Department for Environment Food & Rural Affairs

Llywodraeth Cymru Welsh Government

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Environment Agency

delivering benefits through evidence

Cost estimation for flood storage – summary of evidence

Report –SC080039/R6

Flood and Coastal Erosion Risk Management Research and Development Programme

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We cannot do this alone. We work closely with a wide range of partners including government, business, local authorities, other agencies, civil society groups and the communities we serve.

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Miranda Kavanagh

Director of Evidence

Executive summary

This summary of evidence provides indicative costs and guidance for flood storage measures. The level of information is insufficient to provide suitable cost curves for different flood storage measures (such as reservoir construction, flood embankments and storage ponds), although guidance and collated indicative costs are provided for very high level options.

Flood storage		
Key cost components	Key cost components are likely to be the enabling costs (procurement, planning and design), capital construction costs and post construction monitoring and maintenance costs.	
Key asset types	• In-line flood storage reservoirs • Off-line flood storage reservoirs • Smaller scale excavated storage ponds	
Data reviewed in specific guidance	Key datasets include Environment Agency Unit Cost Database (capital costs)	
Other relevant data	Local or proxy records such as data from Environment Agency SAMPs and local authority information	
Relative cost importance	Enabling costs	Variable costs may be higher than other measures due to the level of consultation, design and preliminary assessments required. Cost of land purchase may be significant in some circumstances.
	Capital costs	Typically high costs but will vary depending on type of storage method, asset length and size, associated structures, landscaping and environmental enhancements.
	Maintenance costs	Operation and maintenance costs and statutory requirements are important elements of whole life costs for flood storage reservoirs.
	Other cost considerations	May include environmental costs, habitat creation and decommissioning costs.
Cost estimation methodology	Initial concept/ national appraisal	Indicative cost curve based on stored volume.
	Strategic, regional, or conceptual design	Capital cost unit rates for other flood risk management aspects to be combined to build up a cost for flood storage.
	Preliminary feasibility/ design	No specific cost information provided. Guidance on data availability and procedures provided.

Design life information	Design life of reservoirs and flood storage is anticipated to be at least 100 years, though some elements may have reduced design lives that need consideration (control structures, MEICA assets, embankments and so on).
Quality of data	A range of limited data sources have been collated and are provided suitable for strategic, early or national level appraisals. Cost estimates for floodplain storage areas vary considerably. Information on the actual costs of flood storage works has not been widely recorded or collated nationally. A number of reviews and case studies have been collated to attempt to determine the cost of providing flood storage by area and volume. This information is provided to be used in the absence of better estimates from other studies for cost estimation at the initial stages of an appraisal. Cost information for individual elements (embankments, culverts, channels and so on) are summarised and linked to other guidance sections to assist those building up costs from asset elements. The same is provided for operation and maintenance cost elements.
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

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Contents

1 Flood mitigation measure – flood storage

Flood storage, as a flood risk management option, is designed to attenuate incoming flood flows passing along a river valley to restrict peak flows downstream by storing the flood volume so that the flood event is discharged in a controlled manner over a longer duration.

Flood storage can be created via a number of methods through the use of reservoir construction, flood embankments and storage ponds. Flood storage can either be online or offline. Online flood storage temporarily stores flood water within the river channel and floodplain upstream of an impounding structure and associated flow control structure. Offline flood storage diverts water into a bunded basin adjacent to the river and subsequently releases it back to the river via an outlet structure.

Online storage works are typically located in the upper catchment, whereas offline storage works are more common on larger rivers with wide floodplains. Online storage also incorporates on an outlet structure (a culvert, gate, weir or hydrobrake for example) which is permanently open and allows low flows to bypass the storage area. During larger events the outflow structure restricts the rate of outflow causing the reservoir to fill. Water may eventually discharge over a spillway at a higher level designed to safeguard against embankment crest overtopping.

Offline storage areas are often created through the use of flood embankments and intake structures to divert water into the storage areas. Such storage areas may be a metre or several metres deep.

A summary of flood storage reservoir classification types is given in Table 1.1.

