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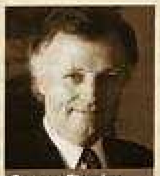
Regeneration of the Forth & Clyde and Union canals, Scotland

R. A. Paxton, MBE, MSc, PhD, CEng, FICE, FRSE, J. M. Stirling, BSc, MBA, CEng, MICE, MIStructE and G. Fleming, BSc, PhD, FICE, FREng, FRSE

Roland Paxton
is an honorary professor at the civil and offshore engineering department of Heriot-Watt University, chairman of the ICE panel for historical engineering works and a member of the Royal Commission on Ancient and Historical Monuments of Scotland

Jim Stirling
is a director of British Waterways



George Fleming
is professor of water and environmental management at the University of Strathclyde, managing director of EnviroCentre and current president of the ICE

The 56 km Forth & Clyde ship canal across Scotland set a new international standard for inland waterways when completed in 1790. Linking Glasgow and the Irish Sea in the west to Falkirk and the North Sea in the east, it was joined in 1822 to Edinburgh by the 50 km Union Canal. But, as traffic moved to rail and then road, the waterway fell into disuse and eventually closed in the 1960s—though it soon became apparent that reopening it for recreational use was vital to regenerating this strategic national corridor. With National Lottery funding, the £78 million Millennium Link scheme—including a spectacular rotating boat lift at Falkirk—is at last underway and set for completion in 2001. This paper reports on the historical, planning and environmental aspects of this landmark regeneration project.

Birth of the Forth & Clyde Canal

In 1726 Daniel Defoe, influenced by earlier proposals and the Languedoc Canal,[1] optimistically suggested that the Forth and Clyde could be joined by a 12·8 km canal with four sluices.[2] But it was not until the onset of the Industrial Revolution that the concept began to make real progress, with a canal survey by Robert Mackell and James Murray.[3] Although their proposal of 1762 was not progressed, it encouraged the Trustees for Fisheries, Manufactures and Improvement in Scotland to commission a survey from Britain's leading civil engineer, John Smeaton (1724–92).[4]

In 1764 Smeaton reported on two possible lines for a 1·5 m deep canal (Fig. 1). One was from the Forth via Stirling and Loch Lomond to the Clyde, mainly using existing rivers and approximately on the line of D&C Stevenson's later ship canal proposal.[5] The other was from the Forth at Carron-mouth (now Grangemouth) via Kirkintilloch to Yoker on the Clyde.[6] He preferred the latter, shorter line estimated to cost £78 970.

The next development, in December 1766, was a proposal by Glasgow interests and Carron Ironworks for a 'small' canal up to 0·9 m deep, modified soon afterwards to 1·2 m deep and 7·3 m wide, from Carron Shore near the ironworks to Glasgow. This proposal, mostly on Mackell's 1762 line, was surveyed and costed by Mackell and James Watt (1736–1819) at £50 000.[7] The Trustees responded to this unwelcome initiative by publishing Smeaton's report.[5] In May 1767 the parliamentary bill for the small canal was successfully opposed by East of Scotland interests, which petitioned for a larger canal to take vessels of 61 t.

The matter evoked several tracts. One writer felt that Edinburgh as

> 'the metropolis… the rendezvous of politeness, the abode of taste… ought to have the lead upon all occasions. The fools of the west must wait for the Wise Men of the East'.[8]

In November 1767 Smeaton's second report was published, proposing a 2·1 m deep canal from Carron-mouth to Dalmuir on the Clyde, estimated to cost £147 340.[9] This report formed the basis for the navigation's founding Act.[10] Smeaton and Mackell were then appointed chief engineer and resident engineer respectively.

The first ever resident engineer

The project was unprecedented in Scotland, at times employing under contracts more than 1000 men. Largely because of the inexperienced workforce, it took much longer to build than planned but it proved a valuable training ground for developing skills that made a fundamental contribution to the national construction industry.

The project's most enduring contribution to the development of engineering practice was Smeaton's 'plan' for managing the work[11,12] and his use of standardized procedures in design. The plan specified the duties of a 'resident engineer', a term he created, and the other

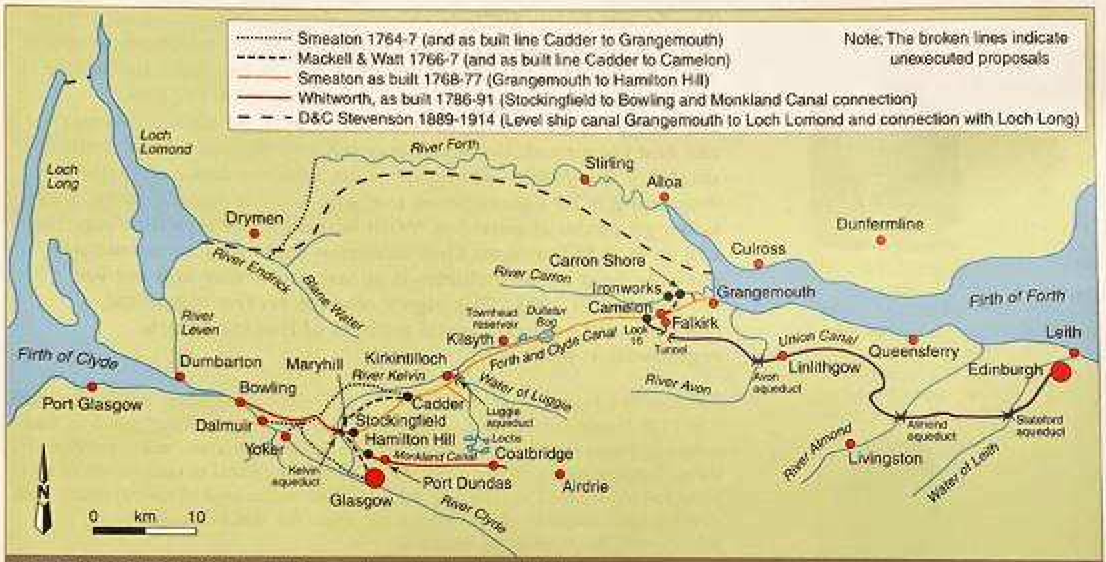


Fig. 1. Scotland's Forth & Clyde and Union canals as planned and constructed

site staff he considered necessary for the satisfactory conduct of the works.

Work gets underway in 1768

In June 1768, the contractor John Clegg, who with John Taylor dug most of the canal to Glasgow, began work at Grangemouth and the canal was made in a westerly direction, becoming operational to key points as shown in Table 1.[13,14] The Carron Ironworks was still dissatisfied with the approved line, which was 6·4 km longer than their 'small' canal proposal and meant their boats had to negotiate the tortuous River Carron before entering the canal, a problem partly resolved by cutting off a bend and permanently reopening the temporary connection with the canal west of Grangemouth in 1782. The ironworks commissioned a report from leading engineers James Brindley, Thomas Yeoman and John Golborne,[15] that was roundly addressed by Smeaton.

