7.3 Reducing the barrier effect: underpasses

Wildlife & Traffic

A European Handbook for Identifying Conflicts and Designing Solutions

7 Fauna Passages and other Technical Solutions
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Underpasses for wildlife include all types of fauna passage built as a connection under the level of the traffic. Many underpasses are built for other purposes, from culverts to allow the passage of water to underpasses designed to lead a forestry road under a motorway. With only limited adaptations these can function as fauna passages.

This chapter starts with viaducts, which are usually not built specifically for wildlife, but which can provide large and suitable passages for wildlife. For wildlife-specific underpasses a distinction is made between underpasses for large and medium-sized animals, i.e. mammals from the size of moose and red deer to roe deer (7.3.2), and underpasses for small animals, i.e. mammals from the size of foxes and badgers down to small mammals such as voles, shrews, reptiles or invertebrates (7.3.3). Separate sections give recommendations on how to adapt underpasses (7.3.4) and culverts (7.3.5) built for other purposes to make them better suited as fauna passages. Passages for fish (7.3.6) and for amphibians (7.3.7) are described in separate sections.

7.3.1 Viaducts and river crossings

General description and targets

In hilly areas a viaduct is a good technical solution to lead a road or railway from one side of a valley to the other. Valley bottoms are preferred routes for many animals, in particular when there is a watercourse present. In these cases measures for wildlife only have to ensure that previously existing movement corridors of animals are preserved or enhanced.

When a road or railway line crosses a valley or other area which lies slightly lower than the target level of the infrastructure, a low viaduct is an ecologically preferable alternative to an embankment. Viaducts are particularly valuable to preserve ecosystems. They are favourable for invertebrates and small vertebrates, which are strongly linked to particular vegetation types and hardly use underpasses without plant cover.

From an economic point of view, embankments are often preferred, especially where excess material from other parts of a development can be used. However, the preservation of the particularly valuable ecosystems and corridors found in floodplains and river valleys usually outweighs the shortterm economic benefi

In general, even low viaducts provide better links and are suitable for a wider range of species than small underpasses. The microclimate in the vicinity of the infrastructure is less affected than by an embankment.

Figure 7.35 - This viaduct in northern England leaves the river valley intact. (Photo by Highways Agency, UK)

Figure 7.36 - Instead of building an embankment, the motorway A20 in northern Germany was built on pillars. This low viaduct preserves the floodplain and marshes below. (Photo by DEGES)

Figure 7.37 - A long viaduct on a slope as opposed to an embankment preserves the habitat and allows animals to move freely, as with this example of a Swiss motorway. (Photo by H. Bekker)

Figure 7.38 - This large viaduct in Spain (road C25 near the Natural Park of Montseny) shows different zones under the viaduct: roads, natural vegetation, etc. Spatial planning has to ensure that the parts suitable for the passage of animals remain so in the long term. (Photo by C. Rosell)

Location

- Viaducts can be built everywhere where lower-lying ground has to be crossed. They are particularly recommended where a watercourse has to be crossed.
- Wetlands (marshes) should only be crossed if they cannot be avoided, but when crossing a wetland is unavoidable, viaducts are preferable to embankments.

Design requirements

- In general, the surface areas beneath the viaduct should be kept or designed to be as natural as possible.

- Vegetation cover should be encouraged where possible. Where watercourses are crossed the vegetation has to be continuous in the aquatic, amphibian and terrestrial parts of the area.
- To allow continuous plant cover, a viaduct should have a minimum height of 5 m. In wooded areas the minimum height should be 10 m.
- Viaducts can have a length of several hundred meters.
- Where rivers are crossed, the width of the viaduct should allow at least 10 m on either side of the water to allow the growth of river bank vegetation.
- Natural floodplains should be spanned completely by a viaduct.
- In the case of wide roads or motorways a separation of the two causeways by a wide gap provides extra light to the ground under the viaduct. However, narrow gaps between the lanes should be avoided, as they lead to sudden bursts of noise from passing vehicles.
- A lack of water and light may limit the growth of vegetation. Where this occurs the ground should be covered with earth and not with gravel, stones or tarmac.
- For larger mammals open unobstructed ground should be provided.
- Watercourses under the viaduct should be kept in a natural state including the riverbed and river banks. Banks should allow the free movement of otters and other riparian species.
- Under wider viaducts the zoning of land use is recommended.
- Roads under the viaduct with night traffic should be screened off from movement corridors of animals to reduce the impact of car lights.
- Rows of tree stumps and heaps of twigs or stones can provide cover for small vertebrates and act as a link between bushes or hedges on either side of the viaduct.

Maintenance

Regular checks must ensure that the area under the viaduct is not obstructed or used for wrong purposes.

Points for special attention

- The area under the viaduct must not be used for storing equipment or be blocked by agricultural machinery, parked cars, fences or other obstructions. Placing large rocks can help to avoid misuse of the passage.
- Long-term connection to the adjacent land must be ensured.

Figure 7.39 - Modified embankments under a bridge over a river.