Table 1.1 Flood storage reservoir types

Storage type	Description
Online	Dry weather flow passes through the storage area.
Offline	Dry weather flow bypasses the storage area.
Dry	Storage area is free of water under dry weather flow conditions – often called washland reservoirs.
Wet	Storage area contains water under dry weather flow conditions.
Wet/dry	Most of the storage area contains water and part is free of water under dry weather flow conditions.

1.1 Data requirements

A number of standard cost parameters are required for flood storage reservoirs. These include:

- initial procurement and enabling costs
- capital costs
- operation and maintenance (O&M) costs (inspection, de-silting, repairs)

- monitoring and inspection costs associated with reservoir safety

There are a number of costs and benefits associated with flood storage that should be considered as part of an appraisal, but will vary according to site circumstances. The value and arrangement of benefits and costs will also reflect the type of benefits to be achieved by flood storage and whether it is to be based purely on flood risk management or the incorporation of habitat creation.

Possible benefits and costs are summarised in Table 1.2. Their inclusion in a project will vary according to its purpose and whether they are determined for appraisal purposes or for estimating financing requirements. Some costs may represent transfer payments and would not feature as a cost in an economic appraisal.

Table 1.2 Costs and benefits of flood storage

Costs	Benefits
• Acquisition of land • Engineering design and supervision • Construction costs • Conservation and habitat creation • Operating costs • Possible payments to landowners where relevant • Reduction in agricultural output, with possible agri-environmental payments	• Reduced flood damages • Increment in conservation and wetland creation • Attenuation and reduction of peak flows • Provision of recreational opportunities • Increased biodiversity value • Possible reduction in defence/drainage maintenance costs for downstream reaches

1.2 Enabling costs

The initial planning, permissions and design stages for flood storage works are likely to be significant due to the range of problems associated with planning, obtaining permissions and designing suitable flood storage areas. Taking the right approach to planning a flood storage area will help to reduce the total costs.

General items that may need to be determined include:

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

Specific detailed costs would be typically broken down into:

- initial preliminary assessment including catchment appraisal of storage options
- advice and engineering for planning and design (the advice of a ‘qualified civil engineer’ under the Reservoirs Act 1975 is required before any design work is undertaken when the reservoir volume is over the threshold capacity in terms of the 1975 Act as amended by the 2010 Act)

- data collection (topographic survey, soils, hydrometric)
- detailed studies to identify the preferred solution in a localised context
- permissions and licences (planning consent, environmental approval, abstraction licence (if applicable), waste management and waste transfer licences (if applicable)
- detailed design including:
    - detailed site survey
    - additional hydrological studies
    - environmental and archaeological surveys
    - site investigation
    - compensation and land purchase
    - public consultation
    - preparation and review of reservoir flood plans (to include reservoir inundation plan and an onsite emergency response plan which includes actions to prevent or minimise a dam failure and a communications plan to activate and inform offsite emergency response) (Defra 2010)

1.3 Capital costs

Capital costs will vary considerably according to scale and the physical attributes of the storage area. Costs tend to be higher for larger schemes and those involving more complex hydraulic control. Costs may also be considerably more expensive for online storage reservoirs where the construction of an impounding dam structure is required.

Costs for capital works are likely to include those for:

- structures – embankments, drainage networks, hydraulic controls and so on
- river formation, restoration and cut and fill/land forming
- landscaping, site access and secondary works
- mechanical and electrical gated structures/pumps and power for monitoring equipment
- protection of buried services (for example, addition of ballast to gas pipeline to prevent flotation during flooded conditions, or installation of cover slab to protect underlying services from subsidence due to additional overburden of flood bank)
- any environmental enhancements or habitat creation
- amenity additions (access including car parking/footpaths and so on)

Cost estimates for floodplain storage areas vary considerably. Information on the actual costs of flood storage works has not been widely recorded or collated nationally. Due to the lack of site conditions and scale of works at an early stage of an appraisal it may not be appropriate to provide indicative estimated costs for flood storage works.