> 'As no difficulty is too great for Mr Brindley, I should be glad to see how he would stow a fire engine cylinder cast at Carron of 6½ ft diameter into one of his 7 ft boats so as to prevent its breaking the back of the boat or oversetting. If engineers are to be constantly brought down to inspect and see how the pot boils, if instead of making plans I am to be employed in answering papers and queries, it will be impossible for me to go on'.[16]

Work continued without further interruption.

In May 1771, acting on a suggestion of Mackell's approved by Smeaton, an Act[17] was obtained to alter the canal line to come more directly to Glasgow via Stockingfield and the 'Glasgow branch' to Hamilton Hill Basin. This change accepted the future requirement for a major aqueduct crossing of the river Kelvin to reach Dalmuir.

By 3 September 1773, the canal was navigable from the Forth to Kirkintilloch. With work on Luggie aqueduct started and Glasgow within reach, Smeaton was allowed to resign. Mackell continued as resident engineer. They were both so busy in 1773 that Smeaton brought in William Jessop (1745–1814) to level and set out the 2·9 km feeder aqueduct southwards from the canal just west of Luggie aqueduct to Bothland Burn.[18]

The money runs out in 1777

By November 1777 the Forth & Clyde Canal had reached Hamilton Hill Basin, Glasgow, and work came to a standstill

Table 1. Progress of the Forth & Clyde Navigation 1774–1850[13,14]

Year	Revenue: £	Canal opened westwards from the Forth: km
1774	678	30 (to Kirkintilloch, 3 September 1773)
1775	1148	
1776	2051	42 (to Stockingfield, near Glasgow, 10 November 1775)
1777	4092	
1778	5102	45 (Glasgow Branch to Hamilton Hill, 10 November 1777)
1786	5781	
1789	6986	
1781	12 336	56 (to River Clyde at Bowling, 28 July 1790)
1792	14 122	46 (Glasgow Branch to Port Dundas, March 1791)
		48 (Glasgow Branch to Monkland Canal, October 1791)
1800	21 607	
1815	46 974	
1839	95 475	
1850	115 621	(amalgamated with the Monkland Canal 1846)

> "unlimited headroom for tall-masted vessels provided by means of 43 aqueducts and 33 timber draw-bridges"

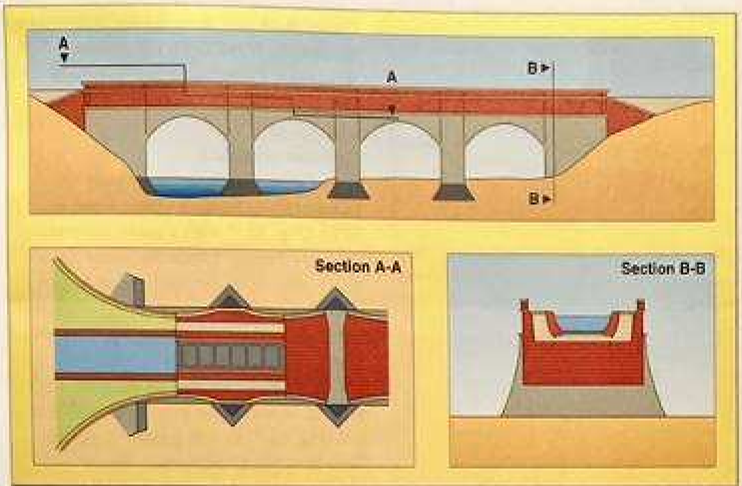


Fig. 2. Elevation, part-sectioned plan and cross section of Kelvin aqueduct, the biggest in Britain at the time.[23] Side walls are curved in plan for extra lateral stability.

with the canal company £40 000 in debt and requiring an additional £60 000 for completion.[19] On 8 September 1779 Mackell died.[20] Despite some management problems, Mackell had Smeaton's full confidence and deserves the greatest credit for his engineering contribution.

Eventually, in 1784, a grant of £50 000 was obtained from the Forfeited Estates Fund for completing the canal. In 1785, after having failed to recruit either Watt or Smeaton, the company appointed Robert Whitworth (1734–99), Brindley's principal assistant, as chief engineer. In August 1785 Whitworth's report was published for completing the canal to Bowling, including the Kelvin aqueduct, at an estimated cost of £56 436.[21]

Structures include Britain's biggest aqueduct

In their design of the Forth & Clyde Canal, Smeaton and Whitworth's main considerations were to achieve the most practicable engineering solutions commensurate with economy and operational requirements. Unlike today they were not required to comply with environmental planning, landfill tax, quality assurance or health and safety legislation.

The large scale of the canal by the standards of its time—17·1 m wide and 2·4 m deep with unlimited headroom for tall-masted vessels provided by means of 43 aqueducts and 33 timber draw-bridges[13]—required many substantial structures.

Kelvin aqueduct

The 19-lock western section of the canal from Maryhill to Bowling included the 135·6 m long by 20·7 m wide Kelvin aqueduct, built during 1787–1789[22] (Fig. 2).[23] Until the Lune aqueduct (1794–96) on the Lancaster Canal, this was the largest in Britain. It was built by Gibb and Muir under Whitworth's direction and cost £9058.[24] Its four 15·2 m spans and horizontal side arches were strongly influenced by the design of Luggie aqueduct.

Luggie aqueduct

Luggie aqueduct (August 1772[25]–1774), a major Smeaton structure, is overall about 33·5 m long, 15·2 high × 27·4 m wide (Figs 3 and 4).[26,27] It is of interest because of the following.

