What is wrong with wildlife fencing and what should we do? A review of fencing guidance for reptiles and amphibians.

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Abstract

Reptiles and amphibians have been recognised as being some of the world's most at-risk species from the impacts of human development. In particular, roads have been identified as having a significant impact on herpetofauna due to roadkill and fragmentation. Despite road mortality affecting herpetofauna greater than other species, the topic of wildlife vehicle collision (WVC) studies, which influence mitigation, is biased towards larger species due to higher human costs from WVCs. In addition to mitigation research, government funding for species protection and recovery has also been found to be highly disproportionate among species groups. This bias has resulted in a lack of research on effectiveness and clear and consistent guidance on mitigation for smaller animals such as reptiles and amphibians. Wildlife fencing is one method of mitigation that has proven to help reduce WVCs and can help maintain connectivity when combined with wildlife crossings. There have been more studies in recent years that have focused on herpetofauna mitigation and these have helped inform best practice guidance. In this article we review current freely available best practice guidance for fencing designed to manage conflict of herpetofauna around transport networks from across the world. We have summarised findings that compare and highlight key factors that include the following: Material type, Fence height, and Fence features. Combining factors from existing guidance, recent research and our practical observations on mitigation projects, we provide a summary of recommendations along with diagrams and descriptions that reflect the analysed guidance. We also identify and highlight any areas that may need further research and investigation to help build upon the status quo and enable us to better utilise fencing as a conflict management tool for herpetofauna.

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This bias has resulted in a lack of research on effectiveness and clear and consistent guidance on mitigation for smaller animals such as reptiles and amphibians. Wildlife fencing is one method of mitigation that has proven to help reduce WVCs and can help maintain connectivity when combined with wildlife crossings. There have been more studies in recent years that have focused on herpetofauna mitigation and these have helped inform best practice guidance.

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Key words: Wildlife fencing, reptiles, amphibians, wildlife vehicle collisions (WVCs), road mitigation

Introduction

Reptiles and amphibians have been recognised as being some of the world's most at-risk species from the impacts of human development. In fact, 15% of reptilian species have been identified as threatened (classified as IUCN categories Vulnerable, Endangered or Critically Endangered), although due to lack of available data the true percentage is likely closer to 19% (Böhm et al, 2013). Amphibians are experiencing the worst global declines of all vertebrates with 32.5% identified as threatened, while 43.2% are experiencing population decreases (Stuart et al, 2004). Human-induced habitat loss and associated fragmentation of habitats has been identified as one of the primary causes of the global decline in populations of herpetofauna (Teixido et al, 2021).

One form of development causing both direct habitat loss and significant fragmentation due to their linear nature are roads. With an estimated 3.0 to 4.7 million km additional road length planned to be built across the world by 2050 (Meijer, J. *et al.* , 2018), herpetofauna are at an increased risk due to habitat loss, fragmentation and road mortality. Among studies that have recorded road mortality for all vertebrate groups, amphibians and reptiles often have the highest rates of mortality (Andrews et al., 2015; Baxter-Gilbert et al., 2015). In a review of thirteen studies, herpetofauna accounted for over 90% of roadkill in four studies and over 50% in eight studies (Colino-Rabanal and Lizana, 2012), and they have been recognised as being particularly vulnerable to the impacts of roads (Colino-Rabanal and Lizana., 2012; Paterson et al., 2019).

Roads can have further impacts on these species through changes to animal behavior, physical or chemical alteration of their natural environment and by non-native species dispersal (Van der Ree, et al., 2011; Colino-Rabanal and Lizana, 2012). Both reptiles and amphibians have low rates of movement compared to other species groups and each group can be specifically impacted by roads due to their ecology (Andrews and Whitefield Gibbons, 2005; Beaudry et al., 2008; Colino-Rabanal and Lizana, 2012). Reptiles also rely on thermoregulation and the surface heat from roads can attract individuals. Many amphibian species have complex life cycles with seasonal migrations that can be directly impacted by road mortality (Bouchard et al., 2009; Colino-Rabanal and Lizana, 2012). Amphibians are further vulnerable from roads due to their permeable skin which makes them even more sensitive to the secondary effects of road pollution (Colino-Rabanal and Lizana, 2012; Brady et al., 2022; Szeligowski et al., 2022).