A number of research projects have attempted to determine the cost of providing flood storage by area and volume. Estimated costs associated with the design and build of washland online retention schemes in Somerset (Morris et al. 2002) ranged between £2 and £5 per m^3 storage capacity. This excludes the costs of land purchase that may be between £0.5 per m^3 and £1.5 per m^3 of flood storage facility or represent an increase in total costs by 33% (Morris et al. 2004). Despite this some information is available from a number of projects and is collated in Table 1.3. These projects provide examples of recent projects from a range of sources and provide some indicative costs for the provision of flood storage in the UK.

Table 1.3 Flood storage reservoir examples

Site	Volume (m^3)	Cost (£)	Cost (£/m^3)	Updated cost (2010) [1] (£/m^3)	Source
Dronfield flood alleviation scheme	Unknown	£681,000			UCD [2]
Melton Mowbray flood alleviation scheme	3,500,000	£6.7 million	1.9	1.9	UCD
Bodmin Town storage pond	20,000	£396,000	19.8	19.8	UCD
Harbertonford flood defence scheme	150,000	£431,000	2.9	2.9	UCD
Afon Adda flood alleviation scheme	3,300	£490,000	148.6	148.5	UCD
Afon Adda flood alleviation scheme	312	£130,000	416.6	416.7	UCD
Harnham flood defence scheme	1,875	£208,000	110.8	110.9	UCD
Blackburn Brook flood attenuation reservoir	32,000	£1.75 million	54.7	54.7	Private developer [3]
Weedon flood storage reservoir	810,000	£1.24 million	1.5	1.9	Environment Agency (2010b)
Bruton flood storage reservoir – improvement works	500,000	£3 million	6.0	5.5	Environment Agency (2010b)
Long Eau	18,300	£75,000	4.1	5.1	Morris et al. (2004)
Harbertonford	35,000	£2.5 million	71.4	110.7	Morris et al. (2004)
Beckingham Marsh wetland initiative	Unknown	£4,000			Morris et al. (2004)
Leigh Barrier	5,580,000	£6 million	1.1	1.3	Morris et al. (2004)
Unnamed	15,000	£70,000	4.7	5.8	Morris et al. (2002)
Unnamed	100,000	£219,000	2.2	2.7	Morris et al. (2002)
Cobbins Brook	758,000	£6 million	7.9	7.9	Environment Agency (2010a)

Site	Volume (m^3)	Cost (£)	Cost (£/m^3)	Updated cost (2010) [1] (£/m^3)	Source
Kersal	650,000	£11 million	16.9	23.2	Bichard and Kazmierczak (2009)

Notes: [1] Due to the age of some costs provided, all costs have been updated using the public works output price indices.
[2] Data from the Environment Agency Unit Cost Database (National Capital Programme Management Services). Personal communication from Ian Wright.
[3] Personal communication, Richard Bamford, CB Richard Ellis

Table 1.3 provides example costs taken from real out-turn costs from flood storage areas constructed in the UK over the last 30 years. Although many more examples are likely to be available and further analysis is required on a larger dataset to distinguish variations in costs by storage type, for example, the above dataset provides a useful dataset to determine the cost of flood storage by design capacity of the storage.

As might be expected, there is a wide variation between costs and storage capacity, although there is a relationship between the two variables in the data available. Plotting costs against storage volume gives the relationship shown in Figure 1.1, that is:

