Planning and Design Considerations for Small Animals and Herpetofauna

**ROAD PLANNING AND MITIGATION DESIGN FOR SMALL ANIMALS:**
**CONCEPTS AND APPLICATIONS**

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**ABSTRACT**

Roads are the most common manifestation of urbanization, connecting communities within and between rural and heavily populated areas. As natural habitat continues to be developed for homes and businesses, and as transportation agencies consider climate change strategies, opportunities exist to preserve and restore connectivity for animals that are forced to move in pursuit of suitable resources. The 2005 Transportation Authorization (SAFETEA-LU) mandates the inclusion of professionally-trained ecologists early in the road planning process. Decision-makers must use the best information available to recommend the most cost-effective and expedient planning and mitigation techniques that minimize ecological disruption. A compilation of concepts and research is an effective means to facilitate proactive transportation planning that enhances both public education, and communication among professional sectors of society to find ways to minimize, mitigate, and even prevent road impacts. Ecologists can draw from a wealth of knowledge with respect to mitigation planning for large vertebrates. However, even though assessments of roads have shown significant negative impacts on small animals, this group has received little attention in the transportation planning process. In response to this knowledge gap, a group of experts have come together to develop a resource manual to maximize the effective use of ecological knowledge in transportation decision-making while raising the profile of small animal considerations among transportation professionals. The manual will focus on amphibians and reptiles when assessing road impacts on small animals. They are well-distributed and diverse in many landscapes, and high road mortality rates have been quantified for these animals. Their range of movements between many ecosystem types (e.g., aquatic-aquatic, aquatic-terrestrial and terrestrial-terrestrial) for breeding, foraging, and hibernation can be extended to other small vertebrate taxa (e.g., fish, small mammals). This paper will provide an overview of the concepts associated with road planning and mitigation design for small animals, including some applicable examples of mitigation solutions. Concepts include small animal natural history as applied to roads, direct and indirect impacts of roads, regional mitigation prioritization, and mitigation design. Throughout the paper we will use an ecosystem approach and consider the concepts and applications as developed in the literature for large vertebrates for application to small vertebrates. We will also briefly address the challenges and emerging considerations associated with transportation planning for small animals, such as the implications of climate change on movement and connectivity.

**OVERVIEW**

We have assembled a suite of experts to develop a resource manual for transportation planners, engineers and biologists that will maximize the effective use of ecological knowledge in transportation decision-making for small animals. The manual will include concepts and applications pertaining to road planning and mitigation design for small vertebrates. Small vertebrate groups include birds, fish, small mammals, and amphibians and reptiles. Much research exists on this topic for large vertebrates (e.g., Clevenger and Huijser 2009) as compared to smaller animals, even though assessments of road effects on small animals have demonstrated significant impacts on taxa such as amphibians and reptiles [herpetofauna] (e.g., Andrews et al. 2008).
Emphasis will be placed on herpetofauna species because revised planning considerations are warranted due to these organisms’ unique biological characteristics. The physiological, ecological, and behavioral traits that characterize amphibians and reptiles enhance their susceptibility to fragmentation and road mortality associated with road development (Andrews et al. 2008). Some examples include 1) their reliance on aquatic and upland habitats, and therefore the necessity to move across fragmented landscapes, 2) long life spans and older ages at first reproduction, and therefore a greater tendency to experience population-level effects from sex-biased mortality, and 3) an avoidance of open spaces for species with avian predators, and therefore increased impacts from barriers and fragmentation. Thus, herpetofauna can serve as models for protocols to resolve wildlife-transportation conflicts, and lessons learned from these animals can have broad applications for other small vertebrate taxa that utilize similar components of the landscape (e.g., fish, small mammals).

To summarize the concepts and applications, we have adopted an ecosystem approach that will look at terrestrial and aquatic landscape elements. For example, we will capture both terrestrial and aquatic passage types for small animals, especially passage types that have received the least attention. This book will be the first of its kind in North America and will provide detailed guidance on concepts such as mitigation design, including specific details such as construction documents and related information where available and tested. We will draw from the expert knowledge with caveats where recommendations have not yet been tested. It will include case studies to help illustrate specific applications of concepts, success stories, and lessons learned. We will acknowledge research gaps to help drive new efforts in less-studied areas. This book will provide the tools to facilitate adaptive management approaches for instances where new targeted objectives are specified, as well as when a need arises to enhance an existing approach.

**CONTENT**

**Policy and Planning**

In our introductory chapters, we will provide background on the current planning and design processes that road planning government agencies typically undertake when building roads or providing new mitigation measures along roads. We will use processes related to the Federal Highway Administration and State Departments of Transportation, as these organizations are key players in transportation planning in many areas. Planning processes often begin 10 or more years in advance of a road building project, so we will discuss the role of Metropolitan Planning Organizations (MPO) as well as options to avoid, minimize, or mitigate potential problems. We will describe the process of working with engineers when specific design considerations are proposed or needed, and developing and/or working within project schedules. In addition, we will provide background on existing Federal, State, and Local legal and regulatory authorities, regulations and processes, with specific details regarding private road design policies and funding sources in addition to compliance with respect to Environmental Impact Assessments, the National Environmental Policy Act (NEPA), and the Endangered Species Act (ESA). We will highlight policies that designate funding for certain types of wildlife-related mitigation and avoidance measures, Project Development and Environment (PD&E) studies and other related opportunities.

**Natural History**

Following the planning and policy background chapters, we will feature life history traits or adaptations such as behavior, vagility, and physiological requirements for small animal species or species groups. We will focus on the most pertinent traits and or adaptations that will influence how they will interact with roads by moving through the landscape to access required resources. These traits are important to summarize because they set the framework to determine road impacts (e.g., the risk of roadkill and fragmentation effects and mitigation solutions) for this group of animals. For example, relative to large animals such as wolves and grizzly bears, small animals typically do not move large distances across the landscape. Even so, in areas with high road density and regional distributions of isolated populations of herpetofauna, road mortality can be a significant threat to these populations (Gunson et al. 2009). In addition, animal behavior and natural history traits can be integrated with mitigation planning to provide effective measures enabling small animals to safely cross roads. Species will be grouped into taxonomic groups or into ecosystem-based similarities (e.g., fully aquatic species vs. aquatic breeders, or fully terrestrial species vs. terrestrial breeders) to best fit the concept currently being discussed.

**Direct and Indirect Effects**

The most obvious impacts of roads are direct effects (see examples in Forman and Alexander 1998), which result in injury or death as a consequence of road construction followed by on-road mortality (roadkills) from contact with vehicles. We will address the direct effects of roads, as separated into two components: landscape effects and population effects. The landscape effects component will include a discussion of road density considerations, habitat
loss (e.g., draining or filling of a wetland or cutting of a forest stand), as well as fragmentation impacts (e.g., roads fracturing a larger habitat, such as a forest or grassland into smaller pieces). The population effects component will include discussion of the impacts of roadkill and fragmentation on small mammal populations (see review by Fahrig and Rytwinski 2009).

