NRW National Culverts Study

Report No: 642

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Report series:	NRW Evidence Report
Report number:	642
Publication date:	December 2022
Contract number:	N/A
Contractor:	Ove Arup and Partners Limited (Arup)
Contract Manager:	Jill Howells / Oliver Lowe / Rhodri Powell

Title: **National Culverts Study**

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Technical Editor: Rhodri Thomas (Senior Geomorphologist, Arup)

Quality assurance: Tier 3: High level internal peer review

Peer Reviewer(s) NRW Project Steering Group, consisting of: Oliver Lowe, Steffan Davies, Chloe, Hatton, Leila Thornton, Hannah Shaw, Scott Griffiths, Dale Cox, Dave Charlesworth, Helen Cariss, Melanie Meaden, Rhodri Powell. Josie Jackson (Integrated Evidence).

Approved By: Oliver Lowe (NRW), Rhodri Powell (NRW)

Restrictions: None

Distribution List (core)

NRW Library, Bangor 2

National Library of Wales 1

British Library 1

Welsh Government Library 1

Scottish Natural Heritage Library 1

Natural England Library (Electronic Only) 1

Recommended citation for this volume:

Ashdown, S; Nelson, J; Smith, V & Thomas, R 2022. NRW National Culverts Study. NRW Evidence Reports Report No: 642, 102 pp, Natural Resources Wales.

Contents

List of Figures

List of Tables

Executive summary

Physical modifications, such as culverts and other types of watercourse crossing, are the main reason for water bodies in Wales not achieving WFD good status. Across NRW's estate there are thousands of river crossings, most of which are culverts due to their low cost and ease of installation. These river and stream crossings enable access for land management and amenity functions. However, these culverts potentially pose barriers to fish movement, disrupt ecological continuity, hamper natural sediment transfer processes, and therefore deteriorate riverine habitats.

NRW seek to ensure watercourse crossings are assessed, maintained, and replaced to ensure they are in line with industry best-practice, taking account of relevant evidence. Currently, there is a tendency to replace failing culverts on a like-for-like basis. This project collates a range of evidence to help NRW improve its management of river crossings.

This report has reviewed existing guidance with regards to the design of watercourse crossings, with reference to forest roads and culverts.

- A high-level whole life costing tool enables comparison between circular HDPE, circular concrete, concrete box, and bottomless culverts, along with basic bridges. The tool demonstrates the cost of moving to more environmentally sensitive structures such as bottomless or oversized box culverts. Eighteen ground truthing sites across North, Mid and South Wales are presented.
- An option selection flowchart guides users to appraise whether their solutions align with the sustainable management of natural resources.

The key conclusions of the study are:

- Single-span structures represent the most environmentally sensitive option.
- Where smaller diameter culverts are suitable, a standard HDPE or concrete circular culvert is significantly cheaper over its lifetime than alternatives. However, for larger diameter culverts (>1m), the cost difference is marginal, with oversized box or bottomless arch culverts perhaps even being marginally cheaper over the lifetime of the structure.
- The national databases used to provide costings, such as the EA culvert cost evidence summary appear not fully reflective of the local savings currently realised by NRW's Forest Engineering teams (e.g., use of locally quarried stone to form headwalls and use of local contractors).
- Inspection and maintenance of closed culverts can pose health and safety risks over alternative structures.

Recommendations include:

- Collation of cost evidence, to provide more certainty on construction and operational costs as the differences between structure are marginal.
- Improving asset records and frequency of inspections to better understand the actual design life of structures.
- Assigning a value to the benefits of different structure types would enable a cost-benefit analysis to be undertaken to support options appraisal.

Background

Physical modifications, such as culverts and other types of watercourse crossing, are the main reason for water bodies in Wales not achieving Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 (WFD Regulations, 2017) good status. Within the Welsh Government Woodland Estate (WGWE) and National Nature Reserves (NNRs) there are thousands of river crossings, most of which are culverts due to their low cost and ease of installation. These river and stream crossings enable access for land management and amenity functions. However, they potentially pose barriers to fish movement, disrupt ecological continuity, hamper natural sediment transfer processes, and therefore deteriorate riverine habitats.

Natural Resources Wales (NRW) is both the competent body with a statutory duty to ensure compliance with the requirements of the Water Framework Directive (WFD) and land managers with responsibility for managing the WGWE and NNRs. The WFD has been retained in UK law following the UK's exit from Europe and at its core, aims to prevent deterioration of the water environment and improve water quality, with the objective of bringing the standard of all European water bodies to "good status" initially by 2015, postponed to 2027.

Managing WGWE sustainably contributes to improved biodiversity and natural habitats, improves the water quality of wooded catchments, and provides attractive places for recreation and community involvement. It also plays a key role in net carbon emissions reduction and harvesting generates an economic return to be reinvested. However, one of the recommendations from NRW's Physical Modifications River Restoration Project was to improve the management of the WGWE when watercourse crossings are assessed, maintained, and replaced to ensure they are in line with industry best practice, such as CIRIA C786 Culvert screen and outfall manual (Benn *et al.*, 2019). The need for change is highlighted in the recent river restoration reports (Haine *et al.*, 2020), themes from the Area Statement within each NRW Operational Area; and the WG Climate and Nature Emergency Strategies.

A key principle of the sustainable management of natural resources (SMNR) is to take account of all relevant evidence and gather evidence in respect of uncertainties. This project collates a range of evidence to help NRW improve its management of river crossings within the WGWE. Currently, there is a tendency to replace failing culverts on a like for like basis. This evidence will inform options appraisals when designing a new or replacement river crossing to ensure the impact on watercourses is robustly considered when set against the requirements of the UK Forestry Standard as well as industry best practice (e.g., CIRIA C786).

Project Outline

The project assesses whole life costs and impacts of different types of watercourse crossings typically used in the WGWE, in comparison to other types of crossing (for example oversized box section culvert, bottomless culvert, baffled culvert, flexi arch, clear span bridge, bailey bridge, fords and piped bridges).

The report includes a decision flow chart to guide evidence-based decision making on the most cost-effective and least environmentally impactful crossing option, considering watercourse characteristics, frequency / type of required access etc. The guidance produced will bring the evidence based decision-making process for WGWE culvert replacements/upgrades in line with NRW's SMNR approach, the UK Forestry Standard and current CIRIA guidance (C786).

Objectives and Scope

The key objectives of this study are to:

1. Review existing industry guidance and best practice to collate evidence for the construction and maintenance of watercourse crossings within the forest road network.

2. Produce a decision chart to support evidence-based decision making for watercourse crossings in the WGWE, in line with NRW's SMNR approach, the UK Forestry Standard and CIRIA C786 guidance.

3. Test the proposed decision tool at pilot sites in the WGWE - as identified and agreed with NRW staff throughout the project.

Definition of a Watercourse

A watercourse is defined in Section 72 of the Land Drainage Act 1991 as including:

"All rivers and streams, and all ditches, cuts, culverts, dies, sluices, sewers (other than public sewers within the meaning of the Water Industry Act 1991) and passage through which water flows."

The Forest Engineering Handbook (2016) provides a similar definition of "*all channels for the passage of water, whether natural or man-made*" and "*channels which would normally be dry, such as many forest drains*".

These are broad definitions that include overland flow routes and artificial ditches that are cut to provide drainage. These small, typically ephemeral, flow routes are not the focus of this evidence report. It is recognised that these features are common across the WGWE and that pipe culverts are often the optimal form of cross-drainage for overland water flows across forest roads.

This evidence report focusses on rivers and streams with a permanent flow of water that support freshwater habitat. Therefore, for the purposes of this evidence report, a watercourse is defined as a blue line on an Ordnance Survey 1:10000 map.

Consenting

The Land Drainage Act 1991 recognises two classes of watercourses with varying consenting requirements:

- Works in (or near) **main rivers** are consented by Natural Resources Wales via flood risk activity permitting. Main rivers are mapped[1] and are typically larger rivers and streams.
- Works in (or near) **ordinary watercourses** are consented by the relevant Lead Local Flood Authority (LLFA). Ordinary watercourses are any watercourses that do not form part of a main river.

Consents typically include requirements for competent contractors to take all reasonable measures not to pollute watercourses, and where possible, any works should not be carried out during the salmonid spawning season from October to March.

Natural Resources Wales have a statutory duty to ensure compliance with the requirements of the Water Framework Directive Regulations 2017. Typically, an assessment of how an activity complies with the regulations is completed in support of a consent application. Operational guidance note (OGN) 072 provides an overview on how to assess and appraise activities, plans and projects to ensure compliance (Natural Resources Wales, 2021).

Other consents (e.g., for works that could affect protected sites or species) may also be required.

[1] https://naturalresources.wales/permits-and-permissions/flood-risk-activity-permits/environmental-permits-for-flood-risk-activities/?lang=en

Methodology

The main tasks that formed the study were set out in the project scope. These are:

- a brief literature review of current legislation, guidance, and definitions of watercourse and watercourse crossings, agreement with the project team to ensure that the agreed ones are used for the project
- a holistic assessment of the whole life costs adopting the “whole life” approach outlined in CIRIA C786, of all types of watercourse crossings
- impacts of all types of watercourse crossings including cylindrical culverts typically used in the WGWE, in comparison to other types of crossing (for example oversized box section culvert, bottomless culvert, baffled culvert, flexi arch, clear span bridge, bailey bridge, fords and piped bridges)
- production of a decision tool flowchart directing internal staff to the most cost effective and least environmentally damaging watercourse crossing option, taking into account water course characteristics, frequency / type / loadings of required access. The outputs will include guidance on avoiding ecologically and geomorphologically sensitive sites and avoidance of detrimental designs and methods wherever possible. Consultants should refer to the Green Infrastructure guidance as an example of a type of flow chart output we require
- pilot / ground truthing of the decision tool in WGWE

This study has been largely desk-based using industry guidance, cost data and experience of the project team to collate evidence around the approach to watercourse crossings in the Welsh Government Woodland Estate and elsewhere.

Site survey was also used for the ground-truthing element. Data was collected via a mobile GIS application.

Literature review methodology

The literature review focussed on current industry guidance as the intention of the study was to be valuable to practitioners and capture real-world practice. The study is reliant on four key industry guidance documents, including:

- CIRIA C786: Culvert, Screen and Outfall Manual (Benn *et al*., 2019).
- Forestry Commission: Civil Engineering Handbook (2016).
- SEPA: Engineering in the water environment: good practice guide – River crossings (2010).
- Environment Agency: Cost Estimation for Culverts – summary of evidence (Keating *et al*., 2014).

Internal cost data was provided by NRW’s Forest Infrastructure Engineering team which formed a key part of the costing tool.

Limitations

This evidence study was completed over a short programme and therefore engagement across NRW was limited. The Project Steering Group did however include representation from a broad range of teams including, Geomorphology, Forest Engineering, Forest Operations, Forest Planning, Fisheries and People and Places.

The cost estimation data is a key limitation of the study. The data used for the cost estimation tool is limited to a small number of NRW projects, largely in the South West region, and may therefore not be applicable across the WGWE. Trialling this tool for watercourse crossing replacement projects across the WGWE would provide evaluation of the costing tool and add to the cost database, thereby iteratively improving the tool.

The Whole Life Costing exercise relies upon design life estimates provided by product manufacturers (50yrs for HDPE and 120yrs for concrete) but these are unlikely to be realistic in most settings.

A literature review of emerging research was not undertaken, although research is known to be taking place in this area (e.g. the AMBER project of which Swansea University is a partner). The literature review focussed on legislation and current industry guidance as the study was intended to capture current practice across the WGWE. Industry guidance relies upon the available research when the document was authored, and therefore does not incorporate the latest research that has been published since that date.

Literature Review

Types of River Crossing

There are various structures which can form a watercourse crossing, as summarised in Table 1.

Table 1: Types of river crossing.

Crossing Type	Photograph Examples
Closed pipe culvert	High-density polyethylene (HDPE)  Photo credit: Arup (March 2022) Concrete  Photo credit: Arup (March 2022) Steel  Photo credit: Arup (March 2022)
Box or Bottomless Culvert	Bottomless arch culvert  Box culvert 
Vented causeway (Piped bridge)	 Photo credit: Arup (March 2022)

Ford	 Photo credit: NRW
Bridge (with and without in-channel supports	Single span bridge  Photo credit: Arup (March 2022)  Source: NRW

Impacts of Poorly Designed Watercourse Crossings

Habitat fragmentation and the physical modification of watercourses are the principal reasons for watercourses across Wales failing to reach the WFD objectives (NRW, 2022). Poorly designed watercourse crossings are a significant contributor to this issue, having impacts at multiple scales.

At a local scale, a structure can alter river hydraulics resulting in deposition at the inlet and erosion (scour) at the outlet (Benn *et al*., 2019). This causes local changes in habitat quality and availability, and often results in a barrier to the movement of fish, such as migratory salmonids (Frankewicz *et al*., 2021).

At a catchment scale, poorly designed watercourse crossings disrupt the downstream passage of sediment and fragment habitats (Mueller *et al*., 2011). This degrades the physical form of freshwater habitats and makes ecosystems less resilient to other pressures, such as poor water quality, floods, or droughts. This ecosystem-level pressure inevitably cascades to individual species of aquatic plants and animals, which often rely on unique habitats sustained by the uninhibited downstream passage of sediment from the headwaters of a catchment.

The accumulative impact on the physical form of a river from multiple poorly designed water crossings in the headwaters of a catchment is difficult to quantify but likely to be significant.

Migration and movement throughout the river catchment are essential to the survival of many freshwater species including salmon, trout, lamprey, otter, and water voles (SEPA, 2010). By inhibiting this movement within a catchment, poorly designed river crossings prevent aquatic species from reaching essential breeding and feeding habitats, leading to a reduction in or loss of populations (Warren and Pardew, 1998; Gibson *et al*., 2005).

Specific issues with poorly designed crossings include:

- Perched inverts (bridge aprons, weirs or culvert outfalls that create a drop from the structure to the downstream riverbed). This can be the result of poor initial design or may arise if the invert is placed at bed level which leads to subsequent erosion downstream. In some cases, erosion may be triggered elsewhere in the river and move up or downstream to the structure, creating a drop.
- Undersized crossings that increase the speed of water flowing through the structure preventing fish passage and/or leading to scour at the downstream end and deposition at the upstream end.
- Excessively wide crossings can create flows that are too shallow for fish to swim through.
- A lack of resting places and pools. Some species of fish can jump obstructions if there are adequate pools downstream. If a crossing is difficult or long for fish to swim through and there are no resting places, then fish can get exhausted and be washed downstream.

Bankside (riparian) habitats can also be impacted by crossings. Wildlife such as otters and water voles not only depend on a healthy river ecology (fish and invertebrates), but also on good riparian habitat where they live and feed. Culverts and other crossings that do not maintain the riparian corridor can create barriers for these mammals as well, preventing them from reaching feeding grounds and establishing populations elsewhere (Seiler, 2004).

Where crossings are poorly designed, particularly where screens are added for debris-capture or security reasons, sediment and woody debris can accumulate which reduces flow capacity and increases flood risk (SEPA, 2010). This may lead to the need for regular debris removal or dredging. This increases long term maintenance costs and can lead to pollution due to the release of finer sediments that can smother the riverbed downstream. Additionally, woody debris removal can result in loss of food for organisms and a decrease in physical diversity of the channel (Gurnell *et al*., 1995).

Culverts

Culverts vary in size, shape (e.g., pipe, box, closed arch) and material (Benn *et al.*, 2019).

Pipe culverts

Circular pipes are the simplest shape, structurally efficient, and in most situations the easiest to install. However, other cross-sectional shapes, such as the arch or ‘D’ shape, are more hydraulically efficient and ecologically acceptable (Benn *et al*., 2019). Concrete, corrugated steel and HDPE pipes are available. HDPE has advantages of being lightweight, strong, and durable, allowing for ease of installation (Benn *et al*., 2019); but requires suitable ground conditions and careful backfill. HDPE is the most comment pipe material for new installations, with concrete and corrugated steel more likely to be a legacy structure. All material types are abundant in the WGWE, as evidenced by the survey work, as summarised in Appendix C.

Further details are provided in Table 2, on the different pipe types for culverts.

Table 2: Pipe types for culverts.

Type of pipe	Material cost	Strength	Buildability	Durability	Carbon
Corrugated steel, galvanised pipes	Cost effective	Strong when installed correctly	Sections can be bolted together to form longer lengths using collars	Liable to corrode if cut, installed poorly, or located in acidic water. Not generally recommended as culverts on watercourses.	Generally larger carbon footprint.
Twin-wall plastic	More expensive than galvanised pipes at larger diameters.	Strong when installed correctly	Light and easy to carry/transport. Relatively simple to join and cut to length as required. Easiest pipe to work with. Ideal for most forestry use, especially in smaller sizes.	Will not corrode in acidic water.	Generally lower carbon footprint.
Concrete pipe	Cost effective	Strong.	Not recommended for forestry use. Installation more complex. Heavier than manual handling limits.	Durable. Fire and corrosion resistant.	Generally larger carbon footprint.

