Road Maintenance and Planning for Terrestrial Connectivity – Review of Guidelines and Best Practices

April, 2013

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Acknowledgements

Principal funding was provided by the US Fish and Wildlife Service and New Hampshire Fish and Game Department through the Competitive State Wildlife Grants Program, under the terms of the State and Federal assistance grant U2-4-R entitled "Staying Connected in the Northern Appalachians: Mitigating Fragmentation and Climate Change Impacts on Wildlife through Functional Habitat Linkages," and by the Wildlife Conservation Society’s Wildlife Action Opportunities Fund, established with support from the Doris Duke Charitable Foundation. The content and opinions expressed herein are those of the authors and do not necessarily reflect the position or the policy of these funders, and no official endorsement should be inferred.

Many thanks to Alison Bowden (The Nature Conservancy), Danielle Garneau (SUNY Plattsburgh), Susan Morse (Keeping Track), Liza Poinier and Kristine Rines (New Hampshire Fish and Game Department), Conrad Reining (Wildlands Network) Chris Slezar (Vermont Agency of Transportation), and Tomas Stevens (Town of Western, NY) for the valuable information they provided in preparing this report.

Please cite this document as:

Project Overview

Project objective: To compile a brief overview of best practices for addressing terrestrial connectivity based on literature reviews, interviews with local experts, and field experience by TNC staff and to provide an indexed spreadsheet of publications and articles for conservation and transportation planners.

Research is focused on work underway or completed in the Northern Appalachian ecoregion to give partners local examples of connectivity solutions. National and international research is included where relevant to ensure that a full range of options is available to conservation planners. In keeping with Staying Connected Initiative priorities, this report largely emphasizes connectivity for wide ranging species. Opportunities to incorporate connectivity for other species or ecological processes are noted when feasible. The process of incorporating connectivity objectives into road maintenance and upgrade planning is highlighted with examples of best practices.

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# Road Maintenance and Planning for Terrestrial Connectivity – Review of Guidelines and Best Practices

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[Available as indexed spreadsheet from stayingconnectedinitiative.org]
Connectivity has emerged as a crucial concern for conservationists seeking to ameliorate the ecological consequences of road development. Securing connectivity is a lofty objective requiring the protection of large blocks of high-quality natural areas and linkages between these core areas. Connected landscapes help wildlife populations sustain long-term viability and increase their capacity to adapt to change.

Although this paper focuses on just one component of connectivity, mitigating the barrier effects of roadways on wide ranging terrestrial wildlife, in the long run barrier mitigation will only be effective if accompanied by land use planning and protection. The converse is also true: land use planning and protection require understanding of barriers between natural areas.

It is unreasonable to expect that opportunities to mitigate barriers and secure natural areas will be presented at the same time. Conservationists and transportation planners must act in the short term, taking advantage of immediate opportunities, but plan in the long term to ensure that actions are complementary and result in lasting contributions to the connectedness of our natural areas.

This report is a snapshot of current concepts and techniques for mitigating barrier effects of roadways. Several comprehensive documents have been published summarizing the variety and merit of approaches to mitigating barrier effects. Largely, they draw upon examples from western North America, where both the natural and cultural landscape has allowed places such as Banff National Park to emerge as global leaders in barrier mitigation strategies. Eastern North America is quite a different landscape. Our goal is to extract the crucial and relevant information from the vast body of barrier mitigation work to guide projects in the North East, highlight regional examples and assess the execution of barrier mitigation projects that have been implemented.

With creativity and foresight, barrier mitigation efforts may meet a wide variety of objectives. Creating an open span bridge at a stream crossing instead of a box culvert can have benefits beyond just enabling free passage of large wildlife. An open span bridge promotes aquatic connectivity, riparian vegetation and natural stream-corridor processes that benefit downstream human and natural communities by providing water filtration, bank stabilization and flood control. Addressing all such opportunities is beyond the scope of this paper, but we urge all those implementing barrier mitigation projects to envision opportunities that meet multiple objectives.
It is essential to work with transportation agencies from the onset in order to address their multiple objectives and assure that work is useful to them. Without their engagement mitigation projects will not be successful. Depending on how barrier mitigation nests with complementary local efforts, other relevant stakeholders should be consulted. Business owners and landowners with property along roadways, hunting and fishing clubs, foresters, loggers and elected officials all offer expertise, experience, and resources that make them important partners.

Balancing multiple objectives is complicated by universal financial constraints. Specialized and costly mitigation projects are unreasonable except in rare circumstances. This paper strives to highlight mitigation options that are reasonably cost effective because they are inexpensive, meet multiple objectives, or integrate long-term road maintenance and planning.

The Pathway to Mitigation

1. Establish Priorities

Articulate Goals
Conservation planners face an overwhelming number of options and decisions as they attempt to develop solutions that meet the unique needs of specific species, landscapes, communities, and projects. Clearly articulated goals streamline decision-making at all levels, ranging from selecting the best spatial model to deciding the optimal size for culverts. Just as importantly, clear goals are attractive to potential partners and provide accountability.