Figure 7.40 - In this example of the RN59 in France, the function of a viaduct to preserve movement of animals is lost, since access is blocked both by a fence and by stored material. (Photo by J. Carsignol)

Figure 7.41 - In Banff National Park (Canada) two parallel structures were constructed to minimise the length of the underpass and to provide increased light below. (Photo by H. Bekker)

Figure 7.42 - Tree stumps were used as shelter for animals under the Zandheuvel viaduct on the A27 in the Netherlands. The screen which separates the road from the stump walls can be seen in the background. (Photo by H. Bekker)

Figure 7.43 - A river crossing in France which preserves the natural river bed and has dry banks for movements by terrestrial animals. (Photo by J. Carsignol)

7.3.2 Underpasses for large and medium-sized animals

General description and targets

Underpasses for large animals are primarily constructed as safe crossing points for mammals. They are a suitable solution particularly in hilly areas or where the infrastructure is built on an embankment. Target species are usually mammals such as deer, wild boar and large carnivores (lynx and wolves). Smaller mammals may readily use these underpasses as well. Underpasses are less suitable for some flying species and for species guided in their movements by light (many invertebrates). Underpasses are also less suitable for connecting habitats, because of the lack of light and water, which allows only limited growth of vegetation.

Location

- An underpass should be located along paths traditionally used by the target species. The identification of such paths is part of an environmental impact assessment (see Chapter 5).
- Where underpasses cannot be constructed directly on the animal paths, linking the passages to the paths is essential.
- Underpasses should be located at sites where local topography channels movements towards the passage.
- Areas where human activity causes disturbance should be avoided.

Dimensions

The dimension of an underpass is defined by height, width and length (Figure 7.44). The length basically corresponds to the width of the road or railway track and is therefore fixed. However, the width and to a lesser degree the height can be chosen according to the requirements of the animals. For a description of the dimensions of an underpass an index of relative openness is often calculated, defined as width x height / length. An underpass with a width of 12 m, a height of 4 m and a length of 25 m would therefore have a relative openness index of 1.9. However, relative openness should never be used as the sole measurement. An underpass with a width of 57 m, a height of 2 m and a length of 60 m would have the same openness index, but a height of 2 m would clearly be insufficient for large species like red deer or moose. Therefore minimum values have to be set for height and width. Relative openness can then be used as a value that reflects the fact that the longer an underpass is, the wider and higher it has to be.

Figure 7.44 - Terminology used for defining length (A), width (B) and height (C) of an underpass. In this handbook length, width and height are defined from the point of view of the animals using the underpass.

Experience indicates that mammals may learn to use underpasses situated in their home ranges. Inexperienced animals, in particular young animals in the dispersal phase or animals that use the underpasses only infrequently during seasonal migration may be more sensitive to dimensions. There has been little research in this area, as monitoring programmes usually focus on the use by animals resident in the vicinity of the underpass. The recommended dimensions take this uncertainty into account.

General recommendations for dimensions:

- Minimum width: 15 m
- Minimum height: 3-4 m
- Openness index (width x height / length: >1.5)

Vegetation and soil cover

- The ground inside an underpass should be natural, i.e. covered with soil.
- Due to the lack of light and water, vegetation will normally not grow inside an underpass, but should be encouraged where possible.
- The vegetation at the entrance of an underpass should be attractive to the target animals.
- Bushes around the entrance may be planted both to guide animals towards the underpass and to provide screening against light and noise disturbance from the road or railway line.

Fences

- Stretches of road or railway where underpasses for large mammals are built ought to be fenced in.
- Fences should be constructed to lead animals towards the underpass.

Points for special attention

- Specific underpasses, i.e. for the exclusive use by wildlife, are recommended as a general rule.
- The joint use of an underpass by animals and vehicles or walkers is possible where traffic is light. Points for special attention for joint-use underpasses are listed in Section 7.3.3.

- A watercourse leading through the underpass may be positive for the acceptance by wildlife.
- Hunting should be forbidden in the vicinity of an underpass in particular where important movement corridors of animals are concerned. There is little knowledge of the size of the no-hunting zone required, but a distance of 0.5 to 2 km may be appropriate depending on the local situation.
- Underpasses must not be used for storing material.
- Access to the underpass should be levelled out and free of obstacles for small animals.
- Design and materials must ensure that standing water does not accumulate in the underpass.
- Places to shelter inside the underpass encourage its use by smaller animals (e.g. logs, rocks, piles of dead wood).

Figure 7.45 - This underpass is below a highspeed railway line in France and has a good openness index, suitable for large mammals. (Photo by SETRA)

Figure 7.46 - This passage under a road which crosses a protected wetland in Spain (Natural Park Aiguamolls de l'Empordà) was constructed with a dividing wall to reduce costs: Dimensions of each section: 10 m wide (5 m each section), 2 m high, 28 m long. It is used by mammals, e.g. otter, polecat, badger and wild boar, but also by some birds from the adjacent wetland. (Photo by C. Rosell)

7.3.3 Modified and joint-use underpasses

The joint use of underpasses by humans (traffic, pedestrians) is only recommended for underpasses >10 m wide. However, improvements are also recommended for smaller existing underpasses, where the length of the underpass is no greater than 25-30 m. With joint use, the potential for disturbance is higher, which means that demanding species like ungulates may be hindered by traffic noise and light.

On the other hand, existing underpasses for human use can be improved to increase the probability that they are used by animals at a local scale. The number of underpasses and of other engineering works is enormous and adapting them could have beneficial effects at a large scale.