We will also discuss the indirect effects of roads, namely the “edge or barrier effects” (Forman and Alexander 1998; Andrews et al. 2008; Jacobson 2009) as pertinent for small vertebrates. More specifically avoidance behaviors (e.g., due to traffic volumes, noise, temperatures, open space or increased artificial light); and attraction behaviors such as roadside litter/food scraps or other roadkill creating foraging locations, differences in soils and open canopies along road edges attracting animals for nesting or basking, and impacts of vegetation communities associated with disturbed road side. Lastly we will discuss differences in crossing behaviors (e.g., freeze response by animals evolved to be camouflaged in natural habitats, Andrews and Gibbons 2005) and their impacts on road mortality risk. We will also consider other indirect effects such as pollution stemming from chemical runoff, noise and light and their impacts on small animals.

**SOLUTIONS**

Regional Mitigation Planning

Following the above chapters introducing and summarizing particular concepts and considerations, we will present applied solutions from an ecosystem perspective. In particular, we will first describe connectivity indices that will include cutting edge concepts for placement of roads and their associated mitigation measures. For example, effective mesh size (Jaeger 2000) which includes road density measures, can identify where fragmentation caused by roads is a concern for the target species, and road bundling can identify where roads can be placed to maximize connectivity or movement of animals.

Transportation planners and decision-makers need to know where cost-effective mitigation measures are most required to create a permeable road network for wildlife to move across the landscape. Often planners rely on connectivity, or linkage, analyses in a Geographic Information System (GIS) that prioritizes locations for wildlife-road mitigation. These analyses are well-established for wide-ranging large mammals and typically use weighted cost algorithms (Boone and Hunter 1996; Schippers et al. 1996; Clevenger et al. 2002; Larkin et al. 2004; Austin et al. 2005) to measure movements in the landscape. However, much of the methodologies defined for large mammals cannot be applied to smaller fauna in a GIS, particularly because they move at smaller scales and utilize more specific habitat not defined by available geospatial layers.

We will first look at a rapid assessment of wildlife linkages developed by Ruediger et al. (2004) that determines where to prioritize mitigation measures along road networks from a broad perspective. We will then zoom in on a suite of tools that take into account small animals that can be used when considering placement of mitigation measures along road networks. These tools will integrate metapopulation theory and the spatial scale of movements to map and connect preferred habitat patches in the landscape, such as preferred wetlands defined for a wetland-forest amphibian or reptile species (Van der Grift and Pouwels 2006). We will then use cutting edge techniques to determine where to prioritize mitigation within metapopulations (e.g., see gravity models in Beaudry et al. 2008).

Following our connectivity approach above we will define methodology that can be used to predict roadkill hotspots proactively along roads that have not been built, or retroactively along roads that already exist. We will use an ecosystem-based approach that considers roadkill hotspots for aquatic and/or terrestrial species. For example, road mortality for amphibians and reptiles is highly elevated where roads bisect wetlands (Ashley and Robinson 1996; Smith and Dodd 2003; Aresco 2005; Langen et al. 2009; Andrews et al. 2008).

Ecosystem-based Mitigation Design

This chapter will provide specific guidance and recommendations for prioritizing mitigation strategies that work well within the scope of the small animal group. We will define road mitigation techniques for wildlife ranging from the use of crossing structures to wildlife warning signage. We will apply lessons that have been learned from mitigation with large vertebrates to smaller animals. For example, many modifications have been made to the traditional crossing structure to accommodate small animals. Van der Grift (2009) describes the use of aquatic pools to facilitate passage by amphibians on overpasses in the Netherlands. Relative to those for large animals, crossing structures for small animals are generally smaller in size (e.g., underpass, Dodd et al. 2004) but can be more numerous throughout road networks. In areas with dense road networks, mitigation measures are required that will be cost-effective, flexible, and that can be placed in
numerous locations as part of a connected landscape strategy. We also provide guidance regarding pre-construction mitigation opportunities and successful case studies for retro-fitting existing structures (e.g., culverts).

Wildlife warning signage is an example of a mitigation strategy that has been used to mitigate impacts of roads on motorists and large mammals (e.g., leaping stag sign) and is currently being applied to small animals, e.g., turtles in Ontario. Wildlife crossing signs serve this purpose because they are relatively cheap (e.g., $500.00 each), easy to erect and less permanent (e.g., they can be deployed seasonally, moved, or replaced by a more substantial mitigation measure such as an underpass). However, these benefits are also disadvantages because they facilitate rapid deployment and may not be strategically placed to maximize performance. This strategy is evolving and requires adaptive evaluations and management to apply what has been learned to new and innovative mitigation scenarios.

In Ontario, the Ministry of Transportation is currently investigating the development of a sign(s) along high volume roads to alert motorists of high risk crossing locations for small animals that are listed as Species at Risk (see http://www.eco-kare.com/turtle_sign_inventory.html) which would include 7 turtle species. The investigation will draw on lessons learned from the placement of over 700 turtle crossing signs by municipalities and non-government agencies and apply them to a provincial sign policy. The project entails obtaining an accurate location inventory of municipal turtle crossing signs for GIS mapping. These locations will then be compared to a validated turtle roadkill hotspot map (Gunson et al. 2009) to determine if they are in the right place. Results will be used to advise the Ministry on effective policy for placement of wildlife caution signs on provincial roads.

In 2010, a monitoring program initiated by the Toronto Zoo Adopt-A-Pond Wetland Conservation Programme and the Ministry of Transportation showed that a retro-fitted culvert was successful at facilitating safe passage for Blanding’s Turtle (Emydoidea blandingii), a species listed as Threatened on the regional Species at Risk list. The culvert was a 25-m long, 1.8-m diameter corrugated steel drainage culvert that had been retro-fitted with the addition of a permanent chain link fence (0.5 m high) with an extension lip, extending approximately 50 m on either side of the culvert on both sides of the road. During two months of monitoring, 46 occasions of culvert use by 14 individual turtles were confirmed by drawing from lessons learned from existing designs for both small and large vertebrates and applying these to new innovative designs for small animals. Traditionally, many crossing structure types have been used that did not take into consideration an understanding of the biological effects of roads on small taxa.

Post Construction Monitoring and Adaptive Management

Following the mitigation design and placement sections we will finish with post-construction monitoring considerations by drawing from lessons learned from existing designs for both small and large vertebrates and applying these to new innovative designs for small animals. Traditionally, many crossing structure types have been used that did not take into consideration an understanding of the biological effects of roads on small taxa. We will provide guidance on specific monitoring approaches that will facilitate our understanding of the efficacy of various mitigation techniques. We will examine monitoring from an adaptive management approach, and define opportunities and constraints for monitoring within the existing policy framework. Furthermore, we will discuss methods for creating baseline datasets that can be supplementary to future monitoring techniques. Finally, we will provide examples for public involvement including “citizen science” to assist in large-scale monitoring programs.

