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# Historical perspectives of engineering project design, organisation and management: construction of the Elan Valley dams

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The Elan Valley estate is situated within mid-Wales, Great Britain. It represents a watershed of approximately 70 square miles and accommodates four dams built at the turn of the twentieth century, along with another completed in 1952. Combined, these supply the city of Birmingham, England, with a significant proportion of its fresh clean water. The dams' engineering design and construction represented a project that overcame huge logistical, technical and management challenges and in so many ways, therefore, was contemporaneously innovative, imaginary and monumental. That project is qualitatively analysed through extant and especially historical literature, complemented with other archive materials. Findings that relate to exemplar engineering project design, organisation and management (EPDOM) of the time are highlighted. By discussing some of these in light of modern engineering convention, observations on EPDOM evolution are made, in addition to providing an historical engineering perspective per se.

*Keywords*: Engineering infrastructure, historical analysis, project organization, management.

## Introduction

> [Elan dam engineers must] *have a clear conception of the work before them. In building a dam they ought never to lose sight of the fact that the execution should always be better than the conception.* (Barclay, 1898)

Representing an area some 14.5 km (9 mi) from west to east and 10.5 km (6.5 mi) north to south (Powys, 2012a), the Elan Valley estate accommodates five dams and associated reservoirs with a total water catchment area of about 180 km$^2$ (~70 mi$^2$) (Elan, 2012). The dams are constructed within the valleys of the estate's river Elan and (its tributary) river Claerwen, which drain the watershed into the nearby river Wye (cf. Lees, 1908, plate 1). The estate is situated approximately 5 km (3 mi) west of the small market town of Rhayader, which in turn is located within the county of Powys in mid-Wales, Great Britain. Its central position is approximated by grid reference SN 86894 67809 and may be viewed on the web as a map or satellite image, using the hyperlink provided in UKGRF (2013), within the list of references.

This location was carefully chosen because of four geographic features that rendered it particularly suitable for several engineering needs of the project. These features were

- narrow valleys—that made selection of the dams' positions (and their construction) easier;
- impermeable bedrock—appropriate for the storage of large volumes of water;
- a high altitude—thereby meeting the (principal stakeholder's) requirement for a gravitational water supply from source to point of discharge (see later); and
- a high annual average[1] rainfall across the watershed (Elan, 2012).

Construction of the four 'first phase' dams occurred at the turn of the twentieth century, commencing in

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1893 and being officially opened by King Edward VII accompanied by Queen Alexandra, on 21 July 1904 (Powys, 2012b). The second phase of construction—that originally planned for three, but ultimately comprised one further dam—commenced in 1946 and was opened by Queen Elizabeth in 1952 (Powys, 2012a).

Design and construction of the dams was reported at the time as '…elaborately planned and executed … ' (Bruce *et al.*, 1912, p. 79) and the 'largest piece of engineering work … in the whole world' (Wrexham Advertiser and North Wales News, 1893, p. 5). They represented a hugely innovative engineering solution, to help satisfy Britain's second city of Birmingham's increasing demand for clean fresh water (Barclay, 1898, ch. 1) (see also Severn Trent Water, 2009). These kind of innovative, imaginative and monumental characteristics of the project as a whole perhaps underline why Unwin *et al.* (1912, p. 58) suggested that '… valuable lessons were to be learned from it'.

As evidenced during their construction, the dams' engineering project design, organization and management (EPDOM) aspects were equally innovative, regarding, for instance, solutions employed to solve the many major engineering challenges presented by the project. These included to source, transport and place as much as 1000 ton of raw materials per day (Clwyd-Powys Archaeological Trust, 2012), which in turn involved stone blocks typically 10 ton [*sic*] in weight (Victorian Powys, 2012); to effectively manage the 5000 men who were needed to build the dams and their viaduct at any one time (Birmingham Daily Post, 1900a), or the 50 000 men employed in total throughout the project's life (Elan, 2012); and to manage the many varied machinery and other equipment essential to complete such a major undertaking (Bruce *et al.*, 1912, p. 72).

## Aim and rationale of the study

Given this background, the overarching aim of this study was to identify and explore major EPDOM innovations, employed in phase 1 of the Elan Valley dam's construction project. This aim refers specifically to the dams and does not include their associated gravity feed and syphon water delivery system to Birmingham—because, albeit part of the overall scheme, engineering challenges and characteristics relating to the latter are quite different in nature and will, therefore, be studied separately. Two objectives related to the said aim were to (i) contrast these innovations with modern engineering conventions, to help position and contextualize them; and (ii) based on the results of this, consider the EPDOM 'evolution' over the last century. Particularly, regarding Cossons' (2012) assertion, that engineers have become more specialized and professional with the passing of time.

Additional to these 'engineering' foci, incidental insights into the 'politics' of the nineteenth-century dam building help supplement knowledge in this area, which has been neglected in the literature (Coopey, 2000). Further, given a dearth of historical construction research per se (Janberg, 2013) and that of building history in particular (University of Cambridge, 2013), the study also addresses this void. There are nonetheless *some* centres of activity in this field, such as the *Construction History Society* in the UK (CHS, 2013a) who also publish an annual journal (CHS, 2013b) and the *Construction History Society of America* (CHSA, 2013). Other publications devoted to dams include *Bulletins and Congress Proceedings* produced by the *International Commission on Large Dams* (ICOLD, 2013) and the official publication of the *British Dam Society* titled Dams and Reservoirs (2013). These kinds of publication do host historical research, but generally, historical engineering studies are dispersed throughout the construction and engineering literature (see, for instance, Ashurst, 1990; Pheng, 2001; Potts, 2009).

## Research methods used and the nature of underpinning data

Being an historical case study (Gerring, 2007, p. 17), the research synthesized contemporary and historic literature along with qualitative analysis of archive, especially news material (cf. Yin, 2009, pp. 102–3). Literature synthesis is a fundamental research tool (for instance, see O'Leary, 2004; Walliman, 2006; Fink, 2010) and as such a prerequisite to most studies. However, in a historical context such as this, it becomes the prime method, whose *raison-d'être* (cf. Levin, 2007, p. 75) is to meet the research aim, given that empirical inquiry is not possible.

Data were captured from extant literature identified mainly through the web, often having being grouped within specialist subject clusters such as in the *Elan Valley Trust* (Elan, 2012); the Clwyd-Powys Archaeological Trust (2012) and the *Powys Digital History Project* (Powys, 2012a). Archive photographic material was observed (and can be viewed at leisure by the interested reader) from the *Royal Commission on the Ancient and Historical Monuments of Wales* website (Royal Commission, 2013), while archive news material was sourced electronically, mainly through the *Nineteenth Century British Newspapers* and *Times* digital archives (University of Central Lancashire, 2013). Some works were particularly insightful and these include Barclay's (1898) detailed treatise on Birmingham's water supply; description of the ('Elan supply') works by Lees (1908); photographic archive material within Morton's (1997) book and several items obtained from the *Institution of Civil Engineers* (ICE, 2013) virtual library.

