will result from the decommissioning process.

Based on our experience of working with Dounreay and partner heritage bodies at the front end of the decommissioning process, we have proven the value of early communications. National agencies such as Historic Scotland, the Royal Commission on the Ancient and Historical Monuments of Scotland, the National Archives and National Museums have complementary remits and work well collaboratively to collect the tangible and intangible parts of Scotland's industrial heritage.[6]

The future

It is clear that the history of the hydro sector in Scotland forms an important part of its future. Hydroelectric power has always been an international industry, with the pioneering technological breakthroughs made on Scottish schemes exported to Nordic and Alpine nations, and German turbines forming a significant part even in early schemes on home soil, such as Kinlochleven. However, this international



7.7 Detail of the control panel at Tummel Bridge power station, 1933, Tummel and Rannoch hydroelectric scheme.

legacy is not just a historic one: nations such as Scotland and Norway, which utilise hydro to the extent that they are exporters of energy, still play a key role in new international projects such as the North Sea Grid. This is an activity that will be crucial to the future security of supply for many European nations.

The industry is also building on the foundations of the pre-war and NoSHEB developments in Scotland, where current estimates project that there are 657 megawatts of financially viable schemes which could be developed in Scotland out of a current total of 1,354 megawatts of installed capacity.[7] Whilst this may be small compared to the 25,615-megawatt scheme being developed at the Three Gorges on the Yangtze River in China, it does illustrate that the faith of the pioneers in Scotland was well placed and that the skill and passion with which they oversaw the development of schemes was consummate. This is an extraordinary feat when considering that modern 21st-century technology can only produce just under half as much again as the capacity installed in the late 20th century. Working together across public and private institutions to understand, promote and celebrate these awesome achievements in Scotland is in itself a worthwhile venture, and one of which all can be proud.

Notes

Chapter 1 – The Pioneers

1. United States Geological Survey (USGS) Hydroelectric power water use, http://ga.water.usgs.gov/edu/wuhy.html.
2. Emma Wood, *The Hydro Boys*, 2002, p.39.
3. *Northern Chronicle*, 27th March 1895. Quoted in Andrew Perchard, *Aluminium in the Highlands*, 2007, p.11.
4. Perchard, p.13.
5. Letter from William Murray Morrison to Dr Lachlan Grant, 1st January 1935, National Library of Scotland Acc 1287/7. Quoted in Perchard, p.9.

Chapter 2 – The Engineers

1 Peter Payne, *The Hydro: A Study of the Development of the Major Hydro-electric Schemes Undertaken by the North of Scotland Hydro-Electric Board*, 1988, p.25. It should be acknowledged that Peter Payne's publication, though over twenty years old, remains one of the most useful sources for hydroelectric history.
2 Payne, p.26.
3 Payne, p.27.

Chapter 3 – The Visionaries

1 Payne, p.34.
2 Payne, p.39.
3 Wood, p.57.
4 Payne, p.44.
5 Payne, p.45.
6 Wood, p.59.
7 ibid.
8 Clive Archer, *Norway outside the European Union: Norway and European integration from 1994 to 2004*, 2005.
9 Wood, p.59.
10 ibid.
11 Payne, p.50.
12 Payne, p.56.
13 Payne, p.58.
14 Wood, p.62.

Chapter 4 – The Designers

1 James Miller, *The Dam Builders: Power from the Glens*, 2002, p.30.
2 Payne, p.63.
3 Kenneth Frampton and Yukio Futagawa, *Modern Architecture 1851–1945*, 1983, p.256.
4 *Global Architecture*, Number 58, 1981, p.3.
5 Siobhan McConnachie, 'James Shearer and the North of Scotland Hydro Electric Board', *Architectural Heritage* (Journal of the Architectural Heritage Society of Scotland), Volume XIV, 2003, pp 104–18 (p.108).

Chapter 5 – The Campaigners

1 Miller, p.43.
2 Payne, p.64.
3 Miller, p.43.
4 Payne, p.65.
5 ibid.
6 Payne, p.67.
7 ibid.
8 Payne, p.68.
9 Miller, p.44.
10 Payne, p.69.
11 Explanatory Memorandum (command paper 6660), 1945.

12 Payne, p.70.
13 ibid.
14 Payne, p.71.
15 ibid.
16 Miller, p.45.
17 Miller, p.47.
18 Strutt & Parker, Scottish Estates Review 2009, http://www.struttandparker.com/uploads/publications/SER_reduced.pdf
19 ibid.

Chapter 6 – The Innovators

1 RESTATS, the Renewable Energy STATisticS Database for the United Kingdom, http://www.restats.org.uk/ (retrieved 6th April 2007).
2 International Commission on Large Dams website, http://www.icold-cigb.net/
3 Miller, p.249.
4 ibid.

Chapter 7 – The Managers

1 Scottish Government website, www.scotland.gov.uk
2 Payne, p.194.
3 ibid.
4 Payne, p.195.
5 Payne, p.198.
6 National Museums Scotland was established as the Industrial Museum of Scotland in 1854, and has maintained an interest in and enthusiasm for the manner in which things work and the technology that underpins the artefact. The organisation is actively involved in science communication and, as the Connect Gallery demonstrates, is keen to commission innovative digital and manual interactives to inspire, engage and inform current and future audiences on the subject of technology.
7 Scottish Hydropower Resource Study: Final Report, 26th August 2008, http://www.scotland.gov.uk/Resource/Doc/917/0064958.pdf