Cost (£/m^3) = 11,239 × volume$^{-0.628}$

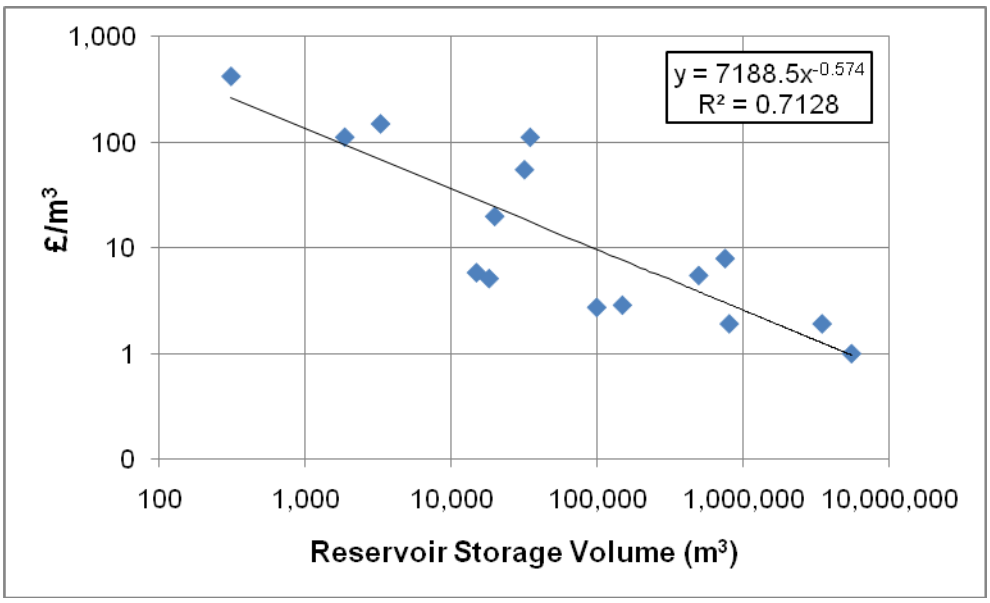

Figure 1.1 Plot of costs against storage volume

This relationship can be used in the absence of better estimates from other studies for cost estimation at the initial stages of an appraisal. For more detailed studies the costs associated with flood storage reservoirs will depend on a wide range of site factors and the associated practical issues used to deal with these factors (Table 1.4).

Table 1.4 Key factors influencing flood storage costs

Factor	Impact on cost estimation
Access to site	Easy access (during construction and subsequent maintenance and operation works) will reduce costs.
Presence of services and other onsite constraints	Implications for the type of construction plant and protection may be needed for buried services.
Presence of contaminated land	Remediation will increase costs.
Height of dam/embankment	Head of water retained affects the width of the wall or embankment needed.
Size of storage area	The larger the storage, generally the greater the costs, although this will depend on the type of storage and type and size of impounding dam or embankments required.
Geology	Impermeable foundations or cut-off required of sufficient bearing capacity to support impounding structure.
Material type and availability onsite	Presence of suitable earth/clay will reduce import costs.
Source of imported material and disposal of waste material	Costs of importing and disposal of material can be significant.
Suitability of site	Taking advantage of a narrower part of a valley for the impounding structure for the reservoir will reduce dam lengths and reduce costs.
River nature	A wide floodplain will maximise storage and reduce impounding structure heights.
Balancing cut and fill	Minimising earthmoving will reduce costs.
Impact of works on environment	Need for the inclusion of environmental impact studies and environmental mitigation/enhancement.
Weather during construction	Adverse conditions will affect efficiencies.

1.3.1 Excavation and earthwork costs for simple storage reservoirs

The booklet, *Thinking about an Irrigation Reservoir?* (Environment Agency and Cranfield University 2008) reviews the costs associated with 20 reservoirs constructed in the past 10 years. While these examples and the costs provided are associated with construction of irrigation reservoirs, they illustrate the range of costs associated with the excavation and simple earthwork construction of clay or artificially lined reservoirs without major impounding dam works or inlet/outlet controls. These examples are typical of sites where the balancing of cut and fill is achieved, and the import of suitable material and the disposal of waste material are not significant. These costs may be similar and representative of those used for smaller pond construction carried out for

the purposes of smaller scale run-off management. Additional discussion and further examples are provided in the land use and run-off management section for comparison. Indicative costs for these reservoirs are summarised in Table 1.5.

Table 1.5 Indicative costs for simple storage reservoirs

Reservoir type	Cost of total capacity (£/m^3)	Range of storage capacity (m^3)	Comments
Clay lined	0.75–1.75	20,000–500,000	Rates are lower for larger reservoirs.
Artificially lined (agriculture)	1.50–4.00	20,000–100,000	
Artificially lined (golf courses)	4.50–6.00	20,000–40,000	
Annual maintenance costs	1% of capital costs		

Notes: Costs based on 2008 prices.
Values do not include costs associated with site investigation, design and professional fees and costs incurred in obtaining permissions. Costs associated with these aspects can be approximately 15% of the total construction costs. Costs associated with site investigation will depend on the complexity of the scheme.
Values do not include costs associated with inlet and outlet works, pumps, access roads, landscaping, fencing and drainage.