Coordinate priorities
When feasible, priorities for barrier mitigation projects should reflect the priorities of larger connectivity initiatives. An initiative, as described in this document, is an organized collection of complementary projects that address the many facets of connectivity across a broad area — including land protection, restoration, and land-use planning as well as barrier mitigation. Existing initiatives may not be directly relevant for small projects but they are essential to successful work in complex, large-scale landscapes.

Working in large-scale landscapes presents certain challenges, including additional data requirements and more cooperation between stakeholders. Ultimately systems-level planning may prove most effective at meeting connectivity objectives and limiting costs (Huijser and Clevenger, 2011).

Models for Mitigation

Project Model: Banff National Park is recognized as a worldwide leader in highway mitigation for wildlife. In the early 1980’s, lane expansions along the Trans-Canada Highway, which bisects the ~2,500 square mile National Park, prompted officials charged with protecting the ecological integrity of the park to employ an unprecedented number and array of mitigation measures along 76km of highway.

Initiative Model: Staying Connected In the Northern Appalachians is an initiative seeking to “safeguard wide-ranging and forest dwelling wildlife...by maintaining and restoring landscape connections across the Northern Appalachians.” The Northern Appalachians Region is an ecologically, socially and politically complex landscape spanning 125,000 square miles. Addressing connectivity here requires cooperation across state and national political boundaries and between myriad government agencies, private landowners, and conservation organizations at multiple scales.
Identify and map linkages

To focus efforts and ensure the best use of scarce resources, many systems-level connectivity initiatives adopt a linkage-based approach. A linkage is an arrangement of habitats, not necessarily linear or contiguous, that enables movement of animals across a landscape (Worboys, 2010). From a conservation planning standpoint, a linkage represents a geographic area that could be a priority area for habitat protection, restoration, and barrier mitigation. Opportunities to mitigate barriers within recognized linkages should be pursued most aggressively, supported by mitigation in surrounding lower priority areas.

A detailed discussion of how to map and prioritize linkages is beyond the scope of this document but the importance of linkage mapping warrants a brief overview. (For an excellent discussion of concepts and techniques for linkage mapping see Beier et al 2007.)

Although linkage mapping could be done by a single agency or organization without the involvement of other stakeholders, inclusion and transparency in the mapping process is essential in laying the groundwork for future action (Beier et al 2007). Stakeholders must be assembled to establish goals, choose which wild areas to connect for which species, and arrive at a consensus of how linkages should be prioritized. These same stakeholders will play a pivotal role in funding, implementing, and maintaining mitigation efforts.

Most linkage mapping projects rely upon spatial models that predict movement pathways for carefully selected groups of species, known as focal species (see Appendix A) between suitable habitat blocks. In one sense, linkage mapping may be considered the first step in barrier mitigation: it provides a geographic boundary to focus efforts and introduces measurable goals (e.g. ensures the movement of species x, y, and z between wild areas A and B). Depending upon the scale at which linkages are mapped and the resolution and quality of data used in the mapping, it may be necessary to conduct further research and data collection to prioritize roads within critical linkages.

Evaluate barriers

*What roads in the linkage are acting as the greatest barriers for the movement of focal species?*

*Where are animals successfully crossing the road?*

*Where are they unsuccessfully attempting to cross?*
Identifying major roadway barriers can be a relatively straightforward task, potentially requiring little more than examining a handful of maps. The largest roads, especially those that bisect a linkage, are likely to be the greatest barriers. Although there is debate about the exact relationship between traffic volume and roadway permeability for wildlife (is it noise disturbance, mortality, or habitat loss that makes roads impermeable?) there is clear consensus that high-traffic roads and associated infrastructure are less permeable for wildlife. Low-traffic roads can also be significant barriers when occurring in high density because they increase fragmentation and increase the likelihood that an animal’s home range will contain roadways. Repeated exposure to even low probabilities of collision with vehicles can lead to elevated risk of collision throughout an animal’s lifetime. (Litvaitis and Tash, 2008).

The degree to which roads or segments of roads are barriers to movement is not always clear. In these cases, it may be possible to use rapid assessment models to examine the configuration of roadways, traffic volume, and adjacent habitat and terrain, to prioritize field work or to identify focal areas where fieldwork is not possible. A general model that predicts high priority animal crossing locations has been developed for the Northeast. (Rinehart, 2011).

Determining successful and unsuccessful crossing locations for wildlife within priority areas is an essential next step towards locating effective mitigation projects. Roads affect the movement of wildlife between fragmented habitats in at least two ways:

- Reducing the number of crossing attempts through disturbance, and
- Reducing the number of successful crossing attempts through mortality from wildlife-vehicle collisions (WVCs)

WVCs are among the most tangible effects of roads on wildlife: the consequences of WVCs are highly visible and intuitive to understand. This, along with the clear link between WVCs and motorist safety, has justifiably placed WVCs at the center of conversations regarding barrier mitigation. Data demonstrating the location of WVCs can aid in identifying locations for mitigation projects. However, unless the goal of the project is exclusively to reduce the number of WVCs, relying upon the locations of WVCs to guide mitigation is incomplete.