Data from these combined sources embraced the qualitative and empirical, but all were explicit and analysable according to the cognitive view (Akerhurst *et al.*, 2011, p. 185)—which explains why literature synthesis is a form of knowledge development (Holt, 2013, p. 52) and especially as here, if sources are triangulated (Edwards and Holt, 2010). Synthesis focussed on the themes of project design (including social underpinnings and technical solutions); organization (including issues of procurement and the substantial human resources employed) and management (especially relating to logistics, construction methods and equipment used). For each of these constructs, their conceptual features were considered (cf. Bazeley, 2007, p. 105). While 'conceptualization' is a less formal hermeneutic (Jasper, 2004) than (for instance) open coding (Babbie, 2012, ch. 13), thematic analysis of this kind is an accepted and frequently used qualitative method (Grbich, 2009, p. 18).

## The need for and formalization of the Elan Valley project

Prior to having too much water (Darteh *et al.*, 2012), at the end of the nineteenth century, Birmingham's City Council Water Committee stated that the requirement for increased supply was a '...grave problem with which we must face' (Barclay, 1898, p. 25). The population census of England and Wales 1891 identified that Birmingham had approximately 480 000 inhabitants (Birmingham City Council, 2013), which meant that it had to provide its consumers with '6,141 million gallons [27,917 million litres] of water for the year ending March, 1891, sufficient to form a lake 3ft [~0.9 m] deep, with a surface area of 12 square miles [~31 km$^2$]' (Barclay, 1898, p. 2).

Birmingham's water problems circa 1890 had been (were to continue to be) exacerbated by its success as an area of growing industrialization (Powys, 2012a), for not only did industry itself require more water but its concomitant (increasing) demand for labour meant that population growth was inevitable as workers took jobs in the new factories and mills (Powys, 2012a). So poor was the situation in January 1891 that the Water Committee met to discuss the ' ... exceptional demand arising out of the frost' and to agree that the water engineer should '...stop the supply at his discretion [and] ... prosecute persons who wilfully waste the water' (Birmingham Daily Post, 1891). Water supply problems frequented the reporting of Birmingham Council matters in local newspapers of the time (Birmingham Daily Post, 1895).

The Corporation were aware that the 'problem' would only get worse as the city's population increased[2] and were probably mindful too that inadequacy of supply led to polluted water and resultant diseases such as typhoid, cholera and diarrhoea (Clwyd-Powys Archaeological Trust, 2012). At about 1890, Birmingham's daily water consumption for all domestic and industrial purposes combined, approximated to 23 gallons (~105 litres) ' ... per head' and was rising at about 3% per annum (Barclay, 1898, p. 5). It was estimated that '25 years hence there would probably be required 11 million gallons [50 million litres] of water more than our present supply can yield, and in 50 years 38 million gallons [172 million litres] more' (Barclay, 1898, p. 7). Resultantly, the city engineer Mr Gray along with a well-known engineering expert Mr James Mansergh (1834–1905) (Morton, 1997, pp. 57–59; Oxford, 2012) were asked to advise how this predicted shortfall might be overcome (Barclay, 1898, p. 7; see also Turpin, 2008, pp. 74–76). Mansergh had earlier (circa 1871) advised Birmingham on its water supply (Coopey, 2000) and would later become Senior Engineer for the Elan Valley project with the ultimate responsibility for its design and management (Barclay, 1898, p. 129).

Mansergh's early surveys of the Elan estate and the possibility of dammed reservoirs being constructed there had been reported positively in the local press: 'If the great work is carried out it will be an excellent thing for the town of Rhayader and its vicinity ... the great works will be of great advantage in this district' (Western Mail, 1890). One might wonder if an element of public relations underpinned this style of reporting, given that strong feelings against the scheme existed among the indigenous population (indeed, beyond). Such feelings were fed by perceived imminent ill effects on local business; loss of property to the area to be inundated by the reservoirs, including a chapel, church, graveyard, farmhouses, cottages, barns and *Cwm Elan* the renowned past residence of the poet Shelley (Western Mail, 1900); and negative impact on other interests such as fishing and general access (Coopey, 2000, p. 377). These would later surface as formal objections to the Bill placed before parliament, for the project. For instance, opposition from a 'Welsh standpoint' [*sic*] (Barclay, 1898, p. 105) by Thomas Ellis M.P. urged '...the Bill should be stopped, on the ground that the water of Wales should be left for the Welsh people' (Barclay, 1898, p. 105).

Notwithstanding Mansergh's suggesting the Elan estate as a panacea to Birmingham's water problems (though it is reported, his ideas were formative 30 years prior (see Webber, 1901; Unwin *et al.*, 1912, p. 58)), voices of support remained for expansion of Birmingham's well system as an alternative (Barclay, 1898, pp. 101–102). These, however, were overcome mainly for reasons of inadequate supply volume and longevity

—although increasing cost of well pumping due to rises in coal prices and the maintenance of engines and boilers was also a factor (cf. Birmingham Daily Post, 1900b). Ultimately, based on the guidance afforded by likes of Mansergh and Gray, Birmingham summarized conditions of its coming to terms with an impending water famine as a requirement for good quality water not likely to deteriorate; sufficiency (of supply) for the next 50 years and sourced from a region high enough in altitude, to supply the city by gravitation as far as is possible (Barclay, 1898, p. 25).

The resulting source '…to which all the experts … without any hesitation, give the preference … is the basin of the Elan and Claerwen (clear white) streams' (Barclay, 1898, p. 29). Based on engineers' reports and cost/savings estimates (cost is further discussed later), Birmingham City Council authorized the Birmingham Water Committee to promote the scheme via a Bill in Parliament and set up agreements for purchase of the necessary land (Barclay, 1898, pp. 56–57). The resulting Act that authorized the project was the *Birmingham Corporation Water Act* (*1892*) (Lees, 1908, p. 3).

## Brief description of the dams and their reservoirs

To help place subsequent EPDOM discussions in context, an appreciation of the estate's dams, their physical form and associated reservoirs is useful. The following description of these may be cross-referenced with the estate map shown in Figure 1.

### Seven dams, two project phases

The original design was for seven dams (Lees, 1908, plate 1) to be constructed in two phases. Four dams represented 'phase 1' of the project. Starting with the lowest dam first and working north up the Elan river valley, they were: (1) Caban Coch dam; (2) Garreg Ddu sunken dam; (3) Pen-y-Garreg dam and (4) Craig-Goch dam. All were completed along with the foundations for Dol-y-Mynach dam between 1893 and 1904.[3] Though Dol-y-Mynach dam was not part of phase 1, its foundations are below the high water level of Caban Coch Reservoir, and so were built at this time prior to the reservoir being flooded. However, Dol-y-Mynach dam was never completed for reasons described later. Today, its foundations are submersed when the Caban Coch Reservoir is full, but visible at low water. 'Phase 2' was to involve construction of the remaining three dams, at a 'later point in time' when Birmingham's demand for water increased (Powys, 2012a). Starting with the lowest dam first and working north-west up the Claerwen river valley, these were (5) (completion of) Dol-y-Mynach dam; (6) Cil-Oerwynt dam and (7) Pant-y-Beddau dam.