1.3.2 Costs based on individual elements

Costs are available from the Environment Agency's Unit Cost Database for embankments (Table 1.6), culverts (Table 1.7) and channels (Table 1.8) that may be relevant for flood storage solutions. Additional local or proxy records may also be available from the Environment Agency (for example, System Asset Management Plan information) or local authorities.

Table 1.6 Embankment unit costs

Volume band	Average (£/m^3)	Number of projects
< 500 m3	188	9
500 - 5,000 m3	94	28
5,000 - 1,5000 m3	64	11
> 15,000 m3	33	18

Source: Environment Agency Unit Cost Database

Table 1.7 Culvert unit 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.
Source: Environment Agency Unit Cost Database

Table 1.8 Unit costs for new channel construction (£/m)

Length	Earth	Hard engineering
50	7,200	4,700
250	1,300	1,200
500	600	700
1,000	300	400
1,500	200	300
2,000	200	200
2,500	100	200

1.3.3 Detailed costs built up from unit rates

Detailed costs will need to be developed using standard rates and a bill of quantities. While the unit rates given above are suitable at outline design stage, only a bill of quantities is appropriate at detailed design stage. A typical bill of quantities is provided in the CIRIA Small Embankment Reservoirs report (Kennard et al. 1996). Other guidance on detailed costs is provided in standard price estimating books such as SPONS (Davis Langdon 2011) and CESMM (ICE 2012).

When assessing costs from unit rates, additional indirect costs must also be included. These include site preliminaries and general items, contractors profit and overheads. The Unit Cost Database indicates that these are typically 30% of the permanent works cost (for example, the physical works including demolition, site clearance and earthworks).

Components of online storage works normally require the following components:

- an impounding structure (earth or concrete structure across the river and floodplain)
- a flow control structure normally located within the impounding structure

- a spillway to ensure safe bypassing of extreme flows over the top of the impounding structure for flows greater than those that the reservoir was designed to hold

Components of inline storage works normally require the following components:

- an intake structure to divert water into the storage area (weirs or sluices)
- a storage basin separated from the river formed from either naturally or excavated low ground levels or by retaining structures (embankments and walls) and any associated embankments to divide the storage area into cells
- an outlet flow control structure normally that returns flows back into the river (gates, weirs or pumps)
- a spillway/weir to ensure safe bypassing of extreme flows over the top of the retaining structure for flows greater than those that the reservoir was designed to hold

Specific costs associated with the above can typically be broken down into the following components:

- site clearance
- access arrangements (temporary for construction and permanent for maintenance)
- demolition and site clearance, piling
- concrete works
- steelwork (including all inflow/outflow structures and screens)
- earthworks
- mechanical, electrical and telemetry elements to measure and control flows
- river training works and drainage works
- service diversions and reinstatement of roads/footpaths
- environmental/landscaping works
- habitat creation
- security and stockproof fencing

1.4 Operation and maintenance costs

The number of routine inspections will depend on the type and complexity of the reservoir, control types, and the type of operating and monitoring equipment. In addition to statutory supervision/inspection requirements (see below), inspections are needed to:

- monitor the behaviour of the newly built dam
- check and clear control structures and mechanical, electrical, instrumentation, control and automation (MEICA) assets

Routine inspections will be supplemented by visits from the supervising engineer.

Frequency of inspections may vary widely and should be reviewed on a site-by-site basis. The frequency of inspections will depend on:

- type and size of the reservoir
- local circumstances
- type of controls used
- complexity of the operating and monitoring equipment

Maintenance activities may be required for the following aspects:

- structural repairs
- mechanical and electrical equipment repairs
- vegetation cutting/clearance
- invasive weed control
- vermin control
- tree work

Typical maintenance costs are often included within initial cost assessments as a proportion of overall capital costs (say 1–5%) of the reservoir and ancillary works. However, it is recommended that the maintenance costs associated with each component of the flood storage structures are obtained from other evidence summaries within this guidance to build up an estimate of the whole life maintenance costs.