Design requirements

- Many of the requirements mentioned in 7.3.2 are applicable to joint-use underpasses as well.
- The adaptation of underpasses for wildlife is only to be considered if traffic density is low.
- Underpasses with lightly used local roads or forestry tracks can be improved for wildlife.
- Underpasses with streams are particularly suitable for improvement.

- Unsurfaced roads in the underpass are recommended.
- An earth-covered strip at the side of the road can improve the movement of animals.
- Shelter inside the overpass (tree stumps, heaps of branches) is recommended for wide underpasses. These elements can be placed in the strip(s) on the side of the road.
- The entrance to an underpass may have to be redesigned.

Figure 7.47 - The entrance design of an adapted underpass. Stones and/or bushes offer extra shelter for small animals.

Figure 7.48 - If bridges over streams are built wide enough to preserve the natural banks of the river, they can be used as underpasses by animals, like in this example from the Czech Republic. (Photo by J. Dufek)

Figure 7.49 - This underpass in Denmark has a diameter of 13 m with 8 m clearance, and is 87.5 m long (at the top), 115 m (at the bottom). It is regularly used by fox, badger, marten, stoat and polecat - as well as by humans and horses. For ungulates the openness index would be too small. For underpasses under motorways the layer of soil above the overpass should be thicker to reduce noise inside the underpass. (Photo by B. Wandall)

Figure 7.50 - An underpass below a railway line in the Czech Republic. It is combined with an agricultural track which is not tarmacked. Its height also makes it suitable for large mammals. (Photo by J. Dufek)

Figure 7.51 - The main purpose of this underpass at the A10 in France is water management in a wetland. The dimensions and the integrated ledge allow movement of small and medium-sized mammals. (Photo by H. Bekker)

7.3.4 Underpasses for small animals

General description and targets

Underpasses for small animals consist of pipes or rectangular tunnels with a diameter/width of usually 0.4-2 m. In contrast to culverts, which are primarily built to enable the flow of water under the road/railway line, they are built primarily as passages for small animals like small mustelids. However, there is potential to combine the two functions. Ways to make water culverts suitable as fauna passages are described in Section 7.3.5.

Where culverts are built at frequent intervals, the most appropriate solution is to improve their design to make them suitable as fauna passages. However, where there is no need to build water culverts, additional small passages should be considered to increase the general permeability of the infrastructure. This is important to allow species dispersal. Specific small passages may also be needed where animals regularly cross an infrastructure and suffer from high mortality. This is the case particularly for species such as badgers or otters that move along clearly defined tracks. In some countries, e.g. the Netherlands, tunnels for badgers have been built in many places. A lot of specific knowledge has therefore accumulated. The most important features are listed in a separate box. Another box provides information on otters, another species where specific information is available. In most cases, however, tunnels for small animals are built for a variety of species.

Figure 7.52 - A pipe in Germany (B31neu) designed as passage for small animals. The bottom is filled in with earth, but with a diameter of 1 m it is rather small. (Photo by V. Keller)

Figure 7.53 - A rectangular underpass for small animals, (1.2 m wide, 0.8 m high and 40 m long; A50 near Hernen, the Netherlands). This underpass is often used by badgers. (Photo by H. Cormont)

Location

- Tunnels for small animals are appropriate where a road or railway line across natural areas is built on an embankment. However, they can also be built where the transport infrastructure lies at surface level.
- Underpasses for small animals are particularly necessary in areas of high species diversity.
- If the target animals are species which use clearly defined paths, the underpass should be placed as closely as possible to the site where the path crosses the infrastructure. (See also box on badger tunnels).

Dimensions

- A diameter of 1.5 m for pipes, or 1-1.5 m side length for rectangular tunnels is suitable for a variety of species. A diameter of 0.3-0.5 m may be acceptable for badgers, but is not suitable for a 'multi-species' passage. Maintenance is more difficult with smaller diameter tunnels.
- The diameter of a pipe has to be large enough to allow the bottom part to be filled in to provide a movement surface.

Design

- Rectangular tunnels are preferable for amphibians, and possibly other species, because the vertical walls provide better guidance. Rectangular tunnels are preferred for new roads and railway lines.
- Pipes are often cheaper than rectangular tunnels and easier to build under existing roads.

- Pre-fabricated concrete elements are appropriate for rectangular tunnels. The connection between elements has to be smooth.
- Concrete or metal pipes can be used, but metal surfaces are avoided by some species, e.g. rabbits and some carnivores.
- The bottom surface of the pipe should be filled to provide a 'horizontal' movement surface.
- Design solutions should be adopted that will prevent the tunnel from becoming waterlogged. To allow a free-draining tunnel, the minimum gradient is 1%. The maximum gradient should be 1:2. Surfaces with a gradient should be rough.
- The bottom of the tunnel should at all times be above the level of the ground water.
- The floor of the tunnel should be as natural as possible: sand, rocks, no asphalt or tarmac.
- The tunnel entrance should be kept free from human disturbance. Artificial light should be avoided.
- Tunnel entrances should be located in recess along the fence line so that animals are guided to them.