Box culverts

Box culverts are typically formed of pre-cast concrete segments that are placed in sequence and joined together on site. They are a hybrid solution between a pipe culvert and a spanning bridge structure. Such structures can be oversized to accommodate a naturalised bed and banks throughout the culvert. This aids the passage of fish and mammals through the structure, as well as ensuring sediment can continue to be transported downstream.

The culvert gradient is a key consideration in the design of such structures, along with the river’s geomorphological response and any long-term incision. Careful consideration of these factors ensures a sufficient depth of sediment remains in place over the base of the structure. Sediment washed out, exposing the smooth concrete base, can cause issues for fish passage.

Bottomless arch culverts

Bottomless culverts are relatively rare in the UK but are becoming commonplace in the USA and Finland. These structures allow the bed and banks of a watercourse to remain in full throughout the culvert, benefitting natural processes and species movement.

Foundation design is a key consideration to ensure structural stability given the bed of the river is not fixed and the structure's load is distributed to the riverbanks.

Culvert design

Whether a culvert is classified as a structure varies between different parties/stakeholders. NRW classify anything over 1200mm as a structure requiring asset inspection. Highway designers typically classify a culvert as having a diameter of more than or equal to 225mm, and over 900mm as a structure (DMRB, 2021). The rail industry class a culvert as having a diameter greater than 450mm and less than 1800mm with a primary purpose to pass water or services under or adjacent to the railway. The canal authorities set no size limits but emphasise that a culvert includes all the associated works such as inlet and outlet, inspection accesses, and any integral overflow weir.

Guidance on culvert sizing is detailed in CIRIA C786 (Benn *et al*., 2019), with the recommendation that the pipe should be oversized to allow the invert to be below the level of the riverbed, which can change with time. Baffles can be installed to help retain material in a continuous bed. Hanging culverts (i.e., where pipes outfall above the stream surface, creating a further barrier to migration) should be avoided. To reduce the risk of blockage, 300mm is the minimum recommended diameter. However, 450mm should be considered as the realistic minimum (as per the Forest Handbook), and if the required diameter exceeds 1200mm, consideration should be given to a bridge option. Most crossings withing the WGWE are ordinary watercourses and therefore are subject to consenting from the Lead Local Flood Authority (LLFA). Some LLFAs have requirements for culverts (such as minimum diameters) and therefore it is recommended to engage with the relevant LLFA at an early stage.

CIRIA C786 (Benn *et al*., 2019) further details that restricting a culvert diameter to the minimum hydraulic design is often a false economy, except where the primary purpose of the culvert is to throttle flows. Selection of the appropriate design flood for sizing should consider exceedance events, climate change allowances and geomorphological considerations (e.g., scour). Minimising the hydraulic design often results in scour and/or blockage that can increase maintenance requirements and cause early structural failure.

Culvert design should also consider whether a culvert screen is needed. CIRIA C786 (Benn *et al*., 2019) details the design process, including maintenance considerations. A well-designed and maintained screen reduces the risk of blockage or unauthorised access. Poorly designed screens can cause local flooding due to blockage, or injury from maintenance or entrapment. They can also negatively impact the movement of fish and other aquatic or riparian species. All practical alternatives should be considered and eliminated before reaching the decision to provide a screen, including the alternatives to a culvert itself. Need for a screen is an indication that the flood and environmental risks associated with the culvert are high. There will be increased inspection and maintenance costs for the asset life and the consequences of failure may be significant (Benn *et al*., 2019).

The Environment Agency (2010) is generally opposed to culverting of watercourses because of adverse ecological, flood risk, human safety, and aesthetic impacts. Instead, in their view, watercourses should be maintained as continuous corridors, and they will only approve a culvert if there is no reasonably practicable alternative.

Inspection and maintenance

A range of inspections of culverts (and screens and outfalls) can be completed (CIRIA C786). The type of inspection will depend on the risk of failure or blockage that the structure has, the level of information that is required, access and safety restrictions and the intervals for inspections. Table 3 shows the common range of inspections completed. Natural Resources Wales uses a similar system of inspections as listed in the "Inspection Manual for Highway Structures" (Highways Agency, 2007).

Maintenance inspection varies by crossing owner. The frequency of inspection conducted by NRW depends on the last known condition of the asset, as well as the risk of flooding.

Table 3: Types of inspection (Benn *et al.*, 2019).

Inspection Type	Details of Inspection	Inspection frequency (as per Table 7.4 of CIRIA C786
Superficial/safety inspection	To identify and report obvious defects that, if ignored, might lead to collapse, blockage or accidents or high maintenance and repair costs. The visual inspection will normally be carried out without entry.	Varies
General inspection	This type of inspection requires the examination of all parts of the structure that can be inspected without the use of access or specialist inspection equipment. Visual aids such as binoculars can be used where necessary. General inspections will normally be carried out without entry.	0.5 to 5 years
Principal inspection	This type comprises a close examination, within touching distance, of all accessible parts of a structure. This should include adjacent earthworks and waterways where relevant to the performance of the structure. A principal inspection should use appropriate inspection techniques, access and/or traffic management works. Suitable inspection techniques for a principal inspection include taking measurements and photographs, and an assessment of condition. Testing is not a requirement for a principal inspection. If appropriate, inspectors may need to be confined space trained. CCTV survey and inspection of culverts is preferred over person-entry, which should be avoided where possible. When arranging video surveys inspectors/assessors should be aware of the range	~ 5 years

	of different types of condition grades used and should specify an appropriate one.	
Special inspection	Any other inspection required from those not already listed, usually as a recommendation following one of the principal inspections or, for example, after very high flows or loading or an earthquake.	As required

Vented Causeways (Piped Bridges)

Vented causeways (also known as piped bridges) typically comprise a series of parallel pipes or culverts cased in a concrete surround to form the carriageway (Forestry Commission, 2016). Such crossings are designed to pass the normal dry weather flow of the river through pipes below the road, with surcharge and overflow during high flows (Larcher *et al.*, 2010). Most often vented causeways are used in level terrain, without steep crossings or longitudinal falls.

Vented causeways are not recommended for forestry use (Forestry Commission, 2011). Their relatively small openings are prone to blockage and disrupt natural flows (Forestry Commission, 2019). They also typically represent a significant barrier to fish migration and alter natural processes, resulting in habitat degradation.

Although cheap, they can be dangerous in time of flood and are liable to be a source of pollution, both during construction and when in use (Forestry Commission, 2011). They can also result in downstream scouring.

Fords

Fords typically comprise a carriageway surface (made of pitched stones, concrete blocks or precast concrete or cast in-situ concrete) continuous with the riverbed (Forestry Commission, 2019). They sometimes have no formal surface and simply cross the natural riverbed, occasionally with boulder bed-checks in place to create a fixed surface. Fords can be a cost-effective and low-impact alternative on infrequently used stream crossings, and for crossing streams that do not flow year-round, or only with minimal water (NC Forest Service, 2014). Fords may be accompanied by steppingstones for pedestrians.

However, despite being low cost and causing minimal interruption to water flows, fords present a danger to users during time of high flows and flooding. A ford is therefore normally only suitable for very minor roads, and paths intended for walkers and horse riders, etc.

Fords also result in the same problems as vented causeways, including pollution risk, alteration of sediment transport and barriers to fish migration. These disrupt natural processes and thereby degrade habitats and species.

Bridges

Single Span Structures

Single span structures span the width of the channel with no in-stream support and do not affect the bed of the river, i.e., they have no artificial invert, and a natural bed is maintained (SEPA, 2010). Bank habitat can be maintained under the crossing if abutments are set back.

Single span structures can come in a variety of forms including pre-cast concrete structures (arch or portal [rectangular]), panel bridges that come in prefabricated sections and bridges designed for site specific requirements. Some prefabricated structures require foundations to be constructed at the site whilst others can have prefabricated foundations provided (SEPA, 2010).

Span Structures with In-stream Supports

In-stream supports (piers) can be used to increase the crossing width where single span is not possible or prohibitively expensive (SEPA, 2010). They are typically used on large crossings that are unlikely to be present in the WGWE. Bed and bank habitat can be maintained under the crossing if abutments are set back.

Multi-span structures can come in a variety of forms, from bridges designed for site specific requirements to panel bridges that come in prefabricated sections with supports (SEPA, 2010).

Preference for Bridges

A bridge is the preferred method of crossing a watercourse in most scenarios as it allows natural river processes and species movement to continue uninhibited. NRW Policy (issued 18/10/2010) is to consider open span bridges and diversions of watercourses before culverts in the options appraisal process.

Welsh Government guidance defines a clear span bridge as having a soffit at least 300mm above the bank tops either side of a watercourse or a minimum of 600mm above the design flood level (if known) (Welsh Government, 2012).

The Forestry Commission Civil Engineering Handbook (2016) details bridge types to be considered against road categories. Additional guidance on bridge material for watercourse crossings in forests is available (Forestry Commission, 2011).

Advantages of Bridges

In comparison to other crossing types, bridges have several advantages:

- Bridges can usually accommodate a much higher volume of water than a culvert or vented causeway at the same depth of flow, and ‘dam’ effect should also be less (Benn *et al.*, 2019).

- Maintenance and inspection activities do not generally require confined space entry. Thus, eliminating this risk in comparison to a culvert, in alignment with the principles of the Construction (Design and Management) Regulations 2015.
- As spanning structures, they allow natural processes and species movement along the watercourse to remain uninhibited.

A cost comparison with other crossing structures is included in this study's subsequent section.

Key Site-Specific Requirements

To carry out a thorough options appraisal it is essential that the key requirements for a site are identified (SEPA, 2010). It is essential that the key requirements are met when assessing the options. Key requirements that should be identified for each site include (SEPA, 2010):

Ecological

- Identify sites that have been designated for nature conservation (SSSI, SAC, SPA) and ensure the conservation requirements for the designated site are met.
- Identify protected species nearby that could be affected (e.g., freshwater pearl mussel, lamprey, river jelly lichen, otters).
- Identify important habitats (e.g., fish spawning and rearing areas) and ensure they are not damaged. These typically consist of sections of clean riverbed gravels.
- Identify fish species upstream and downstream if there is a risk that fish passage may be affected.
- Identify mammals present in the area.

Geomorphological

- Identify the geomorphological features (e.g., bars, riffles, pools) and processes that are present.
- Identify the typical bed load of the watercourse (e.g., sand, gravel, cobble, boulder)
- Consider potential future evolution of the channel (e.g., meander migration, bed incision)

Design of the crossing

- Identify the hydraulic capacity required, including an allowance for climate change and any local requirements (e.g., LLFA policy).
- Identify the risk and consequence of blockage.
- Make further allowance for natural bed material through the crossing (not just hydraulic capacity).
- Consider the amount of freeboard that is required e.g., to aide passage of large woody debris and other water uses (see below).
- Consider exceedance events and the potential for scour.
- Consider measures to minimise maintenance requirements and ensure public safety.
- Connection to the road network – suitable gradients, widths etc.

Other river users

- Identify other users of the river and ensure the use is not affected (e.g., is the river used for navigation, recreation canoeing/rafting).

Site Visits

Site visits were undertaken in February-March 2022 across the WGWE (north, mid-, and south Wales), visiting a series of crossings, including culverts, bridges, weirs, and vented causeways, of varying states of condition, size and material. The purpose of the site visits was to establish a baseline of typical construction and condition of watercourse crossings within the WGWE and to enable the methodology developed in this report to be applied to real-world examples. A map showing the site locations is included in Figure 1.

The site visit records are summarised in Appendix C.

Figure 1: Ground truthing site locations in North, Mid and South Wales.

Whole Life Costing

The selection of a preferred crossing type or types will depend on hydraulic performance requirements, LLFA policy (where on an Ordinary Watercourse), ecological and geomorphological considerations and site characteristics, as noted above. Consideration is then given to affordability, both in terms of initial capital cost (including necessary consents and registration with LLFA), ongoing inspection and maintenance costs and, finally, demolition (Benn *et al*., 2019).

Desk Review of Culvert Costs

A range of sources for capital and maintenance costs for culverts were reviewed at the outset of this study, and an overview is given below. Significant differences were identified between local and national (UK) figures, which are attributed to efficiencies offered by local experienced teams and short supply chains.

Capital costs

Initial costs for installing concrete and HPDE culverts were obtained from the EA culvert cost evidence summary (Keating *et al.*, 2014) and from the NRW South West Integrated Engineering team. The cost comparisons are described below and shown as a graph in Figure 2.

- The high-level guidance in the Evidence Summary (Keating *et al.*, 2014) gives costs per metre of culvert, based on size and total length of installation. They are based on 37 Environment Agency projects, and include all associated out-turn costs i.e., design, supervision, screens, headwalls, traffic, and flow management. The culverts were all concrete square or rectangular. The costs per metre range from £1,100 to £10,600 for a 1m^2 culvert, depending on the length to be installed (range 10-300m). The significant reduction in unit cost for longer lengths are likely to be due to relatively high cost of ancillary works (welfare, screens, fencing etc) which are less dependent on culvert length.

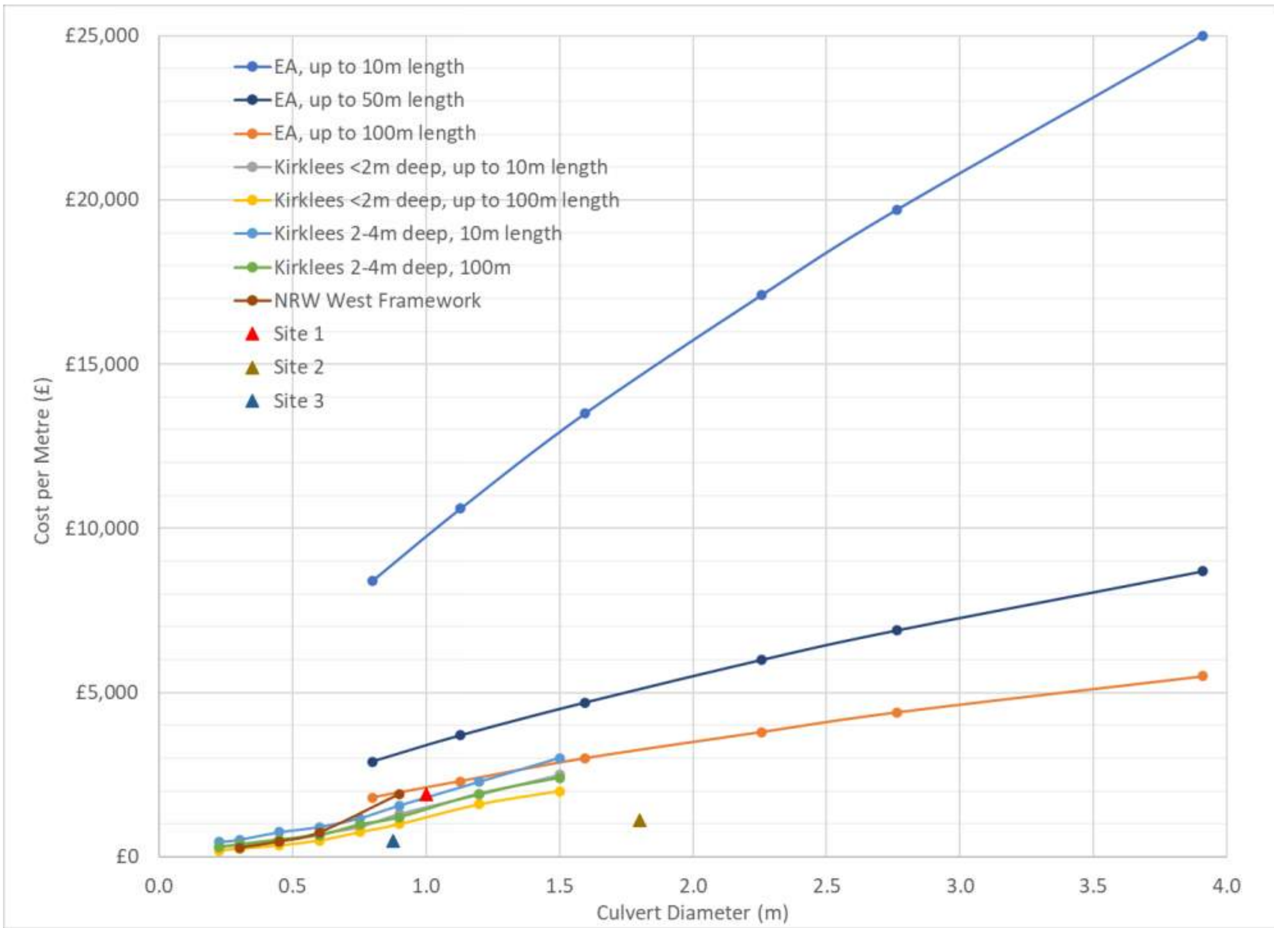
- Data from Kirklees Council, also provided in the Evidence Summary (Keating *et al.*, 2014), gives costs which vary according to depth to soffit as well as size and length of installation. These figures are based on circular culverts of unspecified material. It is stated that these include all staff costs and fees. The costs per metre range from £900 to £2,470 for a 1.2m diameter culvert (1.1m^2), depending on length and depth.