- The canal passes over it at its full width of 17 m, providing the operational benefit of uninterrupted two-way passage.
- Its waterway has horizontal masonry side arches for lateral stability.
- The 15·2 m span arch was built in three stages by means of a timber centering 9·1 m deep which moved on rollers.[28] This novel practice of Falkirk contractor William Gibb (1736–91), founder of the well-known engineering firm, and John Muir produced two joints that are scarcely discernable even today.
- It illustrates the considerable degree of autonomy allowed by Smeaton to

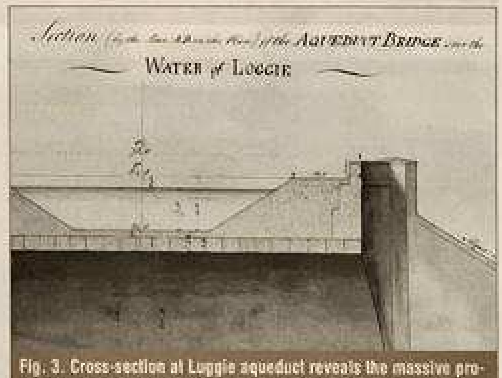


Fig. 3. Cross-section at Luggie aqueduct reveals the massive proportions required by providing a 2·4 m navigable depth over a width of 7·3 m[26]

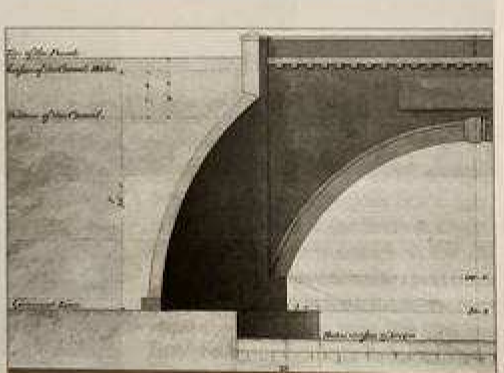


Fig. 4. Elevation of Luggie aqueduct[27]

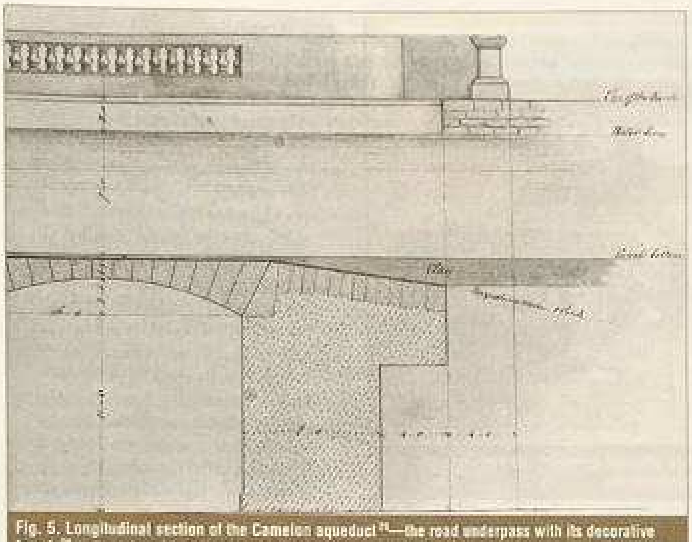


Fig. 5. Longitudinal section of the Camelon aqueduct[28]—the road underpass with its decorative façade[30] was replaced in the 19th century with a swing bridge

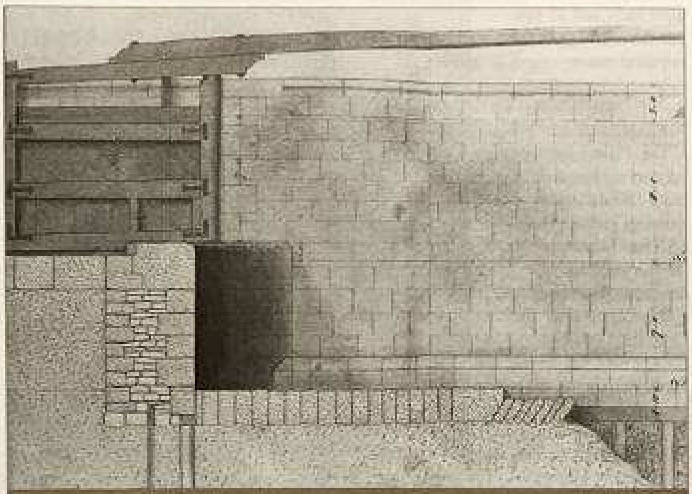


Fig. 6. Longitudinal section of one the Forth & Clyde Canal's 39 locks showing timber piling[31]

Mackell on the construction of aqueducts, even when drawings existed. The span was made 15·2 m instead of 18·3 m and only the upper part adjoining the canal instead of the full depth of the structure was built curved in plan. The existing fine iron railings, not on Fig. 4, may have been a Mackell or Whitworth addition.

In addition to the Luggie aqueduct, engineering on the summit length included water supply from a new reservoir at Townhead and the already-mentioned Bothland Burn feeder aqueduct at Kirkintilloch fed from the Bishop, Woodend, Gartsherrie and Johnston Lochs.

Camelon aqueduct

At Camelon, the underpass of the Edinburgh to Stirling Great Road in 1772 (Fig. 5),[29] with a more decorative masonry façade[30] than the other aqueducts, was replaced by a swing-bridge in the 19th century.

Locks

The 39 locks are 6·1 m wide by 22·5 m long between the gates with a 2·4 m fall (Fig. 6).[31] In soft ground a timber floor and piling were used. From Grangemouth the canal rises 38 m by means of 16 locks over 6·4 km (Fig. 7),[32] and a further four locks in the next 9·6 km to the 29 km long summit-level section from Dullatur Bog to Maryhill.

At Camelon, Smeaton designed the locks 'singly' so as to 'treasure up' a lockfull of water in 0·3 m depth of the channel between each lock. The channel was made wide enough for two vessels, to offer maximum flexibility in use.[33]

Draw bridges

The original timber drawbridges, which had either one or two leaves (Fig. 8),[34] were replaced early last century by cast iron and timber bascule bridges (Fig. 9).[35]

Embankments

Particular difficulties with embankment construction were encountered by taking the canal through, rather than around, Dullatur Bog

> 'it frequently happened, that when the banks were made apparently perfectly, they have sunk down several feet in the course of a day and had to be again renewed, so that it is believed about 55 ft. perpendicular of earth and stones has, at different times, been heaped upon them'.[36]

Salaries and rates of the day

Regarding costs, Smeaton and Mackell received annual salaries of £500, includ-

> "the canal attracted considerable traffic. It had an annual operating profit of the order of twice the annual expenditure throughout most of the 19th century"

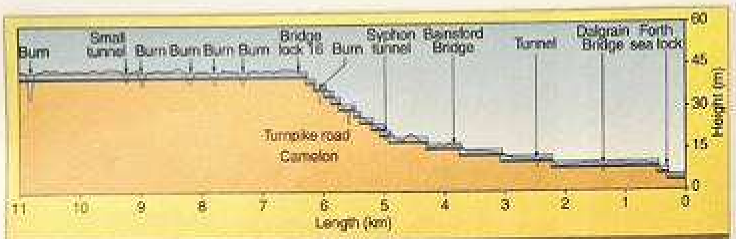


Fig. 7. Longitudinal profile of the east end of the Forth & Clyde Canal showing locks 1–16 required to rise about 38 m.[33] All bridges were drawbridges to provide unlimited head room

