Department for Environment Food & Rural Affairs

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Environment Agency

delivering benefits through evidence

Cost estimation for culverts – summary of evidence

Report –SC080039/R4

Flood and Coastal Erosion Risk Management Research and Development Programme

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Miranda Kavanagh

Director of Evidence

Executive summary

This summary of evidence provides indicative costs and guidance on culverts and associated trash and security screens typical of those used by operating authorities for watercourses in England and Wales.

Culverts		
Key cost components	There are two aspects with regard to the costs associated with culverts: • capital costs associated with new culverts • operation and maintenance (O&M) aspects of existing culverts resulting from debris blockage or sedimentation	
Key asset types	• Culverts • Trash and security screens	
Data reviewed in specific guidance	Key datasets include: • Environment Agency Unit Cost Database (capital costs) • Environment Agency Maintenance Standards (maintenance costs) • information provided by local authorities • Environment Agency labour entry inspection and maintenance costs	
Other relevant data	Local or proxy records such as data from Environment Agency SAMPs and local authority information	
Relative cost importance	Enabling costs	Low costs typically due to typically short length of asset. Longer culverts that pass beneath multiple properties or highways may increase costs due to multiple ownership, restricted access, confined space working and traffic management.
	Capital costs	Variable costs depending on type of asset, length and size
	Maintenance costs	O&M costs are important whole life costs for culverts and trash screens as these may include annual, intermittent and post-flood operation, inspection and maintenance costs. Poorly designed existing structures in high risk environments can result in relatively high maintenance costs. Well-designed assets in lower risk locations will be almost maintenance free.
	Other cost considerations	May include environmental (fish passage retrofit costs), daylighting and decommissioning costs.

Cost estimation methodology	Initial concept/national appraisal	Approximate unit rates for the completed asset available for capital and O&M elements
	Strategic, regional, or conceptual design	Approximate unit rates for the completed asset available for capital and O&M elements.
	Preliminary feasibility/design	No specific cost information provided. Guidance on data availability and procedures provided.
Design life information	Data provided by Environment Agency asset deterioration reports are provided for guidance. Design life will be based on the materials used in construction and maintenance practice.	
Quality of data	Limited data sources have been collated and are provided suitable for strategic, early or national level appraisals. Cost information on both culverts and trash screen operation and maintenance costs is provided based on broad categories of asset length, size/diameter and target condition grades. Capital costs associated with culverts are available from out-turn project costs based on culvert sizing and length, although cost information specifically on trash screens is limited.	
Additional guidance	Checklist of factors likely to influence capital and maintenance costs, and key factors to consider for detailed costs estimation List of R&D and general design guidance Case studies of recent schemes	

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Contents

1 Flood mitigation measure – culverts

Avoidance of culverts is required under the Water Framework Directive. But although the Environment Agency and other responsible organisations have policies incorporating a hierarchy of principals (the first of which is to avoid culverting watercourses where possible), these may not always be viable options. Avoidance of culverts is preferred due to:

- degraded ecological and morphological status
- blockage risks
- health and safety risks
- landscape and amenity impacts
- increased maintenance aspects

There are two types of costs associated with culverts:

- capital costs associated with new culverts
- operation and maintenance (O&M) aspects of existing culverts

1.1 Data requirements

A number of standard cost parameters are required for culverts. These include:

- initial procurement and capital costs
- operation and maintenance costs (inspection, de-silting, repairs)
- trash screen inspection and clearance costs (if relevant)
- remedial, replacement or decommissioning costs

1.2 High level cost estimates

1.2.1 Capital costs

Estimated capital costs for culverts are given in the Environment Agency's *Flood Risk Management Estimating Guide* (Environment Agency 2010a). Indicative costs are available for a range of cross-sectional areas for rectangular or square culverts (Table 1.1). The costs available are based on out-turn costs from 37 projects to install new culverts and include all associated works such as the provision of headwalls, trash and security screens, and fencing.

Table 1.1 Environment Agency Unit Cost Database culvert costs

Length (m)	Cross sectional area (m^2)					
	0.5	**1.0**	**2.0**	**4.0**	**6.0**	**12.0**
10	8,400	10,600	13,500	17,100	19,700	25,000
50	2,900	3,700	4,700	6,000	6,900	8,700
100	1,800	2,300	3,000	3,800	4,400	5,500
200	1,200	1,500	1,900	2,400	2,800	3,500
300	900	1,100	1,500	1,800	2,100	2,700

Notes: Costs are per metre length of culvert.

As part of this project, local authorities were contacted to see if any alternative cost estimates were available for other organisations. Kirklees Council[1] provided the information given in Table 1.2 in relation to indicative capital costs for new pipe culverts. This information is based on experience of constructing culverts by developers on sites where the council takes on the responsibility for long-term maintenance of the culvert.

Table 1.2 Kirklees Council culvert costs

Pipe diameter (mm)	Culvert length (cost per m)			Depth above culvert (% increase)		
	0–10 m	**10–100 m**	**100+ m**	**<2 m**	**2–4 m**	**>4 m**
225	300	200	180	0	50	100
300	350	250	230	0	50	100
450	500	350	300	0	50	100
600	700	500	450	0	30	50
750	900	750	650	0	30	50
900	1,300	1,000	900	0	20	30
1,200	1,900	1,600	1,500	0	20	30
1,500	2,500	2,000	1,800	0	20	30

Notes: Costs are per m length of culvert.
Costs relevant for working in live carriageway and carriageway reinstatement, assume there are no manholes, lateral connections and so on and include all staff costs/fees.

