Engineering the landscape – Capability Brown's role

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Celebrating the 300th anniversary of the birth of Capability Brown is an opportunity to recognise the significant contribution that the eighteenth-century landscape architect made to civil engineering, leaving a sustainable legacy. As a gardener, architect and engineer, he was responsible for over 250 gardens, transforming the landscape by extensive earthworks, drainage schemes, earth dams, roads and planting by using only the power of people and animals. Brown and his contemporaries such as Grundy Jr, Brindley, Ince and Smeaton were responsible for innovative engineering that survives today because of continuing investment and maintenance.

1. Introduction

The year 2016 marked the 300th anniversary of the birth of one of the most iconic UK landscape architects, Lancelot 'Capability' Brown, who, together with John and William Aislaby, William Kent and Charles Bridgman, was responsible for developing the Augustan and Serpentine styles of the English garden (Turner, 2005) that portrayed a natural and wild landscape, enhancing the houses of the wealthy, increasing their value and producing self-sustaining properties. Brown created gardens across England and Wales (Figure 1), the largest of which are noted for a serpentine body of water and open expanses of turf with irregularly scattered individual and clumps of trees (Gregory *et al.*, 2013). These gardens required a mix of landscape design, architectural design, engineering and horticulture, but overall they were an inspirational vision. At that time (1740–1783), it was not unusual to find people practicing one or more of these disciplines. Brown specialised in horticulture and land and water management, which included major engineering works to create earthworks, drainage schemes, roads, bridges and buildings by using techniques that were known since Roman times (Morgan, 1914).

Gregory *et al.* (2013) undertook a review of research into Brown's work on behalf of English Heritage as part of the 300-year celebrations to identify a number of issues to be addressed, including the reputation of Brown, development of an archive of a portfolio of landscapes and the social and economic value of Brown's work. There is no reference to Brown as an engineer, yet at the time, he was variously described as an 'improver', an architect and an engineer. There are very few records of Brown's work, although some letters, bank accounts, maps, plans and contracts (Gregory *et al.*, 2013) do exist. The 2016 International Council on Monuments and Sites-UK conference celebrating Capability Brown concluded that there is little known of Brown's working practice (Icomos-UK, 2016). Authors have relied on secondary literature to develop an understanding of Brown's skills as a landscape designer, architect and horticulturalist. There are very few references to the engineering aspects of the gardens, yet

they were, possibly, the most significant of the time given that they predate the Industrial Revolution and the Canal Age (1763–1790). This paper reviews the construction of these gardens to demonstrate that at that time, these were immense engineering achievements and, through planned maintenance, many still exist today.

2. Lancelot 'Capability' Brown (1716–1783)

Lancelot Brown, the fifth of six children, the youngest of three boys, was baptised on 30 August 1716 in Kirkharle, Northumberland, to William and Ursula Brown. He started working in 1732 as a gardener at Kirkharle Hall for Sir William Loraine. He left in 1739 and, in 1740, was engaged as head gardener by Lord Cobham of Stowe. Shields (2006) suggested that he was appointed because of his knowledge of hydraulic engineering, which he developed at Kirkharle Hall, constructing artificial streams, ponds and fountains and observing the mine pumping systems in Northumberland. She also suggested that he spent the time between leaving Kirkharle and starting at Stowe working in Lincolnshire on drainage and water management schemes possibly for Grundy Sr (1696–1748). While there is much speculation as to his whereabouts in 1739–1740, it is clear that he gained the confidence of Lord Cobham, who initially employed him to repair a breached dam caused by freezing weather. There is also evidence that Brown may have worked at Grimesthorpe prior to Grundy Jr (1719–1783) works on the 'proposed additions to the Great Water'.

In 1750, Brown left Stowe to set up his own architectural practice in London. It is apparent that Brown had developed a network of influential contacts, initially through Lord Cobham, because of the support that he received in his appointment as master gardener at Hampton Court in 1765. It also appears that he built up a professional network of architects, landscape architects, architect engineers and engineers (Table 1) through his practice.

It is estimated that there are 267 sites (Figure 1) in England and Wales which Brown helped design, although there is some question

Figure 1. Sites attributed to Lancelot Brown according to Gregory *et al.* (2013) (geological map data © Natural Environment Research Council (NERC) 2016)

as to the actual number. According to Gregory *et al.* (2013), the number of sites attributed to Brown varies from 214 (Stroud, 1957), 169 (Turner, 2005) to 216 (Parks and Gardens, 2015). It is clear that it was impossible for Brown to supervise all these sites personally, which supports Brown's (2011) view that Capability Brown ran a business making use of his contacts and reputation to gain commissions and using subcontractors and associates to carry out the work. There is also evidence that he remained in contact with the clients through correspondence and site visits.