Points for special attention

- Shelter and guidance for small animals (mice, invertebrates) could be provided with two strips of plants or other material (tree stumps or stones).
- The tunnel should be accessible for inspection. • Access for animals to the underpass has to be unobstructed.
- Tunnel entrances have to be placed outside any fences which run alongside the transport infrastructure.
- No roads or tracks that interrupt the habitat connectivity adjacent to the underpass should be built parallel to the road or railway line.

Figure 7.54 - Entrance to an underpass for small animals at the A8 in Switzerland (diameter 1 m). Stone walls, which in this mountain region are a common feature, guide animals to the passage. (Photo by A. Righetti)

Figure 7.55 - Entrance design of an underpass for small animals. Stones and/or bushes offer guidance to the entrance and extra shelter.

Maintenance

- The inspection of tunnel and fences around the entrances is necessary 2-10 times a year, depending on the situation. Water or street litter in the tunnel is often a problem.
- Proper maintenance is vital for ensuring long-term effectiveness of the underpass.
- The vegetation around the tunnel entrance needs to be well maintained.

Badger tunnels

Badgers are nocturnal animals, which live in family clans in setts which are sometimes used for hundreds of years. On their daily movements between the sett (in bushes and wooded areas) and feeding ground (pastures) they follow established trails which usually skirt woods or run along hedges. When badgers have to cross roads to reach their feeding areas, they are frequently killed. This may lead to whole clans being wiped out, resulting in a decline of the overall population, since areas isolated by transport infrastructure are not easily re-colonised. Badgers have received a lot of attention in some parts of Europe and a lot of knowledge on badger tunnels has been accumulated particularly in the Netherlands.

Location

Badgers use trails within their home range. Placing a tunnel on or as near as possible to an existing badger path is therefore essential. As a general rule, two tunnels per clan territory or a tunnel every 200-400 m in areas with high badger densities should be sufficient.

Design

- Fencing is necessary to guide badgers to a tunnel and to prevent them from getting onto the road. Special badger fences are needed at either side of the crossing point and on both sides of the road. The length depends on the situation. At some sites it is enough to have a length of 10 m at either sides of the entrances. In other cases the whole area, specially feeding grounds, along a highway should be fenced. The advice of a badger expert should be sought.
- Badger fences should have a small mesh (25.4 x 50.8 mm) and be galvanised spot-welded. The fence should be dug into the ground to prevent badgers from digging underneath it. Where this is not possible, folding out the fence and fixing it to the ground is an alternative.
- An exit is necessary for badgers that are caught on the wrong side of the fence. Badger gates may act as a disincentive, but these gates have a tendency to malfunction. An elevated section or ramp on the road side of the fence which allows the badger to jump over the fence is preferable.

Accompanying measures

- Badgers may be encouraged to use new tunnels by laying syrup or peanuts at the entrance or by laying scent trails by using dung produced by the relevant social group
- Shelter around and guidance to the tunnel entrance is very important. Shelter and guidance should be provided by planting hedges and bushes, excavating gullies and avoiding of human activity.

Figure 7.56 - A small fauna underpass in the Netherlands with a badger. This kind of tunnel may be used by small carnivores, mice and amphibians (Diameter: 0.3-0.6 m, length: 560 m). (Photo by Vereniging 'Das en Boom')

Figure 7.57 - This tunnel in the Netherlands has been filled with sand and water. The lesson learned from this example is to construct a tunnel above the ground water level and to build stable slopes around the entrances. (Photo by H. Bekker)

Otter tunnels

Otters live in streams, but often use the banks for movement, too. When they reach a road and the stream is led through culverts not adapted for animals, they often prefer to cross the road at the surface. This may lead to high traffic mortality.

A lot of the information on badger tunnels is suitable for otters as well. However, due to their 'amphibian' lifestyle some requirements differ. In several countries special tunnels for otters have been implemented. Passages for otters can also be provided by adapting ordinary culverts (see 7.3.5).

Location

- Under roads near watercourses used by otters.
- At sites where otters regularly cross roads. These sites are often marked by spraints (faeces).
- Near bridges and dams where otters cannot pass.
- At the shortest connection between two watercourses used by otters.

Points for special attention

- Fences are necessary for 25-50 m on either side of a watercourse, depending on the location
- Although otters are very good swimmers the tunnels have to be (partly) dry inside, or provided with a lateral ledge (sometimes called an 'otter walk' or 'cat-walk').
- A good connection between the passage, the ledge and the embankment is important.

Figure 7.58 - Otters don’t like to use water-filled culverts without dry parts. Small pipes placed above normal water level parallel to culverts, such as these ones crossing under a main road in southern Czechia, are used regularly. (Photo by V. Hlaváˇc)

7.3.5 Culverts modified for use by terrestrial animals

General description and targets

Culverts are designed to allow the flow of water and may contain small streams or drainage water. Some culverts carry water all year round, others only temporarily, e.g. after heavy rainfall or during the period of snow melt. When culverts are dry terrestrial animals may use them; this often requires only little adaptation. In culverts which carry water extra installations for terrestrial animals are usually needed. Modified culverts have been shown to be used by small mammals in particular, including the smaller carnivores (in addition to fish and other aquatic species). In situations where culverts are big and dry during most of the year (e.g. in Mediterranean areas) they may also be used by larger mammals

Figure 7.59 - Small terrestrial animals can use culverts, if dry walkways are provided. A: not suited for terrestrial animals, because water covers the whole bottom part of the culvert. B and C: prefabricated concrete walkways above the water level. D: a wooden board above the water level, fixed to the side wall. E: design perspectives.