For more information about habitat connectivity, consult

**Why did that bear cross the road?**

*A Guide to Habitat Connectivity*

“Whatever the animal’s purpose for traveling, these movements can be important not only in providing the individual animals with the appropriate food and mates, but also for maintaining healthy populations of wildlife across the Northeast.”

Staying Connected Initiative

[stayingconnectedinitiative.org/resources](http://stayingconnectedinitiative.org/resources)
Areas with high numbers of WVCs, often referred to as road-mortality hotspots, may have little in common with areas where animals safely cross roadways. Instead these hotspots may reflect roadway design that impairs visibility of wildlife to motorists, reduces time for drivers to react, or allows vehicles to travel through wildlife movement areas at high speeds (Huijser and Clevenger 2011). For example, Barnum et al (2007) observed that crossing rates of moose in New Hampshire were not significantly related to WVC locations.

Although many states record the locations of WVCs, these data typically only reflect collisions with large mammals. For example, New York only records WVC’s that result in more than $1,000 in damage and describe species involved as deer or non-deer (Clark, 2012). This is a small percentage of the toll WVCs have on an area’s wildlife populations. Careful monitoring of the Bennington Bypass in VT over three summers revealed that 75% of the animals killed on a 7km stretch of road were small (smaller than a rabbit) and 31% of these were frogs and toads (Bellis 2008).

Incomplete WVS data underscore the importance of using several measures to evaluate roadway permeability. A number of techniques are available to determine where animals successfully cross the road and where they avoid it.

Commonly used techniques are:

- **Tracking**: This is a common way to identify crossing locations for individual species and can be used to document other behavior such as road avoidance as well. While track data can be obtained from selectively placed track plates and beds, it is most effectively collected in fresh snow in areas with adequate snowfall. Snow tracking offers several advantages: it can be used to document the presence and behavior of any species that leaves an identifiable track and can capture the full range of interactions between wildlife and roadways, both near and far from the road. One can calculate permeability as the ratio of tracks crossing a road to tracks observed in a transect running parallel to the road (Alexander et al 2005). According to Barnum et al (2007) snow tracking has the “greatest potential to record a wide range of species, and their behavior, at the roadside.” Bellis (2008) contributes a similar sentiment, suggesting that when funding or personnel are limiting, snow tracking is perhaps an ideal single-method monitoring approach. However, snow-tracking has limitations including:
  - Does not capture species that are less-active in the winter (e.g. bears)
  - Only captures behavior of animal movement in one season (Dispersal of juvenile animals in the autumn would not be recorded during winter snow tracking.)
- Relies on sufficient snow conditions to detect tracks.
- Limits conclusions. Tracks may show the behavior of many animals (i.e. approaching, crossing and or retreating from roadways) but not reveal how many individual animals made the tracks (see Bellis 2008).

Numerous examples of study design and format exist. For more information about tracking methodology and study design, consult: Bellis, 2008; Barnum et al, 2007; TNC 2011; Leoniak et al 2009; and Moskowitz, D., M Clarke, J. Watkins, and A. Martin, 2011.

- **Radio/Satellite Telemetry**: This technique relies upon periodically obtaining location data from individual animals equipped with locating beacons. Telemetry can document patterns of movement across a relatively broad scale and provide detailed information about roadway interactions, home-range distribution, and social affiliations of individual animals (Bellis, 2008). It can also be used to examine daily temporal trends in crossing behavior (Gagnon et al 2007).

Telemetry is an expensive method, however. It is difficult logistically to capture and equip animals with transmitters and inflicts a high degree of disturbance on wildlife subjects (Clevenger 2005). The expense and logistic challenges seem to restrict this method to pre and post mitigation monitoring. See Dodd et al 2007, LeBlanc et al 2007, and Gagnon et al 2007 for applications.

- **Live Trapping**: This method is most commonly employed to survey and document the movement of small mammals, particularly those too small to support radio/satellite transmitters or those that have small home ranges. If animals are tagged or otherwise marked upon release from a trap, subsequent recaptures can provide information about the movement patterns of individuals. See Bellis, 2008 for methodology and application.

- **Remote Cameras**: The cost and restricted sampling area of remote cameras may make them unsuitable for detecting crossing locations (Huijser and Clevenger, 2011) however cameras may be...
the most cost effective method for examining how known crossing structures are used (Clevenger et al 2009). One important benefit of remote cameras is the impact pictures can make on partners and on the public. Bobcat photographs taken on a remote camera in New York were circulated on social media and excited hundreds of interested groups and individuals (TNC, 2013). This level of engagement can support the use of funds for wildlife mitigation by municipalities and the protection of specific habitat by conservation agencies.