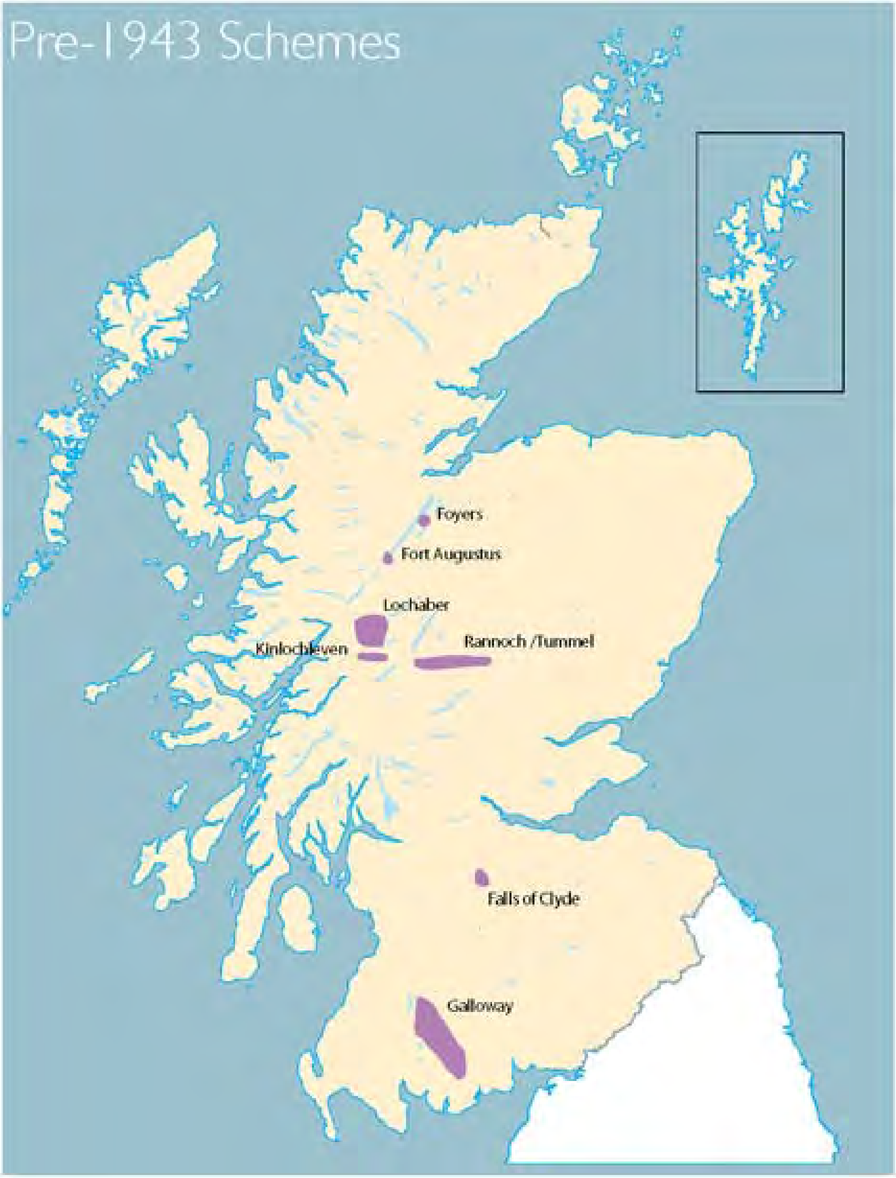
This gazetteer outlines the schemes across Scotland which were developed from the roots of the industry in the late nineteenth century through to the state development of the sector from 1943 onwards. After the founding of the North of Scotland Hydro Electric Board (NoSHEB) by the Hydro Electric (Scotland) Act of 1943 the development of the sector for public supply in Scotland was undertaken by NoSHEB on behalf of the state, with a number of panels – technical, architectural, and fisheries –, providing the main design and technical input. The technical panel was particularly prominent in providing civil and electrical engineering designs for NoSHEB schemes across Scotland. One of the key members of this panel was the prominent engineer James Williamson and his company, James Williamson and Partners, undertook a range of work throughout the period of development by NoSHEB.

As Williamson was identified as the lead member of the technical panel from its early days a number of schemes are attributed to his authorship, or that of James Williamson and Partners who maintained this role after his death, throughout the gazetteer for continuity. However, there is a more detailed authorship of a number of the schemes, beyond the overview of Williamson and the technical panel. Consequently we would like to acknowledge the role of a number of prominent engineering companies and engineers from across Scotland who made key contributions to the design and engineering of schemes on behalf of the technical panel. These companies include, Alexander Gibb and Partners, Halcrow Ltd, Sir William Arrol and Partners and others. Whilst the technical panel played an important role in the overview of all the engineering requirements of the schemes, design work and detailed site consultations was often carried out on their behalf by other specialists.

The pattern of using a panel as the lead for works on each scheme was also replicated with architectural designs for the power stations and other structures. The architecture panel was initially composed of three architects, Reginald Fairlie, Harold Ogle Tarbolton and James Shearer. The intention was that they would judge competition designs for schemes, but this model was quickly abandoned as too costly and they undertook the design of buildings on behalf of NoSHEB. Consequently, after the deaths of Tarbolton and Fairlie early in the life of the Board, the majority of design work was completed by James Shearer and his practice based in Dunfermline. However, particularly in the later years of the Board's work, some of the architectural designs were undertaken by other practices and the contribution of these architects is indicated where their involvement is known.

Gazetteer

Hydroelectric schemes in Scotland 1890-1975



Timeline pre-1943

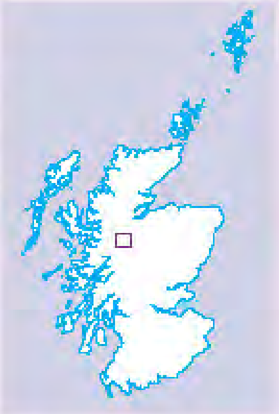
1891	**Fort Augustus**
1896	**Foyers (smelter)**
1909	**Kinlochleven (smelter)**
1925-7	**Falls of Clyde**
1929-34	**Lochaber (smelter)**
1933	**Tummel Bridge and Rannoch**
1934-6	**Galloway**
1943	**Hydro Electric (Scotland) Act**

Fort Augustus (1891)

Architects and engineers	Not known. Built by the monks of the nearby monastery at Fort Augustus.
Components	Small intake on the banks of the River Tarf, concrete-lined aqueduct and turbine hall. Now no longer in use.
Installed capacity on completion	18 KW

The small turbine hall which once formed part of the Fort Augustus hydro scheme.

The turbine hall and aqueduct of the Fort Augustus hydro scheme are the earliest built evidence of a scheme in Scotland. The scheme was built and operated by the monks of the local St Benedict's Abbey in the village and powered the abbey and the homes of the village's 800 inhabitants . Legend has it that when the monks played the electric organ the lights in the village went dim.