The costs given above should be considered to be indicative.

In addition to the cross-sectional area, costs will also depend on other factors as presented in Table 1.3.

[1] Personal communication from Tom Ghee, Kirklees Council.

Table 1.3 Key factors influencing culvert costs

Factors influencing capital costs	Impact on cost estimation
Shape of culvert	Costs above represent square or rectangular culverts only.
Access constraints	Urban/rural locations Distance to site Ease of movement along site Need for temporary access
Weather	Winter working will influence productivity and on-site works duration.
Materials used	The above costs represent pre-cast concrete culverts. Alternative materials may alter or increase the costs used.
Construction method	Culverts built online (and therefore needing water management) will be more expensive than those built offline and in the dry.

1.2.2 Operation and maintenance costs

A key aspect of culvert costs are the whole life costs associated with regular operational works (inspections and screen clearance) and recurrent maintenance actions (such as de-silting, blockage removal and repairs). It is critical that these aspects are fully considered within a cost estimate as these may account for a high proportion of total costs.

Annual O&M costs are available for culverts based on the Environment Agency's Maintenance Standards (Environment Agency 2010b). Costs are available for three target condition grades based on the Environment Agency's Condition Assessment Manual (Environment Agency 2006). Table 1.4, Table 1.5 and Table 1.6 give indicative costs for target condition 2, 3 and 4 respectively. These costs represent a broad range of costs per year per culvert depending on variable culvert size and culvert length. Costs for a target grade 1 are not given as a target grade of 1 is not usually recommended.

Table 1.4 Cost range assuming maintenance to target condition grade 2 (£/year/culvert)

Span/diameter (m)	Culvert length (m)		
	<20	20–50	>50
<1.2	730–2,145	810–2,875	875–350
1.2–4.0	1,760–12,900	3,690–24,800	6,265–47,000
>4.0	1,770–13,900	3,790–25,800	6,365–49,000

Table 1.5 Cost range assuming maintenance to target condition grade 3 (£/year/culvert)

Span/diameter (m)	Culvert length (m)		
	<20	**20–50**	**>50**
<1.2	150–535	190–755	220–945
1.2–4.0	340–3,600	980–7,015	1,945–13,490
>4.0	345–3,900	1,030–7,315	1,995–14,090

Table 1.6 Cost range assuming maintenance to target condition grade 4 (£/year/culvert)

Span/diameter (m)	Culvert length (m)		
	<20	**20–50**	**>50**
<1.2	0–170	0–220	0–265
1.2–4.0	0–790	0–1,480	0–2,695
>4.0	0–840	0–1,530	0–2,795

As the range of costs for culvert maintenance are very wide, use of a weighting and scoring methodology is recommended to determine an appropriate point within the range based on the three key factors that influence operation and maintenance costs as shown in Table 1.7.

Table 1.7 Weighting of factors influencing culvert maintenance costs

Factor that influences maintenance costs	Weight
Difficult access (distance to worksite, protected sites/species, invasive species, overhead power cables, internal services, confined space)	2
Culvert located in channel with silt/debris accumulation problems	1
Properties of the culvert that increase maintenance frequency (steps, bends, changes in cross-section, changes in slope/bed levels/soffit levels, irregular sections)	2

Notes: A score between 0 and 2 is given to each factor. Scores are multiplied by the weight to give a score between 0 and 10. A value of 0 corresponds to the lower end of the cost range and a value of 10 corresponds to the higher end of the unit cost range.

The physical access constraints are more influential than some of the environmental factors in Table 1.7, with inspection and maintenance methods strongly dependent on the following barrel dimensions:

<450 mm difficult to maintain even with remote techniques

<1,200 mm needs remote techniques

>1,200 mm suitable for human entry techniques

Maintenance costs will also depend on barrel material and maintenance methods. For example, masonry in poor condition and plastic pipes are unsuitable for high pressure jetting. CIRIA's *Culvert Design and Operation Guide* (Balkham et al. 2010) provides an overview of the different materials (Section 9.3.4) and repair methods (Table 8.4).

1.3 Detailed cost estimates

1.3.1 Design and inception costs

As with any scheme there are initial procurement and capital costs that cover the initial stages of the project. As culverts are used widely and may represent just one element of a wider scheme, these costs may be already included elsewhere within a cost estimate. The appraiser will need to distinguish whether additional costs for these elements are required.

Items that may need to be determined include:

- professional fees – initial appraisal and design costs
- consultation including planning, management and agreements
- licences and consents – planning permission, land drainage consent and others

Typical enabling costs vary from 8% to 32% of the total scheme cost for flood defence projects, but vary depending on the size of the project and the operating authority undertaking the works. No specific costs are available for culverts as these are usually incorporated within a wider scheme. Indicative values for these enabling works are provided in the generic guidance section for use where more detailed estimates are not available.