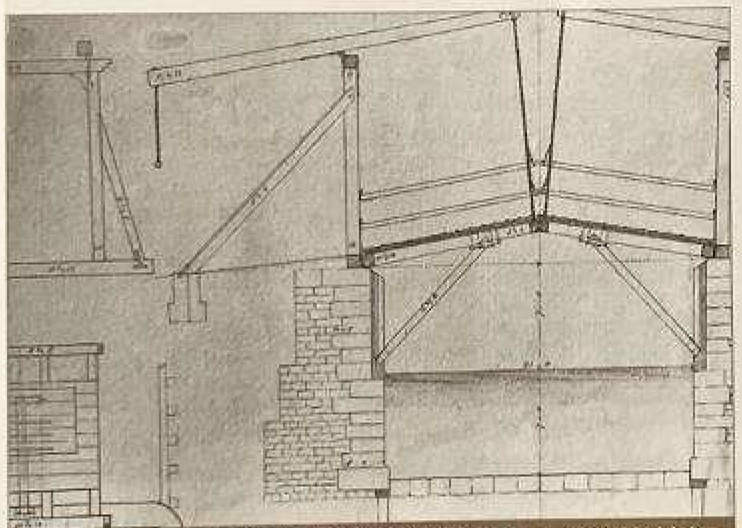


Fig. 8. Typical two-leaf drawbridge over the Forth & Clyde Canal.[34] None of the 33 original timber bridges remain.

Fig. 9. Early 19th century replacement cast-iron and timber bascule bridge at Firrhill in Glasgow, c.1960[35]

ing expenses, and £315 respectively,[37] and Whitworth got £630 including expenses.[38] Surveyors and foremen had salaries of £100 and £52 respectively and labourers were paid 4·2 p a day,[39] around one thousandth of today's rates.[40]

From 1768 to 1790 contract prices for excavation and banking were more or less constant at generally 1·4–1·9 p/m³ [41]—today about 80 times more or 700 times more if the spoil is taken off-site.[40] Masonry contract prices, including 'finding stone, hewing, building lime, sand and carriage', varied from 37–82 p/m³.[42]

Completing the original project

By December 1788 the Forth & Clyde Canal had been deepened to 2·4 m by bank heightening and was opened from sea to sea on 28 July 1790 at a total cost of £305 000.[43] Including the connection to Port Dundas and the Monkland Canal, completed by 31 December 1791, it cost £394 545.[44] This sum is today's equivalent of over £100 million—not allowing for the additional costs which would be incurred now such as for developed land, services diversion, environmental work and stronger bridges.[45]

But even at this high cost, with a horse being able to draw 100 times more on a canal than on a road and with the savings, in distance and shipwrecks, of not having to circumnavigate Scotland, the canal attracted considerable traffic. It had an annual operating profit of the order of twice the annual expenditure throughout most of the 19th century.[46] Some revenue figures are given in Table 1. In 1801 for example the navigation carried 1286 'through' and 1084 'return' boat passages between Grangemouth and Glasgow.[47]

Union Canal adds Edinburgh link

The next major development was the 50 km Edinburgh & Glasgow Union Canal, built during 1818–22 for about £461 760, chiefly to provide Edinburgh with coal.[48] It joined the Forth & Clyde Canal at lock 16 near Falkirk.

For operational economy, the Union Canal was skilfully engineered by Hugh Baird (1770–1827) to be on one level—from the top of the eleven-lock flight adjoining lock 16 via a 636 m tunnel and three 'magnificent'[49] iron-lined aqueducts,

Fig. 10. Aerial view of Wester Hailes, Edinburgh showing the disused canal severed in a large housing estate

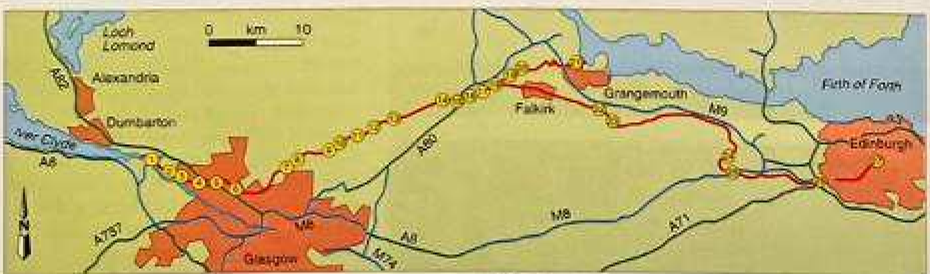
Fig. 12. Glasgow Road bridge, one of four constructed as part of the Glasgow Canal project in 1990 to provide adequate navigational headroom

the largest of which over the River Avon is 247 m long and 26 m high.

Commercially, the venture was in debt from the outset. Despite a valiant effort with 'swift' boats carrying nearly 200 000 passengers in 1836 and a travel time between Glasgow and Edinburgh of less than 7 hours, the canal was unable to compete with the development of railways. It was taken over by the Edinburgh & Glasgow Railway in 1849.[50]

Decline leads to closure in the 1960s

Unusually for canals and a testament to Smeaton's vision, the Forth & Clyde Navigation continued to make an important contribution to the Scottish economy despite the arrival of rail-



1. **Erskine Ferry.** Opening bridge
2. **Dalmuir.** New lock
3. **Kilbowie Road, Sylvania Way, Argyll Road.** New bridges
4. **Duntreath Avenue.** Reconstructed lock 36, build bridge
5. **Blairdardie Road.** Reconstruct locks and basin, new bridge, realign Blairdardie Road
6. **Cleveden Road.** New bridge
7. **Balmuildy Road.** New bridge
8. **Cadder.** Raise bridge
9. **Townhead.** New bridge
10. **Hillhead.** Opening bridge
11. **Auchendavie water main.** Relocate under canal
12. **Twechar.** Opening bridge
13. **Auchinstarry.** New bridge
14. **Wyndford Bridge.** New bridge
15. **A80.** New bridge
16. **Castlecary Bridge.** New bridge
17. **Bonnybridge.** Opening bridge
18. **Falkirk Interchange.** Extend canal, build locks, tunnel, aqueduct and boat lift
19. **Union Road Lock 16.** New bridge
20. **Camelon Road, Merer's Bridge, Bainsford.** New bridges and locks **Abbott's Road.** Stop up road
21. **Grangemouth.** Extend canal to connect with River Forth
22. **A801 Lathallan Road.** Divert canal, build bridge
23. **Vellore Road.** New bridge
24. **Greendykes Road.** New bridge
25. **M8.** Divert canal build bridge
26. **Wester Hailes.** Reform canal 1·7 km, build 8 bridges. **Kinsknowe Road.** New bridge
27. **Leamington Lift Bridge.** Raised and fixed

Fig. 11. Plan of the £78 million Millennium Link canal regeneration project

> In 1933 the connecting flight of locks with the Union Canal at Falkirk were infilled and both canals were eventually closed to navigation in the 1960s

Fig.13. Aerial view of Camelon Road at Falkirk—site of the original Camelon aqueduct—showing the canal blocked by culverts

ways. In 1868 over 3 Mt of goods were carried and even by 1906 traffic was still a significant 1 Mt and 0·7 Mt in 1913.