- **Citizen Reported Wildlife Data:** A number of states have implemented web-based wildlife observation reporting systems (e.g. California Roadkill Reporting System; Maine Audubon Wildlife Road Watch, RoadKillGarneau). Such reporting systems offer the potential to rapidly collect large volumes of wildlife data at minimal cost. Citizen data are opportunistic rather than systematic, and can have limited statistical applications. However, a comparison of data generated by Road Watch in The Pass, a Canadian citizen-science program, to data systematically collected by field researchers found that the two datasets were not significantly different (Paul et al 2009).

Informal information provided by law-enforcement officers, transportation workers, hunters, and long-term residents can also be invaluable.
Regional Examples


Adirondack Tug-Hill Linkage Project: Used GIS-based spatial modeling for focal species to identify linkage areas between the Adirondack Park and the Tug Hill Plateau. Used extensive winter tracking along priority roadsides to develop models that assign crossing probabilities to roads based on relevant infrastructure, terrain, and land cover type variables. Identified priority roads, and currently engaging in outreach with towns and state to identify project areas. Publications include: Brown, et al 2010; Rinehart, 2011; Goodwin, 2012.

Clark, 2012: Used roadkill data provided from New York State in conjunction with linkages derived from focal species modeling (least-cost pathway for carnivores) to predict hotspots in the Split Rock Wildway, Adirondack Park, NY.

Other Examples and Suggested Reading

Conceptual steps for designing wildlife corridors: This document by Beier et al (2007) provides an excellent overview of how to design wildlife corridors and involve a variety of important stakeholders.

II. Take Action.

Prelude to action
The construction of new roads allows transportation and conservation planners to preemptively avoid conflicts with wildlife by adjusting the alignment and design of proposed roadways. However, the majority of highway projects in the US are upgrades, expansions and maintenance of existing roads. Mitigation is therefore the most common and widely publicized approach to integrating habitat connectivity with transportation infrastructure. A wide variety of techniques, structures, and campaigns have been applied to mitigate the barrier effect of highways (Huijser et al 2008). Some work; some do not. Some are expensive; some are not.

In the following section, mitigation strategies that have been effective are highlighted with particular attention to those that may be financially feasible. When appropriate, commonly used techniques (e.g. wildlife crossing signs) that have proven ineffective will be discussed. If available, local examples are provided. The discussion is organized according to the three pathways outlined in Huijser et al 2008 and Seiler 2003:

- Mitigation targeted at driver behavior;
- Mitigation targeted at animal behavior;
- Mitigation targeted at the physical characteristics of the roadway.

Influencing Driver Behavior
Driver alertness, reaction time, and vehicle speed can play a crucial role in the number and severity of WVC’s, making driver behavior an important variable in roadway permeability and human safety. A considerable number of techniques—ranging from signs to onboard animal detection systems to education campaigns—have been developed in an effort to reduce WVCs. Justifiably, the majority of these techniques focus on reducing collisions with large wildlife, especially ungulates that pose the greatest safety risk to humans. It is possible, though, that some of these techniques could be adjusted to reduce the risk of collisions with other animal taxa. For example, speed limits were lowered in select areas in Washington to protect agricultural pollinators (WildlifeandRoads.org).

One of the most common methods to influence driver behavior is also among the least effective. According to Huijser et al (2008), a number of studies have found standard warning signs such as the “Deer Crossing Area” sign are ineffective at reducing the number of collisions.

The efficacy of roadside messages may be increased when associated with public awareness and education campaigns. Perhaps the best-known local example is New Hampshire’s “Brake for Moose” campaign. This campaign has been running for nearly 15 years and uses roadside messages along with bumper stickers, public service announcements, press releases, and a driver education video to distribute information on safe driving tips and relevant moose ecology.
Although no formal evaluation has been conducted, the “Break for Moose” campaign is regarded as a success (L. Poinier, personal communication). Similar to the findings reviewed in Huijser et al (2008), the agency suspects that drivers—especially local residents—have become habituated to the standard moose crossing signs, but the strategically placed scrolling message signs are still influencing behavior (L. Poinier, K. Rines, personal communication). These mobile signs are in place only during seasons when moose are most likely to be on the road and in one particular location are believed to have reduced the number of annual collisions from 2 or 3 to near 0 (K. Rines, personal communication).

Driver behavior can also be influenced through roadway design and management. Approaches include reducing speed limits, traffic calming, temporary road closures and restrictions, and managing the right-of-way for greater wildlife visibility.

Influencing Animal Behavior
Although animal behavior is a critical component of road permeability, few mitigation efforts specifically target the animals themselves, instead favoring environmental management that promotes desired behaviors. That said, a number of methods to irritate, haze, or frighten animals have been proposed to discourage use of the roadway. For example, reflectors that amplify the light from headlights were installed along a section of RT 46 in New York to discourage deer from entering the road at an area that has been the site of many WVCs (T. Stevens, personal communication).

Although not formally evaluated, local officials believe that the reflectors were effective for a year or two, but now have little to no effect—either because deer have become habituated or the alignment of the reflectors has not been maintained (T. Stevens, personal communication). Depending upon project goals and conservation status of species, managers may wish to consider population management to reduce WVCs. This is a strategy only appropriate for reducing WVC’s, not for increasing roadway permeability.