CONCLUSIONS

While our scope focuses on small animals, emphases on particular groups of species (e.g., amphibians and reptiles) will naturally occur. The ecosystem perspective, however, will allow for species groupings beyond taxonomic similarity and into habitat-based similarities or specializations (e.g., fully aquatic species vs. aquatic breeders, or fully terrestrial species vs. terrestrial breeders) to allow for efficient application to all groups of small animals. While road planning and mitigation concepts for many larger vertebrate groups are required for safety reasons due to injuries sustained from humans involved in collisions with wildlife, we will present concepts that go beyond safety and discuss population and metapopulation health for small animals. We will discuss feasible, flexible, and cost-effective solutions that will minimize regulatory burdens (i.e., proactive measures to avoid new ESA listings and to ensure compliance with NEPA). We will use case studies and technical drawings throughout to further illustrate concepts and applications. We will identify post-construction monitoring techniques that will inform proactive placement and construction of new and innovative mitigation designs while also identifying where research and monitoring is lacking. We will integrate emerging issues such as climate change and other rapid landscape-level changes that will impact movement pathways and long-term viability of small animals across regional landscapes. These efforts will combine research guidelines already developed for large mammals with new informed guidelines from experts actively working with roads and small animals to provide a current and detailed source of information for application to transportation mitigation planning, and design for small animals.
ACKNOWLEDGEMENTS

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BIOGRAPHICAL SKETCHES

Andrews received her PhD in Ecology (2010) from the University of Georgia’s Odum School of Ecology through work at the Savannah River Ecology Laboratory (UGA SREL) under the advisement of Dr. Whit Gibbons. She holds a joint position as an Education Program Specialist at SREL and the Research Coordinator at the Georgia Sea Turtle Center on Jekyll Island, GA. Her research focuses on wildlife conservation with emphases on spatial ecology and developing approaches for retaining ecological viability and permeability in urbanizing landscapes. She chairs the PARC (Partners in Amphibian and Reptile Conservation) Roads Task Force group whose objective is to disseminate information, form collaborations, and assist in product development that inform wildlife enhancement components of transportation projects. She conducts road ecology research and assessments, attends conferences focusing on transportation designs and has conducted and completed multiple grants from transportation agencies. Additionally, she works with the Jumby Bay Hawksbill Project in Antigua, West Indies, to develop restoration and management recommendations for hawksbills on developing beaches in the Caribbean. She serves as a researcher and educator for coastal residential development projects in South Carolina which address impacts of development designs on wildlife movement patterns, human-wildlife interactions, water quality and run-off maintenance, and long-term ecosystem functioning. Andrews also holds an M.S. in Conservation Ecology and Sustainable Development (2004) and a B.S. in Ecology (1999) from the University of Georgia.

Nanjappa holds a M.Sc. in Biology from Ball State Univ. (2000) and a B.Sc. in Biology from Iowa State Univ. (1996). She leads the Association of Fish and Wildlife Agencies’ (AFWA) national amphibian and reptile conservation and policy efforts. She provides executive staff assistance to the AFWA Amphibian & Reptile Subcommittee (reporting to the AFWA Wildlife Resource Policy Committee), and coordinates activities with and for the States through PARC. Thus, she has an in-depth working knowledge of the state wildlife agencies at the national level. She was involved previously in regional- and national-scale amphibian and reptile research, monitoring, and conservation activities including the USGS Amphibian Research and Monitoring Initiative, Northeast Region as well as Northeast PARC (2001-2005), and also assisted in the development and national coordination of the National Amphibian Atlas distribution maps website and database (1998-2005). The latter was initiated with her graduate work, in association with the book project, Amphibian Declines: Status and Conservation of United States Species (edited by Michael J. Lannoo, Ph.D.), in which she co-authored the Introduction and several species accounts.

Riley graduated in 1988 from Stanford University with a B.A. in Human Biology, concentrating in Animal Behavior and Ecology and obtained his Ph.D. in Ecology in 1999 from the University of California, Davis. Since his first professional experience with the National Park Service in Washington, D.C. in 1987, Seth has been interested in wildlife in urban areas and the effects of urbanization and habitat fragmentation on animal ecology and behavior. At the beginning of 2000, Seth began in his current position with the National Park Service as Wildlife Ecologist Santa Monica Mountains National Recreation Area, and he also has an adjunct position with the Department of Ecology and Evolutionary Biology at UCLA where he advises students and teaches graduate seminars. His current projects, all related to the impacts of urbanization and fragmentation on wildlife, include a bobcat telemetry study, a mountain lion GPS telemetry study, stream surveys for amphibians, pitfall/drift fence trapping to determine terrestrial reptile and amphibian distribution and abundance, projects with California Department of Transportation to determine road impacts on wildlife, and evaluation of the effects of rodenticides on non-target wildlife. A recent project was co-editing a book on Urban Carnivores, for which Seth co-authored seven chapters.

Gunson holds a M.Sc. in Conservation Biology from the University of Cape Town, South Africa and another M.Sc. in Geospatial Technologies from the State University of New York, in Syracuse, New York and received a B.Sc. in Zoology and Ecology from the University of Calgary. She is a road ecologist and principal for Eco-Kare International, a company initiated in Toronto, Ontario in 2009, in response to a need to translate road ecology science for practical application to...
road mitigation projects. In addition, Kari has presented at four International Conferences in Ecology and Transportation, and most recently at the 2010 European International Road Conference in Hungary, Europe. Kari participated with a team of professionals in the ARC International Wildlife Design Competition where her team was awarded one of five finalist positions. Kari’s passion for road ecology began on the Trans-Canada Highway Project in Banff National Park in 1999, where she worked as a research associate for 6 years, monitoring Canada’s first overpasses, underpasses and culverts. In the past 12 years she has worked with several faunal species including frogs and turtles in Eastern North America, and grizzly bears in Montana, and Alberta. In Ontario, Kari is a co-founder of the Ontario Road Ecology Group, and has been instrumental in designing, and monitoring several road mitigation projects such as the Highway 69 wildlife overpass.

REFERENCES


PERFORMANCE OF WILDLIFE CROSSING ENHANCEMENTS TO EXISTING ROADWAY CULVERTS AND BRIDGES IN CENTRAL FLORIDA

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ABSTRACT

When travel lanes were added to several major roads in central Florida, certain bridges and culverts were upgraded with wildlife crossing accommodations, such as ledges, built as an alternative to expensive dedicated wildlife crossing structures. This paper presents research conducted on the response of wildlife to these enhancements. The study area included thirteen sites on five major state roads across east-central Florida.