- Framework rates from NRW Integrated Engineering South West were provided to the project, with a cost per metre dependant on diameter and depth to soffit. The culverts are circular HDPE. It is assumed that most installations are between 10m and 20m length. Projects typically do not include a screen, fencing or traffic management although flow management would be included. As these are construction costs, they do not include other project costs such as design, supervision and consenting. The cost per metre for a 0.9m diameter culvert (0.64m^2) is £1,910.

- A case study of three recent projects completed by NRW Integrated Engineering South West gave costs between £500 and £1,900 per metre length, again varying by size depth and length. These were all HDPE circular culverts.

It is apparent that the current NRW framework costs are significantly lower than the EA figures in the Guide (Keating *et al.*, 2014), but are generally in line with the Kirklees cost data. As noted above, this is partly because they are construction rather than total project costs, but also due to differences in typical installation details (need for traffic management, use of local stone, requirement for screens etc). This would indicate that whilst standard cost data is appropriate for initial option comparisons, local cost information should be referred to for confidence in absolute costings in later project stages.

Figure 2: Culvert capital cost comparisons.



The key factors to consider in costing a new culvert (Keating *et al.***,** 2014), and their likely impact on typical forestry installations, are summarised in Table 4. On balance, the forestry conditions are likely to have a neutral impact on the cost estimation, with a roughly even split between characteristics which are likely to increase and decrease the costs.

Table 4: Factors influencing culvert capital costs.

Factor	Expected Condition for Forestry Culverts	Potential Impact on cost assumption
Culvert shape	Likely to be square or circular, assumption detailed in unit cost guide.	Neutral
Access constraints		
Rural / urban	Likely to be rural; may need to provide site welfare	Increase
Distance to site	Likely to be quite far from main roads / depots	Increase
Ease of movement along site	Likely to be easy, low traffic volume and good communication with other site users	Decrease
Need for temporary access	Not likely to be required as will be on existing access roads	Decrease
Weather	Timing will depend upon whether it is planned or emergency works.	Increase or decrease
Materials	Use of HDPE is currently more commonly used than concrete, and any stone required for bedding/backfill/headwalls is generally available from a local quarry at low cost.	Decrease
Construction Method	Culverts are likely to be built online with water management. Method and plant depend on culvert material, depth of cover and other site considerations.	Increase or decrease

Inspection and maintenance costs

The Evidence Summary (Keating et al, 2014) provides a framework for estimating annual maintenance and inspection costs, with a high and low limit given depending upon size, length, and target Condition Grade. Table 5 presents a range of typical annual costs calculated using this framework; a whole life inspection and maintenance cost is also given, based on a 60-year appraisal period.

The Summary (Keating *et al.*, 2014) does not distinguish between pipe sizes below 1.2m, although in practice there may be cost differences. Remote cleaning techniques (jetting) are assumed for all pipes below 1.2m, whilst person entry is assumed for larger pipes. The cost is given per culvert, rather than per metre, with additional values given for culvert lengths of 20-50m and >50m. There may be benefit in collecting and reviewing local data to refine these costs, for example to reflect a difference in cost between the smaller diameters, or smaller increments for the culvert lengths.

Table 5: Inspection and maintenance cost ranges (derived from Keating *et al.*, 2014).

Culvert diameter	Length	Target Condition Grade	Annual Cost Range	Whole Life Cost
<1.2m	<20m	3 - Fair	£150 - £535	£3,956 - £14,111
1.2 - 4m	<20m	3 - Fair	£340 - £3,600	£8,968 - £94,951
<1.2m	<20m	2 - Good	£730 - £2,145	£19,254 - £56,575
1.2 - 4m	<20m	2 - Good	£1,760 - £12,900	£46,420 - £340,241

The final estimated inspection and maintenance cost is positioned within the given range using a scoring system. The culvert site is given scores for ease of access, location, and culvert properties; these are then multiplied by fixed weighting factors to give a total score out of ten (Keating et al, 2014). For example, for a 0.5m diameter pipe with Target Grade of 3:

- a score of ten would indicate the top value, £535 per year,
- a score of zero would indicate the lower value, £150 per year,
- and a score of five would indicate a middle value, with annual costs of £343.

Reviewing these factors and selecting a score likely to be typical of most Forestry culvert sites (Table 6), gives a score of 1 out of 10, putting the estimated maintenance cost at the lower end of these ranges.

The Evidence Summary (Keating *et al.*, 2014) does not give specific inspection and maintenance activities and intervals associated with these costs, but it may be assumed that they reflect the costs associated with typical NRW and EA inspection and maintenance regimes as outlined in CIRIA (Benn et al, 2019), summarised in 'Inspection and Maintenance' section of this report. Typical activities may include silt and debris clearance, and patch repairs to pipe joints and headwalls.

Further evidence, particularly at <1.2m diameters is recommended to capture a more representative cost range.

Costing Tool

A costing tool has been developed to provide a high level, whole life cost comparison of preferred crossing options. It has been used to provide the typical costs given in the Option Summary Sheets (Appendix B) and for the Option Selection examples based on recent site visits (Appendix C). It is not intended as a guide to absolute costs, but to give an indication of the relative costs of different options.

The tool may be modified in the future if local cost information is collated, for example if new suppliers are identified and contractors gain experience with the installation of different crossing types.

Overview

The tool is in a spreadsheet format, with a sheet for each crossing option: bridge, bottomless culvert (arch and box), oversized box culvert, circular HDPE, and concrete culvert. The practitioner enters information on the size of the crossing, with options to alter some of the standard assumptions if needed to suit that site. The tool uses this information to calculate a high-level estimate of the construction cost, annual inspection and maintenance cost, and whole life cost for that option.

Cost sources and assumptions

The base year for the costing is 2022; all costs sourced from previous years are uplifted to January 2022 using the Cost Index (CPI). Inspection and maintenance costs are incurred every year for the duration of the assessment (60 years) and discounted to present day values using rates from the Treasury Green Book. -The discount factors used are the Standard Values presented in Table 6 of the Treasury Green Book, which assume a discount rate of 3.5% for the first 30 years of the scheme life, and 3% for years 31 to 60.

Construction cost escalation has continued in 2022, with salary, energy and material price escalation coupled with construction fuel duty exemption ending in April 2022. As such there is greater uncertainty than typical in forecast cost absolute estimates.

Capital costs

All capital costs used in the Tool have been provided by Arup’s Estimating team, with assumptions and inclusions as detailed in Appendix D. They are total project costs, including allowances for design and supervision as well as Contractor’s costs; no contingency is included for traffic management or utility diversions, as it is assumed that for most Forestry sites these will not be significant.

A general optimism bias of 44% is applied as standard for initial high-level cost assessments. A key point to note is that these figures are based on a database of national projects, and that although a Wales regional weighting has been applied, this does not fully account for local cost factors such as the price and availability of quarried stone.

The bridge crossing is assumed to be a weathering steel structure with concrete abutments, with a width of 5m as specified in the Forestry Civil Engineering Handbook (Forestry Commission, 2016). Weathering steel was selected as an economical choice, which requires less maintenance and less use of chemicals (paint), but alternatives could be considered and costed at a later stage.

Bottomless box and arch culverts are currently assumed to cost the same as rectangular box culverts per m^2 of cross-sectional area; this may be refined as more cost data becomes available from projects using these types.

Inspection and maintenance costs

The culvert inspection and maintenance costs used in the tool are from the ranges given in Table 5, uplifted to present day prices. The costs for the different types of culverts are differentiated by selecting appropriate factors for the access, channel location and culvert properties; these factors may be amended in the Costing Tool if there are site specific reasons to do so. These are presented in Table 6.

From this assessment, oversized or bottomless culverts are less expensive to maintain than standard culverts at the same location, due to ease of access and reduced blockage risk which reduces their Channel and Access scores. Concrete culverts are slightly more expensive than HDPE culverts due to their higher Culvert Properties score, which reflects anecdotal accounts of joint problems being more difficult to repair.

Table 6: Weighted factors for culvert inspection and maintenance estimates (based on Keating *et al.*, 2014) [W=weighting, S=score, O=overall weighted score].

		HDPE CIRCULAR			CONCRETE CIRCULAR			CONCRETE BOX OVERSIZED			CONCRETE BOTTOMLESS (ARCH OR BOX)		
Factor	**W**	**S**	**O**	**Comments**	**S**	**O**	**Comments**	**S**	**O**	**Comments**	**S**	**O**	**Comments**
Access Distance to worksite, protected sites/species, invasive species, overhead power cables, internal services, confined space	2	1	2	If >1.2m then decrease as less likely to be confined space If L/H>20, then decrease as risk of entering is lower If site is very remote then increase	1	2	As HDPE circular	0	0	Oversized culverts are less likely to be confined spaces If site is very remote then increase	0	0	As oversized concrete box
Channel Culvert located in channel with significant bedload sediment	1	1	1	Regular culverts interrupt bed material movements and are more prone to blockage Increase if slope > 1 in 200 Increase if there are known silt/debris problems.	1	1	As HDPE circular	0	0	Oversized culverts are less disruptive to material movements and are less likely to block Depends on local knowledge of catchment.	0	0	As oversized concrete box

		HDPE CIRCULAR			CONCRETE CIRCULAR			CONCRETE BOX OVERSIZED			CONCRETE BOTTOMLESS (ARCH OR BOX)		
Culvert Properties Properties of the culvert that increase maintenance frequency (steps, bends, changes in cross-section, changes in slope/bed levels/soffit levels, irregular sections)	2	0	0	Increase if known drop pool or other feature requiring more frequent inspection /maintenance.	1	2	Problems with concrete joints may be more difficult to repair than plastic ones. Increase if known drop pool or other feature requiring more frequent inspection /maintenance.	1	2	As concrete circular	1	2	As concrete circular
TOTAL SCORE (/10)		**3**			**5**			**2**			**2**		

Inspection and maintenance of bridges assumptions and inclusions are as detailed in Appendix D. Key points to note are that General Inspections are biannual, with Principal Inspections every ten years. The expected maintenance activities are concrete repairs, waterproofing and drainage cleaning.

Design Life and Appraisal Period

The design life of each type of structure is assumed as follows, from manufacturers guidance and Arup Estimators:

- HDPE culverts: 50 years
- Concrete culverts (all types), bridge: 120 years

It is noted that, in practice, the life of concrete and HDPE culverts may be shorter than these design values. The Costing Tool could be amended to consider this in the decision process.

The appraisal period is 60 years; since this is longer than the HDPE culvert design life, an additional capital cost is included for replacement or restoration in Year 50. The value of any residual life of the assets at the end of the appraisal period is not quantified.

Most crossings will be constructed as replacements for existing crossings and will in turn be replaced the end of their life. The cost of demolition and any disposal of arisings, which should be included in a whole life cost assessment, is therefore assumed to be included in the construction costs of the replacement asset.

Cost Examples

The Costing Tool has been used to produce high level estimates for the replacement crossing options at two of the sites visited as part of the Ground Truthing exercise. Details of these site visits are contained in the ‘Site Visit’ section of this report, and in Appendix C.

The sites selected to demonstrate the costing tool are Maesnant, in Mid Wales, and Hirnant Tributary in North Wales. These were chosen as they represent a small (450mm) and large (1500mm diameter) culvert that are typical of many Forestry sites.

Maesnant, Mid Wales

The key site information needed for the costing tool is as follows:

- Culvert diameter: 1500mm
- Channel width: 2m
- Length of crossing: 10m
- Target condition grade: 3 (Good)

This information has been entered into the spreadsheet tool to generate the alternative crossing option costs, presented in Table 7 below. Screenshots of each page of the tool are presented in Appendix E, as an example to the practitioner of how it is intended to be used.

Preliminary sizing assumptions have been made as follows

- It is assumed that the existing culvert is undersized for the catchment as the culvert is narrower than the watercourse. Therefore, the replacement culvert is assumed to be 2100mm in diameter. This is only marginally wider than the current watercourse but is the largest diameter typically available for pipe culverts so is selected for this high-level cost comparison.
- The oversized box culvert will be 2100mm wide and 1800mm high, to provide clearance for 300mm depth of local bed material to be placed on the base
- The open bottomed arch or box culvert is also assumed to be 2100mm in width to provide like for like cost comparisons. The height is taken to be 1500mm, as existing.
- The single span bridge is assumed to have a span of twice the channel width, i.e., 4m, in line with Estimator assumptions.

The default maintenance factors for each culvert type are considered to be appropriate for this site and so are unchanged.

Table 7: Summary of option costs for Maesnant, using Costing Tool.

Option	Capital Cost	Annual Maintenance (includes inspection)	Whole Life Cost
HDPE circular culvert 1500mm diameter (like for like replacement – representing business as usual scenario)	£63,800	£1,700	£121,100
HDPE circular culvert	£89,700	£1,700	£153,000
Concrete circular culvert	£103,800	£2,600	£172,000
Oversized box culvert	£74,300	£1,400	£110,000
Open bottomed culvert	£74,300	£1,400	£110,000
Single span bridge	£740,400	£102,000 (whole life)	£842,900

Hirnant Tributary, North Wales

The key site information needed for the costing tool is as follows:

- Culvert diameter: 450mm
- Channel width: 500mm
- Length of crossing: 9m
- Target condition grade: 3 (Good)

This information has been entered into the spreadsheet tool to generate the alternative crossing option costs, presented in Table 8 below. Screenshots each page of the tool are presented in Appendix E, as an example to the practitioner of how it is intended to be used.

Preliminary sizing assumptions have been made as follows, using similar principles to Maesnant:

- It is assumed that the existing culvert has been undersized for the catchment as it is narrower than the watercourse and is causing deposition at the inlet. Therefore, the replacement culvert is assumed to be 750mm in diameter (1.5x channel width).
- The oversized box culvert will be 1500mm wide and 750mm high, to provide clearance for 300mm depth of local bed material to be placed on the base

- The open bottomed arch or box culvert is assumed to be 1.5 x channel width, i.e., 1500mm, to place the side supports outside of the channel. The height is taken to be 450mm, as existing.
- The single span bridge is not costed, as the watercourse is less than 2m width.

The default maintenance factors for each culvert type are considered to be appropriate for this site and so are unchanged.

Table 8: Summary of option costs for Hirnant Tributary, using Costing Tool.

Option	Capital Cost	Annual Maintenance (includes inspection)	Whole Life Cost
HDPE circular culvert 450mm diameter (like for like replacement – representing business as usual scenario)	£24,000	£650	£46,000
HDPE circular culvert	£34,400	£1,100	£69,000
Concrete circular culvert	£36,900	£1,600	£78,200
Oversized box culvert	£69,500	£970	£95,100
Open bottomed culvert	£69,500	£970	£95,100
Single span bridge	n/a	n/a	n/a

It is noted that the capital cost for the oversized box and bottomless culverts are estimated to be the same within the tool. This is because the capital cost is based on cross sectional area, rounded up to the nearest square metre, and they both round up to 1m^2. The maintenance cost is the same as they are both below 1.2m high.

Observations

The high-level option costs for Maesnant, where a large culvert may need to be replaced, indicate that an HDPE circular pipe will have the lowest capital cost, and it would cost approximately 20% more to replace it with an oversized box or bottomless culvert. This difference may be greater in practice, as it is recognised that, locally, HDPE culverts may be installed very efficiently. It is also noted that there may be practical difficulties in getting the required plant (e.g., cranes) and concrete deliveries to site to install a concrete alternative. There is not a significant difference in cost between the different types and sizes of concrete alternatives, as the cost of these is not very sensitive to their size.

The total Whole Life Cost comparison indicates that, over the appraisal period of 60 years, the initial cost saving of the HDPE culvert is outweighed by the maintenance saving of the large concrete alternatives. This is due to the Access, Channel and Culvert Properties factors that are used to calculate the maintenance costs.

The option costing for replacement crossings at Hirnant Tributary show a clearer split in costs between the traditional culvert options and the larger box or bottomless culverts. This is due in large part to the design assumptions used for preliminary sizing, which makes these options significantly larger than the original culvert.

Crossing Option Appraisal

CIRIA (Benn *et al*., 2019) recommend that the following criteria must be met for any new culvert or river crossing: safety, structural performance, hydrology and hydraulics, whole life cost and carbon, environment and geomorphology, conveyance of debris, and constructability. These should be kept under review at each stage of the option selection process, and throughout the life of the asset, to confirm whether the selected option is still the most appropriate (Best Practice Principle 7.5, Benn *et al.*, 2019).

There is also an overarching requirement for NRW to consider Future Generations and ensure that its policy aligns with the Sustainable Management of Natural Resources.

For the purposes of this report, these criteria have been considered for each crossing type as follows:

- Hydrology and Hydraulics; flow considerations for design, safety in use and downstream impacts
- Environment and Geomorphology; local and downstream impacts on fish, mammals and invertebrate movements, bed and bank habitat impacts, likelihood of scour or sedimentation, mitigations
- Constructability; health and safety during construction, site requirements or constraints, availability of materials, ease of construction
- Operation and maintenance; health and safety during maintenance, safety of forestry vehicles and other forest users, expected frequency and type of maintenance, blockage risk, likelihood of sedimentation, features that are likely to make it easier or harder to maintain
- Costing; expected asset life, capital cost and yearly maintenance cost for a given size
- Future Generations – Carbon and Adaptability; qualitative carbon impact, flexibility to deal with future flow increases or changes in forestry management
- Other; any other key considerations not already covered, e.g., availability.