Key

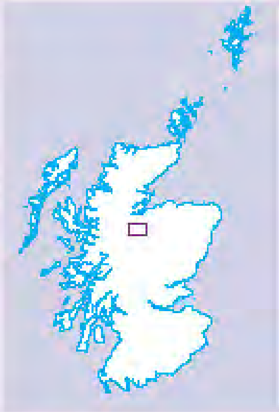
- Dam
- Power Station
- Surge Tower
- Valve House

Foyers (1896)

Architects and engineers	Cameron & Burnett with Lord Kelvin as the scientific adviser to the British Aluminium Company.
Components	Loch Eilde Mor Dam, River Foyers Intake, Foyers powerhouse and integrated smelter (now disused)
Installed capacity on completion	3,750 KW

The powerhouse with integrated smelter at Foyers

The British Aluminium Company development at Foyers was the first large-scale use of hydropower in Scotland. The scheme was highly influential, proving not only the viability of the technology to produce electricity with water-driven turbines but also that the power produced could be successfully applied to industrial processes. The British Aluminium Company went on to develop two other large smelters in Scotland at Kinlochleven and Lochaber.



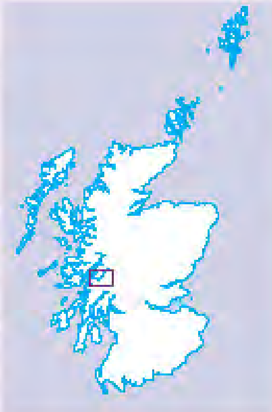
Key
- Dam
- Power Station
- Surge Tower
- Valve House

Kinlochleven (1909)

Architects and engineers	Thomas Meik & Sons, construction engineer Sir Robert McAlpine.
Components	Blackwater Dam, sealed concrete aqueduct, intake gatehouse, penstocks, powerhouse. The site formerly included an adjacent smelter (now demolished) and carbon silos (now redeveloped into an indoor climbing centre).
Installed capacity on completion	25,725 KW

The powerhouse at Kinlochleven with penstocks carrying water through to the turbines inside.

The Kinlochleven water power scheme for BAC was a major technological achievement on its completion in 1909, with an installed capacity of internationally important proportions. The site retains six of the original turbines and generators and the system is still in use to generate power. The smelter closed in 1990 and the site has been subject to redevelopment, including the construction of an indoor ice climbing wall in the former carbon silos.



Key
- Dam
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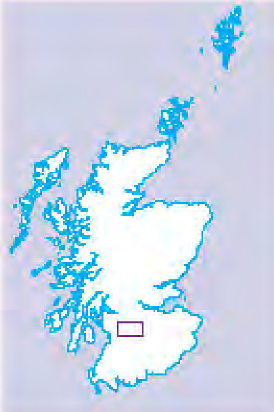
Falls of Clyde (1925–7)

Architects and engineers	Sir Edward MacColl with advice from Amenity Committee consisting of the Earl of Home, Sir John Stirling Maxwell of Pollok and Sir Robert Lorimer, architect; plans and specifications by Messrs Buchan & Partners, engineers; Sir William Arrol & Co civil engineering contractors; the English Electric Company hydroelectric plant.
Components	Bonnington tilting weir; Bonnington Power Station including surge tower; Stonebyres tilting weir; Stonebyres Power Station including surge tower.
Installed capacity on completion	15,520 KW



Stonebyres power station, designed in the Modernist style and almost identical to that at Bonnington located upstream.

The Falls of Clyde scheme is the earliest large-scale scheme for public supply in Britain. The scheme is also of considerable technical importance as an example of run-of-the-river technology being utilised for power generation in a spectacular landscape setting. The Falls of Clyde development consists of two nearly identical power stations at Bonnington and Stonebyres, both of which utilise the flow of the River Clyde for power generation.

Key
- Dam
- Power Station
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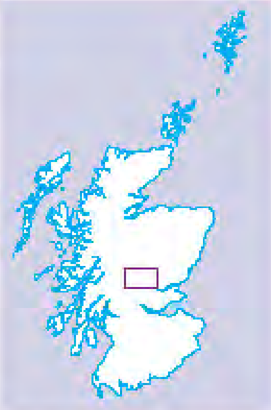
- Valve House

Tummel Bridge and Rannoch (1933)

Architects and engineers	Sir William Halcrow consulting engineer, Balfour Beatty engineers and contractors.
Components	Loch Ericht Dam, Rannoch valve house, Rannoch Power Station, Dunalastair Dam, Tummel aqueduct, Tummel Bridge Power Station.
Installed capacity on completion	82,000 KW (Combined total)

Rannoch Power Station, designed in a Classical Modernist style.

The Grampian Hydroelectric Scheme was the first major public supply development which utilised high-head reservoir storage technology. The geography of the Tummel valley was well suited to the development of a hydroelectric scheme, but local demand for electricity was insufficient to justify its completion. The development of the national grid in the mid-1920s meant that power generated in the Highlands could be exported to the populous central belt.



Key
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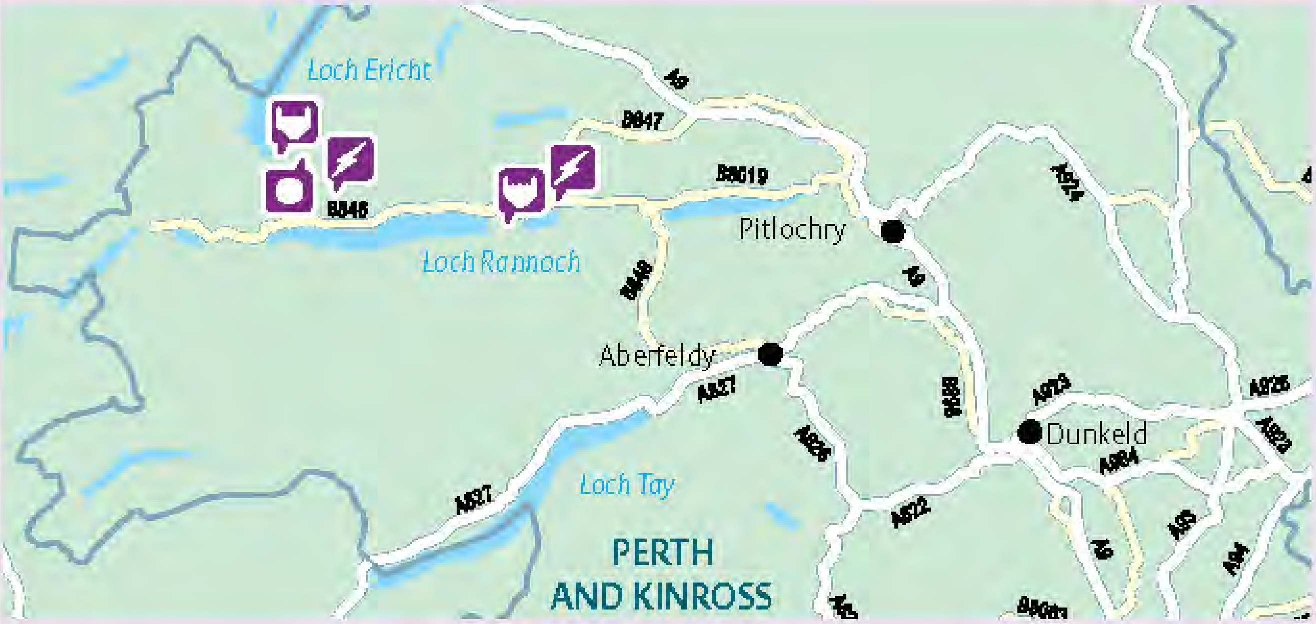
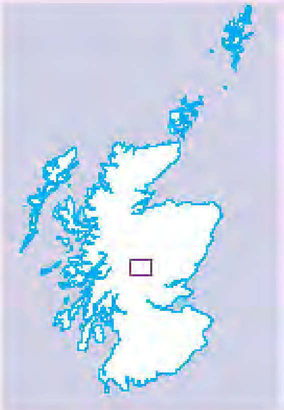