1.4.1 Statutory requirements for the inspection of reservoirs

Reservoir safety in the UK is governed primarily by the Reservoirs Act 1975. This ensures reservoirs and dams are inspected regularly and constructed or altered only under the charge of properly qualified engineers. The 1975 Act applies to 'large raised reservoirs' which are defined as having a capacity of 25,000 m^3 or more above the natural level of any part of the adjacent land.

The Flood and Water Management Act 2010 updated the Reservoirs Act 1975 and reflects a more risk based approach to reservoir regulation. A crucial amendment is the reduction in the capacity at which a reservoir is regulated from 25,000 m^3 to 10,000 m^3. The Flood and Water Management Act 2010 received Royal assent in April 2010 and there is an ongoing programme for its implementation including the registration of reservoirs in this range.

There are significant cost implications involved in compliance with the Reservoirs Act 1975. A panel engineer is required for design, construction overview/supervision and inspections (all by engineers named on the all reservoirs panel list) and continuous supervision (by an engineer named on the supervising engineer panel list) is required for all large raised reservoirs under the Reservoirs Act 1975. Panel engineers are a group of specialist civil engineers appointed by the Defra Secretary of State.

Undertakers are required to employ a supervising engineer to keep the dam under expert regular observation (a continuous appointment). An inspecting engineer must be employed to carry out a detailed inspection at least once every 10 years – more frequently if requested by the supervising engineer.

Owners should keep abreast of any changes in the legal requirements, but inspections are normally required:

- within two years of the issue of the final certificate of construction
- after alterations or repair
- at any time recommended by the supervising engineer
- within 10 years of the last inspection

Detailed inspections by an inspecting engineer may cost in the region of £1,500–2,500 per inspection depending on the complexity of the reservoir. There could be additional costs if works required 'in the interests of safety' are recommended. Such works could include a (updated) flood study, which itself could lead to works necessary 'in the interests of safety' being further recommended by the inspecting engineer.

Typical costs for a supervising engineer will be around £500–1,000 per year, depending on the complexity of the reservoir and whether the inspecting engineer calls for more than one visit a year by the supervising engineer.

Visits by the inspecting engineer will be supplemented by routine inspections by the reservoir regulator.

1.4.2 Reservoir flood plans

The Water Act 2003 amended the Reservoirs Act 1975 to include a new power allowing the enforcement authority to direct an undertaker to prepare a 'flood plan' for a large raised reservoir. The flood plan is intended to improve emergency preparedness for uncontrolled release of water from a reservoir. The plans cover:

- predicted extent and depths of inundation
- risks to life and property
- arrangements to issuing warnings

These aspects are provided in an on-site flood plan, an off-site emergency plan and a reservoir flood map.

Flood maps were prepared for the 200 large reservoirs regulated by the Environment Agency in 2009. For any new reservoirs it is assumed a flood plan will be required. The initial costs of preparing a reservoir flood plan are estimated to be £2,640 with annual costs of £940 to keep the plan up-to-date (Defra 2010).

1.5 Other cost estimate requirements

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. This is important to ensure whole life costs are defined correctly.

1.5.1 Appraisal period/design life

The design life of reservoirs and flood storage is anticipated to be at least 100 years, although some elements (control structures, MEICA assets, embankments and so on) may have shorter design lives that need to be considered.