The Crossing Option Summary Sheets in Appendix B describe the performance of each option against these criteria, using information drawn from the literature review. The summary in Table 9 gives a high-level assessment of each option, ranking each from Best (coloured green) to Poor (coloured brown) in each criterion. Those coloured amber are somewhere in between, and to offer a reasonable level of performance.

Whilst circular culverts are expected to be the least expensive and easiest to install, they are associated with more significant environmental and geomorphological impacts and can pose greater health and safety risks during operation and maintenance. Single span crossings generally perform best across all categories except for cost and constructability;

the use of cranes for lifting concrete sections, and the requirement for engineered bedding / foundations for the single span structures make them more difficult to construct, but the costs may reduce as they become more commonly installed and supply chains / locally experienced teams are established.

Table 9: Summary of crossing options.

Crossing Option	Hydrology and Hydraulics	Environment and Geomorphology	Constructability	Operation and Maintenance	Costing	Future Generations - Carbon and Adaptability
Single Span Crossing - Timber, steel, or concrete bridge	Best – no flow restriction	Best – continuous bed and banks	Poor – complex construction	Best – low blockage risk	Poor – highest WLC	OK – very adaptable to future flow increases or geomorphological change but likely to be higher carbon
Single Span Crossing - Bottomless Arch Culvert	Best – no flow restriction	Best – continuous bed and banks	OK – requires crane	Best – low blockage risk	OK	Best – very adaptable to future flow increases or geomorphological change and likely to be lower carbon than bridge
Oversized concrete box	Best – no flow restriction	OK –impact during construction; bed is continuous if correct depth and gradient	OK – requires crane	Best – low blockage risk	OK	OK – adaptable to future flow increases
Circular HDPE	Poor – flow very constrained	Poor – high impact on bed and fish passage	Best – simple to install, although installation quality if often poor.	Poor – confined space	Best – lowest WLC	Poor – not adaptable to future flow increases and susceptible to geomorphological change.
Circular Concrete	Poor – flow very constrained	Poor – high impact on bed and fish passage	OK – may require crane	Poor – confined space	OK	Poor – not adaptable to future flow increases and susceptible to geomorphological change.

Option Selection Flowchart

An option selection flowchart has been developed following the review of existing guidance to help practitioners appraise more environmentally sensitive options when considering a new or replacement watercourse crossing. The option selection flowchart is included as Appendix A.

The flowchart sets out a decision process for identifying the preferred crossing types at a site, depending on the width of the watercourse and the gradient. The impacts of the three broad types are identified, with single span structures having the least impact, and closed culverts having the highest. This decision tool is intended to be advisory and used in conjunction with the costing information as part of the process of selecting a crossing type.

As with the Costing Tool, the Option Selection Flowchart has been used for two of the sites visited as part of the ground truthing exercise: Hirnant Tributary (North Wales) and Maesnant (Mid Wales). The survey sheets for these two sites are included in Appendix C.

Maesnant Option Selection

The culvert at Maesnant is on an upland watercourse with a slope greater than 1% and is 2m wide. The current crossing is a 1500mm diameter steel culvert, in poor condition. The flowchart indicates that a single span structure would be the preferred crossing type; it may be either an oversized culvert, bottomless arch culvert, bottomless box culvert, or a single span bridge.

Hirnant Tributary Option Selection

Hirnant Tributary is a small lowland watercourse with a slope of less than 1%. It is approximately 1.3m wide. The current crossing is a 450mm HDPE culvert. The flowchart indicates that for a watercourse of this size and slope either a closed culvert or a single span structure could be considered.

Conclusions & Recommendations

This report has reviewed existing guidance with regards to the design of watercourse crossings, with reference to forest roads and culverts, which are common throughout the WGWE. A high-level costing tool has been developed to enable comparison between circular HDPE, circular concrete, concrete box, and bottomless culverts, along with basic bridges.

This tool has been used to evaluate the whole life cost of the various types of watercourses crossing to understand whether there is a cost case for moving to more environmentally sensitive structures such as bottomless or oversized box culverts. Eighteen ground truthing sites across North, Mid and South Wales are presented and evaluated to provide case studies to help engineers appraise the most appropriate solution for their projects. This is supported by an option selection flowchart which guides users to appraise whether their solutions align with the sustainable management of natural resources.

The key conclusions of the study are:

- Single-span structures generally represent the most environmentally sensitive option.
- Where smaller diameter culverts are suitable (e.g., 450mm diameter cost example), a standard HDPE or concrete circular culvert is significantly cheaper over its lifetime than alternatives. However, for larger diameter culverts (~1m+), the cost difference is marginal, with oversized box or bottomless arch culverts perhaps even being marginally cheaper over the lifetime of the structure.
- The national databases used to provide costings, such as the EA culvert cost evidence summary and Arup's internal data, are not reflective of the local savings (e.g., use of locally quarried stone to form headwalls and use of local contractors) currently realised by NRW's Forest Engineering teams.
- The inspection and maintenance of closed culverts can pose significant health and safety risks over alternative structures.

The following actions are recommended to develop the approach further:

- Collation of cost evidence, ideally from within NRW, to provide more certainty on construction and operational costs as the differences between structures can be marginal. This will provide more NRW-specific evidence to inform decision making and address the shortfall of the national cost databases used in this study.
- Better understanding of the actual lifespan of structures within the WGWE. At present the costing relies on design life provided by manufacturers (50yrs for HDPE and 120yrs for concrete) but these are unlikely to be realistic, which would significantly impact upon the whole life cost comparisons between structure types. There is an opportunity to address this in the upcoming NRW Forestry Bridge and Culvert Inspection Programme – a nationwide structural survey exercise planned from FY2022/23 onwards.
- At present, costs are considered in isolation, with benefits only being qualitatively considered. Assigning a value to the benefits of different structure types would

enable a cost-benefit analysis to be undertaken to support options appraisal. The B£ST tool, developed by CIRIA, may support this approach.

- Engage relevant stakeholders (e.g., agricultural sector, private woodland operators, and developers) should this approach be applied more widely than the WGWE.
- Conduct a review of the evidence wider than in the selected industry reports included here. This study focussed on existing industry guidance documents, drawing on approaches elsewhere in the UK and USA. Wider review of emerging research and approaches elsewhere in the world would be of benefit.
- Evaluate the usefulness of this evidence by trialling the costing tool and option selection process developed here. An initial 12-month trial period on watercourse crossing replacement projects across the WGWE, followed by a review of the evidence and tool would provide sufficient insight to evaluate the approach.

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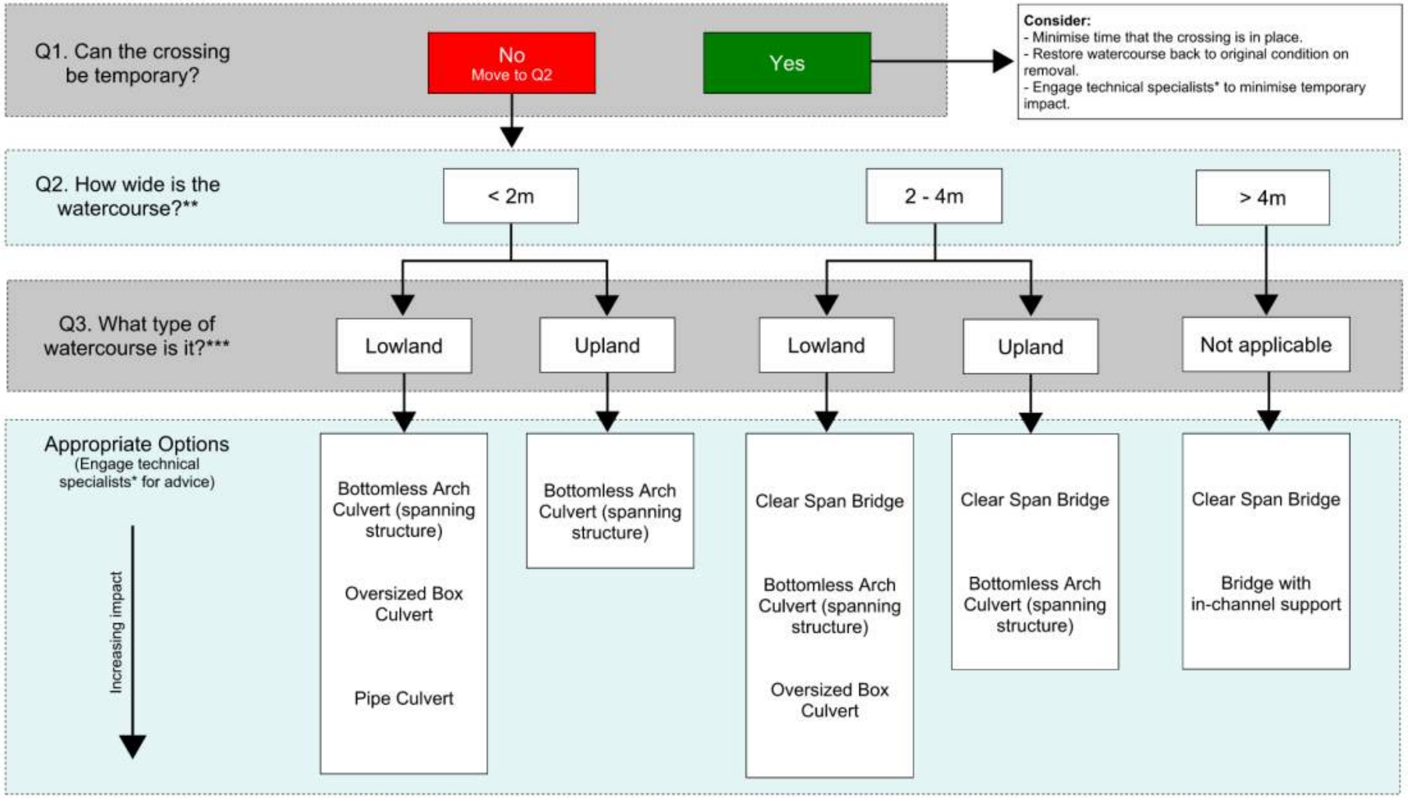
Appendices

Appendix A – Option Selection Flow Chart



Notes:

As detailed in the accompanying report, evidence suggests fords and vented causeways are not suitable crossing options and are therefore not included in this flowchart.

* Technical specialists include NRW area Geomorphology & Fisheries teams. Occasionally, site specific constraints (e.g. steep crossfalls, narrow valleys) will make it difficult to follow the above guidance. Engagement with specialists is key in these instances to select a suitable crossing design.

** Watercourse width is the straight line distance between the toe (bottom) of the riverbanks, including any exposed (unvegetated) sediment and vegetated islands.

*** River type is mostly determined by channel slope, which can be estimated using the contour lines on an Ordnance Survey map. The definitions are:
Lowland: Channel gradient typically less than 0.1% (1 in 1000). Riverbed largely made up of cobbles, boulders and gravel.
Upland: Channel gradient typically greater than 0.1% (1 in 1000). Riverbed largely made up of gravels, sands and silt.

Appendix B – Option Summary Sheets

SINGLE SPAN CROSSING – TIMBER, STEEL OR CONCRETE BRIDGE

The CTH E bridge crosses a branch of the Marengo River in Bayfield County, Wisconsin.

Image source: https://www.ayresassociates.com/taking-notice-is-that-a-bridge-or-a-culvert/

Description

A bridge should be the first choice for watercourses greater than 2m width, and considered as an option for watercourses 1.2 to 2m width (Forestry Commission England, 2011, s6.3.7).

A good bridge design will be sustainable, simple, easy to construct and low maintenance, minimising reliance on heavy plant, cranes and ready mixed concrete (Civil Eng Handbook 2016). The choice of span length and abutment type are important in maximising the sustainability of this option.

Hydrology and Hydraulics

A single span bridge will have very little impact on flow under the road crossing, particularly if bank seats are used (Forestry Commission, 2016 s8.2.1).

Deck may be required to be above the 1 in 100 year + climate change flood level, check Local Authority consenting requirements.

Environment and Geomorphology

A single span bridge will have minimal impact on local environment and geomorphology once constructed.

Consider lengthening span to allow the use of bank seats rather than abutments (Forestry Commission, 2016 s8.2.1) to minimise disturbance to riparian zones.

If abutments are used, consider nesting boxes and bat slits.

Sediment accumulation and downstream scour may occur.

Constructability

Removal of any existing culverted crossing will need to include local reinstatement of channel bed.

A longer span will allow abutments to be built in the dry, reduce impact on local flora and fauna, and make it easier to avoid a pollution incident during construction (Forestry Commission, 2016 s8.2.1)

Operation and Maintenance

Most new bridges have handrails for pedestrian safety (Civil Engineering Handbook, 2016 s8.2.1)

A bridge designed with the recommended load rating, width etc in the Civil Engineering Handbook (Forestry Commission, 2016) will allow forestry vehicles to use it safely.

	If abutments are used, consider incorporating handholds for inspections (Forestry Commission, 2016) Timber will require regular inspection and treatment to prevent/repair water damage.
Costing A bridge will almost always be more expensive than a culvert to construct (Benn et al, 2019), but this may be offset by a longer life span. Design Life: 120 years Watercourse width: 2m Bridge Span: 4m CAPEX:£740,000 OPEX: £102,000 WLC (60yrs):£842,000 Costs from Costing Tool, Maesnant example.	**Future Generations - Carbon Impacts and Adaptability** Very adaptable to future increases in flows; the further the abutments / supports are placed from the bank edge the more additional flow may be accommodated. Use of bank seats rather than abutments will reduce carbon impact (Forestry Commission, 2016) Timber will have lower embodied carbon than a steel bridge, but may have a reduced design life. Timber or steel elements may be reused at end of bridge life. Potential to re-use a bridge from a different site.
Other If installed as a replacement for a culvert, consider potential implications (Table 13.1, Benn at al 2019): downstream flood risk if previously acting as throttle, impact on bank and bed erosion, need for pre-removal survey, regrading channel to correct gradient / alignment. Considerations for abutment choice: bank seats are preferred, as noted above, but if not possible due to site conditions then options are: timber (shorter design life, lower carbon), gabions (shorter design life, lower carbon), geogrid /reinforced earth (if local moraine deposits available then this may be low cost and sustainable), concrete block with anchored geotextile (longer design life, higher carbon, mass concrete with minimal steel (higher CO_2), reinforced concrete (higher CO_2) (Forestry Commission 2016)	

SINGLE SPAN CROSSING - BOTTOMLESS ARCH CULVERT

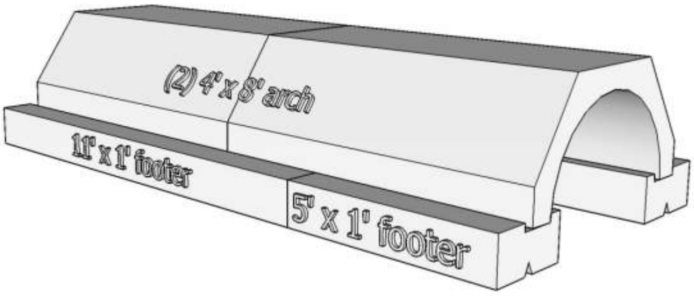


Figure 3.4 Use of pre-cast concrete segments for a bridge as a low-cost alternative to a culvert (courtesy WDR & RT Taggart)

https://www.precastmaine.com/archculvertdesigns.html / CIRIA 786

Description

A bottomless arch culvert will come in pre-cast sections suitable for installing over watercourses with a maximum span of 10m and maximum rise of 4m, depending on supplier. Similar weight and handling issues to concrete culvert sections, but enhanced environmental performance.

Hydrology and Hydraulics

Should be designed for open flows conditions.
Diameter should be selected to be 1.2 to 1.5 times channel width.

Environment and Geomorphology

Allows continuity of natural river bed.
Low impact on fish passage and sediment movement through the catchment.

Constructability

Removal of any existing culverted crossing will need to include local reinstatement of channel bed.

Installation will require a crane and concrete truck to be brought to site. Specialist contractor may be required to assemble the structure.

Footings / foundations will need to be constructed to a high tolerance to achieve design life / loading performance.

Operation and Maintenance

May be susceptible to blockages

May be classified as a confined space (similar to a full culvert) for maintenance purposes, depending on length and rise.

Costing

Design Life: 120 years

Watercourse width: 2m

Assumed culvert size: 3m width, 1.5m high

CAPEX:£72,300

OPEX: £35,800

WLC (60yrs):£111,100

Future Generations – Carbon and Adaptability

Concrete has higher embodied CO_2
Tend to be oversized so will have some capacity for future flow increase.

Costs from Costing Tool, Maesnant example	

Other

If installed as a replacement for a culvert, consider potential implications (Table 13.1, Benn at al 2019): downstream flood risk if previously acting as throttle, impact on bank and bed erosion, need for pre-removal survey, regrading channel to correct gradient / alignment.