Lochaber (1929-34)

Architects and engineers	William Halcrow, supervising engineer; Balfour Beatty general engineers.
Components	Laggan Dam, Loch Treig Dam, penstocks, Lochaber powerhouse and adjacent smelter and Loch Spey Dam (1943).
Installed capacity on completion	86,750 KW

Laggan Dam which provides key storage capacity for the Lochaber scheme.

The Lochaber water power scheme for BAC was one of the most ambitious civil engineering projects of the 20th century in Britain. The development included a pioneering dam at Loch Treig and required a tunnel to be blasted under the shoulder of Ben Nevis. The installed capacity of the scheme was internationally significant and not bettered until 1950. The scheme is still in operation today, providing power to the adjacent aluminium smelter.



Key

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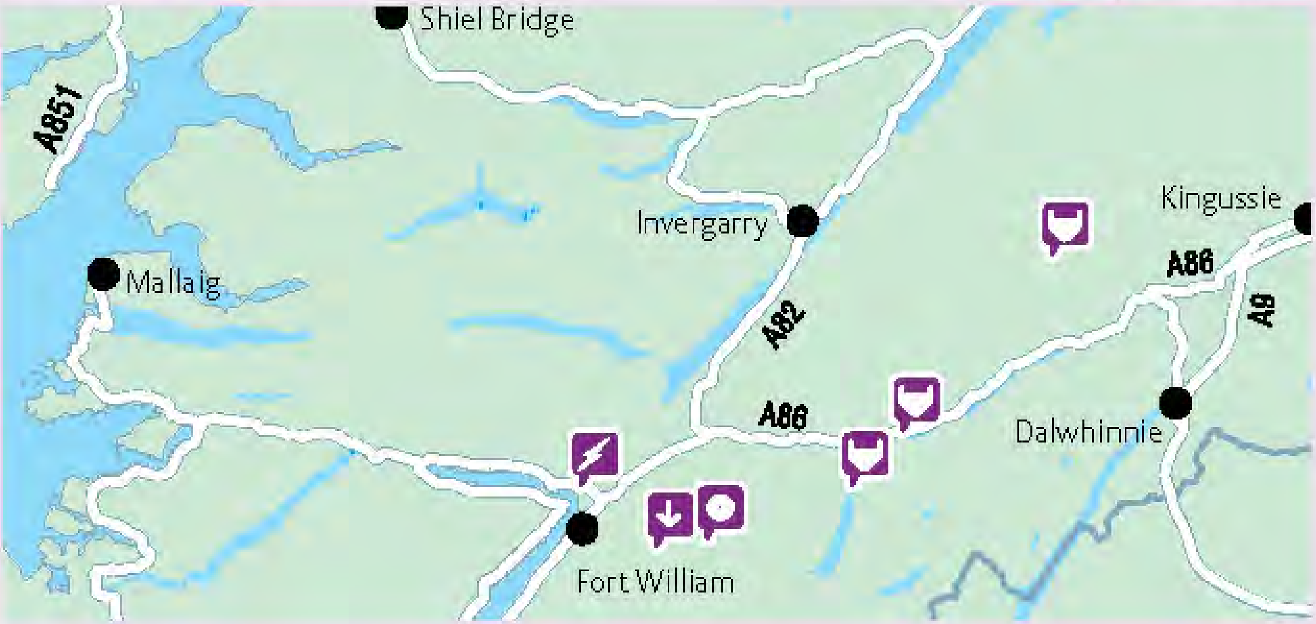
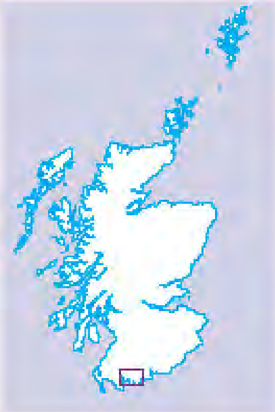


Galloway (1934–6)

Architects and engineers	Sir Alexander Gibb consulting engineer, Merz & McLellan electrical engineers, Payler & Son (Glasgow) construction engineers.
Components	Loch Doon Dam, Kendoon Dams, Kendoon Power Station, Kendoon Surge Tower, Carsfad Dam, Carsfad Power Station, Earlstoun Dam, Earlstoun Power Station, Clatteringshaws Dam, Glenlee Power Station, Glenlochar Barrage, Tongland Dam, Tongland Power Station.
Installed capacity on completion	102,000 KW (aggregate total for whole scheme)