1.3.2 Capital costs

Costs may include:

- materials – including supply, delivery, unloading, storage
- contractor costs – labour, plant, site establishment, temporary works
- supervision and professional fees
- waste disposal
- land purchase/compensation

Costs based on the high level analysis can be used to obtain indicative costs in the first instance of a whole life cost estimate. More detailed analysis will require costs to be determined from price estimating books, previous experience or from tender returns at the design stage of an analysis.

For contractors working under the Environment Agency's National Contractors Framework 2, costs for specific principal work items that cover typical Environment Agency Schemes were provided and agreed for use in project appraisal report (PAR) construction cost estimates and for the benchmarking of prices.

A typical breakdown of element for a pre-cast concrete culvert and in-situ concrete headwalls is shown in Table 1.8.

Table 1.8 Sample work items for detailed cost estimation

Work items for culvert barrel	Work items for culvert inlet/outlet structure
Temporary river diversion and water management	Temporary river diversion and water management
Strip and stockpile topsoil	Excavate in cutting to formation
Trench excavation	Excavate toe
Prepare formation	Preparation of formation
Lay membrane	Provide and place binding concrete to base and toe
Supply and place blinding concrete	Formwork to face, tow, wingwalls and sides and so on
Precast concrete culvert units	Bar reinforcement
Backfill with selected excavated or imported material	Surface finishes to outfall invert, headwall and wingwalls
Replace topsoil and trimming of final surface	Standard toe revetment
Landscaping area	Backfilling
Disposal of surplus material	Disposal of surplus material

Typical costs determined by the Environment Agency's North West Region in 2004 (Environment Agency 2004) suggested the costs shown in Table 1.9 for typical pre-cast culverts and in Table 1.10 with associated inlet and outlet straight line wingwall structures.

Table 1.9 Typical costs per linear metre for pre-cast concrete culverts

Dimensions	Cost for per linear m
1500 mm × 1000 mm	£777
2100 mm × 1200 mm	£938

Notes: 2004 costs

Table 1.10 Example unit costs for inlet and outlet structures

Diameter	Depth (m)	Unit cost
900 mm	1.5–2.0	£3,420
	2.0–2.5	£4,085
1,200 mm	1.5–2.0	£3,970
	2.0–2.5	£5,006
1,500 mm	2.0–2.5	£6,028
	2.5–3.0	£6,675

Notes: 2004 costs

In addition to pre-cast concrete, other culvert barrel materials and construction methods are available such as:

- in situ concrete
- corrugated steel – can be brought to site in panels and bolted together, ideal for difficult access
- plastic – much lighter than concrete
- masonry

Similarly, headwall materials (concrete bagwork, breeze blocks, masonry, gabions and so on), transition types (square headwall, straight line transition, wedge, curved in plan, warped) and construction methods will also vary and will need to be considered in a detailed cost estimate.

Additional items that also need to be considered include:

- security and fencing
- telemetry/CCTV installation
- lighting and signage (health and safety aspects)
- screens (if applicable)

Account should be taken of items that may increase costs or hinder on-site progress. The most important factors influencing costs are provided in Table 1.11.

Table 1.11 Factors influencing culvert capital costs

Factor	Impact on cost estimation
Access constraints	Urban/rural locations Distance to site Confined working conditions Ease of movement along site Need for temporary access
Size and shape of culvert	Cost of precast culverts will vary depending on the shape and size of culvert required. Typical costs from price estimating books may not be

Factor	Impact on cost estimation
	applicable for short culvert lengths.
	Efficiency savings may apply for longer culvert sections.
	Pre-cast concrete units may require crane for lifting.
Depth of culvert	Increased depth of culvert and trench excavation will increase costs.
Weather	Winter working will influence productivity and the duration of on-site works.
Materials used	Alternative materials may alter or increase costs.
Online/offline construction	Online construction will be more expensive due to the need for temporary river diversion and water management.
Tidal working conditions	Tidal working conditions will effect on-site productivity and affect normal output/progress.

1.3.3 Operation and maintenance costs

Operation and maintenance costs need to be properly considered in a whole life cost analysis. Any costs with associated regular inspection and clearance of trash screens will increase maintenance demands and long-term costs. It is therefore essential that all items are included within a whole life cost appraisal.

Operation and maintenance costs will include:

- all relevant inspections – asset condition, post flood, public safety inspections and internal inspections
- operational inspections including the clearance of trash and debris, monitoring and recording (records of activity relating to inspections/cleaning frequency, debris removal and evidence of vandalism)
- maintenance – annual and intermittent
- repairs – blockages cause more costly damage within the culvert
- disposal of waste

A basic approach to costing for operational inspections is to determine the inspection frequency required and to multiply this by the cost associated with an inspection (operative hours required multiplied by operator rates). Guidance on inspection frequencies for culverts is given below.

Inspection frequencies

Culvert inspections have considerable implications for the whole life cost. Inspections frequencies will vary depending on:

- the consequence of failure or blockage of a culvert
- the remoteness of a culvert
- type of inspection required

- visual inspections
- internal/principal inspections (close examination that may require culvert entry and specialist equipment)

Costs for inspections can be calculated by determining the inspection types required for a particular culvert and multiplying these by the staff costs associated with the inspection. Typical inspection regimes for Environment Agency inspections are provided in Table 1.12. Further guidance is provided in the *Culvert Design and Operation Guide* (Balkham et al. 2010, Table 7.1).