Influencing Physical Characteristics of Roads
The diversity of management options makes managing the roadways one of the most promising pathways towards meeting permeability goals. Roadways can be managed to modify human behavior (e.g. roadside clearing to allow greater reaction time), to modify animal behavior (e.g. eliminating highway salt deposits to reduce animal activity near road), or to separate and control animal/roadway interactions. The following section is organized by components of the roadway that can be managed to enhance permeability. Rather than give detailed specifications, which can be found in several excellent publications, this section aims to highlight big-picture considerations and recommendations.

Vegetation

Overview: Widening of the right of way and reduction of tall vegetation can increase the visibility of wildlife to drivers, allowing for greater reaction times that reduce the number and severity of WVC’s (reviewed in Huijser et al 2008). In New Hampshire, vegetation removal along Rte 3—a frequent site of moose-vehicle-collisions—coupled with the elimination of steep grades leading to the guardrail and management of salt lick areas (see following section) was implemented in an effort to reduce collisions with moose (K. Rines, personal communication). While this management effort was not scientifically
monitored, collisions along this stretch of road have fallen from 2-3 per year to less than 1 per year (K. Rines, personal communication).

Although vegetation removal along roadways has been demonstrated to reduce WVCs with large animals, it may lead to conflicting outcomes. Vegetation clearing can create open habitat that may attract certain species, exposing them to greater risk of WVCs. For example, Barnum et al (2007) observed that open roadsides served as the primary habitats for red fox in forested landscapes in New Hampshire and Bellis (2008) observed frequent foraging activity by coyotes for rodents in open roadsides in Vermont. Forestry operations that utilize clear-cuts next to roadways can create attractive foraging sites for deer and moose, leading to localized hotspots for WVCs (K. Rines, personal communication).

Take away: Roadside vegetation is an important variable in roadway permeability, making vegetation management a recommended practice. However, the potential for conflicting outcomes warrants careful consideration when developing a plan for roadside vegetation management. Broadly speaking, roadside vegetation should be maintained to the extent that road design and motorist safety allow. Additional vegetation removal is not recommended except in circumstances where motorist safety would otherwise be compromised. Vegetation management can be used along with other management strategies to make roadways more permeable for wildlife. For example, thoughtful vegetation management is important in promoting the use of crossing structures.

Clearly articulated goals along with a thorough understanding of potential impacts on important species will help guide decisions about vegetation.

Salt

Overview: Salt used in the deicing of winter roads can accumulate alongside roads and attract wildlife, especially in areas without natural salt licks. Alterations of deicing compounds can make road salt less attractive to wildlife. Also, known salt lick areas can be eliminated. In New Hampshire, known salt licks were reduced through ditching and corduroying (placing logs in the ditch) along Rte 3 (K. Rines, personal communication). This practice, along with vegetation management and reduction of steep grades that masked approaching moose, is believed to have contributed to a reduction in moose-vehicle collisions in this area (K. Rines, personal communication).

Take away: Eliminating salt licks created by deicing activity is a recommended practice if it can be done without increasing risk for winter motorists.

Fences

Overview: Fencing can be effective in reducing WVCs, however gaps in fencing and the ends of fences can promote WVCs. However, without gaps in the fence to allow animal movement, the road becomes a total barrier for wildlife attempting to cross.

Take away: Fencing can only be recommended if used in conjunction with structures or management that allows for safe passage across the roadway in certain locations where animals perceive safety.
Crossing Structures

Overview: Crossing structures are passages over or under the roadway that are specifically designed or managed to promote wildlife movement. Crossing structures physically separate wildlife from roadways and provide safe, controlled locations for crossing over or under the roadway. Fencing is commonly used to funnel wildlife towards crossing structures and prohibit animals from entering the roadway. Crossing structures vary in design, cost, and function; ranging from large vegetated overpasses that support movement of a variety of wildlife and continuity for ecological processes to simple drainage culverts strategically managed to promote the movement of certain species. The list below illustrates the range of crossing structures. Local examples are noted.

(For thorough illustration and analysis of each structure see Hotsheets Appendix in Huijser and Clevenger 2011.)

Overpasses (wildlife cross above the road)

- Landscape Bridge: a large vegetated overpass that promotes movement of a wide variety of wildlife, from large mammals to invertebrates, and provides continuity for certain ecological processes.
- Wildlife overpass. Similar to landscape bridge, although they tend to be smaller and specifically designed to move large mammals. A wildlife overpass has been proposed for Route 2 in New Hampshire in an area with confirmed lynx activity; however no progress has been made on this project to date (K. Rines, personal communication).
- Multi-use overpass: Similar to wildlife overpass, but allows for human uses.
- Canopy crossings: link forest canopy above the road for arboreal and semi-arboreal species.