Culverts connecting streams have to be designed to allow the passage of fish. Requirements for this group of species are discussed in Section 7.3.6

Adaptation of culverts and drains

- Where culverts are built to lead a stream under a road or railway line, the design has to be such that the whole ecosystem is led through, not just the water. The same principles apply as for river crossings (see Section 7.3.1).
- In corrugated steel drainage pipes the bottom should be filled with concrete or other material to provide a more suitable surface for animal movement.
- Lowering part of the concrete bottom to channel small amounts of water may provide a guiding line for small animals.
- If the culvert frequently contains water, the bottom must be adapted to keep a part of it dry at all times. This can be achieved with a lateral embankment or ledge (e.g. a wooden board) above the water level.
- Prefabricated rectangular culverts can be designed with an integrated ledge.

Figure 7.60 - Two prefabricated culverts in the Netherlands (A35, A1) with integrated ledges used by small animals. (Photos by G. Veenbaas and H. Bekker)

Figure 7.61 - A large culvert made of corrugated steel in Spain designed to allow the drainage of water after heavy rainfall. Filling the bottom with concrete allows it to be used by mammals. (Photo by C. Rosell)

Figure 7.62 - A board placed inside the culvert is regularly used by otters in this Czech culvert. (Photo by V. Hlaváˇc)

Figure 7.63 - An adapted culvert under a railway in the Netherlands. The ledge needs a good connection with the embankment, a width greater than 0.7 m and to be made of concrete, stone or wood. The design should be as open as possible. (Photo by H. Bekker)

Culvert exits

Culverts often have stepped exits to reduce the erosive force of water on embankments or slopes. They can be a trap for animals using the culvert as a passage and should be modified with structures to reduce the height of the steps. Different modifications can be made, e.g. to open the lateral walls of the stepped channel or substitute the steps with a ramp.

Note:

- The ramps should have a rough surface to provide a good grip, e.g. by combining stones and concrete.
- The recommended slope for the lateral walls of the stepped channel is 30º, with a maximum of 45º.

Figure 7.64 - Stepped exits of drains are traps for small animals (top). The two exits in Spain (centre, bottom) have been adapted so that animals passing through the drainage culverts do not get trapped. (Photos by C. Rosell)

7.3.6 Passages for fish and other aquatic organisms

General description

Fish passages include bridges, fish ladders and culverts. This chapter focuses on culverts and pipes, which are often chosen as the solution to lead smaller streams under roads and railway lines. The traditional purpose of pipes is to transport water, but in most cases new pipes can be adapted to create passages for fish and other aquatic animals at little extra cost. Adapting small existing pipes is difficult so the only effective solution will in many cases be to replace the existing pipe with a new specially designed one. Fish have to be able to move freely both upstream and downstream. Barriers to fish occur mainly for upstream movements, which are particularly important for fish migrating to their spawning grounds.

The requirements of fish are very specific. A lot of knowledge has been gathered for fish passages in general. Consulting a specialist is required in any case. In this handbook only some general points can be described.

Location

Fish passages should be constructed whenever infrastructure crosses fish habitats like rivers, streams and lakes. The optimal location for a fish passage will be where the passage has the same water flow and bottom substrate as the main water course and is accessible for the target species. The design of the passage is usually determined by the location and the chosen solution is often a compromise between the following criteria:

- Not too long.
- Not too steep.
- Not too narrow.
- No outfall drop, or at the very most only a small outfall drop (if cyprinids, juvenile salmonids and invertebrates are expected to pass, there must be no drop at all).

When new stream crossings are planned, attention should be paid to finding a location that will best meet these criteria. The location of fish passages should optimise alignment relative to the upstream and downstream channels and the length of the passage.
A culvert at an extreme skew (greater than about 30º to the channel) will affect the success of fish passing through by increasing inlet contraction and turbulence at high flows. Inchannel deposition and bank scour often occur upstream of pipes/culverts with excess skew. The engineering purpose of increasing culvert skew is usually to reduce the length of the culvert. On the other hand, an increased pipe/culvert length can increase the difficulty of providing fish passage and increase habitat loss.

Design requirements

There are five issues of fish passage design which have to be avoided:

Excess drop at passage outlet

Barriers can be caused by scour pool development at the outlet of a culvert. The scour pool may be a good habitat in itself, but it can create a barrier to upstream migration. For most species drops of 5-10 cm obstruct passage. Technically, the barrier is created by the drop from the water level inside the pipe to the level in the plunge pool. However, even if the culvert is backwatered, i.e. the bottom of the culvert lies below the downstream water level, the step between the bottom of the culvert and the bottom of the plunge pool can act as a barrier. The optimum solution is to avoid any drop at all; if this is not possible, the drop from the end of the culvert to the water should be as small as possible. Any drop should end in a deep pool. This serves two purposes, enabling the fish to get up the speed to jump the barrier, and reducing erosion in the scour pool. Building a riffle (rapid) downstream of the plunge pool can eliminate the drop by elevating the water level in the pool.