Table 1.12 Sample culvert inspection frequencies

Inspection activities:	**Frequency**	**Source**
Superficial inspection	Variable – may be monthly if combined with inlet/screen inspections/clearance	CIRIA Culvert Design and Operation Guide, 2010
General inspections	Target condition grade 2: 1: 5 years	Environment Agency Maintenance Standards
	Target condition grade 3: 3–10 years	Environment Agency Maintenance Standards
	Target condition grade 4: 10+ years	Environment Agency Maintenance Standards
	1-2 years	CIRIA Culvert Design and Operation Guide, 2010
Internal/ principal inspections	Approximately every 5 years	CIRIA Culvert Design and Operation Guide, 2010
	6–15 years	Environment Agency guidance[1]
Special inspections	Dependant on recommendation from above inspections. No defined frequency.	N/A

Notes: The Environment Agency has produced internal guidance for internal culvert inspections (personal communication with Anne Thurston; supporting Environment Agency internal document 166_03_SD02). This guidance provides a risk-based approach based on the current condition grade for a culvert and the risk of culvert failure. For grade 1 or 2 culverts, the internal inspection frequency is 8–15 years depending on the level of receptor risk. For grade 3 assets the frequency is 6–10 years depending on the level of receptor risk. Culverts with a condition lower than grade 3 require immediate remedial works that are programmed separately.

Intermittent maintenance costs

Intermittent maintenance costs and frequencies will vary depending on the risk of culvert flooding and the condition of the culvert. The frequency of de-silting cannot be prescribed, but depends on acceptable degree of sedimentation and the consequences

of too much sedimentation. Typical maintenance activities and suggested frequencies are provided in Table 1.13 and can be used in whole life cost estimates in the absence of more detailed site information.

Table 1.13 Culvert maintenance frequencies

Maintenance activity	Target condition grade	Frequency
De-silting	2	1–10 years
	3	3–20 years
	4	20+ years
Culvert repair works –brickwork, vegetation clearance, signage replacement, sealant replacement, fencing repair	2	2– 3 years
	3	10–20 years
	4	20+ years

Source: Environment Agency Maintenance Standards

As part of this project, Leeds City Council provided a breakdown of all routine and reactive works undertaken as part of its responsibilities for direct maintenance of council-owned watercourses.[2] The record of data covered a period from 2006 to 2010 and includes all maintenance and activities associated with watercourses and culverts. These data were analysed to determine average costs for a range of culvert operation and culvert repair/refurbishment costs. These indicative costs are provided in Table 1.14 (culvert operation) and Table 1.15 (culvert repair/refurbishment) along with the minimum and maximum costs within the dataset. Unfortunately, the length and size of culvert or the extent of works was not recorded and therefore it is not possible to break these costs down to a per metre length or by culvert size. Despite this, the information collated provides some useful indicative costs for various activities associated with intermittent cost activities. It is important to note the high variation in these costs.

Table 1.14 Costs of example culvert operation works

Activity	Count	Maximum	Mean	Minimum
CCTV survey	48	£9,010	£1,560	£70
De-silt culvert	37	£21,440	£1,730	£200
Jet blockage	15	£5,230	£670	£50
Remove debris from inlet	3	£1,900	£1,040	£260
Excavate culvert to remove blockages	15	£15,220	£3,650	£370

[2] Personal communication with David Oldknow, Leeds City Council

Table 1.15 Costs of example culvert repair/refurbishment works

Activity	Count	Maximum	Mean	Minimum
Replace/repair collapsed culvert	8	£33,240	£8,390	£1,400
Construct new inlet/headwall	4	£9,680	£4,460	£1,800
New inlet headwall + screen	2	£10,820	£9,800	£8,790
New/replacement screen	7	£2,340	£1,130	£520
Modify inlet screen	3	£820	£520	£300
Construct new manhole	10	£4,560	£2,950	£630
New/replacement manhole cover and frame	8	£2,350	£960	£110

Key factors that influence culvert maintenance costs include:

- difficult to access or restricted access – high water levels, overgrown vegetation in summer, access restrictions due nesting birds/spawning fish
- remoteness
- temporary works required to carry out maintenance
- culvert dimensions and access to inlet/outlet
- culvert located in channel that carries a lot of silt/debris
- properties of the culvert that increase maintenance frequency – bends, changes in slope/bed levels/soffit levels, irregular sections
- additional inspections following watercourse high flows – especially where the risk of blockage or structural damage is high

Specialist human entry costs associated with culverts

The Environment Agency's North West Region has a specialist team that undertakes human entry activities for assets to cover routine and reactive works to the many culvert systems in the Manchester area. This team is employed on a full-time basis to carry out these tasks.

An inspection programme for all culverts in the area is defined based on a risk-based assessment. Inspection frequencies vary between 6 months and 10 years. Each inspection is recorded along with information on the condition of the culvert, culvert length, risk category and total labour hours associated with the inspection.

While human entry teams vary in size depending on the classification of the space and culvert size, typical jobs require 5–6 operatives due to health and safety aspects of this work and minimum team sizes. The actual costs of the tasks are not recorded – only a total count of the operative hours. Indicative rates for certain tasks can therefore be obtained by applying a standard staff rate. The hours specified therefore incorporate additional tasks such as training, preparation of risk assessments and safe work systems, equipment checks, cleaning and transport to and from sites.