Phase 2 was delayed by the intervening two World Wars, by which time advancements in construction technology—and especially regarding use of mass concrete—meant that even larger dams could be constructed (Powys, 2012a). Another reason that favoured concrete construction was the comparative increased cost of masonry (Turpin, 2008). Given these factors, the three originally planned phase 2 dams were superseded by a much larger dam, the Claerwen. This was built between 1946 and 1952, in a different position to any of the former proposed, in order to create an even bigger reservoir—Claerwen reservoir holds almost as much as the phase 1 reservoirs combined (Powys, 2012a). Also of note, albeit the Claerwen dam is of mass concrete construction, it is faced with stone to match the vernacular architecture of phase 1. As such, it became one of the last masonry-faced concrete dams built in Britain (Turpin, 2008, p. 110). Table 1 summarizes the main specifications of the Elan Valley dams.

### Project cost

The whole of the Elan project was initially estimated at £6 000 000 (Davies, n.d. p. 38; Elan, 2012), which expressed as a percentage of gross domestic product equates to a relative value of £4 650 000 000 at 2010 prices (Measuring Worth, 2012). Corresponding USD values at a 2012 exchange rate of £1 = $1.63 are $9 767 400 and $7 569 735 000, respectively (Measuring Worth, 2012). Looking at these figures in a little more detail, the preliminary estimate for phase 1 was £3 755 350, but this was later increased by £2 129 586 as a result of many factors (Lees, 1908). Two particular items added £750 000, the first being the Dol-y-Mynach dam foundations that had to be included in phase 1 for the reasons explained above. Second, there was deemed a need to construct a series of complex (physical and biological) filter beds, through which the water would pass before embarking on its journey to Birmingham. This decision was based on the experience of Liverpool Water (Powys, 2012a)—who had found that unfiltered water caused build-up of growth on the inside of iron pipes and severely hindered flow (the Elan scheme was to use a series of iron pipe aqueducts). Finally, the Senior Engineer highlighted additional cost items to include: a requirement for more substantial dam foundations; lack of indigenous building stone and costs of importing the same; and considerable labour and materials

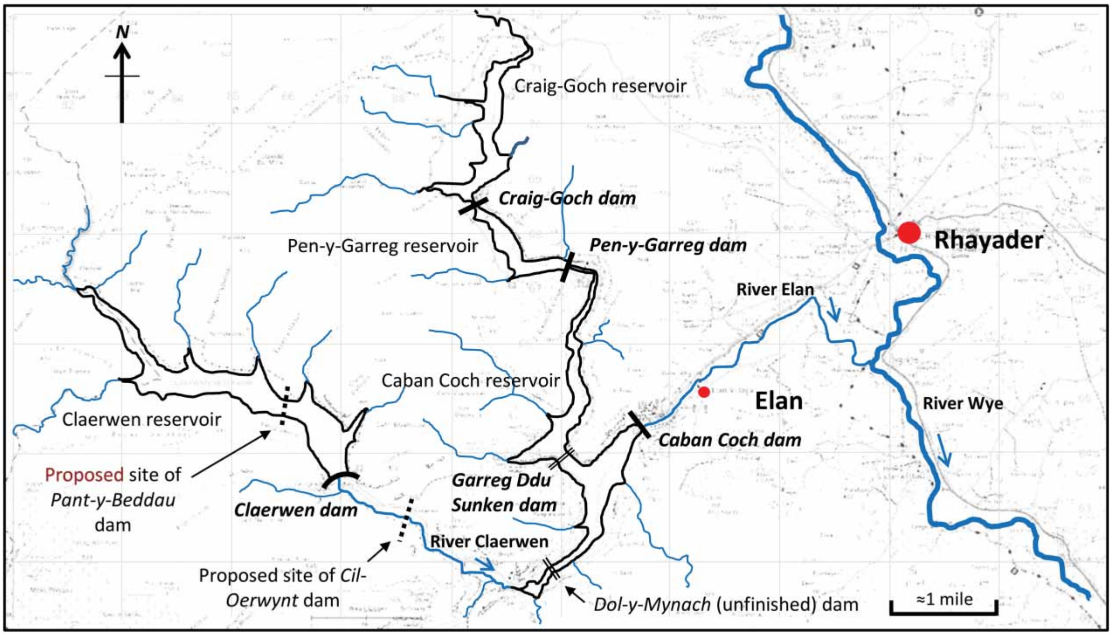

**Figure 1** Map of the dams and their reservoirs. *Source*: ©Crown copyright Ordnance Survey. All rights reserved. Reproduced with permission

inflation since original estimates. As of 1908, the actual cost of completing phase 1 stood at £5 762 853 (Powys, 2012a).

Construction costs were partly offset by savings in well pumping costs within Birmingham, of about £20 000 a year. Further, reductions in water rates from 1876 to 1891 represented a saving of £33 000 per year due to efficiencies from pumping and the Senior Engineer suggested that if a portion of these levies were re-imposed, then with the saving from pumping, this would '…be sufficient to provide the annual charges for the sinking fund and interest on capital required [for the scheme] without any addition to [water] rates' (Barclay, 1898, p. 50). The scheme was designed such that investment in phase 2 dams would not be required until increased demand dictated it; similarly, regarding investment in the many miles of additional iron pipe aqueduct that would be needed as gravitational flow rates increased.

Since 1997, the dams' capacity for generating renewable energy (maximum combined output 4.2 MW) has been realized, using turbines to generate electricity at 415 V (transformed to 11 000 V on site), which is then fed into the national electricity grid (Elan, 2012). The five completed Elan Valley dams continue to provide water to Birmingham (and a few other places too)—though feasibility studies have investigated replacement of the Craig-Goch dam with a new larger one, to significantly increase the capacity of the Craig-Goch reservoir (see 'Plans for a high dam', Elan, 2012). While this has not happened yet, it remains under scrutiny according to the Royal Academy of Engineering (2012).

## Discussion: EPDOM

The EPDOM of the Elan Valley dams was innovative and state-of-the-art for the time. In many respects, this resulted from the vision of its Senior Engineer James Mansergh, notwithstanding the bureaucratic, as well as engineering challenges he had to overcome. As Sir Alexander Binnie, past president of the ICE, noted: 'It was almost impossible to criticize … the way in which the work had been carried out' and, with respect to said bureaucracy, his apparent surprise at '…the slowness with which great ideas were carried out in England' (Unwin *et al.*, 1912, p. 58). The following EPDOM discussion considers aspects of the engineering team, project design, project procurement, management of the workforce, construction logistics/technology, and plant and machinery.