Widely used in USA but not currently available routinely in UK. Ongoing correspondence between Truform Civils (potential supplier), Alex Lumsden (West Wales River Trust) and Oliver Lowe (NRW) to see if supply can be established. FlexiArch products may also be suitable.

SINGLE SPAN CROSSING - BOTTOMLESS BOX CULVERT

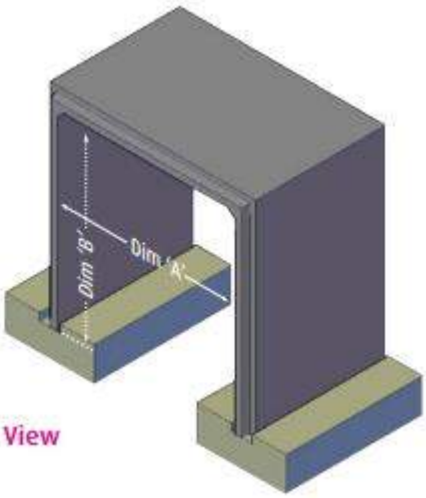


Image source: Shay Murtagh catalogue (www.shaymurtagh.co.uk)

Description

A bottomless box culvert will come in pre-cast sections available in sizes up to 3m high and 8m wide, depending on supplier. Similar weight and handling issues to concrete culvert sections, but enhanced environmental performance.

Hydrology and Hydraulics Should be designed for open flows conditions. Width should be selected to be 1.2 to 1.5 times channel width,	**Environment and Geomorphology** Allows continuity of natural river bed, so lower impact on fish passage and sediment movement through the catchment. Does not constrain bank edge, if sufficiently sized.
Constructability Removal of any existing culverted crossing will need to include local reinstatement of channel bed. Crane will be required for lifting into position. Foundations/base and backfill will be critical for long term performance.	**Operation and Maintenance** May be susceptible to blockages May be classified as a confined space (similar to a full culvert).
Costing Design Life: 120 years Watercourse width: 2m Assumed culvert size: 3m width, 1.5m high CAPEX:£72,300 OPEX: £35,800	**Future Generations – Carbon and Adaptability** Concrete has high embodied CO_2 Tend to be oversized so some capacity for future flow increase, but limited by size.

WLC (60yrs):£111,100 Costs from Costing Tool, Maesnant example	
Other If installed as a replacement for a culvert, consider potential implications (Table 13.1, Benn at al 2019): downstream flood risk if previously acting as throttle, impact on bank and bed erosion, need for pre-removal survey, regrading channel to correct gradient / alignment. These units are available from several concrete culvert manufacturers; may be described as portal frames. Concrete bases / foundation beams may be available as precast units, or may be designed / constructed separately.	

CULVERT – OVERSIZED CONCRETE BOX

<table>
<tr><td colspan="2">
Image source: SEPA Crossing Guide *(check copyright, replace if needed!)*</td></tr>
<tr><td colspan="2">Description
Box culverts may be square or rectangular, in sizes up to 4.2m wide and 2.4m high. They may also be customised with textured bases, mammal ledges etc.

They are typically oversized, to mitigate some of the issues with traditional circular culverts.</td></tr>
<tr><td>Hydrology and Hydraulics
Should be designed for open flows conditions.</td><td>Environment and Geomorphology
Allows some continuity of river bed through the crossing.

Will still constrain bank edges, unlike the bottomless culverts and bridges.

Upstream deposition and downstream scour may occur.

Should be installed to match existing bed slope and alignment.</td></tr>
<tr><td>Constructability
Precast concrete sections are heavy and require assisted lifting.

Consider available depth of cover and requirement for structural backfill.

Accessibility – is it possible to get a crane and concrete truck (if needed for surround) to site.</td><td>Operation and Maintenance
An improved H/L reduces the risks of confined space entry.

Risk of blockage</td></tr>
<tr><td>Costing
Design Life: 120 years</td><td>Future Generations – Carbon and Adaptability</td></tr>
</table>

<table>
<tr><td>Watercourse width: 2m

Assumed culvert size: 1.5m width, 1.8m high

CAPEX:£73,200

OPEX: £35,000

WLC (60yrs):£108,200

Costs from Costing Tool, Maesnant example</td><td>Provides more adaptability than a standard culvert due to the size, but may still constrain flows in future.</td></tr>
<tr><td colspan="2">Other
Consideration will need to be given to how bed material is distributed through the culvert and whether this will require monitoring / maintenance.</td></tr>
</table>

CULVERT – HDPE, CIRCULAR

Image source: Arup, Serena Ashdown, 2022 site visit

Description

Culverts should be avoided as far as possible due to their numerous associated disadvantages (Benn et al, 2019).

May be considered for watercourses up to 2m width. Above 2m, a bridge should be considered (Forestry Commission England, 2015)

Hydrology and Hydraulics

Use of multiple pipes to achieve required cross sectional flow area should be avoided due to increased blockage risks and impact on environment and geomorphology.

If natural channel slope is too steep for culvert to be laid at same gradient, then scour protection, stilling basin or drop pool may be required (Benn et al, 2019, s12.3.6)

Environment and Geomorphology

Barrel slope should match existing watercourse bed slope where possible, to minimise impact on sediment transport and fish/invertebrate passage.

If barrel slope is > 1 : 200 then consider providing resting places (Benn et al, 2019 s12.3.6)

Upstream deposition and downstream scour may require management.

Impact on fish passage may be mitigated with baffles; impact on invertebrates and mammals may be mitigated with wildlife shelf or textured base

Other potential enhancements options to improve environmental performance (Benn et al, 2019, Table 13.5)

Constructability

Relatively easy to install as lightweight and may be cut to suit on site. Preferred to concrete for this

Operation and Maintenance

As part of the regular inspections the need for the culvert should be kept under review (Benn et al, 2019, Good Practice Principle 7.1)

reason (Forestry Commission England, 2011, s6.3.4) Backfill and surround must meet manufacturers specifications to ensure design load rating is achieved and to avoid premature deformation/collapse. Consider available depth of cover. Consider ground conditions; hard bedrock may be difficult to excavate to provide a sufficiently large trench; in this case a simply supported bridge may be an appropriate alternative. Pipes greater than 1m may require special installation techniques (Forestry Commission England, 2011, s 6.3.4) making it more expensive.	Confined space entry may be required for inspection, cleaning and maintenance. Design should ensure that if designed for person entry then Length/Height should be below 20, as this indicates a reduced asphyxiation hazard (Benn et al, 2019 s2.1.3); Downstream stilling pool / drop basin may be hazardous to operatives / walkers. Fish baffles, if used, may be a trip hazard during man entry inspections / maintenance If barrell slope is < 1 in 200 then sedimentaion may be an issue. If sediment management is a recurring issue, consider catchment sediment management options as alternative / addition (Benn et al, 2019, s13.29) General inspection assumed every 0.5 – 5 years (Benn et al, 2019, Table 7.4)
Costing Design Life: 50 years Watercourse width: 2m Assumed culvert size: 1.5m diameter CAPEX:£63,800 OPEX: £57,300 WLC (60yrs):£121,100 Costs from Costing Tool, Maesnant example	**Future Generations – Carbon and Adaptability** Unlikely to accommodate future increases in flows; will need to be replaced as climate change effects are realised. HDPE pipes are fully recyclable.
Other A screen is assumed not to be required, as they should not be needed for new or replacement culverts if designed correctly (Good Practice Principle 4.5, CIRIA 786)	

CULVERT – CONCRETE, CIRCULAR

Image source: NZ Forest Road Engineering Manual

Description

Culverts should be avoided as far as possible due to their numerous associated disadvantages (Benn et al, 2019).

May be considered for watercourses up to 2m width. Above 2m, a bridge should be considered (Forestry Commission England, 2015)

Hydrology and Hydraulics

Use of multiple pipes to achieve required cross sectional flow area should be avoided due to increased blockage risks and impact on environment and geomorphology.

If natural channel slope is too steep for culvert to be laid at same gradient, then scour protection, stilling basin or drop pool may be required (Benn et al, 2019, s12.3.6)

Environment and Geomorphology

Barrel slope should match existing watercourse bed slope where possible, to minimise impact on sediment transport and fish/invertebrate passage.

If barrel slope is > 1 : 200 then consider providing resting places (Benn et al, 2019 s12.3.6)

Upstream deposition and downstream scour may require management.

Impact on fish passage may be mitigated with baffles; impact on invertebrates and mammals may be mitigated with wildlife shelf or textured base

Other potential enhancements options to improve environmental performance (Benn et al, 2019, Table 13.5)

Constructability

Installation is difficult due to weight, and the 1m lengths require push-fit joints which may pull apart (FSC Note 25, section 6.3.4).

Operation and Maintenance

As part of the regular inspections the need for the culvert should be kept under review (Benn et al, 2019, Good Practice Principle 7.1)

<table>
<tr>
<td>Site accessibility – crane may be required.

Backfill and surround must meet manufacturers specfications to ensure design load rating is achieved and to avoid premature deformation/collapse.

Consider ground conditions; hard bedrock may be difficult to excavate to provide a sufficiently large trench; in this case a simply supported bridge may be an appropriate alternative.

Consider available depth of cover and requirement for structural backfill.

Pipes greater than 1m may require special installation techniques (FSC Note 25, s 6.3.4) making it more expensive.</td>
<td>Confined space entry may be required for inspection, cleaning and maintenance.

Design should ensure that if designed for person entry then Length/Height should be below 20, as this indicates a reduced asphyxiation hazard (Benn et al, 2019 s2.1.3);

Downstream stilling pool / drop basin may be hazardous to operatives / walkers.

Fish baffles, if used, may be a trip hazard during man entry inspections / maintenance

If barrell slope is < 1 in 200 then sedimentaion may be an issue.

If sediment management is a recurring issue, consider catchment sediment management options as alternative / addition (Benn et al, 2019, s13.29)

General inspection assumed every 0.5 – 5 years (Benn et al, 2019, Table 7.4)

Concrete pipe joints are more difficult than plastic to repair / pull back into place.</td>
</tr>
<tr>
<td>Costing
Design Life: 120 years

Watercourse width: 2m

Assumed culvert size: 1.5m diameter

CAPEX:£72,600

OPEX: £56,780

WLC (60yrs):£139,400

Costs from Costing Tool, Maesnant example</td>
<td>Future Generations – Carbon and Adaptability
High embodied CO_2

Heavy to transport

Unlikely to accommodate future increases in flows; will need to be replaced as climate change effects are realised.</td>
</tr>
<tr>
<td colspan="2">Other
A screen is assumed not to be required, as they should not be needed for new or replacement culverts if designed correctly (Benn et al, 2019, Good Practice Principle 4.5)</td>
</tr>
</table>

FORD

Image source: By John Walton, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=46740871

Description

A concrete or stone apron to line the channel bed and allow vehicle passage. May be a source of pollution and dangerous during a flood (FSC Note 25, Section 6.3.7)

These are to be avoided for new or replacement crossings in Forestry sites, although some are present as legacy structures.

Hydrology and Hydraulics

No restriction to flow

Alignment and gradient to match existing watercourse, so that they are continuous with the river bed (Forestry Commission 2016, s8.4, 8.5).

Unsuitable for flashy catchments or high flows due to risk of vehicles or pedestrians being swept downstream (Benn et al, 2019, s3.2)

Suitable for channel gradient of up to 8%, as this is the steepest allowable cross fall for a forestry road (Forestry Commission 2016, s6.11)

Environment and Geomorphology

Very high risk of downstream pollution as provides no sediment interception from road surface run-off.

May cause downstream scouring (Forestry Commission England, 2011, s6.3.7)

Constructability

Construction needs to include regrading of track on either side of the ford for 20-40m to provide

Operation and Maintenance

Unsafe to use in high flows (Benn et al, 2019, s3.2) or in flashy catchments.

suitable transition between cambers (Forestry Commission 2016, s8.4, 8.5). Removal of any existing culverted crossing will need to include reinstatement of channel bed either side of the new crossing (Benn et al, 2019)	Forestry vehicles may safely traverse a section of road with up to 8% cross-fall, provided appropriate transition lengths are provided (Forestry Commission 2016, s6.11)
Costing n/a	**Future Generations - Carbon Impacts and Adaptability** n/a
Other Should be avoided as a new build solution due to H&S and environmental risks.	

Appendix C – Ground Truthing Site Records

ARUP

Subject	Site Information Sheets
Job No/Ref	290034
Date	31 March 2022

National Culverts Study Appendix C – Site Visit Summaries

This document contains summarises of data collected during site visits to eighteen sites across Wales as part of the National Culverts Study evidence report. The data was collected in February and March 2022.

Subject	Site Information Sheets
Job No/Ref	290034
Date	31 March 2022

Region: North Wales - 1 Site name: Nant Ystrad-y-groes			
Grid ref. (Lat Long)	52.8640587 -3.5510837	**Crossing type**	Bridge
Watercourse bed material	Gravel	**Crossing material**	Concrete abutments
Upstream of crossing	Flow depth approx. 300mm No deposition upstream	**Crossing condition**	Good condition
Downstream of crossing	Flow depth ~ 300mm No erosion downstream	**Crossing dimensions**	4m long 6m breadth
Current crossing/watercourse	Low gradient	**Crossing notes**	Slight deposition under the bridge. Downstream gabions are at risk of eroding under.

Photographs

Upstream

Downstream

ARUP

Subject	Site Information Sheets
Job No/Ref	290034
Date	31 March 2022

Region: North Wales - 2 **Site name: Nant Hir**			
Grid ref. (Lat Long)	52.871025 -3.520679	**Crossing type**	2 No Pipes
Watercourse bed material	Gravel	**Crossing material**	Concrete with stone headwall
Upstream of crossing	Flow depth ~ 150mm No deposition upstream	**Crossing condition**	Undersized. 1 pipe in good condition, 2nd pipe is half collapsed upstream.
Downstream of crossing	Flow depth ~ 150mm No erosion downstream 500mm drop to bed from outlet.	**Crossing dimensions**	9m long 450mm diameter (both) 1500 mm depth to soffit
Current crossing/watercourse	Moderate flows, moderate gradient.	**Crossing notes**	On class A road at a hairpin bend.

Photographs

Upstream

Downstream

Region: North Wales - 3 Site name: Nant Rhiw-y-llyn			
Grid ref. (Lat Long)	52.875261 -3.554533	**Crossing type**	Pipes
Watercourse bed material	Bedrock & Gravel	**Crossing material**	Concrete
Upstream of crossing	Flow depth ~ 50mm No deposition upstream	**Crossing condition**	Undersized. Inlet has jagged edge. Water seeping beneath culvert outlet.
Downstream of crossing	Flow depth ~ 50mm Significant erosion downstream 2500mm drop to bed from outlet.	**Crossing dimensions**	8m long 450mm diameter 1000 mm depth to soffit
Current crossing/watercourse	Steep gradient. No fish passability.	**Crossing notes**	Culvert gradient minimal compared to fall either side of road.

Photographs

Upstream

Downstream

ARUP

Subject	Site Information Sheets
Job No/Ref	290034
Date	31 March 2022

Region: North Wales - 4 **Site name: Unnamed Watercourse**			
Grid ref. (Lat Long)	52.879571 -3.53832	**Crossing type**	Box culvert
Watercourse bed material	Bedrock	**Crossing material**	Concrete slab with bedrock abutments
Upstream of crossing	Flow depth ~ 250mm Slight deposition upstream	**Crossing condition**	Unclear.
Downstream of crossing	Flow depth ~ 200mm No recent erosion downstream 1200mm drop to bed from outlet.	**Crossing dimensions**	3.5m length 1500mm diameter (span) 250 mm depth to soffit
Current crossing/watercourse	Moderate gradient. No fish passability. Likely perched outlet rather than erosion post-installation.	**Crossing notes**	None.