These records were reviewed as part of this project to identify the costs associated with routine inspections and specific tasks performed by this specialist team. The data

provided cover approximately a thousand inspections between 2004 and 2009.[3] The data were analysed to derive typical costs for both inspections and a selection of typical reactive works based on the information available (Table 1.16). Due to variations in the dataset, the analysis classified culvert lengths into a range of typical culvert lengths.

Table 1.16 Cost per inspection for specialist culvert human entry team inspection

Culvert length (m)	Count of inspections	Maximum cost	Average cost	Minimum cost
0–50	206	£1,300	£400	£100
50–100	143	£2,000	£600	£100
100–250	139	£3,100	£1,000	£400
250–500	70	£7,000	£1,700	£200
500+	50	£18,600	£4,200	£900

Notes: Of the 1,000 records, 608 included sufficient information on operative hours and culvert length for the analysis.
Costs are based on a standard staff rate.

The analysis assessed the variation in costs by culvert length, culvert risk and culvert condition. Costs are most clearly related to culvert lengths as shown in Figure 1.1.

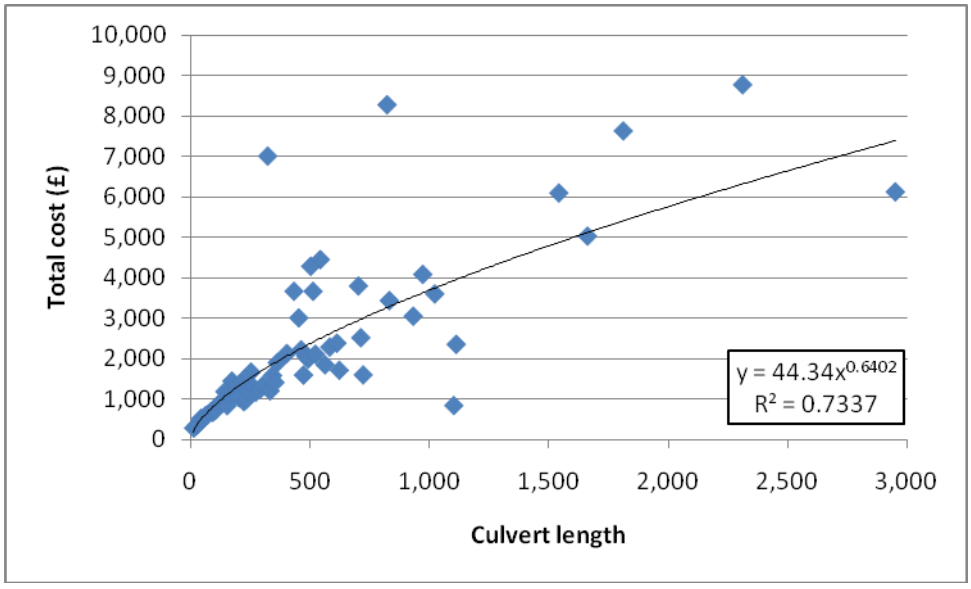

Figure 1.1 Specialist culvert man entry team inspection: correlation between culvert length inspected and total cost

Costs are not particularly correlated to risk categorisation nor to the inspection frequency. However, there does appear to be a moderate correlation between culvert condition grade and cost as shown in Table 1.17the table below.

[3] Personal communication with Nick Mercer, Operations Delivery North West Region, South Area

Table 1.17 Cost per inspection for culvert human entry team by condition grade

Culvert bed grade	Count of inspections	Average cost based on a standard staff rate
Grade 1	3	£1,100
Grade 2	159	£1,200
Grade 3	293	£1,100
Grade 4	37	£1,200
Grade 5	12	£1,500

Notes: Of the 1000 records, 504 included sufficient information on operative hours and culvert grade for the above analysis.

The records also included approximately 400 reactive works covering typical operation and maintenance activities for which specialist human entry is required. The costs of reactive works by unit length of culvert were analysed but are far too variable to provide unit costs.

Standard tasks were selected and average total operator hours collated for each and converted to costs based on the standard operator hours. Table 1.18 presents this information along with the maximum and minimum costs for each aspect. Some costs include works that are not restricted to culverts but where the specialist human entry team was required such as at pumping stations, sluice gates and screens.

Table 1.18 Example costs per maintenance activity

Works	Count	Maximum	Average	Minimum
Assistance	36	£9,300	£1,300	£300
Bed repairs	10	£1,400	£1,100	£800
Blockage removal	104	£5,100	£1,000	£100
CCTV	12	£3,700	£1,700	£600
Checking and locating blockages	24	£2,300	£800	£100
Clear screen	14	£1,100	£700	£200
De-silting operation	10	£218,700	£36,000	£600
General inspection	26	£8,000	£2,100	£300
Remove blockage during inspection	11	£800	£300	£100
Remove debris	2	£3,000	£2,100	£1,100
Remove large blockage	10	£1,400	£1,000	£300
Other	138	N/A	N/A	N/A

1.3.4 Repair, improvement, removal

A culvert will have a specific design life as determined by a number of factors such as the type of culvert, previous maintenance, and the current condition and nature of the flow regime in which the culvert is located.