The effectiveness of the enhancements was evaluated by monitoring successful and unsuccessful (road-kills) animal movements across roads in the vicinity of each crossing. Multiple methods were applied to evaluate activity by different species. For instance, remotely operated cameras and tracking stations were used to capture use by medium to large species, and drift fences/pitfall traps were used to determine use by small mammals and herpetofauna.

We conducted road-kill and track surveys at all wildlife crossing sites. Mark-recapture studies were performed at four of these locations for small mammals and herpetofauna to determine effects of the highways on species presence-absence, avoidance behavior and potential crossing use. Data was collected from November 2004 to April 2010.

Detailed results including species use, presence and absence are presented for each site. For all study locations we documented 176 different species. This included 17 state and federally listed species and 9 other species of conservation interest. Data included a total of 39,993 road-kills and 13,686 tracks within wildlife crossings for all the study sites. Results of mark-recapture studies of small mammals and herpetofauna included 1,250 individuals within wildlife crossings and 5,799 individuals at control locations.

A wide diversity of avian species was negatively affected by vehicle strikes. Most can be reduced by using appropriate fencing to reduce the amount of prey species killed on road-sides and altering flight trajectories into traffic. Numerous rodent, frog, lizard and snake tracks were recorded in the larger wildlife crossings. Large numbers of road-killed frogs and snakes were also observed at nearly all study sites; this was attributed to inadequate fencing, not avoidance of the wildlife crossings. Other than gopher tortoise, few turtle species were recorded as road-kills or using the wildlife crossings. Several factors may contribute to this lack of data: effectiveness of fencing, low population levels, road avoidance, and habitat selection. Carnivores used most of the crossing structures. Road-kills were only significant at one of these locations, occurring beyond the existing wildlife fences. White-tail deer were documented at all study sites, but road-kills were significant at only three sites; these were also a result of individuals circumventing the existing wildlife fencing.

An unexpected finding of this study was that most of the structures had design and/or construction flaws that seriously interfered with their functioning for wildlife use. Problems and corrective measures at each wildlife-crossing location are categorized by structure, approaches, substrate, fencing, and vegetation and cover. A discussion of the shortcomings of the conventional design process and a description of the multidisciplinary Wildlife Crossing Design Team created by the Florida DOT are presented.

INTRODUCTION

Two rural two-lane roads (SR 520 and US 192) in east-central Florida were expanded to four lanes. The roads traversed miles of relatively undeveloped but privately owned ranch land, in which the only identifiable corridors for wildlife movement were along wetland systems. Several of the major systems clearly served as corridors, but no one corridor appeared more significant in the region than any of the others. Therefore, without any clear candidates for significant and expensive regional crossings, wildlife accommodations were retrofitted into the existing drainage structures that crossed the major wetland systems.

This study was intended to test the effectiveness of these compromise solutions and develop design guidelines based on their performance. The effectiveness of the enhancements was evaluated by monitoring successful and
unsuccessful (road-kills) animal movements across roads in the vicinity of each crossing. Multiple methods were
applied to evaluate activity by different species. For instance, remotely operated cameras and tracking stations were
used to capture use by medium to large species, and drift fences/pitfall traps were used to determine use by small
mammals and herpetofauna. The study was conducted between November 2004 and April 2010.

An unexpected finding of this study was that most of the structures had design and/or construction flaws that seriously
interfered with their functioning for wildlife use. Ledges built for walkways ended abruptly at the ends of the structures,
with no transition and even significant obstacles between the ledges and the surrounding habitat. Fields of boulders for
scour protection rendered wide bridged floodplains unfit for passage by deer. Fences had gaps or actually led to the
road. These problems and recommended solutions are described in the Discussion.

METHODS

We conducted road-kill and track surveys at 13 wildlife crossings located on SR 40, SR 46, SR 520, SR 415 and US 192
(fig 1, table 1). The road surface and immediate shoulder were checked in either direction from each crossing structure
for road-kills by driving surveys at 10 or less mph. Distance checked at each site varied to some degree by site
characteristics. Generally, each site was intensively checked approximately 500 m in either direction for all vertebrates.
Sand-tracking stations were placed within or under each structure in dry areas. Tracking stations were 1-m wide, with
tracking material consisting of a native substrate/builder’s sand mix approximately 3-4-cm deep. Tracks were recorded
for all medium-large species. Road-kill and track data was collected from each site for a minimum of two years. At
strategic locations, e.g., by culverts or other road-crossing structures, infra-red triggered 35mm cameras (Camtrakker™)
were placed to supplement tracking stations. Sites were selected to minimize the probability of theft or vandalism.

Mark-recapture studies on small mammals and herpetofauna were performed in the last year of the study at four of
these locations. A stratified random block design (designated sections and traps randomly selected) was used to
determine trap location. Increments of 50 – 200 m, 200 – 350 m, and 350 - 500 m away from each crossing was used
for control sites. Experimental sites included traps within the structure and within 50 m of the crossing (within the road
right-of-way). Data collected was used to compare controls to the experimental locations (crossings) for presence-
absence and potential use by various species in proximity to each wildlife crossing. Drift fence arrays consisted of either
50 ft. metal flash-fence with four 5-gal bucket pitfall traps and two screen funnel traps or 100 ft. silt fence with six 5-gal
bucket pitfall traps and 4 screen funnel traps. Trapping was conducted 3 days per week.
Table 1. Study Site Structural Attributes (also see fig. 1 for site locations).