Inadequate depth within passage

It is important that there is enough water inside the passage for the fish to get through. Different species have different demands during different stages of their life cycle and in different periods of the year, e.g. adult salmon require a water depth of at least 30 cm, while trout require a depth of 10-15 cm, dependent on the size of the fish.

Figure 7.65 - Fish and other aquatic organisms should be able to pass through pipes and culverts. The water level and the design of in and outlets are crucial elements. A: ideal situation. B: the water level in the pipe is too low. C: the outlet is too high above the downstream part of the watercourse.

Figure 7.66 - This pipe in Norway was placed too high above the stream. The outfall drop creates a barrier to fish moving upstream. (Photo by B. Iuell)

Too high velocity within the passage

The flow of water running through a fish passage can be a barrier for juvenile and slow moving fish, but it is difficult to reduce velocity enough for many juvenile fish. For this reason, stream simulation (see section on design) is generally preferred. Passages must be analysed at both low and high flow conditions. As well as the depth, the current velocity can easily be modified by riffle construction. In downstream steep culverts the riffle has to be so high that the water table in the entire culvert is at the same level. This solution requires some maintenance as sediments and debris will be deposited in the pool.

Debris accumulation at passage inlet

Debris and bed material should be managed by allowing it to pass unhindered through the passage. Accumulation of debris can create barriers within the fish passage and a backwater can be created upstream that extends the effect of the pipe/culvert.

Turbulence within the passage

Turbulence caused either by the structure itself or by baffles and debris within the culvert, can be an obstacle for juvenile fish and smaller species.

Design: pipes

Small pipes are mainly used for drainage of very small streams. Often circular or elliptical, they can be made of steel, aluminium, plastic or concrete. Pipes should be wide enough to take care of high flow, but still maintain a certain water level in dry periods, by designing the pipe as a 'standing ellipse', or shaping the bottom of the pipe with a narrower channel. Pipes with corrugation will slow the water velocity.

Design: culverts

Culverts modified to create passages for terrestrial animals are described in Section 7.3.5. Here those features are described which are specific to make them suitable for fish to pass through.

In general, culverts that leave the natural bottom substrate intact should be preferred to closed culverts with a concrete bottom. Closed culverts should have a deeper channel in the bottom to keep a minimum water level through the passage even in dry seasons.

Three different design types are currently used:

Horizontal ('no-slope') design

- Fish passage can be expected if the culvert is sufficiently large and installed relatively flat, allowing the natural movement of bed load to form a stable bed inside the culvert.
- Where no flows or velocities are calculated, the fact that velocities are sufficiently low to allow a bed to deposit in the culvert is accepted as evidence that a broad range of fish species and sizes will be able to move through the culvert.
- Even when a culvert is constructed horizontally, the bed within the culvert must still match the natural slope of the channel.

A successful way of ensuring fish passage through a new culvert is to make sure that the culvert is oversized compared to flow conditions. The bottom level of the culvert should be 15-20 cm below the level of the streambed. This will result in natural sedimentation in the culvert and a natural, meandering stream, which will adapt to the actual water flow at any time.

Hydraulic design

- Culvert design must simultaneously consider the hydraulic effects of culvert size, slope, material and elevation to create depths, velocities and a hydraulic profile suitable for fish swimming abilities. It must be understood that there are many assumptions made in the design process, and that there are consequences to every assumption; adequate information allows the design to be optimised.
- The hydraulic design process is based on the maximum water velocity target fish species can cope with depending on the length of the culvert. The longer the culvert, the lower the maximum permissible velocity. Adding headwalls to each end of the culvert, narrowing the road, or steepening the fill embankments can minimise the length. Reducing the slope or making a rough surface can lower the velocity. The target velocity must not exceed the highest flow expected during the migration of target species.
- Increased velocity from a culvert can erode the downstream banks and thus promulgate the need for bank protection and extend the impacts of the culvert. It is recommended that the culvert exit velocity should not exceed the original channel velocity at the outlet location by more than 25% at the same stream flow (if the original channel velocity is very high, 25% might be too much).

- An undersized culvert creates bed instability upstream. Sites with banks or beds susceptible to erosion may require special consideration.

Stream simulation design

- Stream simulation is a design that mimics a natural stream within a culvert. Sediment transport, fish passage, flood and debris conveyance within the culvert are intended to function as they would in a natural channel. Passage for most species is assured by this option. The premise of stream simulation is that if a fish or other aquatic species can migrate through the channel of the natural stream, they should be able to migrate through the simulated channel in the culvert.
- Stream simulation design culverts are usually the preferred alternative for steep channels and long culverts.
- The primary criterion for stream simulation is the width of the culvert. To achieve stream simulation, the channel bed in the culvert should be greater than the width of the natural channel, so that natural processes can continue through the culvert and bank lines, or channel margins are created to allow passage of weak-swimming fish. • The primary factors that determine the suitability of a site for stream simulation culverts are the channel bed width and the natural slope of the stream. The channel width should be less than 10 m. For wider channels bridge crossings should be considered (see Section 7.3.1).
- Culvert slope should be minimised to decrease shear stress between the culvert bottom and the bed material. Stream gradients should correspond to the natural situation around the culverts. The culvert itself should be installed either flat or at a grade. This depends on length and bed slope. Longer passages will require some slope to maintain waterway area at the inlet.
- Where the stream simulation design will be placed at the same gradient as the channel, the composition and pattern of the adjacent channel (outside the influence of structures) should be used to determine what the bed in the culvert should look like.
- While stream simulation culverts are probably the best culvert alternative for streams with high debris potential, there is still the risk that wood will form a jam inside the passage and back up flow. Bridges are in general much better than culverts for transporting debris.
- The exact type of culvert used for stream simulation is largely a matter of preference. Bottomless structures have been successful and have the advantage that the channel can be built from above before the culvert is set in place.