Photographs

Upstream

Downstream

ARUP

Subject	Site Information Sheets
Job No/Ref	290034
Date	31 March 2022

Region: North Wales - 5 **Site name: Hirnant Bridge**			
Grid ref. (Lat Long)	52.8817889 -3.5515138	**Crossing type**	Bridge
Watercourse bed material	Bedrock & Gravel	**Crossing material**	Concrete abutments, steel beam, concrete slab
Upstream of crossing	Flow depth ~ 300mm No deposition upstream	**Crossing condition**	Good
Downstream of crossing	Flow depth ~ 300mm No erosion downstream	**Crossing dimensions**	3.7m length 15m span
Current crossing/watercourse	Low gradient, valley floor. Clear span structure.	**Crossing notes**	Slight skew to watercourse

Photographs

Upstream

Downstream

Region: North Wales - 6 **Site name: Unnamed Tributary of Hirnant**			
Grid ref. (Lat Long)	52.8833341 -3.5525929	**Crossing type**	Pipe
Watercourse bed material	Coarse Gravel with some Silt	**Crossing material**	HDPE with rock headwalls
Upstream of crossing	Flow depth ~ 100mm Significant deposition upstream – pooling ~800mm wide, 70mm deep	**Crossing condition**	Recently (past 5 years) installed - Good
Downstream of crossing	Flow depth ~ 100mm Slight erosion downstream	**Crossing dimensions**	9m length 450mm diameter 1500mm depth to soffit
Current crossing/watercourse	Moderate gradient, flowing onto valley floor.	**Crossing notes**	Deposition build up at inlet (1m from crest, 1.3m from crest to road). Blockstone headwall. Impassable to fish

Photographs

Upstream

Downstream

Region: Mid Wales - 1 **Site name: Unnamed Watercourse**			
Grid ref. (Lat Long)	52.41893 -3.731391	**Crossing type**	Pipe
Watercourse bed material	Bedrock, limited cobbles	**Crossing material**	Steel
Upstream of crossing	Flow depth ~ 50mm No deposition upstream Watercourse 1m wide	**Crossing condition**	Poor
Downstream of crossing	Flow depth ~ 100mm Slight erosion downstream	**Crossing dimensions**	9m length 1500mm diameter 2200mm depth to soffit
Current crossing/watercourse	Moderate gradient	**Crossing notes**	None

Photographs

Upstream

Downstream

ARUP

Subject	Site Information Sheets
Job No/Ref	290034
Date	31 March 2022

Region: Mid Wales - 2 **Site name: Unnamed Watercourse**			
Grid ref. (Lat Long)	52.419348 -3.730361	**Crossing type**	Pipe
Watercourse bed material	Cobble to Gravel	**Crossing material**	Steel
Upstream of crossing	Flow depth ~ 50mm Slight deposition upstream Watercourse 1.2m wide	**Crossing condition**	Poor
Downstream of crossing	Flow depth ~ 50mm No erosion downstream Watercourse 2m wide Evidence of deposition	**Crossing dimensions**	12m length 1500mm diameter 2000mm depth to soffit
Current crossing/watercourse	Moderate gradient	**Crossing notes**	None

Photographs

Upstream

Downstream

Region: Mid Wales - 3 **Site name: Unnamed Watercourse**			
Grid ref. (Lat Long)	52.425106 -3.71886	**Crossing type**	Pipe
Watercourse bed material	Boulder bed	**Crossing material**	Concrete
Upstream of crossing	Flow depth ~ 50mm Slight deposition upstream	**Crossing condition**	Fair
Downstream of crossing	Flow depth ~ 50mm Slight erosion downstream	**Crossing dimensions**	14m length 900mm diameter
Current crossing/watercourse	Moderate gradient	**Crossing notes**	None

Photographs

Upstream

Downstream

Region: Mid Wales - 4 Site name: Peithnant			
Grid ref. (Lat Long)	52.442061 -3.811386	**Crossing type**	Pipe
Watercourse bed material	Boulder to gravel	**Crossing material**	Steel
Upstream of crossing	Flow depth ~ 70mm No deposition upstream	**Crossing condition**	Poor
Downstream of crossing	Flow depth ~ 200mm Significant erosion downstream – scour pool	**Crossing dimensions**	14m length 1800mm diameter 400mm depth to soffit
Current crossing/watercourse	Moderate gradient	**Crossing notes**	None

Photographs

Upstream

Downstream

Region: Mid Wales - 5 **Site name: Maesnant**			
Grid ref. (Lat Long)	52.46565 -3.689248	**Crossing type**	Pipe
Watercourse bed material	Boulder to cobble	**Crossing material**	Steel
Upstream of crossing	Flow depth ~ 50mm Watercourse 2m wide No deposition upstream	**Crossing condition**	Poor
Downstream of crossing	Flow depth ~ 50mm Slight erosion downstream	**Crossing dimensions**	10m length 1600mm diameter 1800mm depth to soffit
Current crossing/watercourse	Moderate gradient	**Crossing notes**	Inlet headwall in poor condition (tree growing on top of it). ~1m step at outlet.

Photographs

Upstream

Downstream

Subject	Site Information Sheets
Job No/Ref	290034
Date	31 March 2022

Region: Mid Wales - 6 Site name: River Severn			
Grid ref. (Lat Long)	52.466356 -3.678284	**Crossing type**	Bridge
Watercourse bed material	Cobble to fine gravel	**Crossing material**	Concrete
Upstream of crossing	Flow depth ~ 450mm Watercourse 7m wide No deposition upstream	**Crossing condition**	Not assessed
Downstream of crossing	Flow depth ~ 450mm Watercourse 7m wide No erosion downstream	**Crossing dimensions**	3.7m length 7m span
Current crossing/watercourse	Low gradient	**Crossing notes**	Immediately upstream of vented causeway.

Photographs

Upstream

Downstream

Region: Mid Wales - 7 **Site name: River Severn**			
Grid ref. (Lat Long)	52.466334 -3.677763	**Crossing type**	Vented Causeway
Watercourse bed material	Cobble to fine gravel	**Crossing material**	Concrete
Upstream of crossing	Flow depth ~ 400mm Watercourse 8m wide Slight deposition upstream	**Crossing condition**	Not assessed
Downstream of crossing	Flow depth ~ 400mm Watercourse 8m wide Slight erosion downstream	**Crossing dimensions**	4m length – each pipe 450mm dia. 200mm depth to soffit
Current crossing/watercourse	Low gradient	**Crossing notes**	Immediately downstream of bridge. 16no pipes.

Photographs

Upstream

Downstream

Subject	Site Information Sheets
Job No/Ref	290034
Date	31 March 2022

Region: Mid Wales - 8 **Site name: Bydir**			
Grid ref. (Lat Long)	52.552747 -3.81028	**Crossing type**	Culvert
Watercourse bed material	Cobble	**Crossing material**	Steel
Upstream of crossing	Flow depth ~ 100mm Watercourse ~2m wide Slight deposition upstream	**Crossing condition**	Failed at downstream end
Downstream of crossing	Flow depth ~ 150mm Slight erosion downstream	**Crossing dimensions**	Circular 1200mm diameter 14m long 3000mm depth to soffit
Current crossing/watercourse	Moderate gradient	**Crossing notes**	Failed at downstream end – pipe displaced.

Photographs

Upstream

Downstream

Subject	Site Information Sheets
Job No/Ref	290034
Date	31 March 2022

Region: South Wales - 1 **Site name: Unnamed watercourse - Pelenna**			
Grid ref. (Lat Long)	51.677258 -3.691265	**Crossing type**	Culvert
Watercourse bed material	Cobble boulder	**Crossing material**	HDPE with blockstone headwalls
Upstream of crossing	Flow depth ~ 50mm Watercourse ~2m wide Slight deposition upstream	**Crossing condition**	Good
Downstream of crossing	Flow depth ~ 50mm Slight erosion downstream	**Crossing dimensions**	Circular 1750mm diameter 2500mm depth to soffit
Current crossing/watercourse	Moderate gradient	**Crossing notes**	None.

Photographs

Upstream

Downstream

Subject	Site Information Sheets
Job No/Ref	290034
Date	31 March 2022

Region: South Wales - 2 Site name: Unnamed watercourse - Pelenna			
Grid ref. (Lat Long)	51.677684 -3.700364	**Crossing type**	Culvert
Watercourse bed material	Cobble boulder	**Crossing material**	Concrete with blockstone headwalls
Upstream of crossing	Flow depth ~ 75mm Watercourse ~4m wide Slight deposition upstream	**Crossing condition**	Fair
Downstream of crossing	Flow depth ~ 200mm Significant erosion downstream	**Crossing dimensions**	Circular 2000mm diameter
Current crossing/watercourse	Moderate gradient	**Crossing notes**	Confluence immediately upstream – culvert skewed to primary watercourse

Photographs

Upstream

Downstream

Region: South Wales - 3 **Site name: Unnamed watercourse - Halfway**			
Grid ref. (Lat Long)	51.996104 -3.684227	**Crossing type**	Bridge
Watercourse bed material	Cobble boulder	**Crossing material**	Concrete
Upstream of crossing	Flow depth ~ 75mm Watercourse ~4m wide Slight deposition upstream	**Crossing condition**	Not assessed.
Downstream of crossing	Flow depth ~ 750mm No erosion downstream	**Crossing dimensions**	3.7m length 3.8m span
Current crossing/watercourse	Moderate gradient	**Crossing notes**	None

Photographs

Across structure

Downstream

Subject	Site Information Sheets
Job No/Ref	290034
Date	31 March 2022

Region: South Wales - 4 **Site name: Unnamed watercourse - Halfway**			
Grid ref. (Lat Long)	52.009472 -3.682725	**Crossing type**	Pipe
Watercourse bed material	Cobble boulder	**Crossing material**	Steel
Upstream of crossing	Flow depth ~ 50mm Watercourse ~3.2m wide Slight deposition upstream	**Crossing condition**	Poor – due to be replaced.
Downstream of crossing	Flow depth ~ 100mm No erosion downstream	**Crossing dimensions**	12m length 2300mm diameter
Current crossing/watercourse	Moderate gradient	**Crossing notes**	Blockstone fish easement at downstream end causing ponding through culvert – created a natural gravel base.

Photographs

Upstream

Downstream

Region: South Wales - 5 **Site name: Unnamed watercourse - Halfway**			
Grid ref. (Lat Long)	52.040949 -3.691823	**Crossing type**	Pipe
Watercourse bed material	Cobble boulder	**Crossing material**	Steel with gabion basket outlet headwall. Inlet obscured by sedimentation.
Upstream of crossing	Flow depth ~ 30mm Significant deposition – culvert inlet buried and not visible.	**Crossing condition**	Poor – inlet buried.
Downstream of crossing	Unable to access	**Crossing dimensions**	12m length Approximately 1500mm diameter
Current crossing/watercourse	Steep gradient	**Crossing notes**	Located on hairpin bend in steep sided valley. Significant embankment (~8m) above culvert.

Photographs

Upstream

Downstream

ARUP

Subject	Site Information Sheets
Job No/Ref	290034
Date	31 March 2022

Region: South Wales - 6 **Site name: Unnamed watercourse - Halfway**			
Grid ref. (Lat Long)	52.043272 -3.683069	**Crossing type**	Twin Pipe
Watercourse bed material	Cobble to gravel	**Crossing material**	Concrete.
Upstream of crossing	Flow depth ~ 50mm Significant deposition – culvert inlet partially blocked. Watercourse 2.5m wide	**Crossing condition**	Poor, due for replacement.
Downstream of crossing	Outlet headwall failed.	**Crossing dimensions**	12m length 900mm diameter twin pipes. RHS failed.
Current crossing/watercourse	Moderate gradient	**Crossing notes**	Bank slipping above outlet headwall, which appear to have failed due to tree root pressures.

Photographs

Upstream

Downstream

Appendix D – Costing Assumptions

National Resource Wales

Options costing

High level costing

ARUP

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Document Verification

Job Title	**Options costing**	Job Number	**290034-00**
Document Title	**High level costing**	File Reference	
Document Ref			

Revision	Date	Filename			
Draft P01	16/03/2022	Description			
			Prepared by: Harshiv Nayee	Checked by: Justice Sechele	Approved by:
		Description			
		Signature			
Revision	Date	Filename			
Issue P02		Description			
			Prepared by:	Checked by:	Approved by:
		Description			
		Signature			
Revision	Date	Filename			
Issue P03		Description			
			Prepared by:	Checked by:	Approved by:
		Description			
		Signature			
Revision	Date	Filename			
		Description			
			Prepared by:	Checked by:	Approved by:
		Description			
		Signature			

ARUP

Job Title:	Job No:	Base Date of Estimate:
Options costing	**290034-00**	**1Q 2022**
Cost Plan:	*Element:*	*Date:*
High level costing	**Summary**	**16/03/2022**

HDPE Culverts: Circular			**450mm dia**					**900mm dia**				
Description			**5m long**	**10m long**	**15m long**	**20m long**	**25m long**	**5m long**	**10m long**	**15m long**	**20m long**	**25m long**
A	Construction works estimate (Excl. MC Prelim)		£151,943	£153,218	£154,493	£155,767	£157,042	£954,830	£956,733	£958,635	£960,538	£962,440
B	Main Contractor's Preliminaries	25%	£37,986	£38,305	£38,623	£38,942	£39,261	£238,708	£239,183	£239,659	£240,134	£240,610
C	Traffic Management	15%	£22,791	£22,983	£23,174	£23,365	£23,556	£143,225	£143,510	£143,795	£144,081	£144,366
D	**Sub-Total**		**£212,721**	**£214,505**	**£216,290**	**£218,074**	**£219,859**	**£1,336,762**	**£1,339,426**	**£1,342,089**	**£1,344,753**	**£1,347,416**
E	Main Contractor's OHP	8%	£17,018	£17,160	£17,303	£17,446	£17,589	£106,941	£107,154	£107,367	£107,580	£107,793
F	**Total Construction Works Estimate**		**£229,738**	**£231,666**	**£233,593**	**£235,520**	**£237,448**	**£1,443,703**	**£1,446,580**	**£1,449,456**	**£1,452,333**	**£1,455,209**
G	Project/Design Team Fees/Other Development	15%	£34,461	£34,750	£35,039	£35,328	£35,617	£216,555	£216,987	£217,418	£217,850	£218,281
H	Utility Diversions	20%	£45,948	£46,333	£46,719	£47,104	£47,490	£288,741	£289,316	£289,891	£290,467	£291,042
I	Land Costs	excl.										
J	**Total Base Cost Estimate**		**£310,147**	**£312,749**	**£315,350**	**£317,952**	**£320,554**	**£1,948,999**	**£1,952,883**	**£1,956,766**	**£1,960,649**	**£1,964,533**
K	Risk / Optimism Bias	44%	£136,465	£137,609	£138,754	£139,899	£141,044	£857,560	£859,268	£860,977	£862,686	£864,394
TOTAL COST LIMIT (£)			**£446,611**	**£450,358**	**£454,105**	**£457,851**	**£461,598**	**£2,806,559**	**£2,812,151**	**£2,817,743**	**£2,823,335**	**£2,828,927**

ARUP

Job Title:	Job No:	Base Date of Estimate:
Options costing	**290034-00**	**1Q 2022**
Cost Plan:	*Element:*	*Date:*
High level costing	**Summary**	**29/03/2022**

HDPE Culverts: Circular			**2100mm dia**				
Description			**5m long**	**10m long**	**15m long**	**20m long**	**25m long**
A	Construction works estimate (Excl. MC Prelim)		£40,683	£43,940	£47,196	£50,452	£53,709
B	Main Contractor's Preliminaries	25%	£10,171	£10,985	£11,799	£12,613	£13,427
C	Traffic Management	excl.					
D	**Sub-Total**		**£50,854**	**£54,925**	**£58,995**	**£63,066**	**£67,136**
E	Main Contractor's OHP	8%	£4,068	£4,394	£4,720	£5,045	£5,371
F	**Total Construction Works Estimate**		**£54,923**	**£59,319**	**£63,715**	**£68,111**	**£72,507**
G	Project/Design Team Fees/Other Development	5%	£2,746	£2,966	£3,186	£3,406	£3,625
H	Utility Diversions	excl.					
I	Land Costs	excl.					
J	**Total Base Cost Estimate**		**£57,669**	**£62,285**	**£66,900**	**£71,516**	**£76,132**
K	Risk / Optimism Bias	44%	£25,374	£27,405	£29,436	£31,467	£33,498
TOTAL COST LIMIT (£)			**£83,043**	**£89,690**	**£96,337**	**£102,984**	**£109,630**

ARUP

Job Title:		Job No:	Base Date of Estimate:
Options costing		**290034-00**	**1Q 2022**
Cost Plan:		*Element:*	*Date:*
High level costing		**Summary**	**16/03/2022**

Concrete Culverts: Circular			**450mm dia**					**900mm dia**				
Description			**5m long**	**10m long**	**15m long**	**20m long**	**25m long**	**5m long**	**10m long**	**15m long**	**20m long**	**25m long**
A	Construction works estimate (Excl. MC Prelim)		£152,349	£154,030	£155,710	£157,390	£159,071	£955,683	£958,438	£961,192	£963,947	£966,702
B	Main Contractor's Preliminaries	25%	£38,087	£38,507	£38,928	£39,348	£39,768	£238,921	£239,609	£240,298	£240,987	£241,676
C	Traffic Management	15%	£22,852	£23,104	£23,357	£23,609	£23,861	£143,352	£143,766	£144,179	£144,592	£145,005
D	**Sub-Total**		**£213,289**	**£215,641**	**£217,994**	**£220,347**	**£222,699**	**£1,337,956**	**£1,341,813**	**£1,345,669**	**£1,349,526**	**£1,353,383**
E	Main Contractor's OHP	8%	£17,063	£17,251	£17,440	£17,628	£17,816	£107,036	£107,345	£107,654	£107,962	£108,271
F	**Total Construction Works Estimate**		**£230,352**	**£232,893**	**£235,434**	**£237,974**	**£240,515**	**£1,444,992**	**£1,449,158**	**£1,453,323**	**£1,457,488**	**£1,461,654**
G	Project/Design Team Fees/Other Development	15%	£34,553	£34,934	£35,315	£35,696	£36,077	£216,749	£217,374	£217,998	£218,623	£219,248
H	Utility Diversions	20%	£46,070	£46,579	£47,087	£47,595	£48,103	£288,998	£289,832	£290,665	£291,498	£292,331
I	Land Costs	excl.										
J	**Total Base Cost Estimate**		**£310,975**	**£314,405**	**£317,835**	**£321,265**	**£324,696**	**£1,950,739**	**£1,956,363**	**£1,961,986**	**£1,967,609**	**£1,973,232**
K	Risk / Optimism Bias	44%	£136,829	£138,338	£139,848	£141,357	£142,866	£858,325	£860,800	£863,274	£865,748	£868,222
TOTAL COST LIMIT (£)			**£447,804**	**£452,743**	**£457,683**	**£462,622**	**£467,562**	**£2,809,065**	**£2,817,162**	**£2,825,260**	**£2,833,357**	**£2,841,455**