Despite these significant impacts, public awareness and implementation of mitigation is lacking. Public perception of roadkill generally relates to size, and small species such as reptiles and amphibians tend to be given less attention (Colino-Rabanal and Lizana, 2012). Further, the topic of wildlife vehicle collision (WVC) studies, which influence mitigation, is biased towards certain groups of species. In a review, Taylor and Goldingay (2010) found 53% of WVC studies on wildlife studies focused on mammals, compared to only 9% on amphibians and 8% on reptiles. The focus on mammals is likely due to the higher human costs, as WVCs with large mammals result in high medical and vehicle-repair costs (Taylor and Goldingay, 2010). Cost-benefit analysis often forms part of reports for transportation authorities in relation to mitigation for WVCs.

Road mitigation strategies are most often implemented by transportation agencies rather than wildlife agencies, which results in a focus on motorist safety concerns over conservation (Lee et al., 2023). Where road mitigation focuses on species conservation instead, these are most often found along roads in protected areas

rather than the wider road network (Lee et al., 2023). Based on their analysis, Lee et al. (2023) found that these contrasting perspectives result in a misalignment in priorities for certain species. Government funding for species protection and recovery has also been found to be highly disproportionate among species groups (Gerber,2016).

One key tool used to reduce WVC's is wildlife fencing and it has been shown to reduce WVC by up to 80% (Clevenger, et al 2001) and can help to retain habitat connectivity when used in conjunction with wildlife crossings. However, there is also a significant lack of guidance across the world outlining the best approach to take when designing, implementing and maintaining mitigation fencing for reptiles and amphibians. Few biologists, planners and engineers have access to best practice guidance and those that don't, have the freedom to implement unproven solutions. This raises the concern that inappropriate measures may be being used to manage conflict for these vulnerable species. Guidance is also vague and doesn't often provide more details than some recommended materials and measurements to install above and below ground.

While road and transportation mitigation are the primary conflicts and applications for herpetofauna fencing, it has been used for a number of other reasons including: species protection, construction site exclusion, conservation monitoring, pest control, and for the safety of people. Fencing is often made out of a variety of materials including metal, thin plastics such as polyethylene and historically, tarpaper (Dodd, 1991). Recent studies have compared how animals interact with different fence materials and how material opacity impacts the speed in which animals travel along fences (Brehme et al., 2021; Milburn-Rodríguez et al., 2016). Brehme et al., (2021) found that herpetofauna tried to traverse transparent and semi-transparent fencing materials during summer trails in 2018 and 2019. This also caused them to move more slowly along the barrier and highlights the importance of how fence material impacts animal behavior.

In this article we will review current freely available best practice guidance for fencing designed to manage conflict of herpetofauna around transport networks from across the world. Upon reviewing this guidance we will compare and highlight key factors that include the following: o Material type

- o Fence height
- o Fence features

We will then provide a summary of recommendations along with diagrams and descriptions that reflect the analyzed guidance from all the documents we review. We will also identify and highlight any areas that may need further research and investigation to help build upon the status quo and enable us to better utilize fencing as a conflict management tool for herpetofauna.

Methods

This paper focuses on two aspects of a review on best practice for reptile and amphibian fencing. Firstly, a review of available published guidance was conducted. The search methods involved an online search for published guidance on road mitigation that was either specifically for reptiles and/or amphibians or included sections on reptiles and/or amphibians and provided fencing recommendations. The search was undertaken in English and included all countries. It is possible that some non-English countries may have guidance that has not been included in the review.

A total of twelve published reports were identified, which were included in the review. From the reports, the following information was extrapolated for comparison: general recommendations on reptile or amphibian fencing, materials and/or fencing gauge, fencing heights per species group (categorized as lizards, snakes, tortoises, turtles (freshwater), salamanders and newts, toads, and frogs) and finally additional recommendations such as inclusion of anti-dig installation or a top-lip. The data extrapolated from these reports was combined to find mean fencing heights by species group as well as any consistent recommendations.

Further, in creating our recommendations for fencing, in addition to the summaries of guidance documents above, we included recent relevant research that has been carried out that may not have been included in the fencing guidelines as well as our own professional observations. Through Animex International, we supply,

install and consult on fencing for herpetofauna globally and have noted observations that have been found in monitoring on existing projects. Although not all projects are monitored for research purposes, observations on multiple projects can help inform best practice and help identify future research needs.