3. The eighteenth century

There were three significant developments that took place in the seventeenth and eighteenth centuries that supported Brown's work: political stability and monetary policy encouraging a significant investment in manufacturing; improvements in transport to facilitate movement of people and goods; and improvements in land management to enhance agricultural production. The improvement in trade was driven by political stability during the Georgian era, leading to the growth of cities and decline of rural communities, which was facilitated by the Agricultural Revolution. It was the time of global expansion, which was triggered by the government's monetary policy following the creation of the Bank of England, which, in turn, supported the government's economic policies

(Dugan and Dugan, 2000). This was the start of the Industrial Revolution when investment and trade in textiles, iron and porcelain proved possible because of significant improvements in the transport system due to the UK River Navigation Acts (between 1651 and 1850), UK Turnpike Acts (between 1663 and 1836) and the canal era (1763–1790). The eighteenth century also saw a shift in the structure of society encouraging social and professional networks. For example, the Smeatonian Society, formed in 1771 at the peak of Brown's activity, included eminent civil engineers who were known to, and indeed worked with, Brown.

Modern civil engineering began in the eighteenth century with the development of canals to support the Industrial Revolution, but the improvements in road construction, river navigation and land management were already underway, using construction techniques to move/lift materials powered by people and animals, unchanged since Roman times. While the observational technique was practiced, the emergence of the mathematical and theoretical principles that facilitated the design and construction of civil engineering works – that is, the works covered by Tredgold's definition – allowed more ambitious projects to be completed. Engineers such as John Grundy (Jr), John Smeaton, Henry Ince and James Brindley were among the first to distinguish themselves

Table 1. Associates and contemporaries of Capability Brown

Role	Name	Year	Relationship
Surveyors	M. Baker	—	Associate
	Samuel Lapidge	1740–1806	Associate
	J. Spyers	1720–1798	Associate
Contractors	C. Dickson	—	Associate
	M. Milliken	—	Associate
	K. Wilkie	—	Associate
Engineers (Smeatonian Society)	John Armstrong	1674–1742	—
	John Grundy Sr	1699–1748	Employer?
	John Grundy Jr	1719–1783	—
	John Smeaton	1724–1792	—
	Thomas Yeoman	1709–1781	—
	Robert Mylne	—	—
	Joseph Nickalls	1725–1793	—
	John Thompson	—	—
	James Key	—	—
	John Osborne	1724–1783	—
	William Black	—	—
	Robert Whitworth	1734–1799	—
	Hugh Henshall	1734–1816	—
Landscape architects	Charles Bridgeman	1690–1738	—
	William Kent	1685–1748	—
	William Aislaby	1700–1781	—
	John Aislaby	1670–1742	—
Architect	Henry Holland	1745–1806	Associate
	James Paine	1717–1789	—
	Robert Adam	—	Partner

by specialising as civil engineers. This was the time of the Agricultural Revolution, leading to a significant increase in food production driven by changes in the marketing system, transport to move produce and improvements in agricultural processes. One aspect of the revolution and of direct relevance to Brown's work was the art of land drainage. Thought to have been developed in the Netherlands as a way to manage the low-lying flat lands better, the Dutch became pioneers in canal building, and with that, soil restoration and maintenance, soil drainage and land reclamation technology. They established two types of drainage systems, surface and subsurface, both using gravity to serve the same purpose, to control the flow of water and to manage the level of the water table. The reduction in the volume of water in the soil would also consolidate the foundation soils, making embankments more stable, thus reducing the number of failures during construction. Therefore, the experience of land management, the transport network and the social and business networks enabled Brown to produce a large portfolio of work.

4. Capability Brown's roles

Brown, at the time, was known as a gardener, a gardener designer, an improver, an architect and an engineer (e.g. Anon (1770)) at a time when the terms 'civil engineer' and 'landscape architect' had not been introduced. He is now celebrated as a landscape architect. Brown (2011) suggested, based on a review of Capability Brown's bank accounts and estate archives, that he was associated with a project for a number of years but visited the site only occasionally to monitor progress and suggest further improvements. It was his

associates who dealt with the day-to-day supervision of specialist subcontractors, estate workers and local contractors. Hence, Brown created a vision which he sold to the client, leaving others to undertake the technical interpretation and implementation. This technique was used by civil engineers of the time – for example, James Brindley (1716–1772) would set out the alignment of a canal, leaving the construction to his associates (Rolt, 1969).