### The engineering team

As the principal stakeholder, Birmingham City Council intrusted full responsibility for the design and (technical/cost) control of the project in James Mansergh; who reported to Birmingham's Water Committee chaired by Alderman Edward Lawley Parker, Mayor

**Table 1** Brief specifications of the dams

| | | | | Reservoir area | | | Reservoir volume | | |
|---|---|---|---|---|---|---|---|---|---|
| Dam | Height | Length | Type and plan shape | Ha | Mi$^2$ | Water level full[a] | Megalitres | US gallons | Max. hydropower[b] (MW) |
| Caban Coch | 37 m | 186 m | Masonsry face, concrete/stone infill; straight | 202 | 0.78 | 250.5 | 35 530 | 9 386 033 020 | 0.95 |
| Garreg Ddu | | | Submersed dam, pillars, viaduct; masonry face, concrete/stone infill; curved | | | | | | 0.0 |
| Pen-y-Garreg | 37 m | 161 m | Masonsry face, concrete/stone infill; straight | 50 | 0.2 | 288.0 | 6055 | 1 599 561 777 | 0.81 |
| Craig-Goch | 36 m | 156 m | Masonry face, concrete and stone infill; curved | 88 | 0.3 | 317.0 | 9222 | 2 436 194 666 | 0.48 |
| Claerwen | 56 m | 355 | Masonry-faced mass concrete; curved | 263 | 1.0 | 368.8 | 48 300 | 12 759 507 600 | 1.68 |

[a] Above UK Ordnance Datum (m).

[b] Plus 0.3 MW via a turbine in the Foel Tower.

of Birmingham. In later years, Mansergh was joined on the project by his sons Ernest Mansergh MICE and Walter Mansergh MICE, who became joint engineers with him. The project's resident engineer—responsible for all work on the watershed—was George Yourdi (Morton, 1997, p. 59). Yourdi is reported to have been a man of keenness for spotting careless workmanship and one who regularly walked up and down the valleys during construction works, directing his staff in all weathers (Morton, 1997, p. 59).

## Project design

Many project design aspects were innovative in both the aesthetic and engineering contexts. For instance, with regard to the former, Figure 2 shows the Garreg Ddu (submerged) dam located within Caban Coch Reservoir. This supports a series of piers and arches to a height of approximately 24 m that in turn carry the public highway. The 'full' water level can be discerned in the figure by the slight change in stone colour along the springing line of the viaduct arches. When the reservoir is full, the submerged structure is hidden, so the aqueduct's aesthetic represents a 'low bridge' (Birmingham Daily Post, 1900a).

Figure 3 shows this sunken structure during early construction. Upon the sloping face of the sunken dam is a manual crane—the scale of the dam is brought to life by the worker standing middle-bottom of the picture. Figure 4 shows Garreg Ddu at a later stage of construction; five of the arch pillars have been completed and a timber centre has been positioned, ready for the masons to turn the stone arch. The corbelled stones upon which the timber struts (supporting the centre) sit can still be seen today at low water level (refer Figure 2). In the foreground is a manual crane anchored by stone kentledge supported on a timber platform, while workers in the background appear to be 'loading out' materials, as the labourer's hod (used for carrying bricks or mortar) seems to indicate.

The engineering design of the Caban Coch dam (the lowest on the estate—refer Figure 1) and its relationship to the submerged Garreg Ddu dam (discussed above) was particularly innovative. Just 'upstream' of Garreg Ddu submerged dam is the inlet opening to the aqueduct via the 'Foel Tower' The Foel Tower is a stone structure with inlets below the waterline, and represents the point at which water begins its gravitational journey to Birmingham. Hence, if particularly low water conditions occur, then rather than the flow to Birmingham ceasing, the submerged dam comes into effect and retains a suitable water level to continue feeding the tower. The inlet could have been placed lower down the valley nearer Caban Coch dam to achieve a similar effect, but this represented a valuable loss of gravitational head and so (it is assumed here)[4] was impractical.

**Figure 2** Garreg Ddu Combined Viaduct and 'Submersed dam'. *Source*: Geolocation (2013). ©Colin Price

**Figure 3** Garreg Ddu sunken dam. ©Crown copyright: RCAHMW

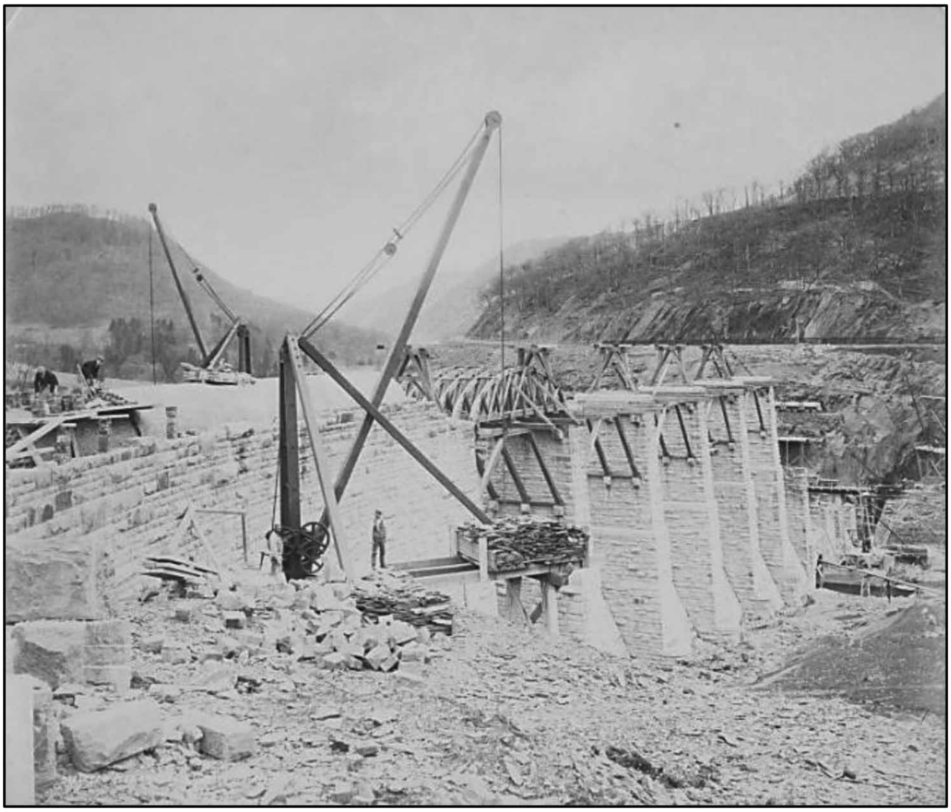

**Figure 4** Garreg Ddu Bridge Arches. ©Crown copyright: RCAHMW

### Project procurement

The procurement of the dams involved the Water Committee first having to settle

> …a most important question [that is] 'whether the whole or any part of the works should be undertaken by the [Birmingham] Corporation, they employing the necessary labour, or whether the whole should be let by tender to contractors in the ordinary way'. (Barclay, 1898, p. 1219)

Regarding 'the ordinary way' it was typical at this time to put work out to tender via open competition, on the belief that maximum competition encouraged lowest tender sum. Procurement methodology has since acknowledged that the lowest tender does not always equal the best value-for-money and so has evolved accordingly (Masterman, 1992, ch. 2; Holt, 2010).