Results

Twelve publications were found in an online search of freely accessible best practice guidelines (*Table 1*). These guidelines are from a range of countries, with the exception of "Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions" which covers Europe as a whole. The earliest guideline was published in 2001 and the latest in 2022, with more frequent publications become available from 2015 onwards. There is also a mixture of how these guidelines recommend fencing for reptiles and amphibians (*Table 2*). Two guidelines (IENE and the Wildlife Institute of India) provide recommendations for reptiles and amphibians as a whole, without subsequently breaking them down into genus. Two guidelines provide recommendations for reptiles and amphibians as a whole and then provide extra information for frogs (Vic Roads) and for frogs and freshwater turtles (Queensland Department of Transport and Main Roads). The Western Transport Institute, Montana State University provides the most comprehensive list of recommendations by detailing specifications for each genus rather than reptiles and amphibians as a whole.

Table 1. A summary of the general recommendations, materials, fence depth below ground and anti-dig and anti-cimb lip provided in the twelve best practice guidelines in this review.

Organisation	**Guideline**
English Nature (now Natural England)	Great crested newt mitigation guidelines
USFWS	Desert Tortoise Fencing Specifications
Amphibian and Reptile Conservation	Common Toads and Roads: Guidance for planner and highwa
Queensland Department of Transport and Main Roads	Fauna Sensitive Road Design Manual Volume 2: Preferred Pr
Vic Roads	Fauna sensitive road design guidelines
Western Transport Institute, Montana State University	Construction guidelines for wildlife fencing and associated esc
Ministry of Agriculture, Food and the Environment (Spain)	Technical prescriptions for wildlife crossing and fence design (
Ontario Ministry of Natural Resources and Forestry.	Best Management Practices for Mitigating the Effects of Roa
Wildlife Institute of India	Eco-friendly measures to mitigate impacts of linear infrastruc
Ministry of Environment and Climate Change Strategy	Guidelines for Amphibian and Reptile Conservation During F
Caltrans	Measures to Reduce Road Impacts on Amphibians and Repti
IENE	Wildlife and Traffic: A European Handbook for Identifying C
Arizona Fish & Game Department	Wildlife Compatible Fencing

Table 2. A summary of the recommended fencing heights from twelve best practice guidelines. These guidelines are a combination of recommendations that group reptiles and amphibians into one or break down fencing heights into different genus'.

Organisation	**Guideline**
English Nature (now Natural England)	Great crested newt mitigation guidelines
USFWS	Desert Tortoise Fencing Specifications
Amphibian and Reptile Conservation	Common Toads and Roads: Guidance for planner and highways e
Queensland Department of Transport and Main Roads	Fauna Sensitive Road Design Manual Volume 2: Preferred Practic
Vic Roads	Fauna sensitive road design guidelines
Western Transport Institute, Montana State University	Construction guidelines for wildlife fencing and associated escape
Ministry of Agriculture, Food and the Environment	Technical prescriptions for wildlife crossing and fence design (seco
Ontario Ministry of Natural Resources and Forestry.	Best Management Practices for Mitigating the Effects of Roads or
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Of the 12 best practice guidelines summarised in this review, a third of them (four) are published in the USA (*Table 3*). These guidelines are published by a mixture of government departments (environment or transport focused), as well as conservation or non-government organisations. Canada, Europe, Australia and the UK have two guidelines each that provide specific guidance for either herpetofauna in general or a specific genus. Two of these guidelines provide recommendations that target a specific species (Desert Tortoise (USFWS) and the Great Crested Newt (ARC)) (*Table 3*). The first best practice guidelines that begin to specifically address fencing requirements were published in 2001 by English Nature (now Natural England) and focused on the Great Crested Newt, with the remaining publications spanning until most recently in 2022 (IENE) (*Table 3*).