ARUP

Job Title:	*Job No:*	*Base Date of Estimate:*
Options costing	**290034-00**	**1Q 2022**
Cost Plan:	*Element:*	*Date:*
High level costing	**Summary**	**29/03/2022**

Concrete Culverts: Circular			**2100mm dia**				
Description			**5m long**	**10m long**	**15m long**	**20m long**	**25m long**
A	Construction works estimate (Excl. MC Prelim)		£44,128	£50,829	£57,530	£64,231	£70,932
B	Main Contractor's Preliminaries	25%	£11,032	£12,707	£14,383	£16,058	£17,733
C	Traffic Management	excl.					
D	**Sub-Total**		**£55,160**	**£63,536**	**£71,913**	**£80,289**	**£88,666**
E	Main Contractor's OHP	8%	£4,413	£5,083	£5,753	£6,423	£7,093
F	**Total Construction Works Estimate**		**£59,573**	**£68,619**	**£77,666**	**£86,712**	**£95,759**
G	Project/Design Team Fees/Other Development	5%	£2,979	£3,431	£3,883	£4,336	£4,788
H	Utility Diversions	excl.					
I	Land Costs	excl.					
J	**Total Base Cost Estimate**		**£62,552**	**£72,050**	**£81,549**	**£91,048**	**£100,547**
K	Risk / Optimism Bias	44%	£27,523	£31,702	£35,882	£40,061	£44,241
TOTAL COST LIMIT (£)			**£90,074**	**£103,753**	**£117,431**	**£131,109**	**£144,787**

ARUP

Job Title: **Options costing**

Cost Plan: **High level costing**

Job No:	Base Date of Estimate:
290034-00	**1Q 2022**
Element:	*Date:*
Summary	**16/03/2022**

Rectangular concrete culvert

	Description		Small 5m long	Small 10m long	Small 15m long	Small 20m long	Small 25m long	Large 5m long	Large 10m long	Large 15m long	Large 20m long	Large 25m long
A	Construction works estimate (Excl. MC Prelim)		£24,645	£34,534	£44,423	£54,312	£64,202	£29,132	£42,357	£55,581	£68,806	£82,031
B	Main Contractor's Preliminaries	25%	£6,161	£8,633	£11,106	£13,578	£16,050	£7,283	£10,589	£13,895	£17,202	£20,508
C	Traffic Management	15%	£3,697	£5,180	£6,663	£8,147	£9,630	£4,370	£6,354	£8,337	£10,321	£12,305
D	**Sub-Total**		**£34,502**	**£48,347**	**£62,192**	**£76,037**	**£89,882**	**£40,785**	**£59,300**	**£77,814**	**£96,328**	**£114,843**
E	Main Contractor's OHP	8%	£2,760	£3,868	£4,975	£6,083	£7,191	£3,263	£4,744	£6,225	£7,706	£9,187
F	**Total Construction Works Estimate**		**£37,263**	**£52,215**	**£67,168**	**£82,120**	**£97,073**	**£44,048**	**£64,043**	**£84,039**	**£104,035**	**£124,030**
G	Project/Design Team Fees/Other Development	15%	£5,589	£7,832	£10,075	£12,318	£14,561	£6,607	£9,607	£12,606	£15,605	£18,605
H	Utility Diversions	20%	£7,453	£10,443	£13,434	£16,424	£19,415	£8,810	£12,809	£16,808	£20,807	£24,806
I	Land Costs	excl.										
J	**Total Base Cost Estimate**		**£50,305**	**£70,491**	**£90,677**	**£110,863**	**£131,049**	**£59,465**	**£86,459**	**£113,453**	**£140,447**	**£167,441**
K	Risk / Optimism Bias	44%	£22,134	£31,016	£39,898	£48,780	£57,661	£26,164	£38,042	£49,919	£61,797	£73,674
	TOTAL COST LIMIT (£)		**£72,439**	**£101,506**	**£130,574**	**£159,642**	**£188,710**	**£85,629**	**£124,501**	**£163,372**	**£202,243**	**£241,115**

ARUP

Job Title:	Job No:	Base Date of Estimate:
Options costing	**290034-00**	**1Q 2022**
Cost Plan:	*Element:*	*Date:*
High level costing	**Summary**	**16/03/2022**

Single span bridge CAPEX: weatherproofed			**5m watercourse**	**25m watercourse**
Description			**10m long 5m wide**	**50m long 5m wide**
A	Construction works estimate (Excl. MC Prelim)		£365,104	£644,497
B	Main Contractor's Preliminaries	25%	£91,276	£161,124
C	Traffic Management	15%	£54,766	£96,675
D	**Sub-Total**		**£511,146**	**£902,296**
E	Main Contractor's OHP	8%	£40,892	£72,184
F	**Total Construction Works Estimate**		**£552,038**	**£974,480**
G	Project/Design Team Fees/Other Development	15%	£82,806	£146,172
H	Utility Diversions	20%	£110,408	£194,896
I	Land Costs	excl.		
J	**Total Base Cost Estimate**		**£745,251**	**£1,315,548**
K	Risk / Optimism Bias	44%	£327,910	£578,841
TOTAL COST LIMIT (£)			**£1,073,161**	**£1,894,389**

National Resource Wales

Weathering Steel Composite Bridge - 10m long

Whole Life Cost

CAPEX	£1,073,161
OPEX	£102,000
WLC	**£1,175,000**
Design Life	**120 years**
WLC Period	**60 year**

TABLE 6.1: THE DECLINING LONG TERM DISCOUNT RATE

Period of years	0–30	31–75	76–125	126–200	201–300	301+
Discount rate	3.5%	3.0%	2.5%	2.0%	1.5%	1.0%

Info from the Green Book

	All	All	All	All	All	All	All	All			UB			
	General Inspections (2 yrly)	Principal Inspections (10 yrly)	Drainage Cleaning (5 yrly)	Parapet Replacement (40 yrly)	Waterproofing (40 yrly)	Concrete Repairs (55 yrly)	Full Resurfacing (20/40 yrly UB/OB)	Surface Dressing (5/10 yrly UB/OB)	Painted steel maintenance (29 yrly)	Weathering Steel Corrosion Rate Monitoring (6 yrly)	Wing wall joint renewal (20 yrly)	**TOTAL OPEX**	**Discount Rate**	**Present Value (PV)**
YEAR														
1												£ -	0.035	£0
2	£400											£ 400	0.035	£372
3												£ -	0.035	£0
4	£400											£ 400	0.035	£347
5			£2,000					UB				£ 2,000	0.035	£1,674
6	£400											£ 400	0.035	£323
7												£ -	0.035	£0
8	£400											£ 400	0.035	£301
9												£ -	0.035	£0
10	£400	£12,950	£2,000									£ 15,350	0.035	£10,749
11												£ -	0.035	£0
12	£400									£0		£ 400	0.035	£261
13												£ -	0.035	£0
14	£400											£ 400	0.035	£243
15			£2,000									£ 2,000	0.035	£1,172
16	£400											£ 400	0.035	£226
17												£ -	0.035	£0
18	£400									£0		£ 400	0.035	£211
19												£ -	0.035	£0
20	£400	£12,950	£2,000				UB					£ 15,350	0.035	£7,528
21												£ -	0.035	£0
22	£400											£ 400	0.035	£183
23												£ -	0.035	£0
24	£400									£0		£ 400	0.035	£170
25			£2,000									£ 2,000	0.035	£821
26	£400											£ 400	0.035	£158
27												£ -	0.035	£0
28	£400											£ 400	0.035	£148
29												£ -	0.035	£0
30	£400	£12,950	£2,000							£0		£ 15,350	0.035	£5,271
31												£ -	0.03	£0
32	£400											£ 400	0.03	£151
33												£ -	0.03	£0
34	£400											£ 400	0.03	£142
35			£2,000									£ 2,000	0.03	£689
36	£400									£0		£ 400	0.03	£134
37												£ -	0.03	£0
38	£400											£ 400	0.03	£126
39												£ -	0.03	£0
40	£400	£12,950	£2,000	£33,000	£30,000		£32,000	£10,000				£ 120,350	0.03	£35,589
41												£ -	0.03	£0
42	£400									£0		£ 400	0.03	£111
43												£ -	0.03	£0
44	£400											£ 400	0.03	£105
45			£2,000									£ 2,000	0.03	£508
46	£400											£ 400	0.03	£99
47												£ -	0.03	£0
48	£400									£0		£ 400	0.03	£93
49												£ -	0.03	£0
50	£400	£12,950	£2,000									£ 15,350	0.03	£3,347
51												£ -	0.03	£0
52	£400											£ 400	0.03	£82
53												£ -	0.03	£0
54	£400									£0		£ 400	0.03	£77
55			£2,000			£150,000						£ 152,000	0.03	£28,464
56	£400											£ 400	0.03	£73
57												£ -	0.03	£0
58	£400								£0			£ 400	0.03	£68
59												£ -	0.03	£0
60	£400	£12,950	£2,000							£0		£ 15,350	0.03	£2,468
												TOTAL		**£102,482**

National Resource Wales

Weathering Steel Composite Bridge - 50m long

Whole Life Cost

CAPEX	£1,894,389
OPEX	£102,000
WLC	**£1,996,000**
Design Life	**120 years**
WLC Period	**60 year**

TABLE 6.1: THE DECLINING LONG TERM DISCOUNT RATE

Period of years	0–30	31–75	76–125	126–200	201–300	301+
Discount rate	3.5%	3.0%	2.5%	2.0%	1.5%	1.0%

Info from the Green Book

	All	All	All	All	All	All	All	All			UB			
	General Inspections (2 yrly)	Principal Inspections (10 yrly)	Drainage Cleaning (5 yrly)	Parapet Replacement (40 yrly)	Waterproofing (40 yrly)	Concrete Repairs (55 yrly)	Full Resurfacing (20/40 yrly UB/OB)	Surface Dressing (5/10 yrly UB/OB)	Painted steel maintenance (29 yrly)	Weathering Steel Corrosion Rate Monitoring (6 yrly)	Wing wall joint renewal (20 yrly)	**TOTAL OPEX**	**Discount Rate**	**Present Value (PV)**
YEAR														
1												£ -	0.035	£0
2	£400											£ 400	0.035	£372
3												£ -	0.035	£0
4	£400											£ 400	0.035	£347
5			£2,000					UB				£ 2,000	0.035	£1,674
6	£400											£ 400	0.035	£323
7												£ -	0.035	£0
8	£400											£ 400	0.035	£301
9												£ -	0.035	£0
10	£400	£12,950	£2,000									£ 15,350	0.035	£10,749
11												£ -	0.035	£0
12	£400									£0		£ 400	0.035	£261
13												£ -	0.035	£0
14	£400											£ 400	0.035	£243
15			£2,000									£ 2,000	0.035	£1,172
16	£400											£ 400	0.035	£226
17												£ -	0.035	£0
18	£400									£0		£ 400	0.035	£211
19												£ -	0.035	£0
20	£400	£12,950	£2,000				UB					£ 15,350	0.035	£7,528
21												£ -	0.035	£0
22	£400											£ 400	0.035	£183
23												£ -	0.035	£0
24	£400									£0		£ 400	0.035	£170
25			£2,000									£ 2,000	0.035	£821
26	£400											£ 400	0.035	£158
27												£ -	0.035	£0
28	£400											£ 400	0.035	£148
29												£ -	0.035	£0
30	£400	£12,950	£2,000							£0		£ 15,350	0.035	£5,271
31												£ -	0.03	£0
32	£400											£ 400	0.03	£151
33												£ -	0.03	£0
34	£400											£ 400	0.03	£142
35			£2,000									£ 2,000	0.03	£689
36	£400									£0		£ 400	0.03	£134
37												£ -	0.03	£0
38	£400											£ 400	0.03	£126
39												£ -	0.03	£0
40	£400	£12,950	£2,000	£33,000	£30,000		£32,000	£10,000				£ 120,350	0.03	£35,589
41												£ -	0.03	£0
42	£400									£0		£ 400	0.03	£111
43												£ -	0.03	£0
44	£400											£ 400	0.03	£105
45			£2,000									£ 2,000	0.03	£508
46	£400											£ 400	0.03	£99
47												£ -	0.03	£0
48	£400									£0		£ 400	0.03	£93
49												£ -	0.03	£0
50	£400	£12,950	£2,000									£ 15,350	0.03	£3,347
51												£ -	0.03	£0
52	£400											£ 400	0.03	£82
53												£ -	0.03	£0
54	£400									£0		£ 400	0.03	£77
55			£2,000			£150,000						£ 152,000	0.03	£28,464
56	£400											£ 400	0.03	£73
57												£ -	0.03	£0
58	£400								£0			£ 400	0.03	£68
59												£ -	0.03	£0
60	£400	£12,950	£2,000							£0		£ 15,350	0.03	£2,468
												TOTAL		**£102,482**

ARUP

Job Title:	Job No:	Base Date of Estimate:
Options costing	**290034-00**	**1Q 2022**
Cost Plan:	*Element:*	*Date:*
High level costing	**Summary**	**16/03/2022**

Ford

Description			0.5m long 2m wide	25m long 2m wide	0.5m long 5m wide	25m long 5m wide
A	Construction works estimate (Excl. MC Prelim)		£132	£5,607	£280	£14,018
B	Main Contractor's Preliminaries	25%	£33	£1,402	£70	£3,505
C	Traffic Management	15%	£20	£841	£42	£2,103
D	**Sub-Total**		**£184**	**£7,850**	**£393**	**£19,626**
E	Main Contractor's OHP	8%	£15	£628	£31	£1,570
F	**Total Construction Works Estimate**		**£199**	**£8,478**	**£424**	**£21,196**
G	Project/Design Team Fees/Other Development	15%	£30	£1,272	£64	£3,179
H	Utility Diversions	20%	£40	£1,696	£85	£4,239
I	Land Costs	excl.				
J	**Total Base Cost Estimate**		**£269**	**£11,446**	**£572**	**£28,614**
K	Risk / Optimism Bias	44%	£118	£5,036	£252	£12,590
TOTAL COST LIMIT (£)			**£387**	**£16,482**	**£824**	**£41,204**

Appendix E – Worked Examples of Costing Tool

Date of Assessment 13/05/2022
Site Location Maesnant, Mid Wales
Reason for assessment Ground truthing of costing tool

Cost Estimate Summary

Option		Costs			
No.	**Crossing Type**	**Capital**	**Maintenance (Annual / Whole Life)**		**Total Whole Life**
1	Culvert - HDPE	£ 89,690	£ 1,728	£ 63,276	£ 152,966
2	Culvert - Concrete circular	£ 103,753	£ 2,588	£ 68,257	£ 172,010
3	Culvert - Concrete box (oversized)	£ 74,259	£ 1,357	£ 35,797	£ 110,055
4	Culvert - Bottomless (arch or box)	£ 74,259	£ 1,357	£ 35,797	£ 110,055
5	Bridge	£ 740,403	n/a	£ 102,482	£ 842,885

If more than one of each type is used, then these will need to be added manually to the summary table
For details of assumptions, caveats and watchits refer to the cost estimation sheet for each option.

Crossing Type: **Culvert - Circular HDPE**

Input Data (Required)	Value	Units	Notes
Required Cross-sectional area	1.000	m2	From dimensions of upstream channel
Pipe Diameter	2.1	m	0.45 up to 2.10m
Length of crossing	10.0	m	
Number of pipes required	1	no.	May adjust pipe size until only 1 is required
Total length of pipework	10	m	Up to 30m may be calculated
Target Condition Grade	3		2 = Fair, 3 = Good

Capital Cost Estimate

Capital cost estimate, based on total length of culvert at the specified size:

£89,690 in Year 0

Operation and Maintenance Cost Estimate

Operation and maintenance costs based on the cost tables and factors in Reference 3, uplifted to 2022 prices.

Based on culvert size, and Target Condition Grade, and total length of pipework

Annual maintenance cost will range from **£439** to **£4,737** per year

Check Length/Height ratio (2.1.3, Ref 2): 4.8 m/m

Weighted Factors, from Table 1.7 Reference 3

Factor	**Weight**	**Default Score**	**Comments**	**Selected Score (0,1,2)**	**Overall Score**
Difficult Access Distance to worksite, protected sites/species, invasive species, overhead power cables, internal services, confined space	2	1	If >1.2m then decrease as less likely to be confined space If L/H>20 then decrease as risk of entering is lower If site is very remote then increase	1	2
Channel Culvert located in channel with silt/debris accumulation problems	1	1	Regular culverts interrupt bed material movements and are more prone to blockage Increase if slope > 1 in 200 Increase if there are known silt/debris problems.	1	1
Culvert Properties Properties of the culvert that increase maintenance frequency (steps, bends, changes in cross-section, changes in slope/bed levels/soffit levels, irregular sections)	2	0	Increase if known drop pool or other feature requiring more frequent inspection /maintenance.	0	0
				Total (out of 10)	**3**

Factored Annual Maintenance Cost **£1,728** per year

Total Whole Life Cost

Using Discount Factors from Ref 4, Capital Cost, Assumed Asset Life (50 yrs), and O&M costs.