This process also extended to his architectural works which included new houses (e.g. Claremont, Surrey; Redgrave, Suffolk; Croome Court, Worcestershire), refurbishment (e.g. Broadlands, Hampshire; Corsham, Wiltshire; Warwick Castle and Newham Paddock, Warwickshire; Burghley House, Northamptonshire), estate buildings (Milton Abbas, Dorset; Combe Abbey, Warwickshire) and garden structures.

His skills as a landscape architect are well known; his skills as an architect less so; and his skills as an engineer are almost unknown, even though he was employed as an engineer on drainage schemes before moving to Stowe and as an engineer in Boston following the 1755 earthquake. Brown's engineering work included drainage schemes, canals, river diversion, dams, weirs, earthworks, bridge, roads and buildings, with earthworks and water engineering being the most significant.

5. Major engineering works

Gregory *et al.* (2013) suggested that draining the land around a house and creating a serpentine lake in the middle distance

defined Brown's style. John and William Aislabie were the first to create this style (began in 1718) at Studley Royal, North Yorkshire, an English landscape of the Augustan style. Stowe, where Brown moved to in 1740, was also an Augustan-style garden designed by Charles Bridgman (1690–1738) and completed by William Kent (1685–1748) and James Gibbs (1682–1754), leading landscape architects of the time. Thus, Capability Brown started his career working with the leading garden designers of the time before developing his own style, the Serpentine style, which is a more abstract style with fewer formal structures compared to those used in the Augustan-style gardens. The other feature of this style of garden was that it was less about a public display of wealth and more about productivity (Turner, 2005). The Serpentine-style garden included a lake shaped in accordance with Hogarth's line of beauty (an S-shaped curved line) (Hogarth, 1753), a perimeter carriage drive, an encircling tree belt, clumps and individual trees and a turfed area below the house sweeping down to the lake. The engineering challenge was to create a landscape which did not necessarily conform to the existing topography yet appeared natural.

5.1 Earthworks

The scale of earth moving in creating an English landscape was substantial and possibly exceeded civil engineering works of the time. The canal era was about to begin, and major fortifications were no longer being built. The majority of Brown's sites were underlain by soft sedimentary rocks of the Cenozoic and Mesozoic periods (Figure 1), which were more easily excavated than the harder rocks of the Palaeozoic era to the north and west of the Tees–Exe line. Creating the English landscape required a significant labour force and time because of the quantity of material that could be excavated, moved and placed as shown in Table 2 and typical volumes of soil that could be dug in a day and transported by barrow or animal-drawn carts. For example, the Grecian garden at Stowe, which involved moving 18 000 m³ of earth, took a year (Hinde, 1986), requiring 9400 man-days or 30 people working 6 d a week to excavate the soil with 225 000 barrow movements.

5.2 Water engineering

Engineering aspects of the water features included earthworks to form canals, embankments, dams and lakes; drainage schemes to supply water and manage the groundwater level to drain naturally boggy land; and sealing of lakes and dams. A key difference between the waterways that Brown developed and those created for the early canals was that Brown created the landscape; canal engineers followed the landscape.

The use of weirs to control rivers, dams to retain water and systems to drain land and move water were well known, but the scale of Brown's work far exceeded those for civil engineering structures of the time. Binnie (1987) suggested that Brown was responsible for at least 40 earth dams, although there is little written evidence of their design and construction. Skempton (2002) suggested that Brown was responsible for more dams at that time than anyone else. Podolak *et al.* (2013) studied 53 water features attributed to Brown to show that 37 still exist today.

Binnie (1987) described the development of water-retaining structures in the UK from the Roman period, which places the work of Brown in context. The Romans built clay core dams with stone facings to retain water and aqueducts lined with puddled clay to transport water. Prior to the canal era, dams and weirs were used to provide power for grinding corn, fulling wool and driving bellows for ironwork; to aid river navigation; and to catch and retain fish. In 1600, John Tavemer described the construction of dams (Binnie, 1987) to use wetted earth to reduce permeability, allow for settlement of the crest before filling, remove turf before construction and use rock-fill to protect the upstream slope from wave action. There was no reference to compaction, even though compaction by ramming was used to create road subbases. Dams were built of earth, rock-fill with clay cores and rock-fill and brushwood depending on the local geology by using the techniques described in Table 3.