<table>
<thead>
<tr>
<th>Site Location</th>
<th>Road</th>
<th>Structure</th>
<th>H (m)</th>
<th>W (m)</th>
<th>L (m)</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Underpass (Wekiva Sp)</td>
<td>SR 46</td>
<td>culvert</td>
<td>2.7</td>
<td>7.5</td>
<td>14.4</td>
<td>upland crossing</td>
</tr>
<tr>
<td>New Underpass (Wekiva Sp)</td>
<td>SR 46</td>
<td>bridge</td>
<td>2.6</td>
<td>18.2</td>
<td>15.3</td>
<td>upland crossing</td>
</tr>
<tr>
<td>Little Tomoka River (LTR)</td>
<td>SR 40</td>
<td>culvert x 2</td>
<td>1.5</td>
<td>3.1</td>
<td>46.8</td>
<td>on either side of creek culvert</td>
</tr>
<tr>
<td>Gator Head* (west of LTR)</td>
<td>SR 40</td>
<td>bridge x 2</td>
<td>1.8</td>
<td>8</td>
<td>13.8</td>
<td>median opening (8.2 m); 11.7 m total width with slopes</td>
</tr>
<tr>
<td>Mud Creek</td>
<td>SR 415</td>
<td>bridge</td>
<td>2.3</td>
<td>13.5</td>
<td>14.3</td>
<td>37 m total width; two earthen ledges</td>
</tr>
<tr>
<td>St. John’s Basin crossing*</td>
<td>SR 520</td>
<td>bridge x 2</td>
<td>2.5</td>
<td>1.5</td>
<td>13.2</td>
<td>median opening (7.7 m); 15.4 m total width with slopes and channel; two 1.5 m wide earthen ledges</td>
</tr>
<tr>
<td>Jim Creek*</td>
<td>SR 520</td>
<td>bridge x 2</td>
<td>2.2</td>
<td>&lt; 3 ea</td>
<td>14.5</td>
<td>median opening (6.5 m); 49.9 m total width with slopes and creek</td>
</tr>
<tr>
<td>Second Creek*</td>
<td>SR 520</td>
<td>bridge x 2</td>
<td>2.2</td>
<td>&lt; 3 ea</td>
<td>14.5</td>
<td>2 x 0.9 m concrete ledges; 3.8 m total culvert width, 2.3 m total culvert ht</td>
</tr>
<tr>
<td>Tootosahatchee Cr. (N 520)</td>
<td>SR 520</td>
<td>culvert</td>
<td>1.1</td>
<td>0.9</td>
<td>50.6</td>
<td>0.9 m concrete ledge; 2.4 m total culvert width, 1.8 m total culvert ht</td>
</tr>
<tr>
<td>Harmony (Jug Creek)</td>
<td>US 192</td>
<td>culvert</td>
<td>1.2</td>
<td>0.9</td>
<td>50.6</td>
<td>median opening (9.1 m); 46.3 m total width with slopes and creek; two 9.1 m wide earthen ledges</td>
</tr>
<tr>
<td>Crabgrass Creek*</td>
<td>US 192</td>
<td>bridge x 2</td>
<td>3.1</td>
<td>9.1</td>
<td>14.5</td>
<td>median opening (7.1 m); 42.8 m total width with slopes and canal; two lower and upper ledges</td>
</tr>
<tr>
<td>Canal C-57*</td>
<td>US 192</td>
<td>bridge x 2</td>
<td>4.3, 0.9</td>
<td>1.4 ea</td>
<td>13.2</td>
<td>median opening (7.8 m); 18.5 m total width with slopes and creek, 1.9 m total ht; two 1.4 m wide ledges</td>
</tr>
<tr>
<td>Sawgrass Creek*</td>
<td>US 192</td>
<td>bridge x 2</td>
<td>0.9</td>
<td>1.4</td>
<td>13.2</td>
<td>median opening (7.8 m); 18.5 m total width with slopes and creek, 1.9 m total ht; two 1.4 m wide ledges</td>
</tr>
</tbody>
</table>

* reflects passage length of single span only (for total passage length, multiply by 2 and add width of median)

RESULTS

For all study locations we documented 176 different species. This included 17 state and federally listed species and 9 other species of conservation interest. Data included a total of 39,993 road-kills (table 2). Diversity of road-kills varied between sites; from 31 to 77 species. We also recorded 13,686 tracks within wildlife crossings for all the study sites; number of species varied between sites, from 3 to 17. Culvert sites had less total tracks and diversity of species than bridge sites. Results of mark-recapture studies of small mammals and herpetofauna included 1,250 individuals within wildlife crossings and 5,799 individuals at control locations. Diversity of species captured was greater in control traps than crossing traps.
Table 2. Site Summary of Road-kill, Track and Trap Occurrences.

<table>
<thead>
<tr>
<th>Roadkills</th>
<th>No. of species</th>
<th>Tracks</th>
<th>No. of species</th>
<th>Captures (in-crossing)</th>
<th>No. of species</th>
<th>Captures (controls)</th>
<th>No. of species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Tomoka Creek*</td>
<td>497</td>
<td>37</td>
<td>299</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gatorhead</td>
<td>4,435</td>
<td>49</td>
<td>307</td>
<td>7</td>
<td>25</td>
<td>13</td>
<td>292</td>
</tr>
<tr>
<td>Wekiva east</td>
<td>10,252</td>
<td>54</td>
<td>3,727</td>
<td>16</td>
<td>1,084</td>
<td>30</td>
<td>4,966</td>
</tr>
<tr>
<td>Wekiva west</td>
<td>792</td>
<td>46</td>
<td>3,435</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mud Creek</td>
<td>2,169</td>
<td>76</td>
<td>1,158</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North 520*</td>
<td>755</td>
<td>58</td>
<td>317</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second Creek</td>
<td>1,962</td>
<td>37</td>
<td>312</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jim Creek</td>
<td>1,997</td>
<td>31</td>
<td>318</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>St. Johns</td>
<td>6,512</td>
<td>77</td>
<td>2,095</td>
<td>16</td>
<td>3</td>
<td>3</td>
<td>195</td>
</tr>
<tr>
<td>Harmony*</td>
<td>2,253</td>
<td>45</td>
<td>57</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crabgrass Creek</td>
<td>2,602</td>
<td>48</td>
<td>159</td>
<td>7</td>
<td>138</td>
<td>13</td>
<td>326</td>
</tr>
<tr>
<td>C-57 Canal</td>
<td>2,837</td>
<td>59</td>
<td>513</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sawgrass Creek</td>
<td>2,930</td>
<td>47</td>
<td>989</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>39,993</strong></td>
<td><strong>13,686</strong></td>
<td><strong>1,250</strong></td>
<td><strong>5,779</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: tracks include only those that successfully used the crossing; an asterisk denotes a culvert site.

Wekiva East, Saint Johns and Gatorhead had the greatest number of road-kills while Wekiva East and West, Saint Johns and Mud Creek were the most productive wildlife crossings (see track data, table 2). Wekiva East also exhibited the greatest abundance and diversity of captured small mammals and herpetofauna. This site was the oldest structure of all study locations (10 yrs old when the study began), while most other structures were replaced during this study (except Mud Creek and Wekiva West) and experienced significant local habitat disturbance from construction activities. These factors may contribute to lower abundance and diversity as some wildlife need time to acclimate to changes in habitat and road configuration. Performance of each structure is discussed in more detail below.

Species Use, Presence and Absence by Structure

**Culverts – Small Structures**

**Little Tomoka Creek.** Only three species (rabbit, raccoon and river otter) were recorded moving through the west culvert from one side of the road to the other. A total of 563 individual crossing opportunities were recorded at Little Tomoka Creek from 2008 - 2009. Only raccoons consistently used the structure (54% or 297 of 547 crossed through). Other species or faunal groups present at the site (from tracks, live observations or road-kills) included wild turkey, 10 other species of birds, bobcat, canids, grey squirrel, nine-banded armadillo, Virginia opossum, white-tailed deer, American alligator, 12 snake, 7 turtle, and 3 frog species.