Table 3. Summary of best practice guidelines grouped by country

Location	Organisation	Guidelines
USA	Caltrans	Measures to Reduce Road Impacts on Amphibian
	Western Transport Institute, Montana State University	Construction guidelines for wildlife fencing and as
	USFWS	Desert Tortoise Fencing Specifications
	Arizona Fish & Game Department	Wildlife Compatible Fencing
Canada	Ministry of Environment and Climate Change Strategy	Guidelines for Amphibian and Reptile Conservati
	Ontario Ministry of Natural Resources and Forestry.	Best Management Practices for Mitigating the Ef
Europe	IENE	Wildlife and Traffic: A European Handbook for I
	Ministry of Agriculture, Food and the Environment (Spain)	Technical prescriptions for wildlife crossing and fe
Australia	Queensland Department of Transport and Main Roads	Fauna Sensitive Road Design Manual Volume 2:
	Vic Roads	Fauna sensitive road design guidelines
UK	Amphibian and Reptile Conservation	Common Toads and Roads: Guidance for planner
	English Nature (now Natural England)	Great crested newt mitigation guidelines
India	Wildlife Institute of India	Eco-friendly measures to mitigate impacts of linea

The most recommended materials are HDPE plastic and the specific mention of using an "opaque material" as a method of fencing (*Figure 1*). Technically, insertion rubber and concrete walls can be considered as an opaque material and therefore, that would make this the most commonly recommended material and method of fencing in these guidelines. The use of transparent materials and thinner plastic were the most commonly recommended options pre-2015, with only TMR suggesting the use of insertion rubber as a fencing material (*Table 4*).

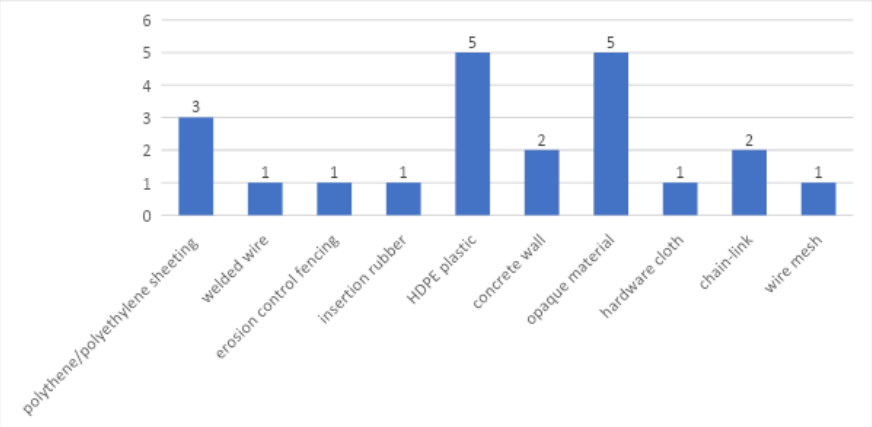

Figure 1. Counts of the most recommended materials to use for reptile and amphibian fencing across the twelve best practice guidelines

From 2015 onwards guidelines began suggesting opaque fencing (*Table 4*), with the exception of Caltrans recommending the use of woven polypropylene or polyethylene sheets for temporary projects, as well as the Western Institute for Transportation suggesting adaptations to chain-link and the Spanish Ministry of Agriculture, Food and the Environment suggesting standard mesh (2cm x 2cm) (*Table 4*). In the reviewed guidelines, conservation and non-governmental organisations often recommend opaque panels, whereas government departments often recommend thin plastic or mesh-based materials as well (*Table 4*).

Table 4. A summary of the recommended materials to use for reptile and amphibian fencing across the 22 year period that these best practice guidelines have been published in

Year	Organisation	Materials
2001	English Nature (now Natural England)	polythene sheeting & woven polypropylene
2005	USFWS	welded wire
2009	Amphibian and Reptile Conservation	smooth panels
2010	Queensland Department of Transport and Main Roads	woven vinyl erosion control fencing & insertion rubber
2012	Vic Roads	recycled polyethylene sheeting; galvanised roof purlin; fine wire mesh
2015	Western Transport Institute, Montana State University	HDPE plastic; barrier wall; chain-link
2016	Ministry of Agriculture, Food and the Environment (Spain); Ontario Ministry of Natural Resources and Forestry (Canada); Wildlife Institute of India	hardware cloth (Spain, Canada); chain-link (Spain, Canada); cement concrete wall (India);
2020	BC	opaque fencing materials
2021	Caltrans	thick plastic fencing materials; solid perforated visual barrier; woven polypropylene or polyethylene sheets

Year	Organisation	Materials
2022	IENE	opaque smooth materials (metal, concrete, HDPE)

Not all publications provide a fencing height for each genus however, where heights are provided for a specific one, there is commonly a large range in the suggested fencing height (*Table 5*). The range for the above-ground height for fencing for each genus is often more than 20cm. Only three publications provided specific recommendations for lizards but the difference in height between these is 77cm (33cm – 110cm). Snakes also have a larger range of 62cm across five publications (*Table 5*). Salamanders and newts have the lowest range of a 20cm difference in recommended height across the five guidelines that have specifications for this genus (*Table 5*).