However, Grangemouth Docks were closed to merchant shipping throughout the first world war, effectively killing major traffic.[51] In 1933 the connecting flight of locks with the Union Canal at Falkirk were infilled and both canals were eventually closed to navigation in the 1960s.

Following closure, the canals were severed or blocked in over 30 locations. In the simplest cases, opening bridges became fixed. In other cases roads were built at grade across new culverts. Lengths totalling 7 km were infilled, the most damaging being over 2 km at Grangemouth and 1·7 km through a large peripheral housing estate at Wester Hailes in Edinburgh (Fig. 10).

Locks fell into disrepair and a multitude of public utility services was placed across the canals.

Millennium Link—a mechanism for change

The £78 million Millennium Link project was conceived as a mechanism by which the restoration of 110 km of the Forth & Clyde and Union canals would become the focus for a much broader transformation (Fig. 11). The project is the culmination of over 25 years of campaigning by canal-side communities—major losers from economic restructuring. The regeneration of the waterways is intended to act as a stimulus for wider community and environmental renewal.

Local pressure contributed to closure, but attitudes changed with new local pressure to improve the amenity and safety of the canals. As early as 1976, less than 14 years following closure, the value of the Forth & Clyde Canal for recreational purposes was recognized to be of regional significance. This change in attitude led through a series of stages to the formal adoption in November 1988 of the Forth & Clyde Canal local plan. This statutory plan is unusual in that it is linear and crosses local authority boundaries.[52]

The will for restoration was growing, but not the means. Some piecemeal improvements were implemented during the late 1980s and early 1990s, when four culverted crossings were replaced by fixed bridges giving navigable headroom (Fig. 12). A long-term project of lock gate renewal was also begun at that time.

National Lottery enables complete regeneration

With the onset of the National Lottery in 1994 it became realistic to consider full restoration from Grangemouth on the Forth to Bowling on the Clyde and between Glasgow and Edinburgh. British Waterways accepted the lead role as project promoter and project manager.

The civil engineering to restore both

> "The real challenges lay in establishing the value of the project and in putting together the required funding"

canals is challenging and complex (Fig. 13). Apparently simple new bridge crossings involve difficult road geometry, complicated service diversions and important local planning issues. The tight budgetary control, programming and procurement issues are also familiar. It is important not to diminish the significance of these challenges nor the hard work and dedication required to achieve engineering success.

However, the construction industry is used to such challenges with experienced people and organizations being available with established skills. Arguably Smeaton would recognize these challenges and skills while being amazed at the sheer volume of legislation and procedures to be followed.

Establishing the value of regeneration

The real challenges lay in establishing the value of the project and in putting together the required funding (Table 2). The improvement of canals in England and elsewhere had been shown to lead to wider regeneration,[55] with some notable successes such as in Birmingham. The main drivers were the creation of colourful activity on the water and an improved environment along the canals. Activity could be quickly generated through the extensive network of canals across England.

The canals in Scotland are different. They are discrete and not integrated into a network. A significant level of activity on the water required at least the reopening of the canals between Glasgow and Edinburgh. By also reopening between the North Sea and the Atlantic, the west of Scotland sailing waters could be made accessible to an additional 500 000 craft in northern Europe.[54] Unlikely to risk the long open voyage to the more northerly and much larger Caledonian Canal, these coast-hopping smaller craft would provide a target market for the much more accessible Forth & Clyde Canal (Table 3).

Social exclusion may be a current buzz phrase, but the underlying values are real. The canals pass through many areas of deprivation. Real sustainable development is now recognized as the combination of environmental, economic and social exclusion considerations.[55,56]

Table 2. Major contracts

Contract ref.	Value: £ million	Site	Scope	Contract form
1	3	A801 Lathallan Road	Fixed bridge	ICE design and construct
		Vellore Road	Fixed bridge	
		Greendykes Road	Fixed bridge	
		M8 Broxburn	Fixed bridge and realigned canal	
2	2	Townhead	Fixed bridge	NEC/ECC, option C—target contract with activity schedule, design and construct
		Cadder	Raise bridge	
		Balmuildy	Fixed bridge	
3	4·5	Clevedon Road	Fixed bridge	ICE design and construct
		Cloberhill pipes	Fixed bridge	
		Duntreath Avenue	Fixed bridge	
4a	2·5	Wester Hailes—Phase 1	Canal and bridges	NEC/ECC, option A—priced contract with activity schedule, design and construct
4b	7	Wester Hailes—Phase 2	Canal and bridges	NEC/ECC, option A—etc
6	17·5	Falkirk Interchange	Canal, tunnel, aqueduct and wheel	NEC/ECC, option A—etc
7	5	Lock 16	Fixed bridge	NEC/ECC, option A— etc
		Lock 11 Camelon Road	Fixed bridge and new lock	
		Merer's bridge	Fixed bridge and new lock	
		Bainsford	Fixed bridge and new lock	
8	4·5	Grangemouth Link	Canal and 2 locks	NEC/ECC, option A—etc
9	5	Dalmuir pipes	Fixed bridge and droplock	NEC/ECC, option A— etc
		Kilbowie Road	Fixed bridge	
		Argyll Road	Fixed bridge	
10a	1·5	Twechar bridge	Opening bridge recommissioned	NEC/ECC, option A—etc
		Hillhead bridge	Opening bridge recommissioned	
		Erskine Ferry bridge	Opening bridge recommissioned	
10b	1·75	Bonnybridge	New opening bridge	NEC/ECC, option A—etc
		Sylvania Way	Twin footbridges	
10c		Leamington Lift bridge	Fix bridge in open position	TBO
11	2·5	A80	Fixed bridge	NEC/ECC, option A—etc
		Castlecary bridge	Fixed bridge	
12	1·75	Wyndford	Fixed bridge	NEC/ECC, option A—etc
		Auchinstarry	Fixed bridge	

Note: In addition to the major contracts the Millennium Link project includes repairs to masonry bridges, aqueducts, weirs and culverts, installation of timber lock gates, dredging and landscaping.