Existing culverts may require the following three options at the end of its design life:

- rehabilitation – returning a culvert to its as-designed performance
- replacement/improvement – with a different or improved structure
- removal – daylighting and returning watercourse to a more natural state

Each of these options will require additional professional fees, licences and consents, demolition costs, disposal of waste for the construction of replacement culverts. This is especially the case where culverts may need to be upgraded.

The cost of these options will only need to be incorporated into an economic appraisal where the design life is less than the appraisal period (typically 100 years). Previous high level studies have suggested that the cost of replacement and refurbishment will be a proportion of the total capital costs.

Where replacement is assumed, the cost will be the similar to the capital cost, with any adjustments for increased complications for dealing with the removal of the old culvert, increased capacity or climate change. Refurbishment costs as a proportion of capital costs were assumed to be 46.5% for the Environment Agency's Management of Third Party Assets study (Environment Agency 2010c).

Daylighting may be an option and is likely to be less costly. Costs for daylighting schemes are not widely available due to the limited number of these types of project although some case studies are available from the River Restoration Centre (RRC 2013). Specific costs for this option will need a more detailed cost estimation, especially where bank protection, bank stabilisation, diversion or decontamination issues are involved.

Other structural modifications may be needed where a culvert is to be maintained – no other options for relocation, daylighting and so on are viable but possible environmental impacts need to be mitigated. The following measures may be required:

- refurbishment works – a full list of possible refurbishment works for masonry, steel, plastic and concrete culverts is given in CIRIA's *Culvert Design and Operation Guide* (Balkham et al. 2010)
- improved culvert inlets/outlets – weirs or similar works to ensure that fish are not discouraged or prevented from entering or exiting the culvert
- improved flow conditions within a culvert – such as weir baffles, corner baffles and notch battles to slow flows and locally increase depths.
- improved substrate conditions
- improved fish passage – reduced velocities, increased depths, removal of sudden changes in invert levels, creation of resting places and smoothing of transition of hydraulics at inlets, pool and weir passes, baffled passes, pre-barrages, natural bypasses and rock ramps

Additional information on these environmental mitigations is given in the Water Framework Directive Mitigation Measures Online Manual (Environment Agency, no date). No costs are available for these measures and specialist advice should be sought for the retrofit or development of these costs.

Specific costs associated with the retrofitting of fish passes to culverts and weirs are given in the *Environment Agency Fish Passage Manual* (Environment Agency 2010d) for a number of different fish pass types. Costs include estimates for construction costs and project management fees, and are based on experience and example case studies. Armstrong (2010) gives two examples of fitting baffles to an arch and circular culvert in Wales – approximately £19,000 each for the baffle cost and installation.

1.4 Trash and security screens

Trash and security screens may be required on culvert inlets to:

- reduce the degree of debris entering a culvert and thus the risk of internal blockage
- prevent unauthorised access into a culvert (for safety and security reasons)

1.4.1 Capital costs

Trash and security screen capital costs will depend on a number of factors such as:

- size of screen required
- number of tiers and panels and complexity of design
- health and safety fittings (for example, safe access, lighting and working arrangements)
- whether any associated telemetry or CCTV is required
- security measures to restrict public access such as fencing and anti-vandalism measures (for example, CCTV and protected locks)

Very few examples and typical costs suitable for broad scale or early stage appraisal processes are currently available.

Data from Environment Agency System Asset Management Plans (SAMPs) were provided[4] as part of this project and reviewed. Specific data on individual trash and security screen works were extracted to assess the variation in costs associated with new or replaced screens (NB these costs are based on estimated costs rather than actual costs). Data on a total of 43 new, refurbished or replaced screens were extracted, although no specific information on the size of the screens was available.

The average cost was £14,000 but costs ranged between £2,000 and £50,000. New screens averaged £18,000 and replacement screens averaged £13,000.

Costs from actual examples were collated from three sites in the Environment Agency's North East Region.[5] Full construction costs (design, fabrication and installation) for these three sites varied from £35,000 to £15,000. Costs per m^2 for total screen area varied from £1,200 for the larger screen to £1,550–1,750 for the smaller screens.

It is hoped that the analysis can be extended to include additional examples and information from the Environment Agency's National Capital Programme Management Services (NCPMS) Unit Cost Database. Additional examples and costs will be provided once this information is available.

[4] Personal communication from Lyn Hensman, Project Board
[5] Personal communication from Ryan Farrell, Operations Delivery Technical Support

1.4.2 Operation and maintenance costs

Regular cleaning of the screen and the safe disposal of accumulated trash and debris are vital. It is also essential to maintain screens in a safe working condition. This involves:

- routine clearance – debris removal at intervals dictated by the rate at which debris accumulates on the screen (normal clearance frequency of a trash screen can vary between twice a week to monthly)
- non-routine clearance before, during and after flood events to ensure screen is kept clear (blockage is correlated with high flow conditions)
- removal of material to an appropriate waste disposal site (transport costs should be taken into account)
- telemetry maintenance/repairs

A basic approach to costing for operational inspections is to determine the inspection frequency required and to multiply this by the cost associated with an inspection (operative hours required multiplied by operator rates). Guidance on inspection frequencies for trash screens from the Environment Agency's Maintenance Standards (Environment Agency 2010b) are discussed below.