These publications span 22 years and across this timeframe the minimum height suggested for each genus has remained similar between the relevant guidelines with the exception of snakes (*Figure 2*). Between 2015 and 2021 the recommended fence height to target snakes rose from 110cm to 200cm in 2016 and then back down again. This trend can also be seen with the fencing recommendations for reptiles and amphibians who have been grouped together in four publications, rising from 40cm in 2012 to 80cm in 2016 before reducing back to 40cm in 2022 (*Figure 2)* .

Table 5. The minimum and maximum fencing heights suggested across published guidelines that provide recommendations for each genus and the difference between these heights (cm).

	Reptiles & Amphibians	Lizards	Snakes	Tortoises	Turtles (freshwater)	Salamanders & Newts	Toads	Frogs
Range (cm)	40-80	33-110	60-122	15-60	30-91	30-50	40-64	40-97
Difference (cm)	40	77	62	45	61	20	24	57

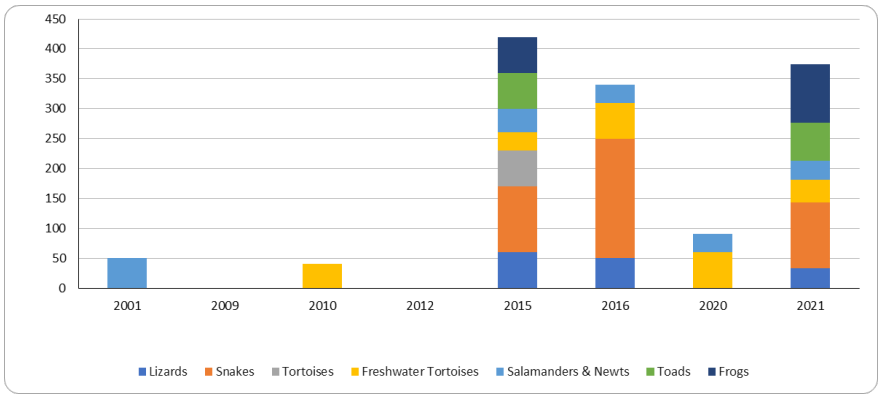

Figure 2. Above ground height recommendations from all 12 guidelines by different species by year.

All but two guides provide a recommendation on the length of fence that should be buried below ground to prevent wildlife passing or digging beneath the fence (*Figure 3*). This measurement has varied across the years, from 6cm to 30cm. There is no obvious increase or decrease in this length across the years however the most recent published guidelines by IENE recommend fencing be buried 20cm (*Figure 3*).

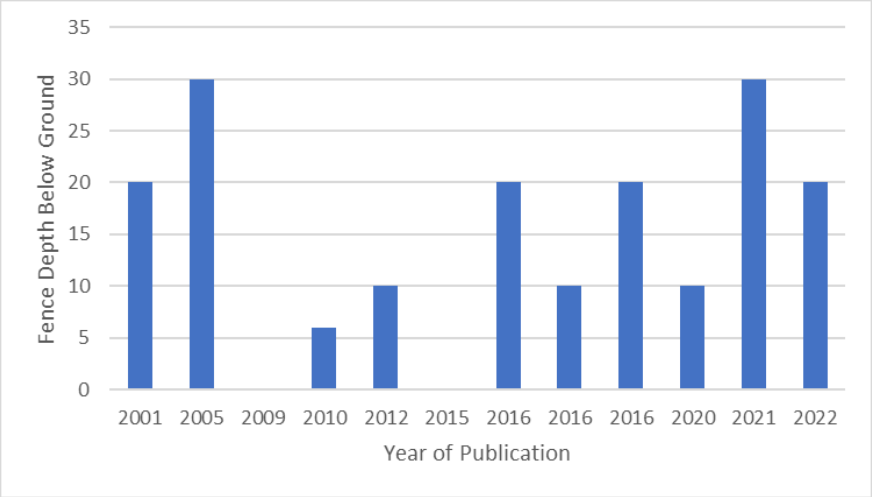

Figure 3. Below ground installation depth recommendation from all 12 guidelines shown across years.