Table 3. Navigation parameters

Navigation parameter	Forth & Clyde Canal	Union Canal	Caledonian Canal
Limiting dimensions—craft			
Length: m	20·12	21·34	45·72
Breadth: m	5·79	3·65	10·67
Draught: m	1·63	0·90	4·11
Air draught: m	2·95	2·70	27·4
Canal channel			
Clear water depth over 6 m wide channel: m	1·83	1·07	
Towpath width: m	2·50	1·80	
New bridges			
Height from water to canal bridge soffit: m	3·00	2·74	
Height from towpath to bridge soffit: m	2·60	2·45	
Clear water width: m	6·35	3·85	
Clear water depth: m	1·83	1·07	
Towpath width under fixed bridges: m	3·00	2·50	

"The canal in itself must generate sufficient revenue income through charges to boat users, developers and water charges to sustain the navigable waterway to the environmental quality standards of today and of the future"

This project, which on the face of it is about civil engineering, is in fact the key first stage of an exemplar for sustainable development. It brings civil engineering into the mainstream. Civil engineers must be able to understand the real why of what they do.

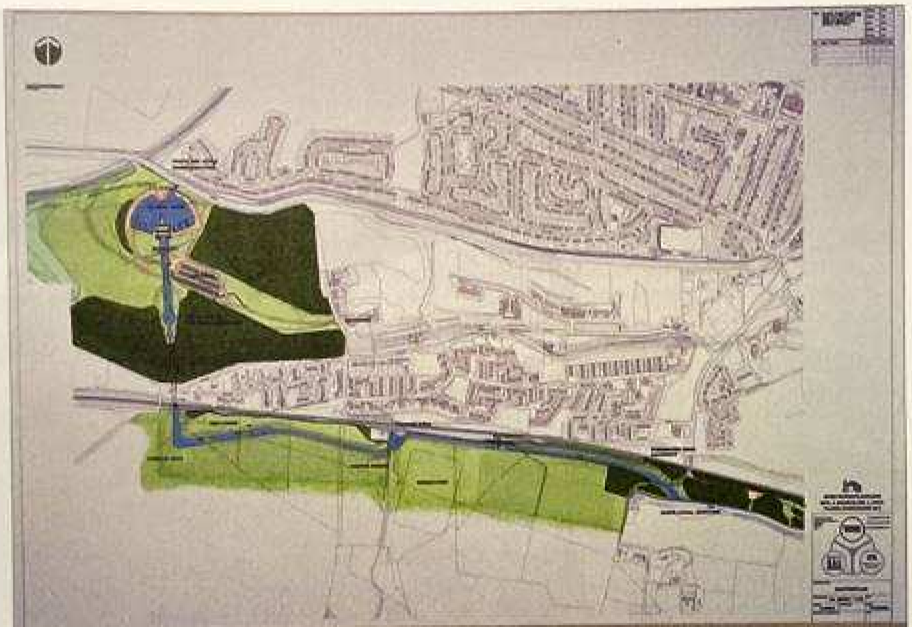


Fig. 14. Plan of the proposed Falkirk interchange between the Forth & Clyde and Union canals

Building the funding partnership

The capital investment for restoration had to be justified but, unlike in Smeaton's day, not necessarily with a direct commercial payback. The investors have their own objectives, including social, economic and environmental aspects. Although broader in concept these are often interpreted from a narrow organizational viewpoint.

The revenue costs of the reopened canals also had to be justified. Step income had to match or exceed step costs to allow British Waterways to continue in the role of owner and manager.

The lead role and the financial risk lies with British Waterways. The over-arching document is the contract between British Waterways and the Millennium Commission. This sets a completion date of September 2001 and defines project purpose as the restoration of navigation coast to coast and between Edinburgh and Glasgow. British Waterways has similar legal agreements with Scottish Enterprise and with the local authorities.

All responsibility and risk for delivery of the £78 million canal restoration, including any cost overrun, lies with British Waterways, which is also the recipient of a European Regional Development (ERDF) grant. This willingness by one party to take a strong lead and accept clear responsibility was instrumental in the success in securing the partnership and the funding package (Table 4). Each funding partner has clarity of responsibility and contribution. A partnership steering committee chaired by a local authority councillor monitors progress.

Local authorities were mostly interested in the local social and environmental benefits of the particular section of the project through their area. The support of canal-side communities was as crucial as any projected benefits produced by professional analysis.

The Millennium Commission, having been convinced of the community support, appointed consulting engineers to carry out a detailed appraisal of technical and financial aspects, including the likely achievement of the multitude of statutory approvals required. Scottish Enterprise evaluated a broad range of economic and environmental benefits.

Obtaining EDRF support required a full socio-economic cost–benefit analysis in accordance with rules laid down by the European Commission. The analysis required the full cost to be justified regardless of the level of grant.

The environmental aspects had to be approved by Scottish Natural Heritage to allow that body to validate the project to the satisfaction of the EDRF. Throughout this process, which ran from the summer of 1994 until the funding package was finally secured in March 1998, the lead was taken by civil engineers.

Table 4. Project funders

Funder	Amount: £ million
Millennium Commission	32·20
Scottish Enterprise Network	18·70
Strathclyde European Partnership (ERDF)	4·75
Eastern Scotland Eur. Partnership (ERDF)	3·84
British Waterways	9·30
City of Edinburgh Council	1·70
West Lothian Council	0·55
Falkirk Council	0·55
North Lanarkshire Council	1·28
East Dunbartonshire Council	0·44
Glasgow City Council	2·35
West Dunbartonshire Council	0·33
Private and voluntary sector	2·40

Falkirk Wheel—a symbol

Historically, the two canals met near Falkirk, with a traditional flight of eleven locks overcoming the 33·5 m level difference. A new route and a new method of connecting the canals have been devised,

Fig.15. Artist's impression of the spectacular Falkirk Wheel, centrepiece of the project

intended as a landmark for modern engineering.

Innovatively combining proven technologies, a striking rotating boat lift will transport leisure craft and visitors (Fig 15). Its sheer scale and uniqueness should be a magnet for visitors and it is expected to become an international tourism attraction in its own right.

The wheel is symbolic of the purpose of the Millennium Link as a catalyst for sustainable change. On the site of former opencast mining and an old tar works, adjacent to the Antonine Wall which marks the northernmost boundary of the Roman Empire, the Wheel is more than simply a device for moving boats between two canals. Its presence should stimulate development and create opportunities for local people, groups and businesses.

Environmental legislation governing the project

Public awareness on environmental and sustainability issues only really started in the 1960s. The Millennium Link represents both environmental and sustainability awareness and the need to sustain infrastructure which has both social and environmental benefits. An earlier example of a project where socio-environmental benefits outweighed economic benefits was the 1967 Strathclyde Park scheme.[57] This involved formation of the Strathclyde Loch between Motherwell and Hamilton with the aim of regenerating the area to provide benefits to the local community for recreation and sport. The Millennium Link project fits exactly into that kind of framework, where the benefits will be to the communities along the length of the canal in terms of sport, recreation and environmental regeneration.