**Little Tootoosahatchee Creek (North 520).** From 2005 - 2008 a total of 360 individual crossing opportunities were recorded. Six different species or faunal groups were recorded crossing through the culvert at this site. Only raccoon and Virginia opossum were abundant and they used the structure to cross from one side of the road to the other at rates of 91% and 86%, respectively. Other species or faunal groups present at the site (from tracks, live observations or road-kills) included wild turkey, 14 other species of birds, bats, hispid cotton rat, other shrews and rodents, bobcat,
coyote, other canids, marsh rabbit, cottontail rabbit, nine-banded armadillo, striped skunk, white-tailed deer, American alligator, 10 species of frogs, 4 species of lizards, 21 species of snakes and 6 species of turtles.

Harmony (Jug Creek). The wildlife crossing structure was used by bobcat, domestic cat, raccoon, river otter and Virginia opossum. A total of 81 crossing opportunities were documented from 2008 – 2010. Similar to Little Tomoka Creek, raccoons were most abundant and crossed through most often (66% or 43 of 65 recorded). Other species recorded at the site, but not using the structure (from tracks, live observations or road-kills) included coyote, other canids, nine-banded armadillo, white-tail deer, hispid cotton rat, other rodents, wild turkey, 9 other species of birds, American alligator, brown anole, 6 species of frogs, 18 species of snakes and 7 species of turtles.

The structures at North 520 and Harmony are not large enough to accommodate white-tail deer or other large wildlife, therefore wildlife-vehicle collisions with these species will continue in the absence of adequate fencing.

Bridges or Bridge Culverts – Large Structures

Gatorhead. From 2008 – 2010 we recorded 397 crossing opportunities (from track data). The wildlife crossing was used by 9 species or faunal groups documented at the site. These included great blue heron, wild turkey, domestic cats/dogs, raccoon, river otter, Virginia opossum, white-tail deer and southern toad. Raccoon was most abundant (229 of 279, 82% crossing rate), Wild turkey (30 of 31, 97% crossing rate), Virginia opossum (33 of 35, 94% crossing rate) and white-tail deer (9 of 36, 25% crossing rate) also commonly visited the crossing. The lack of data on use by smaller species is likely due to reduced capture success because the concrete base underlying the structure prevented us from installing pitfall traps.

Other species or faunal groups recorded at the site (from tracks), but not observed using the structure included bobcat, nine-banded armadillo, other birds, bobcat, rabbits, snakes, coyote and other canids. Several additional species were recorded as road-kill and absent from the crossing data including: round-tail muskrat, cottontail rabbit, brown anole, six-lined racerunner, American alligator, 6 frog, 18 snake, 5 turtle and 15 bird species. Besides road-kills we also captured several species in control traps that were not documented within the wildlife crossing: 5 small mammal, 5 frog, 4 lizard and 2 snake species.

Wekiva East. The oldest of all the wildlife crossings monitored in this study (built in 1994), resident wildlife are well acclimated to its location and surroundings. This is reflected in the track data collected. From 2007 – 2010, we recorded 3,727 individuals of 19 species or faunal groups using the structure. Raccoon (533), Virginia opossum (529), white-tail deer (500), FL black bear (381), bobcat (354), snakes (293), nine-banded armadillo (263), coyote (191), rabbits (182), wild turkey (180) and gray fox (164) were most abundant. We also recorded one small mammal, six frog and five snake species (from in-crossing traps) using the wildlife crossing at Wekiva East.

Several additional species were recorded as road-kill and absent from the crossing data at each site including: domestic cat, 6 snake, 3 turtle, 2 small mammals and 13 bird species. Besides road-kills we also captured several species in control traps at Wekiva East that were not documented within the wildlife crossing: 4 small mammal, 10 frog, 1 salamander, 6 lizard and 7 snake species.

Wekiva West. Though not as old (construction completed in late 2004) or with as well established vegetation and cover as Wekiva East, this was also a highly functional wildlife crossing. From 2007 – 2009 we recorded tracks of 3,435 individuals of 18 species or faunal groups using the structure. White-tail deer (935), nine-banded armadillo (653), Virginia opossum (574), raccoon (336), FL black bear (310), coyote (139) and bobcat (131) were most abundant. Cameras also captured photographs of additional species, river otter and wood stork, using the wildlife crossing. We recorded several species of road-kill absent from the crossing data at each site: brown anole, 6 frog, 16 snake, 4 turtle, 5 small mammals and 7 bird species.

Bridges with Ledges

Mud Creek. A total of 1,158 individuals of eighteen species or faunal groups were recorded using the wildlife crossing from 2005 – 2008 (from track and photographic data). Raccoon (714), nine-banded armadillo (212) and Virginia opossum (90) were most abundant. Other notable species using the structure were FL black bear (2), bobcat (33) river otter (5), wild turkey (9) and white-tail deer (15). Other species present at the site (from tracks, live observations or road-kills) but not recorded using the crossing included bats, wood stork, 24 other species of birds, American alligator, 5 lizard, 10 frog, 26 snake, 6 turtle and 7 small mammal species.

Second Creek. A total of 436 individual crossing opportunities were recorded from 2008 – 2009. Ten species or faunal groups (bobcat, other felids, nine-banded armadillo, raccoon, river otter, Virginia opossum, white-tail deer, wild pig,
Egrets and snakes) were recorded moving through the wildlife crossing. Only bobcat (68% or 27 of 40 crossed through), raccoon (60% or 183 of 303 crossed through) and Virginia opossum (59% or 33 of 56 crossed through) were relatively abundant and consistently used the structure. Other species or faunal groups documented at the site (from tracks, live observations and road-kills) but not using the structure included coyote, other canids, striped skunk, American alligator, 2 lizard, 6 frog, 3 turtle, 14 snake, 12 bird and 3 small mammal species.

Jim Creek. In 2008 and 2009 a total of 442 individual crossing opportunities were recorded. Eleven species or faunal groups (bobcat, coyote, other felids/canids, marsh rabbit, nine-banded armadillo, raccoon, striped skunk, Virginia opossum, birds and snakes) were recorded using the wildlife crossing. Only bobcat (84% or 26 of 31 crossed through), nine-banded armadillo (77% or 94 of 122 crossed through) raccoon (65% or 124 of 192 crossed through) and Virginia opossum (70% or 54 of 77 crossed through) were relatively abundant and consistently used the structure. Several species were present at the site (from tracks, live observations and road-kills) that were not documented using the structure including river otter, wild pig, white-tail deer, American alligator, 3 turtle, 7 frog, 12 snake, 7 bird and 4 small mammal species.

Saint Johns. Monitored from 2006 to 2010, we recorded 2,095 successful crossings out of 2,254 attempts. Structure use by 14 different species or faunal groups was documented. Only bobcat (85% or 143 of 168 crossed through), river otter (95% or 366 of 387 crossed through) raccoon (93% or 1,163 of 1,255 crossed through) and Virginia opossum (100%, 307 crossed through) were relatively abundant and consistently used the structure. No small mammals, reptiles or amphibians were captured in traps located within the wildlife crossing. These results should not be interpreted to reflect lack of use by these smaller species; the substrate and design of the structure prevented us from installing pitfall traps and drift fences that dramatically reduced our capture success.