While there are few records of Brown's work, it is known that he built earth dams (e.g. Wakefield Lodge), rock-fill dams with a clay blanket covered by a layer of rock-fill on the upstream face

Table 2. Rate of excavation and transporting earth (after Rolt (1969))

Nature of soil	Volume excavated: m ³ /8 h	
	By hoe	By pick/shovel
Soft (alluvium, sandy soil)	2.5–3.0	3.5–4.0
Moderately hard (loam, light clay)	1.5–2.0	2.5–3.0
Hard (heavier clay)	1.0	2.2–5.0
Water saturated	0.8–1.5	1.5–2.0
Haulage equipment	Recommended hauling range: m	Capacity: m ³
Head basket	4–50	0.02
Western wheelbarrow	25–150	0.08
Chinese wheelbarrow	50–400	0.16
Animal cart	100–500	0.70
Tractor and trailer	250–5000	3.0–3.5
Tipper truck	2000 upwards	5–6

Table 3. Construction steps used to create a clay core dam in the eighteenth century (based on information provided by Binnie (1987), Grundy (1766) and Hinde (1986) cited by Roberts (2001))

- Dig a sizeable trench for the foundation of the clay core; excavate the ground until solid bedrock is uncovered.
- Use the clay that has been discovered for the clay core; this should be rammed and built upwards.
- Layer the clay in sheets between 6 and 7 inches (0.152 and 0.178 m) for the core; if a dusting of sand had been applied to the clay, it prevented the tools that were in use from sticking to the clay.
- Raise the sides of the dam simultaneously to the height of the core; the earth should be rammed.
- Graded slopes on the dam upstream with protection in the form of stone pitching and a ratio between 5:1 and 3.5:1 and on the downstream slope protect the slope with a ratio of 2:1 with sods of earth.

(e.g. Lince dam, Blenheim), rock-fill with a clay core (e.g. Grand Cascade, Blenheim) and rock-fill dams with a clay core and clay cut off (e.g. Burton Constable) similar to the examples shown in Figure 2.

The type of dam depended on the availability of clay. An abundance of clay led to an earth dam with stone protection on the upstream face; limited clay led to rock-fill dams with clay cores and/or clay blankets. The superficial deposits also influenced the construction of the lake in order to prevent water loss. Table 4 describes the process of creating clay liners attributed to Grundy Jr. Hinde (1986) suggested that Brown was using clay to seal dams and lakes in 1750 before the concept was introduced by Brindley in 1762 to the House of Commons.

Brown created the lakes by damming an existing river or by lowering the level of the land and filling it with water from nearby springs supplemented by drainage systems used to drain the land, in particular around the house, to maintain the groundwater level.

Brown's first major project was the design of the 700-acre (283-ha) gardens at Petworth House, West Sussex (1753), where the upper part of the lake is underlain by Atherfield Clay, a generally massive sandy mudstone which weathers to clay, and the lower part of the lake and dam are founded on Hythe Beds, fine to medium sands, sandstones and silts (Figure 3). This 165-m-long, 7-m-high dam with an 11-m crest earth fill dam has a clay core with masonry protection on the upstream face. The artificial lake

Figure 2. Examples of dams of the eighteenth century: (a) Grimesthorpe (Grundy Jr) rock-fill dam with a clay core and cut-off trench; (b) Cusworth (Wood) stone wall/rock-fill with clay core and cut off; (c) Carron Works (Smeaton) rock-fill with clay core; (d) Coquet (Smeaton) stone wall/clay fill overlain by rock-fill; (e) Burton Constable (Brown) rock wall/clay wall/rock berm; and (f) Petworth (Brown) rock-fill with clay core and clay blanket protected by stone

Table 4. Construction steps for the lining of the dam in the eighteenth century (based on the information provided by Binnie (1987), Grundy (1766) and Hinde (1986) cited by Roberts (2001))

- Clear the excavated ground of objects such as stones and rocks; use clay to fill any holes on the ground.
- Cover the excavation in the initial clay lining, approximately 6 inches (0.152 m) thick, starting at the lowest end.
- Use slaked lime on the clay to ease the ramming works and reduce the excess water through absorption. This method also prevents foreign bodies sticking in the clay.
- Rammers are used by the labourers working in gangs. Tread on the clay in boots or use trained animals (sheep).
- Flat beaters are used by labourers to clear the floor for another layer of clay.
- At each additional clay layer, add water to prevent the clay from drying out and cracking and to make the clay workable.
- Repeat the number of layers until the desired height is reached. Allow each layer to consolidate before adding a new layer.
- Cover the penultimate lining with 2 inches (50.8 mm) of chalk, and add a final outer layer of clay.
- Smooth the top layer with the back of a spade, for example.
- The sides of the lake should have a thicker layer of clay to prevent them from drying out when there is less water in the lake in summer.

at Petworth required some 60 000 t of soil to be excavated and moved (Attar, 2010). The south end of the lake is lined, possibly using excavated clay from the north end. The excavated soil was used to build the earth dam (approximately 15 000 t), leaving the remainder to modify the topography of the estate, thus creating the artificial landscape. It would have taken 20 people 2 years to excavate the soil involving 416 000 barrow movements (Table 2).