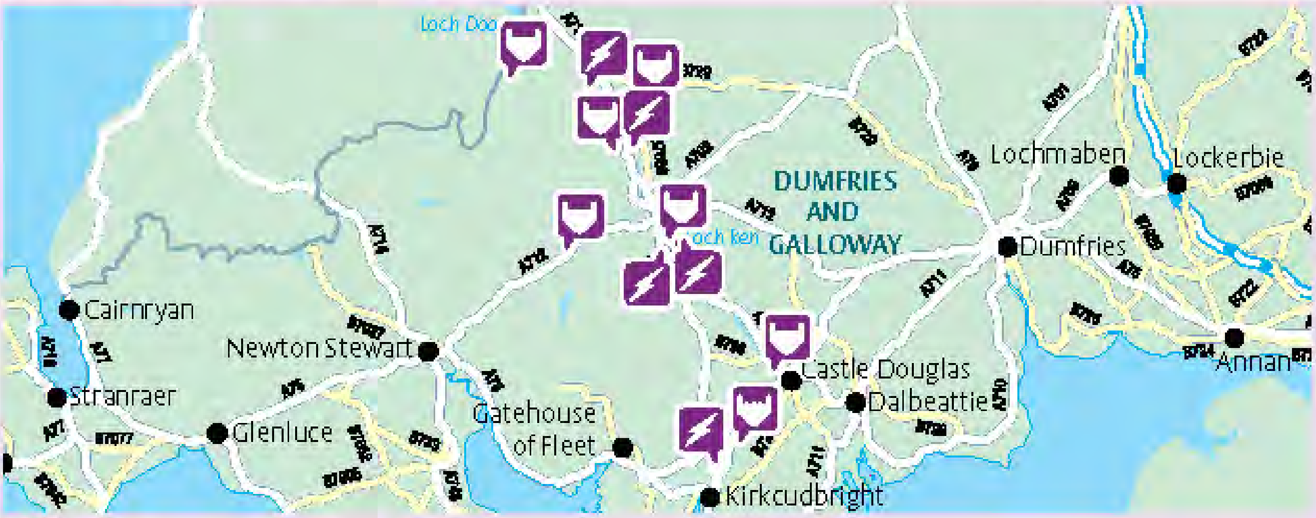


Interior of Kendoon power station, one of 5 power stations on the scheme.

The Galloway scheme was a pioneering development using hybrid run-of-the-river technology, specifically designed to be highly responsive to spikes in demand on the national grid. It was a significant achievement, something which many sceptics had thought would not be possible. The design is highly efficient with water having been used up to four times to generate power by the time it reaches Tongland at the bottom of the scheme.

Key

- Dam
- Power Station
- Surge Tower
- Valve House



Post-1943 Schemes

Timeline post-1943

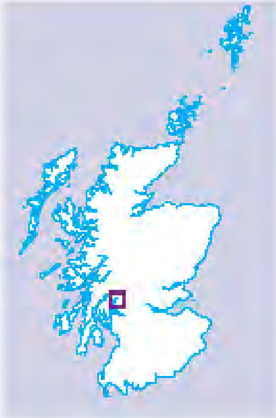
1943	**Hydro Electric (Scotland) Act**
1944-59	**Sloy / Awe**
1951-8	**Tummel Valley**
1952-63	**Affric-Beauly**
1957-61	**Conon Valley**
1957	**Great Glen**
1960	**Loch Shin**
1961	**Breadalbane**
1965	**Cruachan**
1969-75	**Foyers (conversion to pumped storage)**

Sloy / Awe (begun 1944, expanded 1951 and 1959)

Architects and engineers	James Williamson & Partners engineers, NoSHEB Amenity Panel.
Components	Sloy Dam, Sloy Power Station, Allt-na-Lairige Dam and Power Station, Clachan Power Station, Sron Mor Dam and Power Station, Inverawe barrage, Inverawe Power Station, Nant Power Station.
Installed capacity on completion	341.9 MW (aggregate total for whole scheme)

Allt-na-Lairige Dam, the first in Western Europe to use pre-stressed concrete for construction.

The Sloy scheme was the first major development undertaken by the North of Scotland Hydro Electric Board (NoSHEB) following their inception in 1943. The initial phase of the scheme, completed in 1951, was relatively modest in size compared to the later extension, with a single dam and power station at Sloy on the banks of Loch Lomond. The bold Classical Modernist design emphasised the confidence of NoSHEB in their new venture.



Key
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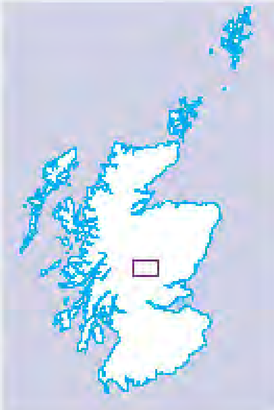
Tummel Valley (begun 1951, expanded 1955 and 1958)

Architects and engineers	James Williamson & Partners engineers, NoSHEB Amenity Panel, including James Shearer
Components	Pitlochry Dam and integrated Power Station, Clunie Dam, Clunie Power Station, Errochty Dam, Errochty Power Station, Trinafour Power Station, Guar Dam, Guar Power Station, Cuaich Dam, Cuaich Power Station.
Installed capacity on completion	163.7 MW (aggregate total for whole scheme excluding pre-1943 components)

Errochty Power Station, designed by James Shearer and an archetypal example of his use of exposed coursed local stone facings.

The Tummel–Garry scheme was a development incorporating the pre-existing infrastructure from the pre-1943 Rannoch and Tummel schemes with several phases of expansion to create a scheme with nine power stations spread over a large geographic area. The scheme operates as a cascade down the Tummel Valley, with water reaching Pitlochry Power Station likely to have previously gone through up to five power stations higher up the scheme.