In January 2011, ARC International Wildlife Crossing Infrastructure Design Competition announced that HNTB Engineering with Michael Van Valkenburgh Associates, Inc. (HNTB+MVVA) won the first international wildlife crossing structure design competition. Five design firms from around the world competed to develop the next generation wildlife crossing.

ARC is actively partnering with Rocky Mountain Wild and others to build this wildlife crossing over I-70 in Colorado. It is hoped that construction will begin in the next few years.
Underpasses (wildlife cross below road)

- **Viaduct/Flyover/Open Span Bridges**: largest underpass, often built to meet multiple objectives; including maintaining stream hydrology and riparian vegetation, avoiding substantial cut and fill operations, as well as promoting wildlife movement. Open Span bridges were part of a mitigation strategy for a newly constructed highway that bisected a known deer yard in Quebec (Leblanc et al 2007).

- **Large Mammal Underpass**: designed for large mammals, but may require specific design to meet the needs of particular species. These underpasses can be designed or managed to facilitate use by small-medium wildlife too. Underpasses were constructed as part of a mitigation strategy for highway construction in Quebec as well as for the Bennington Bypass in Vermont (described in Bellis et al 2007; Bellis 2008).

- **Multiuse underpass**: similar to above, but allows human uses.

- **Underpasses with water flow**: Meets the needs of wildlife and moving water. Can be managed for large-small animals. “Shelves” that enhance passage can be installed that don’t require animals to move through swift flows. (Forseman, 2004)

- **Small-medium sized mammal underpass**: More of a solution in highly permeable landscapes. May be necessary for small mammals. One study demonstrated that mice and chipmunks might be more affected by the physical features of the road than the amount of traffic it receives. McGregor et al 2008.

- **Amphibian/reptile tunnel**: tunnels specifically designed for reptiles and amphibians, some are designed to ensure ambient light and temperature. Amphibians require fencing to direct them into the underpass.

### Minimum Preferred Crossing Dimensions for medium and large mammals - some examples

<table>
<thead>
<tr>
<th>Species</th>
<th>Structure type</th>
<th>Minimum width (span)</th>
<th>Minimum height (rise)</th>
</tr>
</thead>
<tbody>
<tr>
<td>bobcat, fox</td>
<td>culverts (metal pipe, small box culvert)</td>
<td>5 ft plus</td>
<td>5 ft plus</td>
</tr>
<tr>
<td>black bear</td>
<td>box culvert, small bridge</td>
<td>5-8 feet</td>
<td>5-8 foot</td>
</tr>
<tr>
<td>deer, moose</td>
<td>box culvert, small bridge</td>
<td>20 feet plus</td>
<td>8 feet plus</td>
</tr>
</tbody>
</table>

Crossing structures have proven to be effective at providing safe passage for wildlife across busy roadways and reducing the rate of WVCs. Location, design, and management are among the most important variables that determine the influence of crossing structures on roadway permeability. Structures must be located where wildlife will use them and be designed to meet the specific needs of the animals for which they are designed. Design will also be driven by project goals, site considerations, and budget concerns. The physical infrastructure of the crossing structures and support fencing will require maintenance as well as adaptive management informed by scientific monitoring.

Recommendations for size, materials, spacing, species-specific considerations, and estimated costs for the range of crossing structures can be found in documents listed under suggested reading.

### Crossing Structure Highlights

**Bigger is better.** Crossing structures designed to accommodate large wildlife, such as bear, moose, and deer, can be managed to facilitate the movement of small and medium sized wildlife as well. In structures designed to also accommodate water flow, bigger structures last longer and are more likely to survive extreme flood events.

**Under is easier than over.** Wildlife will use both underpasses and overpasses, but according to K. Rines (personal communication), the general consensus is that it is more difficult to encourage wildlife to use overpasses than underpasses. Behavior varies by species.

**Meet multiple objectives.** Crossing structures can perform as road and drainage infrastructure, provide long-term savings and maintain aquatic connectivity.

**Stay in your own lane.** Permitting human passage (either pedestrian or motorized) in crossing structures is not recommended.

### Suggested Reading


Vermont Stream Crossing Handbook: Excellent, accessible, overview of culvert designs for aquatic passages.

Take away: Crossing structures and associated fencing are recommended for enhancing the permeability of roadways for wildlife. Opportunities to meet multiple objectives should be pursued, to enhance drainage, to obtain greatest return on the investment of crossing structures and to engage more potential partners.

Coordinating Action with Ongoing Upgrades

Due to cost new crossing structures are likely to be most feasible during new road construction or the replacement of existing infrastructure. Many drainage culverts and bridges in the Northeastern US are aging. A large-scale inventory of culverts is underway in New England, the results of which are available in an excellent web-accessed database. Initial results of this inventory suggest that many culverts are inadequate for function and connectivity. Researchers, including The Nature Conservancy of Massachusetts, are making a priority list for upgrades and replacement. Results are available through Critical Linkages.