Hence, it was a bold decision by Mansergh that the project was to be implemented by the Corporation. This was justified by the explanation:

> …it was essential that these dams be constructed in the way that would best secure their being absolutely safe and water-tight, and in view of the immense responsibility, both legally and morally, resting on the Corporation [contractors would not be used]. (Barclay, 1898, p. 130)

History demonstrates the robustness of this decision and is equally supported by contemporary views among the literature which generally accept that project control per se is better facilitated through the use of employed workers vis-à-vis contractors (cf. Dykstra, 2011, p. 310).

### Management of the workforce

Upon commencement of the works, Birmingham Corporation set about advertising for workers in newspapers, throughout the whole of Britain (Dundee Courier & Argus, 1899; North Wales Chronicle, 1899; Reynold's Newspaper, 1899). Review of these advertisements offers insight into the way workers were organized and managed. Manual workers were described as 'Navvies and able-bodied labourers…' (Reynold's Newspaper, 1899). 'Navvies' or its corresponding singular 'navvy' was an informal term originally used to describe a labourer who works on roads, railways or canals. It is a shortening of the term 'Navigator' which was also formerly used in this sense (Oxford Dictionaries, 2012).

Within the advertisements, navvies' work was stated as '…concrete mixing, and other public works duties…' that involved working hours of 'Full time, 55½ hours per week in Summer, 50½ in Winter' and for which they were paid between '…5d to 5½d an hour'[5] (North Wales Chronicle, 1899). For comparison, this amount approximates to 2.25 British post-decimal pence (£0.025), which in terms of 'economic status value' (the relative 'prestige value' of an amount of income) equates to £11 at 2010 prices (Measuring Worth, 2012) or US$18 using £1 = US$1.6 exchange rate. Hence, navvies were paid in the region of £610 (US$976) for a 55½ hour week at 2010 prices. Morton (1997, p. 70) gave further examples of remuneration levels in 1895 prices and these include (in parentheses are approximations calculated as per above): Engineer, £250 p.a. (2010 ≈ £151 200 or US$241 920 p.a.); Assistant Engineer £13 per month (2010 ≈ £7 863 or US$12 580 per month) and Stonemason maximum 10d per hour (2010 ≈ £25.40 or US$40.64 per hour). The 'value' or purchasing power of currency can be represented in various ways (Measuring Worth, 2012), so these figures are all purely indicative. Nonetheless, they suggest that workers were well paid which again underlines the importance that was placed on people, in striving to maintain the levels of quality on the project made explicit at its outset.

Upon arrival at the worksite, potential workers were first bathed and housed in the 'dosshouse' for a week to ensure their health and check for any infectious diseases before being considered for employment. If subsequently offered such, they then joined fellow workers in the Elan Village (Elan, 2012). The latter village was specifically constructed by the Corporation for employees' temporary residence while working on the project and included a hospital and a school. The village was only accessible across the river Elan via a bridge constructed for this purpose; and a bridge keeper monitored comings and goings and checked carts on the way in for illicit goods. The village had its own canteen which was in effect a public house. This was established so that the sale of alcohol could be controlled rather than allow its unauthorized purchase and unrestricted consumption. It was reported in The Times (1895) that the 'canteen' '…is an illustration of a municipal public-house [*sic*] on the lines suggested by the Bishop of Chester, and … is the only thing of the kind in the United Kingdom' (Reynold's Newspaper, 1899, p. 5).

## Aspects of construction logistics and technology

From a construction standpoint, it is interesting to first consider how the logistics of moving many tons of stone over great distances was overcome. To achieve this, a dedicated railway was constructed that ran from '…the Elan Valley junction at a point near Rhayder' (The Sheffield and Rotherham Independent, 1899) to the various points of construction. The railway was built by a contractor and it is said that problems encountered during that contract (including safety issues) was one of the reasons that the Corporation ultimately decided to employ direct labour to build the dams (Morton, 1997). The railway was used exclusively for materials and Figure 5 shows a branch line delivering stone blocks to Pen-y-Garreg dam culvert. Workmen were not allowed to travel on the railway, which seems a little odd, given that six second-hand passenger coaches were purchased at a cost (then) of £50 each, from the Great Western Railway (Morton, 1997). Perhaps these were exclusively for esteemed visitors? There were several such visits reported at the time made, for example, by the Birmingham Water Committee to view the works in progress (Western Mail, 1897; Birmingham Daily Post, 1900a).

The dams' foundations were afforded particular technological consideration. One reason for this was a belief that the earlier failings of certain dams in America was 'usually' by way of foundations giving way, in turn, attributed to the fact that ' … financial considerations were apt to prevail over engineering ones' (Unwin *et al.*, 1912, p. 59). This resonates with the trade-off faced by contemporary engineers regarding the time, cost, quality triangulate (Hacket *et al.*, 2007, Ch. 3) and somewhat reiterates the engineers' aspirations to maintain quality control through directly employed workers. This 'robustness' of construction continued as the dams progressed vertically and was described in a newspaper report (of a visit by Birmingham City Council to the project in June of 1990) as 'Cylopean masonry' (Birmingham Daily Post, 1900a). The report explained:

> The body [of the Craig-Goch dam] … is faced with dressed stones. [then within the body of the dam] Huge stones … are placed in irregular relation to one another so as to distribute the stresses, and the interspaces filled with concrete applied in a nearly fluid state and carefully rammed … as the core rises the facings are continued….

Regarding the importance of foundations explained above, the article also confirmed that

> …the dam is somewhat curved in plan, presenting its crown against the water pressure while on the lower face a sort of curvilinear water race is constructed near each bank to prevent the cataract beating into corners and damaging the foundations…. (Reynold's Newspaper, 1899)

This innovative form of dam construction was labelled the 'block system', in contrast to the more conventional