Failures of Brown's water-retaining structures were not unknown. For example, in 1756 he wrote to the Petworth steward stating that 'I am doubtful the springs have abated. If that should be the case the sinking is the less to be wondered at, however if there are faults they shall be mended', suggesting that the water level was falling, which was either due to a reduction in supply from the springs that

fed the lake or a leak from the base/sides of the lake. Brown suggested that it was a leak, which meant a failure of the clay liner. His commitment to repair the leak is a characteristic of his work; he would charge for the work he did and repair if necessary.

Artificial lakes were also created by lowering the ground such as that at Burton Constable (1759), where Brown created a 1- to 1.5-m-deep lake in glacial till underlain by the Flamborough Chalk Formation to lower the water table, avoiding boggy areas in the vicinity. The excavated material was used to create islands, another feature of Brown's designs. Hall (1995) uncovered minutes of meetings between Brown and his client, William Constable (of Burton Constable, East Yorkshire), which provides an insight into the development of Brown's thinking through a series of plans and notes. Most of the notes refer to planting, but there are references to drainage, the lake and the Bridge. In particular, Brown required a clay wall to be constructed in a 0.5-m-wide trench excavated down to the natural clay and backfilled with strong clay, creating an impermeable barrier, evidence of a clay cut-off trench.

In 1751, Brown was engaged by Lord Coventry of Croome Court not only to develop the gardens but also to refurbish the house, his first major architectural commission. The house was located in a swamp which required a system of culverts to drain the land into a pond and a 2000-m lake (Stroud, 1957) (Figure 4), the level of which was maintained by nearby springs. Brown spent some 12 years at Croome Court, which is underlain by river terrace gravels and the Branscombe Mudstone Formation, a silty mudstone/clay. The lake had to be lined with clay, possibly quarried from the nearby Westbury Formation. The 1.5-mile-long (2.41-km-long) lake was created by damming a stream running through the estate by using a weir formed of rock-fill with an external clay wall (as opposed to a clay core).

Earth dams were used where there were significant deposits of clay such as the glacial till deposits found at Harewood House (1772) (Figure 5). Skempton (2002) suggested that the 115-m-long, 7.6-m-high dam was constructed of glacial till; Binnie (1987) reported that the dam leaked as they filled the lake for the first time. It proved to be leakage along the side of the sluice, which was permanently sealed possibly with clay. Brown also

Figure 3. The relationship between the lake and the geology at Petworth Park showing the water supply and drainage (geological map data © NERC 2016)

Figure 4. The relationship between the lake and the geology at Croome Court showing the water supply and drainage (geological map data © NERC 2016)

introduced siltation ponds at Harewood, possibly because he became more aware of sedimentation in lakes later in his career.

The gardens at Blenheim Palace (1763–1773) are considered the most impressive works of Brown and, as it is a World Heritage Site, the most important. Brown was engaged by the fourth duke of Marlborough to create the 150-acre (60.7-ha) Great Lake, which included the Grand Cascade dam, a 134-m-long by 8.8-m-high limestone rubble dam with a clay core, and the Lince dam, a 4-m-high limestone rubble dam with a clay blanket on the upstream face. He also rerouted the River Glyme through a canal cut into the side of the valley. The underlying rock is limestone overlain by alluvium in places. It was necessary to line the lake, possibly using clay loam topsoil because of the lack of locally available clay.

Table 5 provides further details of gardens constructed over a 30-year period, highlighting the relationship between the underlying geology and method of constructing the dams and lining the lakes. It appears that Brown and his associates developed their knowledge of water engineering through experience and working with other eminent professionals of the time.

6. Discussion

6.1 Engineering the landscape in the eighteenth century

Gregory *et al.* (2013) suggested that Brown was responsible for less than 5% of the gardens developed between 1740 and 1783 – that is, landscape architecture in the eighteenth century had a significant social and economic impact. The terms ‘landscape architect’ and ‘civil engineer’ were introduced by Humphry Repton (1752–1818) in 1804 and John Smeaton (1774–1792) in 1771. Prior to that,

architects were responsible for buildings and gardens and surveyors for roads. It was clear that the professionals developed their reputation across a number of disciplines. Shields (2006) suggested that Brown worked on Deeping Fen, a 47-square mile (122 km²) low-lying area in Lincolnshire, under the direction of Grundy Sr (1696–1748) prior to moving to Stowe. This project included a reservoir, embankments, dredging and sluices. Grundy Jr (1719–1783) not only worked with his father from 1739 but also undertook estates work at Grimesthorpe for the duke of Ancaster, including the construction of a dam and reshaping the land in front of the castle, although the design of the estate is attributed to Brown.