The need to replace these structures provides an opportunity for transportation and conservation planners to incorporate the needs of terrestrial and aquatic wildlife in culvert design and construction. Bridge lengthening, increasing culvert opening size, and eliminating elevated outlets to prohibit entry by aquatic and terrestrial organisms are suggested modifications (C. Slezar, personal communication). In Vermont, these modifications are suggested in priority locations and framed as cost saving opportunities because structures that can withstand 100-year flood events rather than 20-30-year flood events are more cost effective in the long run (C. Slezar, personal communication). This message resonates with transportation officials, especially after recent extreme weather events (C. Slezar, personal communication).

Opportunities to retrofit or manage existing roadway infrastructure to serve as crossing structures should be emphasized. It is relatively rare that the size, location, human influence, and other factors of existing structures enhance permeability for wildlife, especially for medium to large carnivores and ungulates (Ruediger et al 2008; Shingleton and Lehmkuhl 1999; Seiler 2009). Ensuring that culverts are not obstructed, have contiguous natural cover at openings, and proper fencing can improve their function. Large drainage culverts with flowing water can be retrofitted with elevated walkways that provide safe passage for medium sized wildlife (Foresman 2004). Natural resource agencies may wish to discourage trapping and harvesting near to openings of culverts especially those that have received investment.

III. Monitor and Adapt

Monitoring should be considered an essential part of any mitigation project, even those with modest goals. Monitoring provides accountability and necessary information to adapt management practices and ensure that actions accomplish project goals. Furthermore, monitoring yields information that can streamline future mitigation projects, saving time and money and increasing effectiveness.
Individual mitigation projects require individual monitoring plans. For example, if the project seeks to reduce WVCs along a stretch of road by using fencing, regular surveys for road kill in and outside of the mitigation site are an important component of the project’s overall plan. When possible, monitoring should employ multiple techniques to capture the range of effects that roads have on wildlife movement and the extent to which mitigation alleviates those effects (Bellis, 2008). This may be particularly true for mitigation utilizing crossing structures. Most crossing structures are simply monitored for use, but it is also important to gather information on species or individuals that do not use structures (Bellis, 2008).

The methods available to monitor barrier mitigation are similar to those previously described for locating and designing mitigation projects. Remote cameras are the most cost effective way to monitor use of crossing structures for extended durations (Clevenger et al 2011). Cameras, especially those equipped with video, can also document animal behavior and interactions with the crossing structure (Bellis 2008, Rogers et al 2009, Clevenger et al 2011). However, detecting small wildlife with remote cameras is difficult. Pinch points created by crossing structures may allow the opportunity to obtain hair samples for genetic testing. Genetic testing can reveal the absolute number of individuals using a crossing structure and, if combined with population data, can indicate the extent of gene flow across the roadway. (See Clevenger et al 2011).

Ideally, monitoring plans will be developed during the project planning process and be implemented before mitigation begins. With forethought, it may be possible to use the same techniques and protocols for project monitoring that were used for the initial fieldwork to locate and design the mitigation strategy. For example, if snow tracking was used to obtain species inventories and evaluate roadway permeability to select the location and design of crossing structures, using the same procedures for post-mitigation monitoring would allow the results of the initial fieldwork to serve as pre-mitigation data, saving an additional round of data collection.

Monitoring should be conducted for as long as feasible to capture the adaptation and response of wildlife to mitigation as well as the potential influence of external changes (e.g. climate change or substantial habitat modification). On average, mitigation efforts are monitored for less than two years, which may not be long enough to capture the adaptation period (Bellis, 2008). According to Clevenger et al 2009, long-term monitoring of wildlife crossing structures in Banff revealed an “adaptation period and learning curve for large mammals using the wildlife crossing structures, and that ungulates adapt

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**Regional Examples**
Bell 2008: Applied multiple monitoring techniques to evaluate the effectiveness of mitigation measures incorporated into a stretch of new highway in southern Vermont.


**Suggested Reading**
Clevenger et al 2009: Details the findings of long-term monitoring of crossing structures in Banff. Banff is home to one of the longest running monitoring programs.

Huijser and Clevenger 2011: Provides framework for creating monitoring plans.
more quickly than carnivores.” Use of crossing structures by these species increased for a period of 4-6 years and then remained steady (Clevenger et al 2009).

Collaboration can lighten the burden of monitoring. Organizations and individuals with relevant resources, expertise, and time to contribute can share monitoring responsibility. Academic organizations and students commonly are able provide support. Citizen volunteers can also be used although a small, dedicated group of volunteers may be more effective at routinely collecting consistent data than a large group (Rogers et al 2009). When using volunteers, a high degree of standardization is needed. Organizations such as Keeping Track are instrumental in training volunteer scientists.

**IV. Stay Current**

The fields of road ecology and barrier mitigation are evolving rapidly. New concepts, tools, and resources are continuously becoming available to planners. See proceedings of national and regional conferences.

Appendix 1: Focal Species

Typically focal species are wide-ranging mammals (frequently large carnivores) that are native to a region, however, a number of studies use amphibians, reptiles, and even birds as focal species. Focal species are chosen for a variety of reasons.