Species recorded at the site (from tracks, traps, live observations and road-kills) that were not observed using the wildlife crossing included FL black bear, wild pig, white-tail deer, skunks, Seminole bat, 8 small mammal, 21 bird, 6 turtle, 26 snake, 7 lizard and 13 frog species.

Crabgrass Creek. From January to March 2010 we recorded 193 crossing opportunities (from track data). The wildlife crossing was used by 6 species or faunal groups documented at the site. These included wild turkey, nine-banded armadillo, raccoon, river otter, Virginia opossum and white-tail deer. Raccoon was most abundant (79 of 116, 68% crossing rate). Wild turkey (25 of 26, 96% crossing rate) and Virginia opossum (30 of 39, 77% crossing rate) also were common and exhibited high crossing rates. We also recorded two small mammal, three frog and one lizard species (from in-crossing traps) using the wildlife crossing.

American alligator, bobcat, wild pig, spotted skunk, 3 lizard, 3 turtle, 10 frog, 22 snake, 10 bird and 5 small mammal species were also observed at or near the site (from tracks, traps, live observations and road-kills), but not within the wildlife crossing.

C-57 Canal. A total of 566 individual crossing opportunities were recorded from 2006 – 2008. Fifteen species or faunal groups were recorded using the wildlife crossing to pass from one side of the road to the other. Only raccoon (92% or 168 of 186 crossed through), Virginia opossum (96% or 163 of 169 crossed through), nine-banded armadillo (84% or 46 of 55 crossed through) and rabbits (73% or 52 of 71 crossed through) were relatively abundant. Several species were present at the site (from tracks, live observations and road-kills) that were not documented using the structure including gray fox, striped skunk, wild pig and white-tail deer, brown anole, 2 turtle, 7 frog, 19 snake, 21 bird and 4 small mammal species.

Sawgrass Creek. From 2006 to 2008 a total of 1,083 individual crossing opportunities were recorded. Sixteen species or faunal groups were recorded using the wildlife crossing. Five species were relatively abundant: raccoon (92% or 427 of 462 crossed through), Virginia opossum (91% or 222 of 244 crossed through), river otter (96% or 49 of 51 crossed through), bobcat (95% or 52 of 55 crossed through) and snakes (70% or 43 of 61 crossed through). Species present but not observed using the wildlife crossing (from tracks, live observations and road-kills) included: fox, wild pig, white-tail deer, spotted skunk, wild turkey, 2 turtle, 8 frog, 22 snake and 10 bird species.

DISCUSSION

General Trends

It should be noted that most birds recorded would not take advantage of the wildlife crossings as a means to cross the road (exceptions include wild turkey and bobwhite quail). Nevertheless, it is evident that a wide diversity of avian species is negatively affected by vehicle strikes. Raptor road-kills can be reduced by simply reducing the amount of prey
species killed on road-sides. Vehicle-related mortality of other birds is tied to habitat use. Most birds will typically perch in the tree-line adjacent to the road, or in the case of wading birds and waterfowl forage in roadside ditches or other adjacent water bodies. The flight trajectory on take-off for these taxa leads them into traffic where they are at risk for collisions with vehicles. Fencing could be one mechanism to change flight paths of birds to reduce the number of bird strikes with vehicles.

Numerous rodent, frog and lizard tracks were recorded in the wildlife crossings in the beginning of the study period. The high density of tracks and erratic movement paths made it difficult to record travel direction and thus distinguish those individuals using the crossings to get from one side of the road to the other versus those that resided in the vegetation and/or rocks near the structures. As a result, we stopped recording their tracks and made the assumption that the area under the structures not only served as suitable wildlife crossings for these taxa, but also as habitat. Large numbers of road-killed frogs were also observed at nearly all study sites; this is primarily a result of inadequate fencing, not reluctance to use the wildlife crossings. Few lizard and rodent road-kills were recorded. Road crossing avoidance by certain species of mice and rats has been documented in previous studies (Fahrig and Rytwinski 2009).

Numerous snake road-kills were documented at most sites; in addition we documented generic tracks of snakes using most of the wildlife crossings. We assume that many of the species documented as road-kills are the same species as those leaving generic tracks under the crossings. This demonstrates that snakes will use the crossings, but the associated fencing at present is ineffective at preventing access to the road and/or directing individuals to the location of the wildlife crossings.

Few turtle species were recorded as road-kills or using the wildlife crossings. Aside from gopher tortoise and Florida box turtle, most of the species observed were aquatic turtles. Several factors may contribute to this lack of data. First, the current fencing may be effective in preventing road-kills except in isolated situations where there was a break or gap in the fence. Second, the fact that most turtle species are aquatic dependents, they likely preferred to use the watercourse to cross under the road. Since we did not perform aquatic trapping, we cannot confirm this assumption. Third, the absence of data may reflect low population levels or road avoidance by certain species or cohorts of species, but since we did not perform any census of the turtle populations, we cannot evaluate this possible explanation. It is highly probable that all of these factors contributed to the amount of data we collected on turtle movement. Most turtle road-kills can be prevented by appropriate fencing.

Few road-kills of carnivores were recorded at the study sites except at Wekiva East. We recorded use by carnivores at most sites where they were present and the structure was of the appropriate size to accommodate them. Wekiva East was a problem site because of two factors: the distance between wildlife crossings (Wekiva East and Wekiva River) was too great and the fencing between these structures was inadequate.

Ungulates, in particular white-tail deer were documented at all study sites. Road-kill numbers were highest at the SR 40, SR 46 and C-57 Canal sites. In the case of SR 40 (Gatorhead) and SR 46 (Wekiva East and West) white-tail deer were recorded using the wildlife crossings. The road-kills were a result of animals circumventing the existing wildlife fencing at these sites. At Little Tomoka Creek and C-57 Canal we did not observe any use of the wildlife crossings by white-tail deer. Corrective measures will be needed at these sites and others to improve their function for white-tail deer.

**Identified Problems and Proposed Corrective Measures**

Based on the data collected from the study and observations made during site visits we documented problems at each site that would negatively influence their performance. These were divided into five major categories: structural, approaches, substrate, fencing, and vegetation and cover.

**Structural**

Three wildlife crossings possess structural inadequacies that need to be remedied to improve function.