With increased public awareness of the environment and sustainability it is not surprising that there has been a plethora of environmental legislation since around 1967. The legislation is also reflected in the membership of the European Union. By 1992, over 200 legislative acts, directives and regulations had been promulgated by the European Union and are mandatory on all member states. This is in addition to the considerable legislation that is also passed through the UK parliament on environmental issues. Table 5[58] shows some of the legislation affecting the construction industry and specifically the Millennium Link.

The combined Forth & Clyde and Union canals have become a scheduled ancient monument under Historic Scotland and a listed building under the planning regulations. This requires a higher standard of reconstruction and a more rigorous case for planning.

The canal passes through several local

Table 5. Legislation affecting the civil engineering of the Millennium Link[58]

Sector	Legislation
Water	Control of Pollution Act
	Drinking Water Directive
	Urban Wastewater Directive
	Bathing Water Directive
	Protection of Groundwater Directive
	Framework for Water Policy Directive (to be enacted)
Air	Air Pollution Directive
Land	Environment Bill
	Landfill Tax Bill
	Aggregate Tax (to be enacted)
	The Landfill Directive
General	Environmental Impact Assessment Directive
	Conservation of Birds Directive
	Waste Management Directive

"The canal in itself must generate sufficient revenue income through charges to boat users, wayleaves and water charges to sustain the navigable waterway to the environmental quality standards of today and of the future"

authority areas and is thus subject to a number of different planning authorities. Each civil engineering project associated with the canal requires planning permission. This in turn requires the full rigour of environmental legislation to be applied, in particular the environmental impact assessment required to plan and design the operation and maintenance of the system.

BWB's environmental code

British Waterways Board has established an environmental code of practice that includes the preparation and publication of an environmental policy. Every major maintenance project—including dredging and alterations to the towpath—requires an environmental appraisal.

For example, an environmental appraisal for dredging operations requires environmental consideration of the operations themselves as well as proposals to reduce any detrimental impact. Certain sections of the canals contain contaminated silt, which may exclude disposal of spoil to adjacent land due to high levels of heavy metals. In compliance with the environment bill, such spoil needs to be transported to commercial landfill sites and subject to landfill tax.

The impact of dredging operations requires a number of surveys to be undertaken to ensure that the ecology of the canal is not adversely affected and to protect rare species. These therefore include plant species surveys, breeding bird surveys and others in order to design operations and ensure that environmental quality standards are satisfied. Table 6[59] shows a typical example of a plant species survey carried out in the canal.

All planning applications require consultation with the various statutory authorities in Scotland, including the Scottish Environment Protection Agency, Scottish Natural Heritage and the Royal Society for the Protection of Birds. In taking forward an environmental policy and having an environmental code of practice, the British Waterways Board has demonstrated to the various environmental regulatory bodies and conservation groups that the Millennium Link project will be of environmental benefit to the area and can be undertaken without severe environmental impact on the ecology of the system. In this way environmental legislation such as the Conservation of Birds Directive, the Waste Management Directive, Environmental Impact Assessment Regulations, the Control of Pollution Act and the Environment Bill are satisfied and the construction process is not seen as a detrimental problem.

It is the opinion of the authors that future civil engineering projects require the framework for an environmental code of practice in order to ensure smoother progress to the approval of projects and their future management within a nation's environmental infrastructure.

Socio-environmental benefits of the project

The canal project will reopen a waterway capable of transporting vessels 20 m long by 4 m wide between the North Sea and Irish Sea. In places the canal runs parallel to the Antonine Wall, significantly improving access to what was the most northerly line of Roman occupation. It will promote cycling as a recreational sport by reopening towpaths with special provision for cyclists and pedestrians.

The canal will enable increased interest in ecology by encouraging schools as part of their curriculum and volunteer groups to access the canal towpaths to enjoy the biodiversity that already exists there, both in flora and fauna. The redevelopment will be signposted to identify plants, animals and birds in their canal habitats.

The canal will also give engineers and lay people alike a much greater appreciation of the civil engineering excellence generated in the 18th and 19th centuries by Smeaton and others. The American Society of Civil Engineers and the Institution of Civil Engineers panel for historical engineering works (PHEW) have designated the site of particular importance and plan to register it as an international heritage site.

The reopening of the Forth & Clyde Canal and the Union Canal, together with the other Scottish and English canal systems, will enable the resurgence of boating activities which use canals and will enable them to link to other international canal projects through the international canal network.

The Millennium Link also passes through depressed socio-economic areas and by regenerating a canal these areas will benefit in the form of improved recreation and benefits in small business start-ups associated with the canal project.

A question of sustainability

The original Forth & Clyde Canal cost £394 545 to build, which to build now on the same line, for modern traffic, and complying with current codes of practice and regulations, would represent an investment probably in the order of £400 million. The £78 million investment in regenerating it and the Union Canal therefore represents only a small fraction of the cost of creating this facility now.

The project's sustainability, however, must be within a socio-environmental framework. The canal in itself must generate sufficient revenue income through charges to boat users, wayleaves and water charges to sustain the navigable waterway to the environmental quality standards of today and of the future. Only then will the 'enviro-capital investment' be justified.

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Table 6. Example of a plant species survey[59]

Species	Common Name	GB	F&C	Notes
Ceratophyllum demersum	Hornwort	3	13	Notable Scottish species
Myriophyllum spicatum	Spiked water millfoil	3	4	Limited to shallows
Potamogeton friesii	Flat-stalked pondweed	2	12	Notable Scottish species
Potamogen obtusifolius	Blunt-leaved pondweed	1	6	Notable Scottish species
Potamogen x bennettii	Bennett's pondweed	4	5	Endemic to canal

Notes:
1. GB, Glasgow Branch
2. F&C, Forth & Clyde Canal
3. Notable Scottish species include those which are scarce in Scotland (found in <100 10 x 10 km squares in Scotland) and/or have localized distribution in Scotland