Focal Species Selection Table
The following table shows the application of focal species criteria to a variety of species considered for modeling during an Adirondack-Tug Hill linkage study by The Nature Conservancy, Adirondack Chapter, in 2012.

<table>
<thead>
<tr>
<th></th>
<th>Bobcat</th>
<th>Marten</th>
<th>Black bear</th>
<th>Otter</th>
<th>Moose</th>
<th>Lynx</th>
<th>Wolf</th>
<th>Cougar</th>
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</thead>
<tbody>
<tr>
<td>Extant wide-ranging species – terrestrial</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Extant wide-ranging species – aquatic</td>
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<td>X</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Extirpated wide-ranging species</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Keystone species</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Foundation species</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Umbrella species</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Habitat specialist</td>
<td>X</td>
<td></td>
<td>?</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitive to human disturbance (e.g. road density over given threshold) - LOW, MED, HIGH</td>
<td>MED</td>
<td>MED</td>
<td>LOW/MED</td>
<td>MED</td>
<td>LOW</td>
<td>HIGH</td>
<td>HIGH</td>
<td>HIGH</td>
</tr>
<tr>
<td>Vulnerable - NY Species of Greatest Conservation Need</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Information availability - LOW, MED, HIGH</td>
<td>MED</td>
<td>HIGH</td>
<td>HIGH</td>
<td>?</td>
<td>MED</td>
<td>MED/HIGH</td>
<td>MED</td>
<td>LOW</td>
</tr>
<tr>
<td>Social acceptance - LOW, MED, HIGH</td>
<td>MED</td>
<td>MED</td>
<td>MED</td>
<td>HIGH</td>
<td>HIGH</td>
<td>MED/LOW</td>
<td>LOW</td>
<td>LOW</td>
</tr>
</tbody>
</table>

The selection of focal species is an important one, influenced by an initiative’s goals and by practical considerations such as data availability and budget constraints. When feasible, a greater number and diversity of focal species should be selected to capture the full spectrum of habitat requirements, sensitivity to development, risk of extinction, and reliance upon critical resources (CorridorDesign.org).

The Southern Rockies Ecosystem Project selected 28 focal species, including, birds, reptiles; small, medium, and large carnivores; rodents, and ungulates. Some of these species were habitat specialists and others were habitat generalists. This breadth of selection is not common, as it is cost and data prohibitive for many linkage mapping projects. Instead, many connectivity initiatives select a smaller
group of focal species, targeting species with the most stringent requirements under the assumption that these species capture the needs of species with less stringent requirements. CorridorDesign.org suggests using at least 10 focal species.

Advantages for planners are that focal species set reasonable parameters on the type of data that must be obtained or developed to map linkages. These parameters not only limit the costs of mapping, but also introduce a degree of accountability, measurable goals, and standards to monitor changes in landscape permeability.

Disadvantages of using focal species as a basis for connectivity stem from our limited understanding of the life-history needs of some species as well as our inability to manage all landscapes for all needs that are currently recognized.
Appendix 2: How High is too High in High-Traffic Roads?

The answer, of course, is “It depends.”

Some species are highly sensitive to road-related disturbance and are less likely to cross as disturbance increases. Some species are more vulnerable than others to road-related mortality. Mitigation projects to improve road safety for motorists by reducing wildlife-vehicle collisions may focus on different stretches of road than projects to mitigate the greatest barriers for low-density, high-sensitivity species.

In the conceptual model of the relationship between traffic volume and roadway permeability presented in Seiler (2003) and Huijser and Clevenger (2011), traffic has two impacts on permeability:

- Disturbance that repels individual animals, reducing the number of attempted crossings
- Wildlife-vehicle collisions that reduce the number of successful crossings.

\[\text{AADT=Annual Average Daily Traffic; VPD=Vehicles Per Day}\]

- At low traffic volumes (<2,000-3,000 AADT) crossing success is high, avoidance is low, and mortality is low, resulting in minimal influence on populations.
- As traffic increases, (<10,000 AADT) crossing success decreases, avoidance increases, and mortality peaks.
- At high traffic volumes (>10,000 AADT), crossing success is low, but high avoidance of roads brings mortality down, suggesting that the road has become an impermeable barrier for wildlife.

Additionally,
- At 300-500 VPD, carnivore movement in Banff was impaired (Alexander et al 2005).
- 500-5,000 VPD impaired ungulate movement in Banff (Alexander et al 2005)
• <2,400 VPD may increase risk of collision for moose in VT. (Mountrakis and Gunson 2009)
• 4,000 VPD may be enough to kill most amphibians that attempt to cross the road. They are slower moving and spend more time in the roadway. (Seiler 2003).
• >5,000 VPD is enough to kill 50% of Blanding’s turtles (Litvaitis and Tash, 2008).
• A translocation study of small mammals (Chipmunk and mouse) indicated that the physical infrastructure of the road was the barrier, not traffic. Crossing success was the same along roads with comparable design but different traffic volumes. (McGregor et al 2008).
Citations


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