Discussion

It is our understanding that the first fencing used for reptiles and amphibians was for drift fence as a common sampling technique for herpetofauna studies. We believe it is from this application where other fencing guidance and best practices have been developed. As guidelines have developed it shows that recommendations have moved away from highly transparent, mesh type materials towards more opaque solid barriers.

It is our understanding that the use of readily available cheap construction materials such as silt fence, shade, and hardware cloth has been continually recommended despite the absence of any research to test its suitability, effectiveness or assess animal behaviours when they encounter such materials. Only in the most recent guidance has animal behaviour been studied and highly opaque / solid fencing been highlighted as a more suitable barrier type. Transparent mesh products have ceased to be acknowledged as appropriate.

One factor that is raised for consideration between solid opaque barriers is when drainage is a concern. Recommendations suggest using pre-perforated solid products is a solution along with and should be considered before any mesh product. If mesh has to be used, then this should be used sparingly and with holes no larger than 3mm to minimize the risk of animals becoming entangled.

There are also suggestions for the use of different material types depending on the duration of the project and application. Lighter grade products may be more suited for short term projects whereas heavier grade products should be utilized for long term applications.

Shelters have also been identified as a useful addition to a fence line to help provide animals refuge as they move along. The details of these are yet to be determined and require further research.

We identified some significant difference in fence height above ground ranges for a few species' groups. Due to this we have split our recommendations into small & large species variations for some species. Further research needs to be conducted to improve the understanding of fencing methods for unique species and localized biological knowledge should always be considered.

Despite the variations and considerations that need to be made for species variability (as not all species on all continents are the same and will respond to fences the same) we believe these recommendations will be suitable for most herpetofauna species currently and commonly managed with fencing as a conflict management tool.

Recommendations also take into consideration the presence of other species that may not be the "target" for the project. If a project is focused on controlling the movement of turtles, the chances are there may

be other herpetofauna and other wildlife in the same habitat that might benefit from the installation of a fence or barrier. As it is known these species commonly share the same habitat types, we feel it would be advantageous to include the anti-climb lip on all barriers. When determining recommended heights, we have also taken the presence of other species into consideration. A slight increase in height will only positively impact the fences over all functionality without negatively impacting the potential fence cost, installation method of long-term maintenance. We have also standardized the depth of the fencing to be installed below ground along with the inclusion of an anti-dig lip for the same reasons.

Some guides also suggest an anti-climb top lip to be folded over, but this is also inconsistent and may only be recommended for certain species. The exact shape of this lip also varies and although more research needs to be done on this, we have based our recommendations on the most effective shape for most species known to date.

Some guides suggest folding an anti-dig lip in the ground, but this is inconsistent across all of them.

We recommend that in the absence of best practice guidance and for ease of wider implementation that anti-dig and anti-climb lips be applied to all fences

The fence profile or shape is represented as a bold black line comparable to the shape of the letter "C". Fences can be installed on their own as a "free-standing" barrier or attached to existing fences. Irrespective of the installation method the measurements, features and considerations should remain the same. The illustrations do not induce details of any supportive posts or fixings that may be required to ensure the fence is complete. The measurements shown are minimum requirements appropriate to the specific fence barrier component for the listed herpetofauna only. These recommendations are just recommendations and should be considered as such.

Recommendation 1 : 50cm (20in)

Species suitability: Newts, Salamanders, Toads, Tortoises, Frogs (small), Turtles (small), Lizards (small)

Material(s): Solid or highly opaque barrier - eg. HDPE, metal or concrete

Height above ground: 50cm (20in)

Anti-climb lip: 10cm (4in) long with 5cm (2in) overhang

Depth below ground: 20cm (8in)

Anti-burrow lip : 10cm (4in)