Although it is not possible to determine the frequency of reactive inspections due to their dependence on weather and the consequences of flooding at the site, the estimates in Table 1.19 are provided in the absence of site-specific information. For more detailed assessments, inspection frequencies should be determined according to the risk of flooding in the vicinity of the screen.

Table 1.19 Environment Agency maintenance frequencies for screens

Maintenance activities	Target condition grade	Frequency
Routine inspection and clearance	2	Weekly to monthly
	3	Weekly to bi-monthly
	4	Bi-monthly to annually
Reactive inspection and clearance	2	2–4 times a year
	3	1–3 times a year
	4	Every 1–5 years
Vegetation clearance	2	2–6 times a year
	3	1–4 times a year
	4	1–2 times a year
Screen repairs	2	Every 2 years
	3	Every 2-3 years
	4	Every 5+ years

Indicative routine inspection and maintenance costs

Leeds City Council is responsible for 98 grids/screens. Inspections are made according to fortnightly, monthly, two-monthly and three-monthly rotas. Information relating to the number of inspections and cost of inspections was provided by the council for a period in 2009-2010.[6] The total costs over this period were divided by the total number of inspections to give an average inspection cost per screen to give an average cost per grid of approximately £50 per inspection. This figure assumes that a team is responsible for grid clearance and a routine is in place to proactively clear a number of screens. In the case of Leeds City Council the average weekly number of separate screen inspections is 60, which varies between 40 and 95 weekly inspections. The costs associated with a single inspection would be much higher.

The annual operation and maintenance costs given in Table 1.20, Table 1.21 and Table 1.22 for target grade conditions 2, 3 and 4 respectively are available for culverts based on the Environment Agency's Maintenance Standards (Environment Agency 2010b) and Condition Assessment Manual (Environment Agency 2006). These costs are indicative costs and represent a broad range of costs per year per culvert depending on variable culvert size and culvert length.

Table 1.20 Cost range assuming maintenance to target condition grade 2 (£/year/screen)

Catchment type	Manual or automated clearance	Mechanical (machine) clearance
Urban/suburban	1,460–7,020	1,760–7,600
Woodland/open to public/not open to public	860–4,160	1,150–4,600

Table 1.21 Cost range assuming maintenance to target condition grade 3 (£/year/screen)

Catchment type	Manual or automated clearance	Mechanical (machine) clearance
Urban/suburban	760–4,160	1600–4,600
Woodland/open to public/not open to public	440–2,550	590–2,180

Table 1.22 Cost range assuming maintenance to target condition grade 4 (£/year/screen)

Catchment type	Manual or automated clearance	Mechanical (machine) clearance
Urban/suburban	150–1,300	180–1,455
Woodland/open to public/not open to public	110–950	140–1,100

[6] Personal communication, David Oldknow, Leeds City Council.

As the range of costs for culvert maintenance is very wide, the Environment Agency recommends use of a weighting and scoring methodology to determine an appropriate point within the range based on the factors that influence operation and maintenance costs (Table 1.23).

Table 1.23 Weighting of factors influencing maintenance costs

Factor that influence maintenance costs	Weight
Difficult access (distance to work-site, protected sites/species, invasive species, overhead power cables, confined space)	2
Factors relating to the properties of the screen that increase the likelihood of blockage (e.g. under designed or incorrectly placed screen)	2
Screen is located in a channel that carries a large amount of vegetation/debris	2
The maintenance of this asset is undertaken as a standalone maintenance activity	1

Notes: A score between 0 and 2 is given to each factor. Scores are multiplied by the weight to give a score between 0 and 10. A value of 0 corresponds to the lower end of the cost range and a value of 10 corresponds to the higher end of the unit cost range.

Other considerations could include:

- screen design and ease of clearing (poor design can increase costs)
- urban debris or contaminated sediment which increases the cost of disposing to landfill

The probability of blockage also depends on:

- length of contributing watercourse
- nature of catchment (for example, urban/suburban/rural, level of economic deprivation)

Further guidance on this is provided in the Environment Agency's *Trash and Security Screen Guide 2009* (Environment Agency 2009a).

1.5 Other cost estimate requirements

In addition to the cost estimates noted above, the following parameters are required to ensure whole life costs are defined correctly for incorporation into an appraisal. The design life and discount rates are used to convert future costs over a scheme life to 'present values' so that they can be compared against the benefits.

1.5.1 Appraisal period/design life

The design life is typically defined as the minimum length of time that a scheme is required to perform its intended function. The design life for appraisals is typically taken to be 100 years, although alternative periods can be used.

The design life is an important consideration in whole life costing as a design's component assets may have a shorter service life and not be last as long as the design life of the asset as a whole. This has implications for cost estimates to ensure that a whole life cost estimate correctly identifies all long-term maintenance and asset replacement costs over the intended appraisal period.

A culvert will deteriorate if there is no maintenance or intervention, The Environment Agency's asset deterioration project (Environment Agency 2009c) provides the asset deterioration rates given in Table 1.24 for maintained and non-maintained scenarios for culverts. The table provides an indication of the likely deterioration rates from a new (grade 1) culvert to gradually poorer asset conditions. It can be seen that a new and maintained culvert would need replacement at year 100, although site specifics or the type of culvert constructed could vary this from year 35 to year 120.