Key
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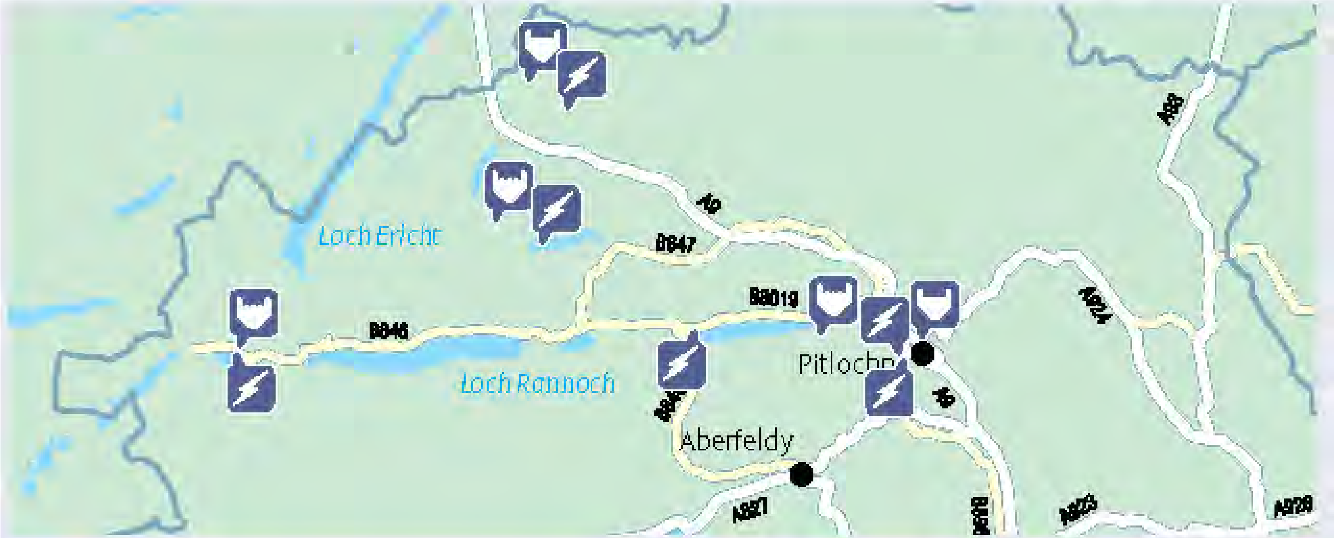
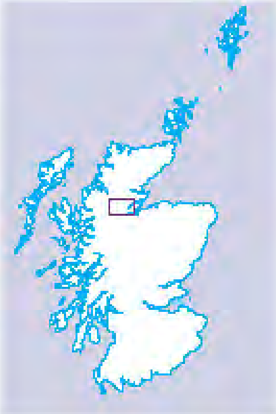


Affric–Beauly (1952, expanded 1963)

Architects and engineers	James Williamson & Partners engineers, NoSHEB Amenity Panel.
Components	Mullardoch Dam, Mullardoch Power Station, Fasnakyle Power Station, Monar Dam, Deanie Power Station, Loichel Dam, Beannachran Dam, Culligran Power Station, Aigas Dam, Aigas Power Station, Kilmorack Dam, Kilmorack Power Station
Installed capacity on completion	168.4 MW (aggregate total for whole scheme)



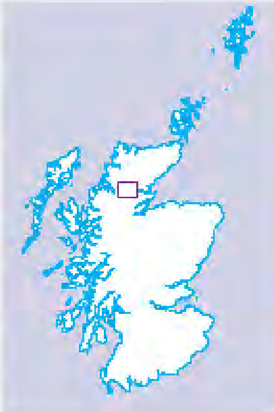
Kilmorack power station is at the bottom of the scheme and is integrated into the dam which regulates the follow of the River Beauly.

The area of the upper tributaries of the Beauly River was identified as early as 1918 as a potential site for hydro. The Affric–Cannich section of the scheme was developed initially and with great regard to scenic amenity, with the upper reaches of the valley containing remnants of Caledonian pine forest. In the later northern section, Loch Monar is a double-arch dam, unique in Scotland.

Key
- Dam
- Power Station
- Surge Tower
- Valve House

Conon Valley (1957, expanded 1961)

Architects and engineers	James Williamson & Partners engineers, NoSHEB Amenity Panel.
Components	Fannich Dam, Grudie Bridge Power Station, Glascarnoch Dam, Vaich Dam, Mossford Power Station, Bran barrage, Achanalt Power Station, Meig Dam, Luichart Dam, Luichart Power Station, Torr Achilty Dam, Torr Achilty Power Station, Orrin Dam, Orrin Power Station.
Installed capacity on completion	107.3 MW (aggregate total for whole scheme)



Orrin power station receives water from Orrin dam and is set into a steep bank with a partially buried turbine to maximise the head of water.

The Conon Valley scheme was developed in three phases between 1946 and 1961 with seven dams and associated power stations utilising a broad catchment from near Ullapool in the north, to Dingwall in the east and Achnasheen in the west. The scheme contains some unusual fish passes, including that at Orrin which is composed of four parallel chambers to accommodate frequent changes in water level which characterise this dam.

Key
- Dam
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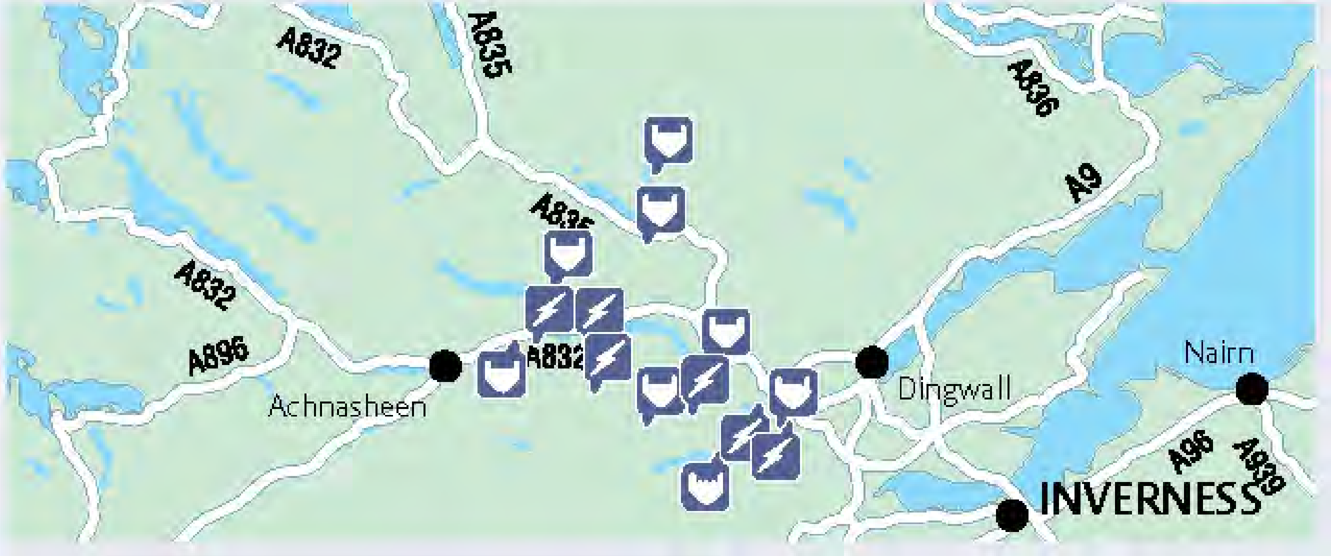
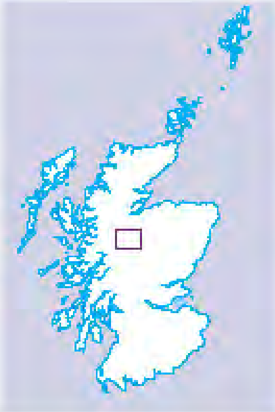