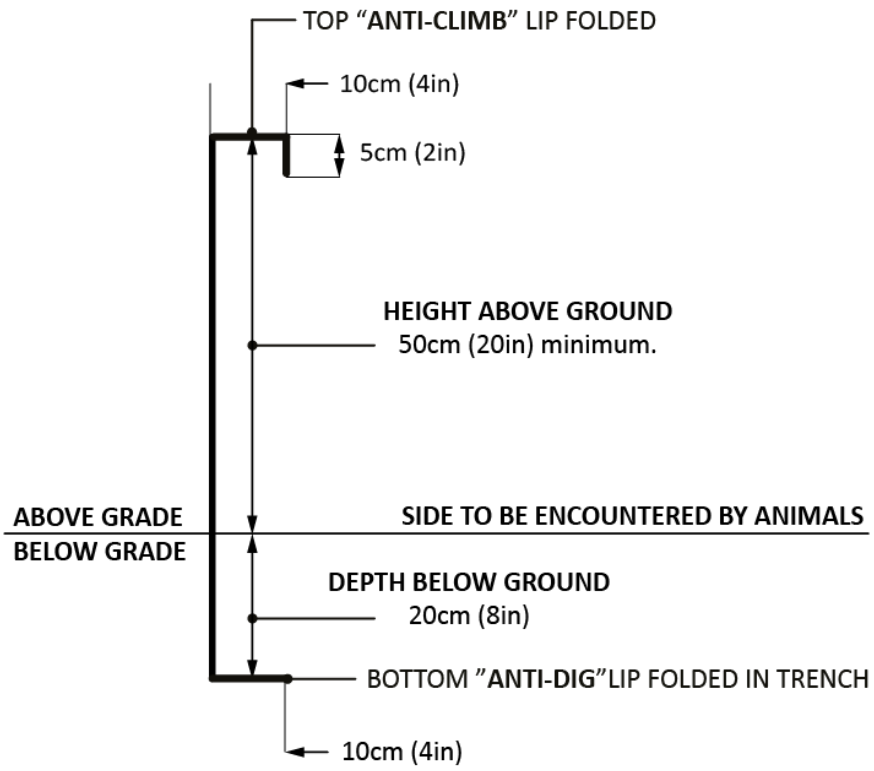

Figure 4. Illustrative fencing profile and measurements for minimum above ground height - 50cm (20in)

Recommendation #2 - 70cm

Species suitability: Snakes (small)

Material(s): Solid or highly opaque barrier - eg. HDPE, metal or concrete

Height above ground: 70cm (28in)

Anti-climb lip: 10cm (4in) long with 5cm (2in) overhang

Depth below ground: 20cm (8in)

Anti-burrow lip : 10cm (4in)

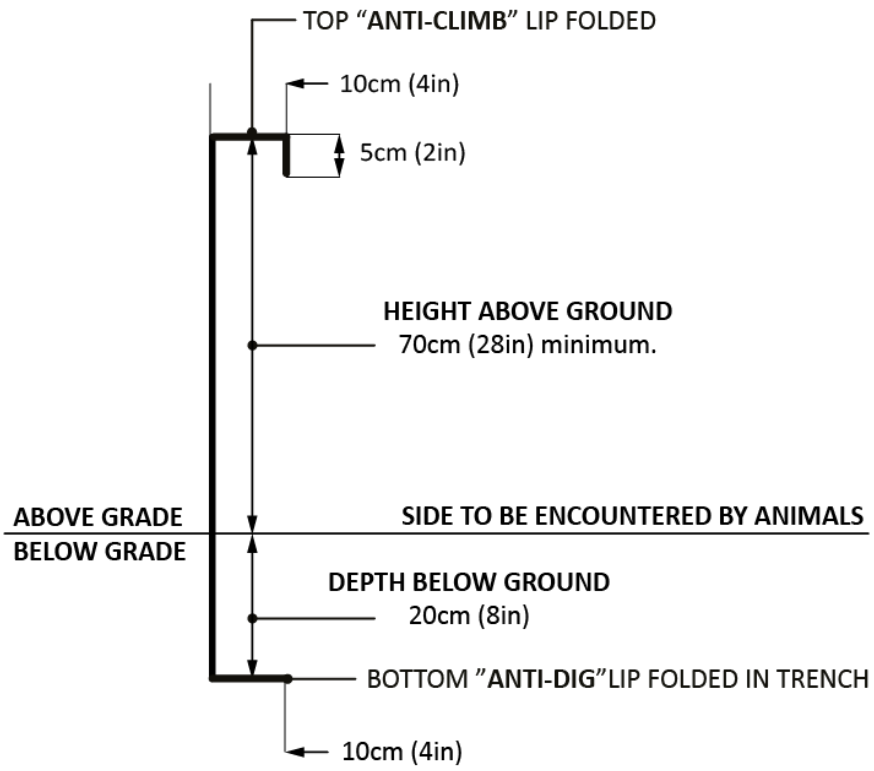

Figure 5. Illustrative fencing profile and measurements for minimum above ground height - 50cm (20in)