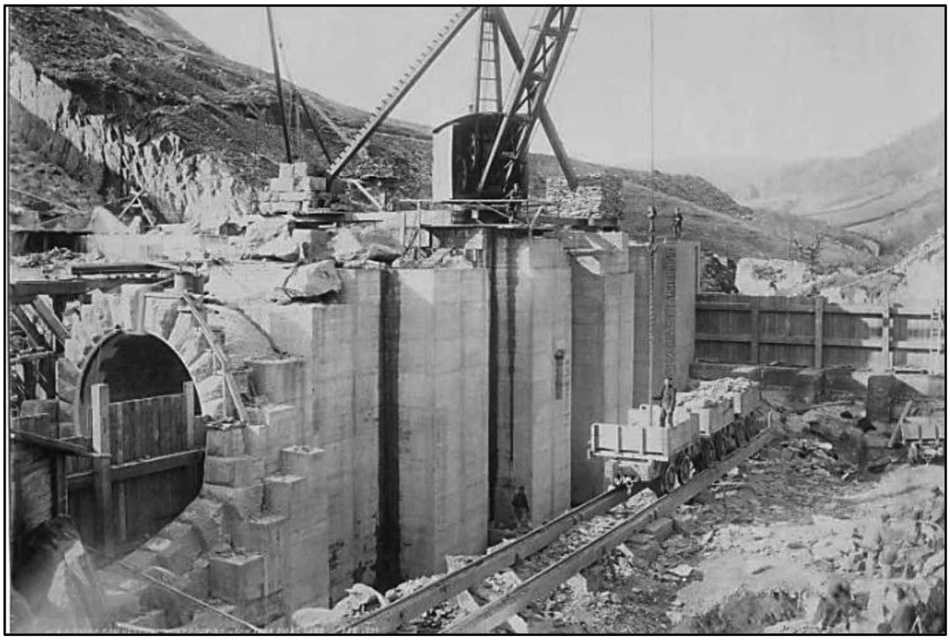

**Figure 5** Pen-y-Garreg Dam Culvert. ©Crown copyright: RCAHMW

method, known as the 'layer system'. In the latter, dam construction was restricted vertically to only a few feet (<1 m) at a time, whereas the block system ignored this restriction and in so doing, overcame the engineering difficulty of contending with thermal expansion and contraction (Unwin *et al.*, 1912, p. 62). This resulted from the block system providing '…a number of small expansion joints and prevented the structure from cracking afterwards' (Reynold's Newspaper, 1899). Less formalized placement of infill stone additionally engendered stronger ties between adjacent materials and so also provided strength (cf. Birmingham Daily Post, 1900a).

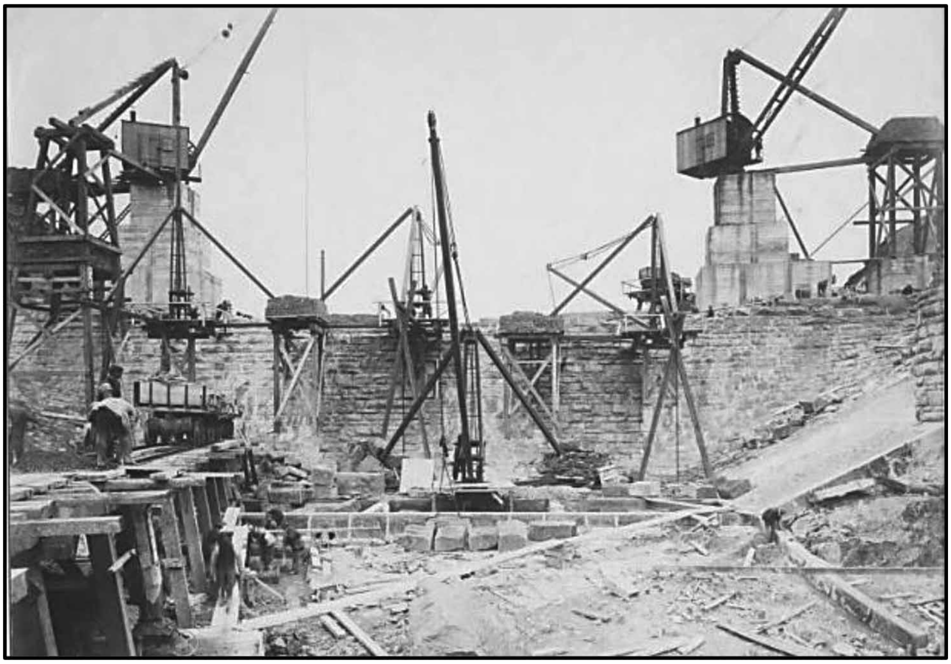

**Figure 6** Craig-Goch dam (downstream face) showing reliance on cranes during construction. ©Crown copyright: RCAHMW

### Plant and machinery

It was 'normal' at the time to employ aerial ropeways for the distribution of materials on construction work, but the project employed a high number of cranes instead, despite their being a 'costly…' item of plant (Bruce *et al.*, 1912, p. 72). The bigger work was undertaken by steam cranes though manual cranes were in abundance too. The decision to rely on craneage was based on their being more suitable to the construction conditions (Reynold's Newspaper, 1899, p. 86) and intuitively, because of the heavy loads that would be encountered (mentioned earlier, to include stones of 10 imperial tons in weight). Figure 6 shows an example of how several cranes of varying size worked together during the construction (in this instance on Craig-Goch dam) and the large number used would somewhat be a function of their limited reach and manoeuvrability in contrast to modern-day equivalents (although some of the steam cranes were rendered mobile by working them on sections of railway tracks). It is assumed (see Note 4) from Figure 6 that the two larger (highest) steam cranes have been mounted on concrete blocks (cast *in situ*) and that these blocks would remain as the random stone infill described above was constructed around them.

The use of compressed air tools were commonplace as a means to '…saving labour and time and for the furtherance of economical construction' (Barclay, 1898). This was provided by a steam apparatus known colloquially as a 'wind-jammer' that relayed its steam produced compressed air via tubes to rock drillers, hammers, and for the cleaning out of foul air in the tunnels. This was quite an innovation at the time and it was calculated that the savings from using compressed air over steam-driven tools would recover the costs of the compressed air plants over two years' usage (Barclay, 1898).

## Conclusions

The Elan Valley dams project overcame huge bureaucratic, logistical and construction challenges and in so doing, exhibited impressive EPDOM that in many ways were highly innovative at the time. It is clear that the project came to fruition as much a result of the brilliance and foresight of its Senior Engineer James Mansergh; as it did for its potential to satisfy Birmingham's growing demand for fresh water. It is reported that Mansergh had been seen surveying and sketching the Elan Valley estate—in formulating his vision for the project—some 30 or so years before it officially commenced.

Particular EPDOM features of note include the following. Notwithstanding their mass-fill construction, the dams were designed to harmonize with the local vernacular using a face of dressed stone that was imported from Glamorgan, South Wales (indigenous stone was not robust enough to withstand the water and weather erosion so this was used mainly for the stone/concrete fill). The Claerwen dam was one of the last stone-faced mass concrete dams to be built in Britain. Another significant design aesthetic is that of the sunken dam Garreg Ddu, whose viaduct appears to represent a low stone bridge at the normal water level, despite standing on towers over 24 m tall.

The project's organization similarly exhibited unique aspects. Perhaps most notably, the decision to abandon the normal procurement route of competitive tender and use of contractors, in favour of retaining full control of the project using directly employed labour. This came about on specific recommendation of Mansergh. Many other project organizational issues stand out, including the pre-employment de-lousing and health checking of workers; their subsequent on-site housing in a dedicated village with good facilities (hospital, school and social hub); and provision of a strictly managed public house to deter over-consumption of alcohol.

From a construction standpoint, the dedicated railway distribution network encouraged efficient logistics and the extensive use of craneage was a novel departure from the aerial ropeways more familiar at the time. The technology of the construction using 'cyclopean masonry' infill—the combining of large random rocks set in liquid concrete—raised in similarly random stages that contradicted the more usual 'layering' technique, proved not only to be strong, but also helped conquer the problems of heat-induced cracking due to mass-fill cement hydration.