Great Glen (1957)

Architects and engineers	James Williamson & Partners engineers, NoSHEB Amenity Panel.
Components	Quoich Dam, Quoich Power Station, Garry Dam, Invergarry Power Station, Loyne Dam, Cluanie Dam, Ceannacroc Power Station, Dundreggan Dam, Glenmoriston Power Station, Livishie Power Station
Installed capacity on completion	110 MW (aggregate total for whole scheme)

Invergarry power station contains a single high load factor turbine, using water with a low head from the nearby dam.

The Garry–Moriston scheme is centred on the area to the west of Fort Augustus in one of the wettest areas of the UK. Loch Quoich is the main storage for the southern section of the scheme and is the largest rockfill dam in Scotland. Ceannacroc Power Station was the first in the UK to be built underground, with the bare walls of the machine hall showing the hewn rock.



Key
- Dam
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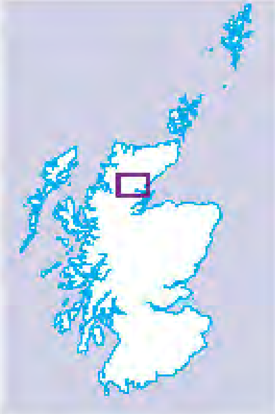
- Surge Tower
- Valve House

Loch Shin (1960)

Architects and engineers	James Williamson & Partners engineers, NoSHEB Amenity Panel.
Components	Lairg Dam, Duchally weir, Lairg Power Station, Shin Power Station and Dam, Cassley Power Station.
Installed capacity on completion	32.1 MW (aggregate total for whole scheme)

The Loch Shin Power Station is incorporated into the dam and is directly opposite the small village of Lairg.

The Loch Shin scheme is the most northerly of the HEP schemes in Scotland and is situated in an area of lower relief, giving it a relatively modest output for the size of catchment. The scheme is centred around Loch Shin with the diverted headwaters of the Cassley and Brora rivers. As the small station at Duchally is so remote it is operated automatically by the water level and control gates.



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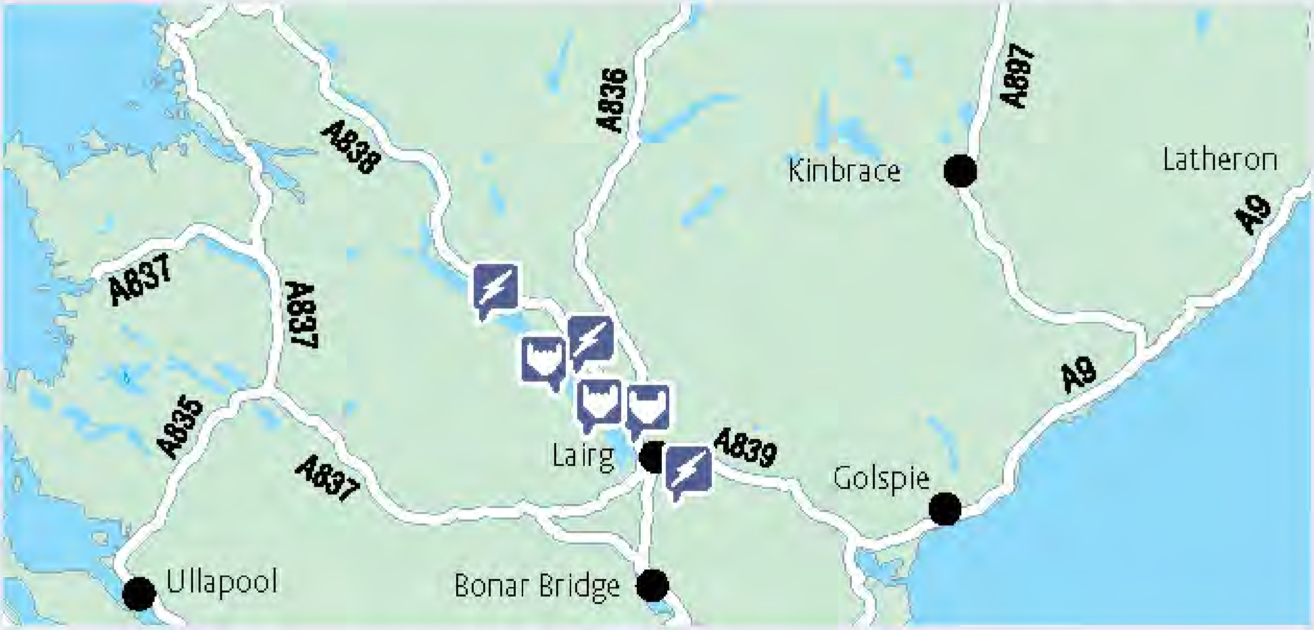
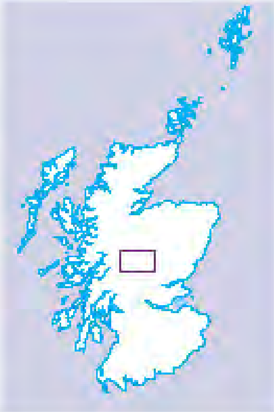


Breadalbane (1961)

Architects and engineers	James Williamson & Partners engineers, NoSHEB Amenity Panel.
Components	Ben Lawers Dam, Finlarig Power Station, Breaclaich Dam, Lednock Power Station, Lednock Dam, St Fillans Power Station, Dalchonzie Power Station, Lubreoch Power Station, Lochay Power Station, Cashlie Power Station, Giorra Dam, Stronuich Dam.
Installed capacity on completion	100.3 MW (aggregate total for whole scheme)

Dalchonzie power station, an example of a smaller station forming part of the Breadalbane scheme.