Total Maintenance Cost **£63,276** over 60 years

Total Whole Life Cost **£152,966** over 60 years

Crossing Type: **Culvert - Circular Concrete**

Input Data (Required)	Value	Units	Notes
Required Cross-sectional area	1.000	m2	From dimensions of upstream channel
Pipe Diameter	2.1	m	0.45 up to 2.10m
Length of crossing	10.0	m	
Number of pipes required	1	no.	May adjust pipe size until only 1 is required
Total length of pipework	10	m	Up to 30m may be calculated
Target Condition Grade	3		2 = Fair, 3 = Good

Capital Cost Estimate

Capital cost estimate, based on total length of culvert at the specified size:

£103,753 in Year 0

Operation and Maintenance Cost Estimate

Operation and maintenance costs based on the cost tables and factors in Reference 3, uplifted to 2022 prices.

Based on culvert size, and Target Condition Grade, and total length of pipework

Annual maintenance cost will range from **£439** to **£4,737** per year

Check Length/Height ratio (2.1.3, Ref 2): 4.8 m/m

Weighted Factors, from Table 1.7 Reference 3

Factor	**Weight**	**Default Score**	**Comments**	**Selected Score (0,1,2)**	**Overall Score**
Difficult Access Distance to worksite, protected sites/species, invasive species, overhead power cables, internal services, confined space	2	1	If >1.2m then decrease as less likely to be confined space If L/H>20 then decrease as risk of entering is lower If site is very remote then increase	1	2
Channel Culvert located in channel with silt/debris accumulation problems	1	1	Regular culverts interrupt bed material movements and are more prone to blockage Increase if slope > 1 in 200 Increase if there are known silt/debris problems.	1	1
Culvert Properties Properties of the culvert that increase maintenance frequency (steps, bends, changes in cross-section, changes in slope/bed levels/soffit levels, irregular sections)	2	1	Problems with concrete joints may be more difficult to repair than plastic ones. Increase if known drop pool or other feature requiring more frequent inspection /maintenance	1	2
				Total (out of 10)	**5**

Factored Annual Maintenance Cost **£2,588** per year

Total Whole Life Cost

Using Discount Factors from Ref 4, Capital Cost, Assumed Asset Life (120 yrs), and O&M costs.

Total Maintenance Cost **£68,257** over 60 years

Total Whole Life Cost **£172,010** over 60 years

Crossing Type: **Culvert - Oversized Concrete Box**

Input Data (Required)	Value	Units	Notes
Culvert Width	2.1	m	From dimensions of upstream channel
Culvert Height	1.8	m	Should be high enough to allow base to be buried
Cross-sectional area (rounded)	4	m^2	Costed range is $1m^2$ to $17m^2$
Length of crossing	10.0	m	Up to 30m may be calculated
Target Condition Grade	3		2 = Fair, 3 = Good

Capital Cost Estimate

Capital cost estimate, based on total length of culvert at the specified size:

£74,259 in Year 0

Operation and Maintenance Cost Estimate

Operation and maintenance costs based on the cost tables and factors in Reference 3, uplifted to 2022 prices.

Based on culvert size, and Target Condition Grade, and total length of pipework

Annual maintenance cost will range from **£443** to **£5,012** per year

Check Length/Height ratio (2.1.3, Ref 2): 5.6 m/m

Weighted Factors, from Table 1.7 Reference 3

Factor	**Weight**	**Default Score**	**Comments**	**Selected Score (0,1,2)**	**Overall Score**
Difficult Access Distance to worksite, protected sites/species, invasive species, overhead power cables, internal services, confined space	2	0	Oversized culverts are less likely to be confined spaces If site is very remote then increase	0	0
Channel Culvert located in channel with silt/debris accumulation problems	1	0	Oversized culverts are less disruptive to material movements and are less likely to block Depends on local knowledge of catchment.	0	0
Culvert Properties Properties of the culvert that increase maintenance frequency (steps, bends, changes in cross-section, changes in slope/bed levels/soffit levels, irregular sections)	2	1	Problems with concrete joints may be more difficult to repair than plastic ones. Increase if known drop pool or other feature requiring more frequent inspection /maintenance.	1	2
				Total (out of 10)	**2**

Factored Annual Maintenance Cost **£1,357** per year

Total Whole Life Cost

Using Discount Factors from Ref 4, Capital Cost, Assumed Asset Life (120 yrs), and O&M costs.

Total Maintenance Cost **£35,797** over 60 years

Total Whole Life Cost **£110,055** over 60 years

Crossing Type: **Culvert - Bottomless (Box or Arch)**

Input Data (Required)	Value	Units	Notes
Culvert Width	2.1	m	1.2 to 1.5 times channel width
Culvert Height	1.5	m	
Cross-sectional area (rounded)	4	m^2	Costed range is $1m^2$ to $17m^2$
Length of crossing	10.0	m	Up to 30m may be calculated
Target Condition Grade	3		2 = Fair, 3 = Good

Capital Cost Estimate

Capital cost estimate, based on total length of culvert at the specified size:

£74,259 in Year 0

Operation and Maintenance Cost Estimate

Operation and maintenance costs based on the cost tables and factors in Reference 3, uplifted to 2022 prices.

Based on culvert size, and Target Condition Grade, and total length of pipework

Annual maintenance cost will range from **£443** to **£5,012** per year

Check Length/Height ratio (2.1.3, Ref 2): 6.7 m/m

Weighted Factors, from Table 1.7 Reference 3

Factor	**Weight**	**Default Score**	**Comments**	**Selected Score (0,1,2)**	**Overall Score**
Difficult Access Distance to worksite, protected sites/species, invasive species, overhead power cables, internal services, confined space	2	0	Oversized culverts are less likely to be confined spaces If site is very remote then increase	0	0
Channel Culvert located in channel with silt/debris accumulation problems	1	0	Oversized culverts are less disruptive to material movements and are less likely to block Depends on local knowledge of catchment.	0	0
Culvert Properties Properties of the culvert that increase maintenance frequency (steps, bends, changes in cross-section, changes in slope/bed levels/soffit levels, irregular sections)	2	1	Problems with concrete joints may be more difficult to repair than plastic ones. Increase if known drop pool or other feature requiring more frequent inspection /maintenance.	1	2
				Total (out of 10)	**2**

Factored Annual Maintenance Cost **£1,357** per year

Total Whole Life Cost

Using Discount Factors from Ref 4, Capital Cost, Assumed Asset Life (120 yrs), and O&M costs.

Total Maintenance Cost **£35,797** over 60 years

Total Whole Life Cost **£110,055** over 60 years

Crossing Type: **Bridge**

Input Data (Required)	Value	Units	Notes
Watercourse Width	2	m	From dimensions of upstream channel
Bridge Span	4	m	Watercourse width x 2 (up to 20m)

Capital Cost Estimate

Capital cost estimate, based on specified bridge span:

£740,403 in Year 0

Operation and Maintenance Cost Estimate

Operation and maintenance costs based on the weathered steel structure

£102,482 factored total, over 60 years. Design life 120 years.

Total Whole Life Cost

Using Discount Factors from Ref 4, Capital Cost, Assumed Asset Life (60 yrs), and O&M costs.

Total Maintenance Cost	**£102,482**	over 60 years
Total Whole Life Cost	**£842,885**	over 60 years

Date of Assessment	13/05/2022
Site Location	Hirnant Tributary, North Wales
Reason for assessment	Ground truthing of costing tool

Cost Estimate Summary

Option		Costs			
No.	**Crossing Type**	**Capital**	**Maintenance (Annual / Whole Life)**		**Total Whole Life**
1	Culvert - HDPE	£ 34,379	£ 1,070	£ 34,993	£ 69,372
2	Culvert - Concrete circular	£ 36,857	£ 1,567	£ 41,317	£ 78,173
3	Culvert - Concrete box (oversized)	£ 69,447	£ 972	£ 25,648	£ 95,095
4	Culvert - Bottomless (arch or box)	£ 69,447	£ 972	£ 25,648	£ 95,095
5	Bridge	n/a	n/a	n/a	n/a

If more than one of each type is used, then these will need to be added manually to the summary table
For details of assumptions, caveats and watchits refer to the cost estimation sheet for each option.

Crossing Type: **Culvert - Circular HDPE**

Input Data (Required)	Value	Units	Notes
Required Cross-sectional area	0.100	m2	From dimensions of upstream channel
Pipe Diameter	0.75	m	0.45 up to 2.10m
Length of crossing	9.0	m	
Number of pipes required	1	no.	May adjust pipe size until only 1 is required
Total length of pipework	9	m	Up to 30m may be calculated
Target Condition Grade	3		2 = Fair, 3 = Good

Capital Cost Estimate

Capital cost estimate, based on total length of culvert at the specified size:

£34,379 in Year 0

Operation and Maintenance Cost Estimate

Operation and maintenance costs based on the cost tables and factors in Reference 3, uplifted to 2022 prices.

Based on culvert size, and Target Condition Grade, and total length of pipework

Annual maintenance cost will range from **£324** to **£2,809** per year

Check Length/Height ratio (2.1.3, Ref 2): 12.0 m/m

Weighted Factors, from Table 1.7 Reference 3

Factor	**Weight**	**Default Score**	**Comments**	**Selected Score (0,1,2)**	**Overall Score**
Difficult Access Distance to worksite, protected sites/species, invasive species, overhead power cables, internal services, confined space	2	1	If >1.2m then decrease as less likely to be confined space If L/H>20 then decrease as risk of entering is lower If site is very remote then increase	1	2
Channel Culvert located in channel with silt/debris accumulation problems	1	1	Regular culverts interrupt bed material movements and are more prone to blockage Increase if slope > 1 in 200 Increase if there are known silt/debris problems.	1	1
Culvert Properties Properties of the culvert that increase maintenance frequency (steps, bends, changes in cross-section, changes in slope/bed levels/soffit levels, irregular sections)	2	0	Increase if known drop pool or other feature requiring more frequent inspection /maintenance.	0	0
				Total (out of 10)	**3**

Factored Annual Maintenance Cost **£1,070** per year

Total Whole Life Cost

Using Discount Factors from Ref 4, Capital Cost, Assumed Asset Life (50 yrs), and O&M costs.

Total Maintenance Cost **£34,993** over 60 years

Total Whole Life Cost **£69,372** over 60 years

Crossing Type: **Culvert - Circular Concrete**

Input Data (Required)	Value	Units	Notes
Required Cross-sectional area	0.100	m2	From dimensions of upstream channel
Pipe Diameter	0.75	m	0.45 up to 2.10m
Length of crossing	9.0	m	
Number of pipes required	1	no.	May adjust pipe size until only 1 is required
Total length of pipework	9	m	Up to 30m may be calculated
Target Condition Grade	3		2 = Fair, 3 = Good

Capital Cost Estimate

Capital cost estimate, based on total length of culvert at the specified size:

£36,857 in Year 0

Operation and Maintenance Cost Estimate

Operation and maintenance costs based on the cost tables and factors in Reference 3, uplifted to 2022 prices.

Based on culvert size, and Target Condition Grade, and total length of pipework

Annual maintenance cost will range from **£324** to **£2,809** per year

Check Length/Height ratio (2.1.3, Ref 2): 12.0 m/m

Weighted Factors, from Table 1.7 Reference 3

Factor	**Weight**	**Default Score**	**Comments**	**Selected Score (0,1,2)**	**Overall Score**
Difficult Access Distance to worksite, protected sites/species, invasive species, overhead power cables, internal services, confined space	2	1	If >1.2m then decrease as less likely to be confined space If L/H>20 then decrease as risk of entering is lower If site is very remote then increase	1	2
Channel Culvert located in channel with silt/debris accumulation problems	1	1	Regular culverts interrupt bed material movements and are more prone to blockage Increase if slope > 1 in 200 Increase if there are known silt/debris problems.	1	1
Culvert Properties Properties of the culvert that increase maintenance frequency (steps, bends, changes in cross-section, changes in slope/bed levels/soffit levels, irregular sections)	2	1	Problems with concrete joints may be more difficult to repair than plastic ones. Increase if known drop pool or other feature requiring more frequent inspection /maintenance	1	2
				Total (out of 10)	**5**

Factored Annual Maintenance Cost **£1,567** per year

Total Whole Life Cost

Using Discount Factors from Ref 4, Capital Cost, Assumed Asset Life (120 yrs), and O&M costs.

Total Maintenance Cost **£41,317** over 60 years

Total Whole Life Cost **£78,173** over 60 years

Crossing Type: **Culvert - Oversized Concrete Box**

Input Data (Required)	Value	Units	Notes
Culvert Width	0.8	m	From dimensions of upstream channel
Culvert Height	0.8	m	Should be high enough to allow base to be buried
Cross-sectional area (rounded)	1	m^2	Costed range is $1m^2$ to $17m^2$
Length of crossing	9.0	m	Up to 30m may be calculated
Target Condition Grade	3		2 = Fair, 3 = Good

Capital Cost Estimate

Capital cost estimate, based on total length of culvert at the specified size:

£69,447 in Year 0

Operation and Maintenance Cost Estimate

Operation and maintenance costs based on the cost tables and factors in Reference 3, uplifted to 2022 prices.

Based on culvert size, and Target Condition Grade, and total length of pipework

Annual maintenance cost will range from **£362** to **£3,415** per year

Check Length/Height ratio (2.1.3, Ref 2): 12.0 m/m

Weighted Factors, from Table 1.7 Reference 3

Factor	**Weight**	**Default Score**	**Comments**	**Selected Score (0,1,2)**	**Overall Score**
Difficult Access Distance to worksite, protected sites/species, invasive species, overhead power cables, internal services, confined space	2	0	Oversized culverts are less likely to be confined spaces If site is very remote then increase	0	0
Channel Culvert located in channel with silt/debris accumulation problems	1	0	Oversized culverts are less disruptive to material movements and are less likely to block Depends on local knowledge of catchment.	0	0
Culvert Properties Properties of the culvert that increase maintenance frequency (steps, bends, changes in cross-section, changes in slope/bed levels/soffit levels, irregular sections)	2	1	Problems with concrete joints may be more difficult to repair than plastic ones. Increase if known drop pool or other feature requiring more frequent inspection /maintenance.	1	2
				Total (out of 10)	**2**

Factored Annual Maintenance Cost **£972** per year

Total Whole Life Cost

Using Discount Factors from Ref 4, Capital Cost, Assumed Asset Life (120 yrs), and O&M costs.

Total Maintenance Cost **£25,648** over 60 years

Total Whole Life Cost **£95,095** over 60 years

Crossing Type: **Culvert - Bottomless (Box or Arch)**

Input Data (Required)	Value	Units	Notes
Culvert Width	0.8	m	1.2 to 1.5 times channel width
Culvert Height	0.5	m	
Cross-sectional area (rounded)	1	m^2	Costed range is $1m^2$ to $17m^2$
Length of crossing	9.0	m	Up to 30m may be calculated
Target Condition Grade	3		2 = Fair, 3 = Good

Capital Cost Estimate

Capital cost estimate, based on total length of culvert at the specified size:

£69,447 in Year 0

Operation and Maintenance Cost Estimate

Operation and maintenance costs based on the cost tables and factors in Reference 3, uplifted to 2022 prices.

Based on culvert size, and Target Condition Grade, and total length of pipework

Annual maintenance cost will range from **£362** to **£3,415** per year

Check Length/Height ratio (2.1.3, Ref 2): 20.0 m/m

Weighted Factors, from Table 1.7 Reference 3

Factor	**Weight**	**Default Score**	**Comments**	**Selected Score (0,1,2)**	**Overall Score**
Difficult Access Distance to worksite, protected sites/species, invasive species, overhead power cables, internal services, confined space	2	0	Oversized culverts are less likely to be confined spaces If site is very remote then increase	0	0
Channel Culvert located in channel with silt/debris accumulation problems	1	0	Oversized culverts are less disruptive to material movements and are less likely to block Depends on local knowledge of catchment.	0	0
Culvert Properties Properties of the culvert that increase maintenance frequency (steps, bends, changes in cross-section, changes in slope/bed levels/soffit levels, irregular sections)	2	1	Problems with concrete joints may be more difficult to repair than plastic ones. Increase if known drop pool or other feature requiring more frequent inspection /maintenance.	1	2
				Total (out of 10)	**2**

Factored Annual Maintenance Cost **£972** per year

Total Whole Life Cost

Using Discount Factors from Ref 4, Capital Cost, Assumed Asset Life (120 yrs), and O&M costs.

Total Maintenance Cost **£25,648** over 60 years

Total Whole Life Cost **£95,095** over 60 years