In contrast to Cossons's (2012) suggestion, it is difficult to see how modern-day engineers have become 'more professional' than their forerunners, based on the characteristics displayed by Mansergh and his team. Modern-day engineers are in comparison, however, more specialized—mainly due to the advancement of technology among engineering specialisms (such as surveying, structural design, project control, etc.). However, when one considers that these earlier engineers did all of these things combined; often 'long hand' with little technology; employing mass human labour and minimal mechanization; only serves to reinforce their obvious skill, determination and dedication to the engineering profession.

*The Elan Valley dams remain testament to that assertion.*

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## Notes

1. Average annual rainfall for England is ~855 mm (Met Office, 2012); average annual rainfall for Elan estate is ~1830 mm (Elan, 2012).
2. The England and Wales census of 2011 confirmed that Birmingham's population had increased from 480 000 in 1891 to 1.04 million in that year (Birmingham City Council, 2013). A general treatise on economic growth and water use is offered in Cole (2004), while Warren and Holman (2012) elucidate effect of climate change on water resources for Birmingham, UK.
3. It is stated that phase 1 actually took 13 years to complete, from 1893 to 1906 but, that such was 'substantially' complete and so officially opened, in 1904 (Powys, 2012a).
4. The author would be pleased to hear from anyone who can add anything to this assumption or, any other aspect of the subject presented in this paper. Contact details are given on the title page.
5. The 'd' was used in British pre-decimal currency to signify 'pence' and under this currency there were 12 pennies (12d) to the shilling (written as 1s or 1/−) and 20 shillings to the pound (£1).

## References

Akerhurst, G., Rueda-Armengot, C., López, S.V. and Marqués, D.P. (2011) Ontological supports of knowledge: knowledge creation and analytical knowledge. *Management Decision*, **49**(2), 183–94.

Ashurst, N. (1990) Understanding dampness in historic buildings. *Structural Survey*, **8**(3), 268–77.

Babbie, E. (2012) *The Practice of Social Research*, 13th edn, Wadsworth, Cengage Learning, Belmont, CA.

Barclay, T. (1898) *The Future Water Supply of Birmingham*, 3rd edn, Cornish Brothers, Birmingham; London: Simpkin, Marshall and Co.

Bazeley, P. (2007) *Quantitative Data Analysis with N-Vivo*, Sage Ltd, London.

Birmingham City Council (2013) *Birmingham's Population* [online], available at www.birmingham.gov.uk/census (accessed December 2012).

Birmingham Daily Post (1891) The Birmingham water supply. Preventative measures against waste. *Birmingham Daily Post* (Birmingham, England), Saturday, 10 January, Iss. 10156.

Birmingham Daily Post (1895) Birmingham city council. *Birmingham Daily Post* (Birmingham, England), Wednesday, 2 October, Iss. 11635.

Birmingham Daily Post (1900a) The welsh water scheme. City council at the Elan Valley. *Birmingham Daily Post*, (Birmingham, England), Wednesday, 20 June, Iss. 13111.

Birmingham Daily Post (1900b) Birmingham Water Department. Progress of the new works. *Birmingham Daily Post* (Birmingham, England), Thursday, 17 May, Iss. 13082.

Bruce, A.F., Cornish, J.E., Dick, F.J., Friend, C.A., Hazen, A., Horton, R.E., Husband, J., Kennedy, R., Nowroji, H., Smith, C.W., Mansergh, E.L. and Mansergh, W.L. (1912) Correspondence. The works for the supply of water to the City of Birmingham from mid-Wales. *Minutes of the Proceedings of the Institution of Civil Engineers*, **190**(01), 72–88.

CHS (2013a) *Construction History Society* [online], available at http://www.constructionhistory.co.uk/ (accessed March 2013).

CHS (2013b) *The Journal of the Construction History Society* [online], available at http://www.constructionhistory.co.uk/journal.php (accessed March 2013).

CHSA (2013) *Construction History Society of America* [online], available at http://www.constructionhistorysociety.org/ (accessed March 2013).

Clwyd-Powys Archaeological Trust (2012) *Historic Landscape Characterisation the Elan Valley* [online], available at http://www.cpat.org.uk/projects/longer/histland/elan/evrese.htm (accessed December 2012).

Cole, M.A. (2004) Economic growth and water use. *Applied Economics Letters*, **11**(1), 1–4.

Coopey, R. (2000) Politics, imperialism and engineering: the construction of the Birmingham welsh water system, 1861–1952, in *Water in the Celtic World: Managing Resources for the 21st Century* [online]. Second Inter-Celtic Colloquium, University of Wales Aberystwyth, 3–7 July, available at http://hydrologie.org/ACT/CIC/CIC_2_375.pdf (accessed December 2012).

Cossons, N. (2012) Does the engineering heritage matter? *Proceedings of the ICE—Engineering History and Heritage*, **165**(4), 211–19.

Dams and Reservoirs (2013) *Dams and Reservoirs Official Publication of the British Dam Society* [online], available at http://www.icevirtuallibrary.com/content/serial/dare (accessed March 2013).

Darteh, B., Sutherland, A., Chlebek, J., Denham, G. and Mackay, R. (2012) *Managing water risks in Birmingham, the city with the tastiest tap water in Britain* [online], available at http://www.switchurbanwater.eu/outputs/pdfs/w6-2_cbir_rpt_switch_city_paper_-_birmingham.pdf (accessed December 2012).

Davies, L. (n.d) *Cambridge County Geographies*, Radnorshire, Cambridge University Press, Cambridge.

Dundee Courier and Argus (1899) Advertisements. *The Dundee Courier and Argus* (Dundee, Scotland), Saturday, 9 September, p. 1, Iss.14417.

Dykstra, A. (2011) *Construction Project Management. A Complete Introduction*, Kirshner Publishing, Santa Rosa, CA.

Edwards, D.J. and Holt, G.D. (2010) The case for '3D Triangulation' when applied to construction management research. *Construction Innovation: Information, Process, Management*, **10**(1), 25–41.

Elan (2012) *Elan* [online]. The Elan Valley Trust, available at http://www.elanvalley.org.uk/home/ (accessed December 2012).

Fink, A. (2010) *Conducting Research Literature Reviews*, Sage Publications, Thousand Oaks, CA.

Geolocation (2013) *Separating Dam at Caban Coch* [online], available at http://www.geolocation.ws/v/W/File%3ACaban%20Coch,%20Elan%20Valley.jpg/-/en (accessed January 2013).

Gerring, J. (2007) *Case Study Research Principles and Practice*, Cambridge University Press, New York.

Grbich, C. (2009) *Qualitative Data Analysis. An Introduction*, Sage Publications Ltd, London.

Hacket, M., Robinson, I. and Statham, G. (eds.) (2007) *The Aqua Group Guide to Procurement, Tendering and Contract Administration*, Blackwell Publishing, Oxford.

Holt, G.D. (2010) Contractor selection innovation: examination of two decades' published research. *Construction Innovation: Information, Process, Management*, **10**(3), 304–28.