The fact that Brown worked with Grundy Jr suggests that many of the techniques that he used were adopted from Grundy Jr's designs. His ability to develop his skills and knowledge by observing another's work is a feature of Brown's career. He worked with Robert Adam (1728–1793), the architect at Luton Hoo, Harewood House and Compton Verney, yet he ran his own architectural practice from 1750.

Most of Brown's major designs adapted existing parkland to create the Serpentine-style garden – that is, he had a master plan which could be adapted to suit the local topography. Brown had a reputation of being able to ride around an estate and develop a plan that led to a commission which would last several years. During that time, he would visit the estate on several occasions, review work in hand and give further instructions. The pace of construction together with the improvements in transport meant that this was entirely feasible.

Thus, Brown, by working with other professionals, developing partnerships, creating teams and maintaining contact with the

Figure 5. The relationship between the lake and the geology at Harewood House showing the siltation pools (geological map data © NERC 2016)

clients, was able to develop a successful business at a time when there was sufficient wealth and labour to transform country estates.

Brown did undertake engineering works and was employed as an engineer on at least one occasion, but most of his engineering works were part of the overall design to create a style of landscape garden. His ability to appreciate the image that his design would create, which included the landscape, the aspect from the house and horticultural features, was very important because the time it took to create the landscape and for the trees to grow meant that clients had to have faith in his vision.

Brown's work included remodelling of complete estates, design of new and refurbished buildings and amendments to existing estates. He did not supervise the work on a day-to-day basis but employed surveyors, foremen, architects and others to undertake the work. In turn, they employed a local labour force. Thus, it was his ability to delegate the construction to his associates and maintain the confidence of his clients over a sustained period of time that contributed to his success.

6.2 Conserving the eighteenth-century landscape in the twenty-first century

There have been a number of eras of civil engineering that created a legacy that still function today (e.g. drainage schemes (seventeenth century), canals (eighteenth century), railways (nineteenth century)

and motorways (twentieth century)). The eighteenth-century English landscape gardens, even though they are not national infrastructure, can be added to this list because of the scale of the engineering works and the fact that many still function today because of planned maintenance. They can be publicly or privately owned or owned by organisations such as the National Trust and English Heritage; collectively they help protect the UK's heritage and opens spaces.

The eighteenth-century landscape gardens were designed to be sustainable, and they continue to be through management of the land, water features, drainage schemes, roadways and buildings. For example, in 2009 a new dam was constructed at Blenheim Palace to replace one which had been subject to leaks since the 1840s. The dam retains 6 000 000 m³ of water and, to comply with the Reservoirs Act 1975, has to withstand a 1-in-1000-year flood and overtopping in a 1-in-10 000-year flood event (Anon, 2009). The original dam with a clay-and-rubble core was repaired by installing a bentonite-filled trench to prevent leaks and reinforced with 6000 m² of concrete blocks to resist the overtopping replacing the earth-covered stone walls used by Brown.

Firth (1980) described the case for identification, preservation and adaptation of the landscape at Harewood, Yorkshire, representative of the problems facing many other English eighteenth-century landscapes – that is, sustainable management of the estate. Much of the eighteenth-century masonry and structural work remains

Table 5. The underlying geology and engineering works of significant landscapes by Brown (after Hinde (1986), Stroud (1957), Brown (2011) and Turner (1985)) (continued on next page)