1.6 Cost estimation methodology

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

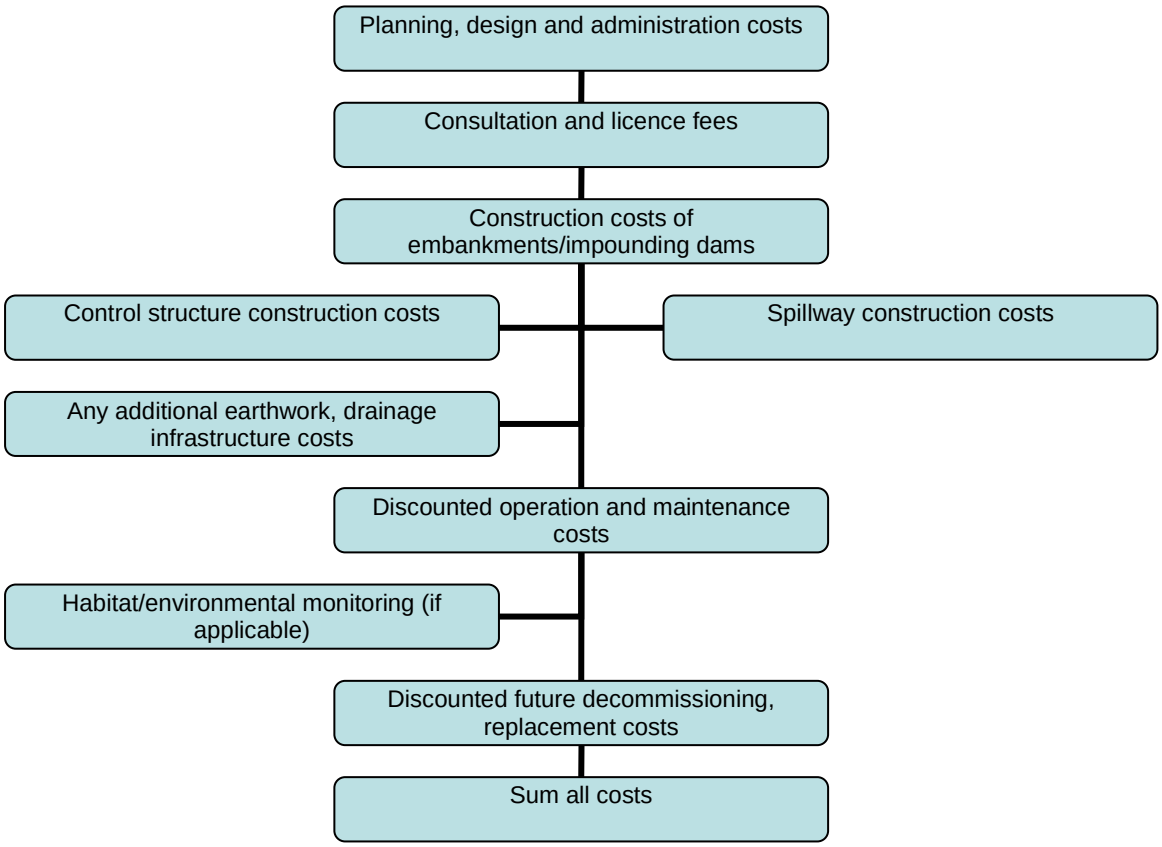

Figure 1.2 Flow diagram for flood storage whole life costs

1.7 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 flood storage

Item	Description	Frequency	Comment
Planning costs			
Professional fees	Initial appraisal and design costs	One-off	
Consultation, licences and consents	Including planning permission, management, consultation, liaison, land drainage consent and other agreements	One-off	
Capital			

Structures	Embankments, drainage networks, hydraulic controls and so on	One-off
Earthworks	Earthworks if required. General landscaping, site access and secondary works	One-off
MEICA costs	Mechanical, electrical, instrumentation, controls, automation for gated structures/pumps and power for monitoring equipment	One-off setup costs
Environmental enhancements	Enhancements or habitat creation	One-off and initial maintenance
Operation & maintenance		
Monitoring behaviour of the newly built dam/embankments		Annual
Maintenance of structural aspects		Annual
Statutory requirements for supervision/inspection		Annual and intermittent
Maintenance of monitoring and control equipment	Maintenance of gated structures/pumps and power for monitoring equipment	Annual
	Annual cost for electricity	
Preparation exercising and review of reservoir flood plans	Includes reservoir inundation plan and an on-site emergency response plan	Intermittent

1.8 R&D and general design guidance

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