Recommendation #3 - 90cm

Species suitability: Lizards, Frogs (large), Snakes (large)

Material(s): Solid or highly opaque barrier - eg. HDPE, metal or concrete

Height above ground: 90cm (36in)

Anti-climb lip: 10cm (4in) long with 5cm (4in) overhang

Depth below ground: 20cm (8in)

Anti-burrow lip : 10cm (4in)

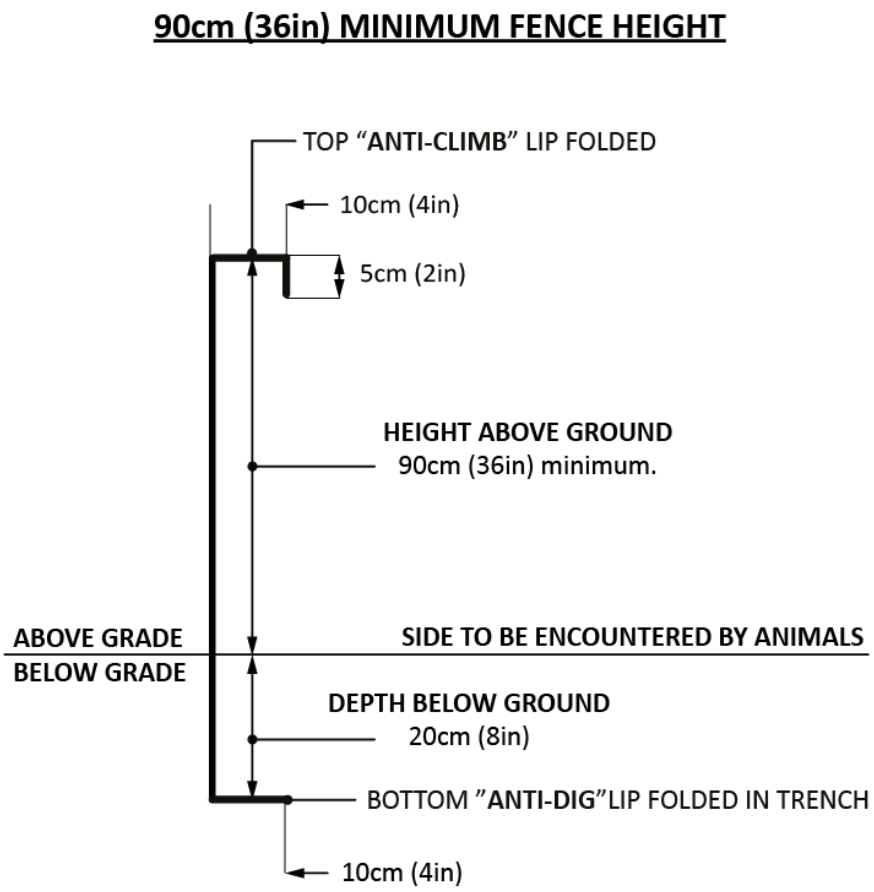

Figure 6. Illustrative fencing profile and measurements for minimum above ground height - 90cm (36in)

Conclusion

Despite reptiles and amphibians being recognised as two groups most affected by roads due to road mortality and fragmentation, they tend to be under-represented when it comes to mitigation as research and mitigation has historically focused on large mammals that cause WVCs with a higher cost to humans. This has resulted in a previous lack of research on effectiveness and clear and consistent guidance on mitigation for small animals. Wildlife fencing is one method of mitigation that has proven to help reduce WVCs and can help maintain connectivity when combined with safe wildlife crossings. Over the years studies have helped informed best practice guidance and this paper has provided a review of existing guidance, which has summarised recommended materials, fencing heights, and any other considerations such as top lips or anti-dig installation within the guidance. Based on recent research, the existing guidelines and our own observations on mitigation projects, we have provided recommendations for reptile and amphibian fencing for various species groups and installations. Moving forward, we believe there is still a great need for further research into the effectiveness of small animal fencing. Each region may require local fencing specifications based on the target species present and local climate conditions that can affect materials differently. However, we consider the recommendations in this paper to provide a global standard for reptile and amphibian fencing that can be used as a starting point while more specific research-based guidance is developed.

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