Date	Location	Solid	Drift	Earthworks	Water features	Dams	Drainage
1748	Stowe	Bladen Member (limestone, mudstone)	Glaciofluvial deposits	Contouring, reprofiling of vistas; Excavation of 18 000 m ³ of glacial till for creation of Grecian Valley	Planned but with inability to source water		
1748	Wakefield	Great Oolite Group (limestone and argillaceous rocks)	Alluvium gravels	Removal of topsoil and reprofiling for area of 'smooth turf'	Unlined valley lake	213-m-long by 7.6-m-high earth embankment of glacial till	
1749	Warwick Castle	Bromsgrove Sandstone, Mercia Mudstones	Alluvium and river terrace gravels	'Curved sweep of lawns down to river'; raising/levelling of ground by using building rubble from castle	Excavation of lake within marshy/boggy valley and unlined fed by drainage and brook	Construction unknown; sluice and dam	Draining of land
1750	Croome Court	Silty mudstone/clay	River terrace gravels and clay	Deposition of excavated lake material to create raised ground north of house	Expanded stream channel with puddled lining	Clay wall with limestone fill	Drainage of marshland beneath house using 1.5-mile-long (2.41-km-long) limestone conduits
1750	Moor Park	London Clay/Lambeth silty sandy clays	Gravels and alluvium	Removal of unstable 'made ground' forming terrace to create more natural slope with hillocks to undulate slope			
1752	Petworth Park	Hythe Bed Sandstone with Weald Clay	Sandy loam topsoils, silts in saturated valley floor	Regrading of slopes, replacement of formal gardens with level ground, using building rubble/excavated sandstone/partial excavation of sandstone/clay for lake	Puddled lining for part of lake on greensand, the rest unlined; 60 000 t of earth excavated for two lakes	Two 100 m long and 20 m high, with sandstone rubble fill with clay wall, possibly clay blanket	Brick arch drainage conduits to channel spring water to lakes
1757	Longleat	Oxford Clays, mudstones, oolitic limestones, sandstones	River alluvium/gravels	Removal of gardens and creation of 'fine lawns'	Unlined 1-mile-long (1.61-km-long) lake	Construction unknown	Lake acting as drainage of surrounding parkland
1758	Wimpole	Chalk, Gault Clays, Woburn Sands	Alluvium beneath lake	Substantial earthworks to undulate topography, usage of chalk and clay rubble	Two unlined lakes, upper and lower interconnected constructed from stream course	Construction unknown	Contouring to channel water down to lakes
1759	Trentham Park	Siltstone/sandstones above micaceous silty mudstone	Alluvium, Devensian Till	Removal of topsoil for creation of lake, re-emplacement of material to form embankment separating lake from channelised river	Unlined 0.75-mile-long (1.21-km-long), 0.25-mile-wide (0.402-km-wide) lake supplied by River Trent	Embankment (0.75 mile (1.21 km)) with weir at southern end (construction unknown)	

Table 5. Continued

Date	Location	Solid	Drift	Earthworks	Water features	Dams	Drainage
1759	Burton Constable	Flamborough Chalk Formation	Devensian Till with occasional glaciofluvial deposits	Levelling and reprofiling of lawns separating house from lake	Puddled lining; lowering and extending the existing lake and rounding the edges	Clay core wall, blanket unknown	
1761	Doddington	Wilkesley Halite Member – mudstone	Glaciofluvial deposits of sands and gravels	'Fine contouring in a narrow Cotswold valley'	Three lakes interconnected and fed by stream with puddled lining	Long earth embankments (construction unknown)	
1761	Chatsworth	Millstone grits and shales	Shallow drift deposits, river gravels in vicinity of river	Levelling of ground around house, pronouncement of hummocks in parkland and removal of fields and tress	Widening of river, removal of meanders close to house	Millstone grit weir to raise and slow river	Stone instead of brick on puddled clay before being buried to remove water from park
1762	Temple Newsam	Sandstone/Mercia Mudstones	Fluvial deposits in vicinity of stream	Excavation to weathered sandstone and reprofiling of slope into valley, sandstone fill material then used for creation of hummocks	Creation of three lakes by removal of topsoil and flooding of valley with puddled lining	Small earth dams with sandstone cascades with clay core wall	
1762	Gatton Park	Lewes Nodular Chalk	Clay with flints, fuller's earth	Recontouring to create undulations in parkland	Several lakes with puddled lining	Construction unknown	
1762	Audley End	Lewes Nodular Chalk	Glacial tills, river gravels/alluvium	Grading of slopes down to river	Widening of existing river valley to create lake with puddled lining	Construction unknown; inclusion of sluices	
1764	Blenheim Palace	Oolitic white limestone, rubble limestone, clays on higher ground	Sporadic patches of alluvium at base of river valley	Reprofiling of valley topsoils forming embankments, excavation of limestone rubble from areas of parkland	Puddled lining using clay loam topsoil; clay core, likely clay blanket	Large dam with cascade; 0.5-mile-long (0.804-km-long), 4-m-high second dam downstream, both using limestone rubble fill	
1770	Coombe Abbey	Bromsgrove Sandstone/Mercia Mudstones	Glaciofluvial and river terrace deposits	Creation of lake and characteristic parkland from agricultural fields	Unlined 80-acre (32.4 ha) lake, 1.4 m deep	Weir outlet dam (construction unknown)	Difficulty in obtaining/maintaining adequate water supply for lake
1771	Grimsthorpe	Limestone/clays	Glacial till in valleys	Recontouring of parkland	Investigated accumulation of muds/silts		
1772	Harewood House	Grits, occasional sandstones	Devensian Till (clay) and river valley gravel deposits	Sloping and contouring of gradient to lake; recontouring of parkland to create undulations/pronounced hills	Flooding of valley to create lake with puddled lining fed by stream; inclusion of siltation pools	115 m long, 7.6 m high, constructed of glacial till	
1774	Claremont	Bagshot Formation – pale yellow brown sand/clays	None present	Reprofiling of grassland, infilling of clay pits used for brick manufacture for house; excavation of		Sandstone rubble fill, possible use of flinty chalk for abrasive surface	