Holt, G.D. (2013) Construction business failure: conceptual synthesis of causal agents. *Construction Innovation: Information, Process, Management*, **13**(1), 50–76.

ICE (2013) *Ice | Virtual Library Essential Engineering Knowledge* [*sic*] [online], available at http://www.icevirtuallibrary.com/ (accessed January 2013).

ICOLD (2013) *International Commission on Large Dams. Publications* [online], available at http://www.icold-cigb.org/GB/Publications/publications.asp (accessed March 2013).

Janberg, N. (2013) *Construction History Internet Portal for an Emerging Academic Discipline* [online], available at http://www.construction-history.com/academia.html (accessed March 2013).

Jasper, D. (2004) *A Short Introduction to Hermeneutics*, John Knox Press, Louisville, KY.

Lees, A. (1908) *Elan Supply: A Description of the Works*, Cornish Brothers for Birmingham Corporation, Birmingham.

Levin, P. (2007) *Excellent Dissertations!*, McGraw-Hill International (UK) Ltd, Maidenhead.

Masterman, J.W.E. (1992) *An Introduction to Building Procurement Systems*, E & FN Spon, London.

Measuring Worth (2012) *Five Ways to Compute the Relative Value of a U.K. Pound Amount, 1270 to Present* [online], available at www.measuringworth.com/ (accessed December 2012).

Met Office (2012) *Rainfall, Sunshine and Temperature Time-Series* [online]. Meteorological Office, available at http://www.metoffice.gov.uk/climate/uk/actualmonthly/ (accessed December 2012).

Morton, R. (1997) *Building of the Elan Valley Dams*, Brian Lowndes Print Ltd, Walsall.

North Wales Chronicle. (1899) Advertisements. *North Wales Chronicle* (Bangor, Wales), Saturday, 9 September, Iss. 4820.

O'Leary, Z. (2004) *The Essential Guide to Doing Research*, Sage Ltd, London.

Oxford (2012) *Mansergh, James* [online], Oxford Dictionary of National Biography, available at http://www.oxforddnb.com/view/article/34861 (accessed December 2012).

Oxford Dictionaries (2012) *Navvy* [online]. Oxford Dictionaries, available at http://oxforddictionaries.com/definition/english/navvy (accessed January 2013).

Pheng, L.S. (2001) Construction of dwellings and structures in ancient China. *Structural Survey*, **19**(5), 262–74.

Potts, K. (2009) Construction during World War II: Management and financial administration, in Dainty, A. (ed.) *Proceedings of the 25th Annual ARCOM Conference* [online], 7–9 September, The Association of Researchers in Construction Management, Nottingham, pp. 847–56, available at http://www.arcom.ac.uk/-docs/proceedings/ar2009-0847-0856_Potts.pdf (accessed March 2013).

Powys (2012a) *Powys Digital History Project. The Elan Valley Dams from Shelley to the Dambusters* [online], available at http://history.powys.org.uk/history/rhayader/elanmenu.html (accessed December 2012).

Powys (2012b) *Local Studies Notes 50. The Elan Valley Waterworks* [online], available at http://www.powys.gov.uk/uploads/media/Elan_Valley_en_01.pdf (accessed December 2012).

Reynold's Newspaper (1899) Advertisements. *Reynold's Newspaper* (London, England), Sunday, 27 August, Iss. 2559.

Royal Academy of Engineering (2012) *Engineering the Future of Water. Review of 2011 Discussion Series* [online], available at http://www.raeng.org.uk/news/publications/list/reports/Engineering_the_future_water_Review_2011.pdf (accessed December 2012).

Royal Commission (2013) *The Royal Commission on the Ancient and Historical Monuments of Wales* [online], available at http://www.rcahmw.gov.uk/HI/ENG/Home/ (accessed January 2013).

Severn Trent Water (2009). *Severn Trent Water—Water Resources Management Plan 2009—Volume 1: Appendices* [online]. Appendix E1: Overview of the Severn Trent Water Supply System, available at http://www.stwater.co.uk/upload/pdf/E1__Overview_-_final.pdf (accessed December 2012).

The Sheffield and Rotherham Independent (1899) Birmingham's Welsh Water Reservoirs. *The Sheffield and Rotherham Independent* (Sheffield, England), Wednesday, December, Iss. 14080.

The Times (1895) Publichouse [*sic*] Reform. *The Times*, 16 September, Iss. 34683, p. 5, col. G.

Turpin, T. (2008) *Dam*, Reaktion Books Ltd, London.

UKGRF (2013) *UK Grid Reference Finder* [online]. Approximate Centre of Elan Valley Estate, available at http://gridreferencefinder.com/?gr=SN8689467809%7CPoint_s_A%7C0&z=10&v=h&t=Point_s_A (accessed May 2013).

University of Cambridge (2013) *History and Development of Building Construction* [online], available at http://www.arct.cam.ac.uk/research/researchgroups/sustainablebuilding/traditional-building-construction-research/history-and-development-of-building-construction (accessed March 2013).

University of Central Lancashire (2013) *The Nineteenth Century British Newspapers* [and] *Times Digital Archive* [university affiliation or Athens required for full access] [online], available at http://www.uclan.ac.uk/students/library/19thc_news.php (accessed January 2013).

Unwin, W.C., Mansergh, E.L., Binnie, S.A., Hill, E.P., Lewis, S.C., Rutter, H.F., Hawksley, C., Hunter, W., Mill, H.R. and Macaulay, F.W. (1912) Discussion. The works for the supply of water to the city of Birmingham from mid-Wales. *Minutes of the Proceedings of the Institution of Civil Engineers*, **190**(01), 58–71.

Victorian Powys (2012) *Victorian Powys for Schools. Rhayader the Elan Valley Dams* [online], available at http://history.powys.org.uk/school1/rhayader/elanmenu.shtml (accessed December 2012).

Walliman, N. (2006) *Social Research Methods*, Sage Publications Ltd, London.

Warren, A.J. and Holman, I.P. (2012) Evaluating the effects of climate change on the water resources for the city of Birmingham, UK. *Water and Environment Journal*, **26**(3), 361–70.

Webber, W.H.Y. (1901) How the welsh water will come to Birmingham. *The Pall Mall Magazine*, **24**(98), 181–91.

Western Mail (1890) The Birmingham water supply. Proposed reservoirs in Wales. *Western Mail* (Cardiff, Wales), Saturday, 6 December, Iss. 6725.

Western Mail (1897) Welsh watersheds. *Western Mail* (Cardiff, Wales), Monday, 31 May, Iss. 8742.

Western Mail (1900) Birmingham water supply. The Elan Valley undertaking. *Western Mail* (Cardiff, Wales), Monday, 26 November, Iss. 9830.

Wrexham Advertiser and North Wales News (1893) Wales and Birmingham's water supply. *The Wrexham Advertiser and North Wales News* (Wrexham, Wales), Saturday, 17 June, 19th Century British Library Newspapers, part II.

Yin, R.K. (2009) *Case Study Research Design and Methods*, 4th edn. Sage, Thousand Oaks, CA.