References

1. TELFORD T. Navigation inland. *Edinburgh Encyclopaedia*. Edinburgh, 1830, XV, 223–224. First published in 1821.
2. DEFOE D. *Tour Thro' the Whole Island of Great Britain*. 1727 (1726), III, p. 101 (Scotland).
3. HOPKIRK J. *Account of the Forth and Clyde Canal Navigation*. Glasgow, 1816, p. 7.
4. Smeaton described himself as a 'Civil Engineer' as early as 1754 in a report of 21 September 1754 on the drainage of Lochar Moss, near Dumfries. Dr W. Singer. *General View of the Agriculture… of Dumfriesshire*. Edinburgh, 1812, p. 491.
5. LESLIE J. and PAXTON R. *Bright Lights—The Stevenson Engineers, 1752–1971*. 1999, p. 120.
6. SMEATON J. *The Report of John Smeaton, Engineer and FRS, Concerning the Practicability and Expense of Joining the Rivers Forth & Clyde by a Navigable Canal…*, Edinburgh, 1767.
7. MACKELL R. and WATT J. *An Account of the Navigable Canal, Proposed to be Cut from the River Clyde to the River Carron*. 1767, p. 16.
8. LINDSAY J. *The Canals of Scotland*. Newton Abbot, 1968, p. 18.
9. SMEATON J. *The second report of…* Edinburgh, 1767. Partnership, Dunfermline, 1998.
10. Act. 8. Geo. III, c.63. (8 March 1768).
11. SMEATON J. *Reports of the late John Smeaton, FRS Made on Various Occasions in the Course of his Employment as a Civil Engineer*. 1812, II, pp.122-124.
12. Dr Martin Barnes in the 1999 ICE Smeaton Lecture. *NCE*, 5/12 August, 1999, p. 20.
13. Compiled by the author from Hopkirk, op. cit. 75 and National Archives of Scotland, BR/FCN/1/37, 211–214.
14. *Imperial Gazetteer of Scotland*. Fullarton, c.1856, I, 687.
15. BRINDLEY J., YEOMAN T. and GOLBORNE J. *Reports by… Relative to a Navigable Communication Betwixt the Friths of Forth and Clyde*. Edinburgh, 1768, p. 13.
16. SMEATON J. *A Review of Several Matters Relative to the Forth and Clyde Navigation, as Now settled by Act of Parliament: with Some Observations on the Reports of Mess. Brindley, Yeoman and Golborne*. Edinburgh, 1768.
17. Act. 11. Geo. III, c.62.
18. National Archives of Scotland, BR/FCN/1/5 365–378.
19. LINDSAY. Op. cit. 26.
20. National Archives of Scotland, BR/FCN/1/11, 140.
21. WHITWORTH R. *Report of… to the Company of Proprietors of the Forth and Clyde Navigation. Relative to the Tract of the Intended Canal, from Stockingfield West-ward, and Different Places of Entry into the River Clyde. With Estimates… and Pointing out Where Several Additional Supplies of Water may be Got… August 2, 1785*. (n.p., 1785). To be read in conjunction with ref. 32.
22. National Archives of Scotland, BR/FCN/1/37, 211–214.
23. TELFORD. Op. cit. pl. (414)
24. HOPKIRK. Op. cit. 30.
25. National Archives of Scotland, BR/FCN/1/5, 75.
26. The Smeaton drawings at the Royal Society, London, V, f. 27.
27. The Smeaton drawings at the Royal Society, London, V, f. 26v.
28. HOPKIRK. Op. cit. 25.
29. The Smeaton drawings at the Royal Society, London, V, f. 29.
30. The Smeaton drawings at the Royal Society, London, V, f. 28.
31. The Smeaton drawings at the Royal Society, London, V, f. 11.
32. Part of 'A Plan of the Great Canal from Forth to Clyde by Robt. Whitworth Esqr and Mr John Laurie'. Drawn and engraved by John Ainslie, 1785. Another edition was published in 1790.
33. Forth Ports Authority. Copy letter J. Smeaton to A. Hart, Agent to the Navigation, 29 Nov. 1769.
34. The Smeaton drawings at the Royal Society, London, V, f. 9v.
35. Author's photograph *ex dono* the late John G. James.
36. HOPKIRK. Op. cit. 25
37. National Archives of Scotland, BR/FCN/1/1, 69. Minutes of meeting of 15 April 1768.
38. National Archives of Scotland, BR/FCN/1/12; FPA, Whitworth letter 29 April 1788.
39. National Archives of Scotland, BR/FCN/1/1. Lindsay. Op. cit. 20, 26.
40. Based on a discussion about present-day rates with A. Robertson of Barr Ltd, Ayr.
41. National Archives of Scotland, BR/FCN/1/1, 91. Minutes of 7 June 1768. BR/FCN/1/7, 209. BR/FCN/1/5. Smeaton's report to Edin. Meeting 2 August 1773.
42. National Archives of Scotland, BR/FCN/1/8. Report to committee 13 November 1786. The rates varied from £6.15s to £15 per rood; that is 36 sq. yds superficial at a notional 2 ft thick reduced from the measured area and thickness or 24 cu. yds.
43. HADFIELD C. Rivers and canals. *John Smeaton, FRS* (Skempton A. W. (ed.)). Thomas Telford, London, 1981, p. 123.
44. According to Patrick Colquhoun who was Superintendent of the Navigation until 1792.
45. Using the factor of 280 from Paxton R. A. Conservation of Laigh Milton Viaduct, Ayrshire. *Proceedings of the Institution of Civil Engineers, Civil Engineering*, 1998, **126**, May, 74, which is probably conservative in this case.
46. LINDSAY J. Op. cit. 220–221.
47. LINDSAY J. Op. cit. 217–218.
48. LINDSAY J. Op.cit. 65, 210.
49. TELFORD. Op. cit. 311.
50. LINDSAY J. Op. cit. 83.
51. LINDSAY J. Op. cit. 49.
52. *Forth and Clyde Canal Local Plan*, Strathclyde Regional Council, Glasgow, 1988.
53. *Canals—A Catalyst for Regeneration*. Conference Proceedings, British Waterways, Glasgow, 1995.
54. Ash Consultants and Coopers and Lybrand. *Tourism Study for British Waterways and Scottish Tourist Board*. British Waterways, Glasgow, 1995.
55. *Consultative Report—The Sustainable Development Project*. Eastern Scotland European Partnership, Dunfermline, 1998.
56. *Down To Earth—A Scottish Perspective on Sustainable Development*. The Scottish Office, Edinburgh, 1999.
57. FLEMING G., FRAZER W. and ALLEN J. H. *Sediment Movement in the Clyde In The Section of Hamilton Low Parks*. Report to Binnie & Partners, HO-67-13, Department of Civil Engineering, University of Strathclyde. November 1967.
58. KRAMER L. *Focus on European Environmental Law*, Sweet & Maxwell, 1992, p. 86.
59. *The Millennium Link—Dredging Operations and Environmental Considerations and Mitigations for Spot Dredging between Speirs Wharf and Stockingfield Junction in Spring/Summer 1999*. British Waterways report, May 1999.

Note: (Smeaton, J.) *A catalogue of the civil and mechanical engineering designs 1741–1792 of John Smeaton, FRS, preserved in the library of the Royal Society*. Newcomen Society, 1950, includes details of 40 Forth & Clyde Canal plans from Smeaton's own collection (1768-92).

Discussion

If you would like to contribute to the discussion please post/fax/e-mail your comments (500 words maximum) to the editor by 31 August 2000.