This scheme is located in an area well suited to HEP with steep relief and high levels of rainfall. Behind Ben Lawers a system of pipes and tunnels collects water, diverting it into Lochan-na-Lairige. Water then descends 415 metres (the largest head of any Scottish HEP scheme) to Finlarig Power Station on the shores of Loch Tay. The scheme also contains an unusual diamond-headed buttress dam at Lednock.



Key

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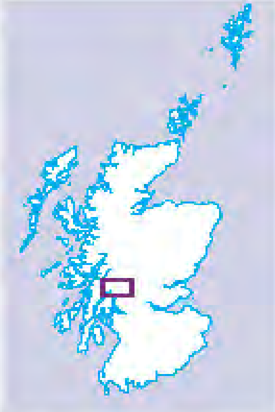
Cruachan (1965)

Architects and engineers	James Williamson & Partners engineers, NoSHEB Amenity Panel.
Components	Ben Cruachan Dam, Ben Cruachan turbine hall (contained in an underground chamber).
Installed capacity on completion	440 MW

The turbine hall of Cruachan Power Station, buried deep in an excavated cavern beneath the mountain.

Cruachan Power Station is a pioneering example of pumped storage and the first to be built on this scale in the UK. Water is received via pressure pipeline from Ben Cruachan Dam (above the turbine hall) and is used to generate power. At periods of cheap electricity the turbines are run in reverse to pump water back from Loch Awe to the reservoir. It can then be used subsequently for further generation.



Key

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Foyers (1969–75)

Architects and engineers	James Williamson & Partners engineers, NoSHEB Amenity Panel .
Components	Loch Eilde Mor, River Foyers intake (both part of 1896 scheme), Foyers pumped storage power station
Installed capacity on completion	200 MW
	Foyers Power Station is an example of pumped storage technology. The existing infrastructure for the 1896 scheme developed by the British Aluminium Company was redeveloped to provide the water storage required for the pumped storage scheme. Much like Cruachan (see previous), Foyers can respond to peak demands for electricity, and is able to begin generating from a cold start in under two minutes, or from a 'spinning reserve' in under 30 seconds.

Key

- Dam
- Power Station
- Surge Tower
- Valve House

Post-1943 Smaller schemes

Glossary

arch dam – a concrete or masonry dam which is curved in plan so as to transmit the major part of the water load to the abutments

barrage – a dam-like structure composed of gates which can be raised or lowered depending on the water level; often used in areas of flood risk

buttress dam – a dam consisting of a watertight upstream part supported at intervals on the downstream side by a series of buttresses

compensation set – a small turbine generating electricity from the water supplied to the river below a station to maintain the flow of the river downstream

discharge – the volume of water that passes a given location within a given period of time; usually expressed in cubic feet (or cubic metres) per second

catchment – the area surrounding a hydro scheme from which water is gathered via natural flow and commonly a series of aqueducts and pipes feeding into reservoirs

fish ladder – a device made up of a series of stepped pools, similar to a staircase, that enables adult fish to migrate up the river past dams, sometimes incorporated into the structure of a dam or power station

generator – machine for power generation, usually connected with a turbine. The kinetic energy of the turbine shaft generates electricity in the generator. This is caused by the movement of an electrical conductor in a magnetic field.

gravity dam – a dam constructed of concrete and/or masonry which relies on its mass for stability

high-head scheme – a hydro scheme which uses a reservoir at a higher level than the power station, with the fall of water in between generating the required pressure to turn the turbines. The scheme can include multiple dams and power stations operating as a cascade, such as at Glen Affric

hydro scheme – a set of components, consisting of a dam, penstock and power station containing turbines, which function together to generate electricity from water power

intake – point of diversion of stream flow into a conduit or irrigation system conveyance

NoSHEB – the North of Scotland Hydro Electric Board, who were responsible as a government organisation for the promotion and development of a range of schemes across Scotland following their creation in the 1943 Hydro-Electric Development (Scotland) Act

penstock – a large pipe or conduit to carry the water from the reservoir or dam to a turbine or water wheel

powerhouse – the building downstream of the dam which houses the turbines and generating equipment; usually associated with industrial power generation, such as for aluminium smelters at Kinlochleven

power station – the building located downstream of a dam or penstock which houses the turbines and other plant and equipment; usually associated with the generation of power for supply to the national grid

pumped storage – a hydro scheme similar to a high-head scheme where the turbines can be run in reverse to pump water back up to the storage reservoir for reuse at a later date, such as at Ben Cruachan

run-of-the-river scheme – a scheme which utilises the natural flow and volume of water in a river to generate power, such as the Falls of Clyde; commonly there is no storage or impoundment of the water

smelting – an industrial process, often associated with hydropower, to produce a metal such as aluminium through electrolysis

spillway – the structure on or at the side of a dam that contains and guides the flow of the excess water within the reservoir

surge tank or **shaft** – a vertical shaft, commonly subterranean, which contains water to maintain the pressure in the tunnel following sudden changes in pressure caused by increases or decreases in water level, thus protecting the turbines from damage

tailrace – the discharge channel from a turbine or set of turbines which guides water into the outlet (river or penstock) downstream of the power station

turbine – machinery used to convert rotary mechanical energy generated by a flow of water, commonly passing over blades or paddles, into electrical energy via an attached generator

valve house – a small building, usually at the top of a penstock, where valves are used to split water between a number of pipes, allowing isolation of the individual pipes

watt – a unit of electrical power used to measure the capacity of generation. A large commercial building will often consume several megawatts in electrical power for light and heat

weir – a low dam which is designed to provide sufficient upstream depth for a water intake while allowing flow to pass over its crest

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HISTORIC SCOTLAND
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Power to the People:
The built heritage of Scotland's hydroelectric power

The significant and early development of hydroelectric power in Scotland results not least from its combination of topography and weather. But this potential would not have been realised without the pioneering vision of a handful of architects, engineers and politicians whose personal energy and skills meant that Scotland has led the world in the development of this green energy source at various times in its history. This book traces the development of the industry through the ground-breaking technical achievements realised by Scottish engineers and the important contribution of a number of distinguished pre- and post-war Scottish architects.

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SCOTTISHPOWER

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