Table 5. Continued

Date	Location	Solid	Drift	Earthworks	Water features	Dams	Drainage
1775	Burghley Park	Lower Lincolnshire Limestone Member/Northampton Sand Formation	None present	5-m sandstone cut to divert London–Portsmouth road; excavation of tunnel and sunken courtyard Reprofiling of topsoil across parkland	32-acre (12.9 ha) unlined lake; inclusion of siltation pools	Clay core wall and blanket	
1776	Sherborne Castle	Fuller's earth beneath lake/Frome Clay	Alluvium, river terrace deposits	Reprofiling earth movements of topsoil/clays forming slopes down to lake	50-acre (20.2 ha) unlined lake over original T-shaped canal	7-m-high dam formed of sandstone fill with a clay core wall and blanket	

intact because of the original over engineering. The drainage system and the bridges are still operational. The lake was drained and dredged around 1900 because of siltation, and the weir forming the major trout pond was washed out in 1950 and repaired in 1963.

Podolak *et al.* (2013) undertook a review of the 53 water features on 23 estates produced by Brown and noted that 70% still exist today due to periodic maintenance. This includes dredging to remove sediment, removing vegetation and repair of water-retaining structures. Most of the gardens lie to the south of the Tees–Exe line in an area underlain by the ‘softer’ rocks of limestones, sandstones, chalk and clays. These were easier to work by hand, allowing significant volumes of soil and rock to be excavated and moved by cart. The sediment yield for lakes formed from existing streams is significant, leading to ongoing maintenance or partial or total loss of a lake (Podolak *et al.*, 2013), although silt ponds were introduced by Brown towards the end of his career. Geological knowledge at the time was limited, so the observational technique was used, and it is clear that historical and contemporary knowledge was developed because of the advances in construction techniques shown in Table 5. For example, excavations for lakes that encountered sand and gravels would require a puddled clay liner; water-retaining structures had clay blankets or clay cores in areas where sources of clay were limited.

These gardens are part of the UK's heritage which was recognised in Finance Act 1975 as exempt from capital transfer tax, ensuring that land was not sold off to pay for death duties. Some of the water-retaining structures are subject to the Reservoirs Act 1975. These have helped create a sustainable future for the immense civil engineering works of the eighteenth century.

7. Conclusions

Celebrating Capability Brown's reputation as a landscape architect 300 years after his birth was an opportunity to review engineering

aspects of his works. Brown was operating at a time when substantial modifications to country estates were underway. The social, political and economic conditions facilitated their development, which helped transform the English countryside, leaving a legacy that is still in use today. The modifications collectively were probably the most significant civil engineering works of the time, although by the end of the eighteenth century, modern civil engineering had begun with the canal era, leading to the Industrial Revolution. The steam engine had been invented and was in use to dewater mines, but the power Brown needed came from people and animals. Therefore, the scale of his work was all the more impressive given that it relied on a large workforce distributed throughout the country during the 33 years he ran his architectural practice.

Brown is known as a landscape architect, but at that time, he would have been known as a gardener or architect given that architects designed buildings and gardens. There are references to Brown as an engineer, and it is clear that many of his commissions included substantial engineering works. However, it does appear from the secondary literature that he left the detail to associates, which included architects (e.g. Henry Holland), surveyors (e.g. Samuel Lapidge) and contractors (e.g. Milliken). Given that the detail of the engineering works was within the construction team, there was little engineering design. It was based on existing knowledge, experience, learning from others and the observational technique, creating a legacy that exists today. Brown's aim was to produce a sustainable landscape, which has been demonstrated through continued maintenance of the planting and engineering structures.

Much of Brown's work has survived. This is partly due to over engineering and partly due to planned maintenance. The main issues have been the silting of lakes and ponds and loss of water from lakes due to leakage through the liner or earth dams. Many of the water-retaining structures are subject of Reservoirs Act

1975, which, together with increased public access, has ensured that the remaining gardens continue to be engineered.

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