Points for special attention

Species and size of fish

The design of fish passages following the principles for hydraulic design should be based on the weakest species or size of fish. What species are potentially present? When are they present? This information should be obtained at an early stage.

Upstream migration of juvenile salmonids (50-120 mm trout and salmon) is also important at many sites. These fish are small and weak and therefore require a very low passage velocity and low level of turbulence. A culvert specifically designed for 200 mm trout will in many cases also provide passage for juvenile salmonids, and hydraulic characteristics suitable for passage of adult trout during peak flows may provide passage of juveniles during lesser flows.

Accompanying measures

Baffles

Baffles are a feature added to a culvert to increase the hydraulic roughness of the culvert and reduce the velocity for culverts designed by the hydraulic system. They can also be used to keep a minimum water level in the passage through the dry seasons. The tendency of baffles to catch woody debris reduces the culvert capacity and can create a fish barrier as well as culvert blockage. For maintenance access, baffles should not be installed in culverts with less than 150 cm of headroom.

Figure 7.67 - Baffles in a fish passage in Norway during and after construction. (Photos by B. Iuell)

Debris rack

- The debris rack should be mounted high on the culvert above the ordinary high water level.
- The space below the rack should be left open for flow.
- Openings should be no smaller than 20-25 cm.
- A specific monitoring and maintenance plan should be developed for any debris rack.

Maintenance

- Barriers in fish passages are often the result of a lack of maintenance.
- The outlet drop should be checked after every flood period and at least twice a year.
- Culvert maintenance for the purpose of high flow capacity is often different from that required for fish passage. Debris blocking slots in baffles may not affect the flow capacity of a culvert but may be critical to fish passage.

Frequent inspection and maintenance of baffled culverts is necessary. Passage for many salmonid species is most critical during spates in the autumn months, when there is the greatest risk of floods and quantity of debris. Maintenance is usually impossible during high flow conditions and passage is lost for at least part of a season when passages fail or plug. Baffles and other potential barriers are out of sight and difficult to monitor in high water conditions.

7.3.7 Amphibian tunnels

General description and targets

Most amphibians need water bodies for breeding, whereas during the non-breeding period of their life cycle they may live in the water, at the water's edge or on land. Many species thus migrate seasonally between different habitat types. In spring, adults migrate from their winter habitats to their breeding sites which some of them then leave after breeding to reach their terrestrial habitat. During summer after metamorphosis juveniles leave their birth pond to migrate to terrestrial habitats. In autumn, some species migrate back to their winter habitats. Some amphibians will return to their natal pond year on year, e.g. common frog and common toad have been reported to return to their breeding site even several years after its destruction. Other species breed in temporary aquatic ponds.

The concentration of movements towards spawning sites requires specific measures to ensure safe crossing of transport infrastructure. Additional measures aiming at reducing mortality on and around transport infrastructure, such as sloping kerbs and adaptation of drains are dealt with in Section 7.4.6.

Figure 7.68 - Common toads are often killed in high numbers when they cross roads on their migration to breeding ponds. (Photo by A. Toman)

Measures have the following aims:

- To block the access onto the road to prevent road kills.
- To enable amphibians to safely cross roads while moving between breeding and non-breeding sites.

Amphibians don't necessarily need special types of crossing structures. Culverts designed for a variety of small animals can be suitable for amphibians as well. Some points are however particularly important for amphibians:

- Guiding structures leading the animals to tunnels are particularly important and have to be fitted very carefully (see below for details).
- Amphibians are sensitive to drying out, in particular young animals. Long dry tunnels are therefore unsuitable, while a combination of functions with a drainage channel or stream can provide humid parts at the edge of the stream.

In many countries specific guidelines for amphibians already exist. Not all of these take into account the latest research on the effectiveness of structures. On the other hand, they may take into account local factors. In this section those systems that can be considered a current standard are described. Not all of the details can be described. In any case, an expert familiar with the particular requirements of amphibians should be consulted.

Location

- At road sections with high numbers of road kills of amphibians or low numbers of road kills of endangered species of amphibians.

- On the seasonal migration routes of the amphibians between their terrestrial habitats and spawning grounds.

Temporary installations

General description

A barrier is built temporarily on the migration route to block access to the road and to guide the amphibians to buckets, which are dug into the ground. The animals are collected in the buckets and released on the other side of the road on a regular basis. The system is usually installed where volunteers are available to check the installations.