Table 1.24 Environment Agency asset deterioration rates (years)

		Target condition grade				
		1	**2**	**3**	**4**	**5**
Culvert not maintained	Best estimate	0	20	50	70	90
	Fast estimate	0	5	10	15	20
	Slow estimate	0	20	60	85	100
Culvert maintained	Best estimate	0	20	50	100	120
	Fast estimate	0	10	25	35	50
	Slow estimate	0	20	60	120	150

Source: Environment Agency (2009c)

1.6 Cost estimation methodology

The flow diagram in Figure 1.2 summarises the key aspects required to generate a whole life cost for a culvert to include all relevant capital costs and O&M costs.

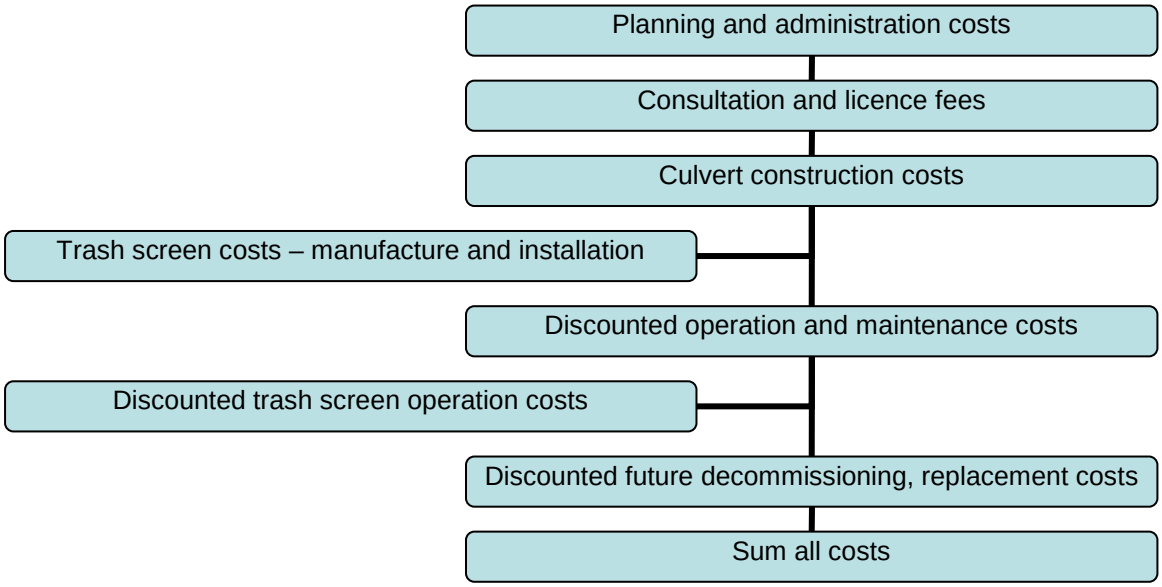

Figure 1.2 Flow diagram for culvert whole life costs

1.7 Case studies

The following case studies may help those producing cost estimates for culvert assets.

- Opening up a culverted stream. Case study 1.6 from *Manual of River Restoration Techniques,* River Restoration Centre. Available from: http://therrc.co.uk/MOT/Final_Versions_%28Secure%29/1.6_Ravensbourne.pdf [Accessed 16 January 2014]
- Daylighting. Paper in *Water and Environment Journal* (Wild et al. 2010)
- Daylighting of a culvert at River Pinn in Hatch End. Environment Agency Fluvial Design Guide Case study 8.4. Available from: http://evidence.environment-agency.gov.uk/FCERM/en/FluvialDesignGuide/CaseStudy8_4.aspx [Accessed 16 January 2014.]

1.8 Checklist

Use the checklist to:

- identify the key cost elements required for watercourses
- ensure all relevant whole life costs are incorporated into the cost estimate

Whole life cost estimate checklist for culverts

Item	Description	Frequency	Comment
Enabling costs			
Professional fees	initial appraisal and design costs	One-off	May be sunk cost by time

Item	Description	Frequency	Comment
			of appraisal.
Consultation	including planning, management and agreements	One-off	
Licences and consents	planning permission, land drainage consent and others	One-off	
Capital costs			
Construction	Culvert and screen costs	One-off	
Inspections			
Superficial inspection	Non-entry inspection to assess condition and obvious defects	Intermittent	
General inspection	Non-entry inspection to examine all parts of the structure May include public safety inspections.	Recurring or intermittent	Risk-based
Principal inspection	Close examination of all parts of the structure. May include small repair works as part of inspection. May include human entry or remotely with CCTV.	Intermittent	Risk-based
Special inspection	Post-storm or other inspection (may be a recommendation from another type of inspection)	Intermittent	
Maintenance			
Inlet and screen clearance	Culvert inlet and trash screen inspection and clearance	Recurring	Highly variable depending on risk
Culvert repair	Repair works and frequency will depend on type of culvert and materials. Vegetation clearance	Intermittent	Highly variable and related to age and condition of assets
Internal maintenance works	Generally, de-silting and blockage removal	Intermittent	Related to risk and condition of asset
Decommissioning			
Replacement/ decommissioning	May include rehabilitation, replacement/improvement or removal.	One-off	Inclusion in appraisal depends on design life of asset.

1.9 R&D and general design guidance

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1.10 References

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