Figure 7.69 - A bucket to collect amphibians. It is placed close to the fence to prevent animals from passing the bucket without being caught. (Photo by P. Schlup)

Buckets

- The buckets should be at least 30-40 cm high.
- The edge of the buckets should be level with the ground.
- The recommended distance between the buckets is 10 m.
- During the peak migration period, buckets have to be checked frequently. The frequency depends on the number of animals present: at least one to three times per 24 hours, in areas with large numbers of amphibians up to every half hour.
- Water gathering in the buckets should be poured out to prevent other animals from drowning.
- In some situations a bucket with a broad rim is recommended to prevent newts, young frogs and toads or tree-frogs from climbing out.
- At locations where mice and shrews could get trapped in the buckets a thin stick may help them to get out. Fences
- Wire mesh and nets are not recommended, because animals may climb over them. Nets in particular have only limited guiding ability.
- Fences should be used to guide amphibians to the buckets.
- A bucket should be placed at the ends of the fences. Alternatively, the ends should be U-shaped to minimise the number of animals leaving the fence.
- The minimum height of the fence should be 40 cm; in presence of the agile frog the height should be at least 60 cm.
- The fence must be extended into the ground and prevent animals from climbing over, e.g. by bending the upper part.
- Stakes should not be places on the side where amphibians are moving. • Magnetising material should not be used, because this could disorient the common toad.

Temporary installations can also be suitable for the migration of juveniles from birth sites to their terrestrial habitats. Buckets are not suitable for juveniles. A successful method for juveniles is to block the animals with barriers, which are opened from time to time while the traffic on the road is stopped. In dry weather the road surface should be wetted to facilitate the juveniles' crossing.

Figure 7.70 - A strong opaque plastic foil can be put up without stabilising wire mesh, as in this example from Hungary. However, the posts should not be placed on the side the amphibians approach from to improve the guiding function of the fence. (Photo by M. Puky)

Permanent installations

These installations consist of a guiding structure and a tunnel. The former directs animals to the tunnel in which they can cross under the road. The guiding structures should not bar the way for animals coming from the road. The tunnels should be placed exactly on the migration routes. If the guiding structures are parallel to the road, the distance between the tunnels should be less than 60 m. If the guiding structures are leading in V-shape towards the tunnel, spacing of 100 m can be considered. Small mammals will also benefit from these structures. Where there are streams a culvert with permanently dry parts besides the stream is the best type of passage for amphibians.

Guiding structures

- Joining the vertical part and the movement surface with a 90° angle is important. Rounded angles don't provide adequate guiding.
- The ends of the fences should be Ushaped to stop the animals from leaving the fence.
- The height should be at least 40 cm (60 cm if the agile frog is present).
- The top end of the fence should be bent over to prevent animals from climbing over.
- A movement surface free from vegetation is recommended. Vegetation adjacent to the movement surface is recommended to provide cover.
- The guiding structures should be placed as close to the road as possible to minimise the length of the tunnel. A crash barrier avoids vehicles from getting caught in the guiding structures when veering off the road.
- Where the guiding structure joins the entrance to the tunnel corners and edges should be avoided.

Figure 7.71 - A U-shaped end of the fence forces amphibians to turn back and reduces the number of animals continuing onto the road at the end of the fence. (Photo by S. Zumbach)

Figure 7.72 - View of a rectangular tunnel in Germany with neatly fitted guiding structures. (Photo by J. Niederstrasser)

One-pipe tunnel system

One-pipe tunnel systems (also called two-way system) allow animals to move in both directions in the same tunnel. If the diameter of the tunnel is large enough (cf. Table 7.3), free movement is possible. This system has been successfully tested and is also suitable for small mammals.

Figure 7.73 - A one-pipe tunnel for amphibians.

Table 7.3 - Minimum size requirements for different construction types depending on the length of the tunnel, i.e. the width of the road.

Figure 7.74 - Amphibian tunnel with open grid in Spain. (Photo by Giasa, Spain)

Figure 7.75 - At road junctions, U-shaped tunnels (0.4 m deep and 0.3 m wide) covered with iron bars or a grid (60 x 100 mm) are necessary to join the guiding structures which would otherwise be cut by the side road where it joins the main road.

Figure 7.76 - For amphibians and other small animals, half-pipes can be used as passages under the rails where larger tunnels are not possible. (Photo by U. Bolz)

Figure 7.77 - A sheet steel buffer forces amphibians to jump into the half-pipe under the rail. (After Müller & Berthoud 1996)

Points for special attention

- Tunnels with rectangular cross-sections are recommended because of the larger bottom compared to pipes of similar clear heights. It is also easier to fix the guiding structures neatly to the tunnel.
- If round pipes are used, the bottom of the pipes should be filled with concrete to enlarge the surface area suitable for animal movement.
- Concrete is preferable to steel, plastic or other materials. • If amphibian tunnels are also used for drainage, an embankment that stays permanently dry is necessary.
- Water should drain easily from the tunnels.

Double-pipe tunnel system

One of the first systems developed for amphibians consisted of two different tunnels. Animals fall into a trap at the roadside only getting out after having crossed the road in the tunnel. While the system seems to be effective for certain target species, e.g. toads, in some cases a considerable mortality was detected for newts and juvenile frogs and toads. These systems are not suitable for small mammals. The double-pipe or one-way tunnel system is therefore no longer recommended.

Maintenance

- Many passages do not work due to lack of maintenance. Regular maintenance at the critical points is necessary (fences, obstruction of the tunnel by water, soil or litter, faults in guidance structures).
- A maintenance control pit is necessary for tunnel inspection and to enable the removal of any obstacles.