1. The outside culverts flanking Little Tomoka Creek (SR 40) are flooded or retain water for the majority of the year. Water does not appear to flow properly from the wildlife culverts to the stream culvert, possibly as a result of erosion and deposition of sand from the steep ditch bank between the culverts, and/or possibly because their elevations are too close to the elevation of the stream channel culvert. **Corrective Measures:** FDOT Maintenance is evaluating corrective action. If repair of the erosion problem doesn’t dry out the wildlife culverts, it may be necessary to raise the base elevation of these structures, even though some overhead clearance would be lost.
2. The North 520 wildlife crossing was constructed with no means for wildlife to access the concrete ledges. Until a connection from the adjacent habitat is provided, this structure remains nearly non-functional. **Corrective Measures:** A project to correct some of the deficiencies discovered during the course of this research is under design as of the date of this document. Approach ramps for this crossing are included.

3. The wildlife crossing at Saint Johns (SR 520) has wire-enclosed gabions underlying the central channel. Smaller aquatic turtles observed using this channel have become entangled in the wire resulting in mortalities. These gabions need to be retrofitted to eliminate this problem. **Corrective measures:** The planned design specifies filling the space between the wire mesh and the rock fill with grout.

**Approaches**

Four of the wildlife crossings needed modifications to the approaches.

1. The drainage swales connecting the wildlife culverts and the stream culvert at the Little Tomoka Creek (SR 40) crossing also are flooded most of the year. **Corrective Measures:** If the swales continue to hold water after the flooding in the culverts is resolved (see the “Structural” and “Substrate” discussion sections for this crossing), then the swales may need to be piped to carry water under a dry approach path.

2. The approaches at North 520 also need to be elevated over adjacent swales. The ramps need to be at a gradual angle extending from the height of the ledges to the adjacent habitat. **Corrective Measures:** The approaches are designed to have dry pathways to the adjacent habitat.

3. Saint Johns (SR 520) sits above a low elevation marsh area to the south. An increase in terrestrial use would result from the creation of a raised trail across this marsh to adjacent habitat areas approximately 50 m to the southwest and southeast.

4. The Harmony (US 192) culvert approaches need to be redesigned. The north side ends in a closed depression; this causes drainage problems and results in increased water levels within the structure sometimes rendering the ledge impassable by terrestrial species. **Corrective Measures:** The northern approach needs to be re-contoured to reduce the slope leading to the adjacent property. In addition, stormwater conveyance at the north end needs to be redesigned, possibly diverting or detaining the flow into the structure. The southern approach has a similar problem as it sits below the grade of the adjacent habitat.

**Substrate**

Six wildlife crossing structures needed modifications to existing substrate to improve performance.

1. Silt build-up within the Little Tomoka Creek (SR 40) outside culverts has acted to block free flow of water. The result is a permanent pool of water within the structure. **Corrective Measures:** If proper flows can be restored, the silt may wash out; otherwise, it will need to be flushed out. If the elevations need to be increased, adding approximately one ft. additional concrete base within the structure would keep it dry for a larger percentage of the year and reduce potential silting and stormwater blockage. An alternative method is the use of a hanging metal shelf. The design should include a trough or other measure to maintain soil as a substrate, if possible.

2. At Mud Creek (SR 415) the northern ledge needs soil stabilization. Significant erosion has occurred from high flow velocities. In addition, large rip-rap partially blocks the NW corner of the path. **Corrective Measures:** Raising the elevation of the ledge and using multiple sized rip-rap along the shoreline for stabilization would improve the function of this for larger wildlife.

3., 4., 5. North 520, Second and Jim Creek all need significant modification. Large rip-rap has been placed across the entire movement path and acts as a significant barrier to movement by many species of wildlife (especially white-tail deer at Second and Jim Creek). **Corrective Measures:** An elevated path clear of obstruction needs to be established on both sides of the creeks (north end of North 520 and south ends of Second and Jim Creeks). Options include removing some of the rip-rap or using bedding stone or poured concrete between large rip-rap to create a raised, clear path among the large boulders. Preferable substrate over the permanent base material of the created paths is native soils. Walkable pathways at these crossings are being designed.
6. The ledges at the Saint Johns (SR 520) wildlife crossing have experienced some erosion in the median section due to precipitation and stormwater runoff. Currently, soil ledges are retained by a synthetic textile material. This material is somewhat flexible and allows for washouts to occur. **Corrective Measures:** We suggest a more permanent retainer such as a poured concrete edge or lip on the channel side be created to help stabilize the bank and reduce opportunities for washouts; plans include reinforcing the ledges at this crossing.

**Fencing**

All the wildlife crossing sites in the study required some modification to the fencing. Depending on the study site, three types of fencing needs were described: extension of large wildlife fencing (10 ft. high), extension of standard field fence (5 ft. high), and installation of fine mesh (¼ in. mesh, 3 ft. above and 1 ft. below ground) for herpetofauna.

Miscellaneous gaps in existing wildlife fences at several wildlife crossings also need to be fixed. Sites include Gatorhead, Mud Creek, Second Creek, Jim Creek, St. Johns, Crabgrass Creek, C-57 Canal, and Sawgrass Creek. First, the wildlife fences need to be connected to the structures so that wildlife cannot climb the slope and access the road. Second, a lower-level fence also needs to be installed in the median (except Mud Creek) and along the outer section of the outside-lane barrier walls to prevent human access (at present it is easy to simply jump over the wall/guardrail). Many of these gaps are designed for correction. Lockable gates would be needed to allow access for maintenance and monitoring activities, once the gaps are closed.

**Vegetation and Cover**

Deficiencies existed at all crossings in the study with regard to landscaping. We recommended that native tree, shrub and groundcover enhancements be established at all wildlife crossing sites. Each site should be evaluated independently, but general guidelines for design can be applied universally.

Two types of species must be accommodated at most wildlife crossings. Certain prey species like white-tail deer prefer an open clear view through the crossing. They rely on wariness using acute sight and hearing to avoid predation. Whereas smaller prey species such as rabbits, mice and certain herpetofauna prefer vegetation, woody debris or other cover materials and hide to avoid predation. Therefore landscape or site plans for bridge crossings should include an open central path that has a clear view from one side to the other; it also should be bordered by a variety of native trees, shrubs and groundcover on the approaches and shade tolerant shrubs and groundcover within the crossing where light is sufficient. These plantings can be supplemented with the above discussed woody debris placed within the structure where light is insufficient. Smaller crossings are more limited and the landscape plan should fit that of the species that will be using it.

Planting arrangements should be non-uniform or random as to mimic natural recruitment. Density of plantings and diversity of species should be similar to adjacent habitat. Plantings at xeric sites should be interspersed with open sandy areas for species that prefer this substrate for movement.

Landscape management of wildlife crossing sites should be similar to that of adjacent habitat. Standard mowing practices are not appropriate at these sites as they should provide natural transition to habitat areas on either side of the road. By allowing similar shrub and groundcover heights to that of adjacent areas, it provides for unimpeded animal movements. Prescribed burning would be preferable if consistent with adjacent habitat management. Alternative mechanical methods for keeping vegetation of the same character as adjacent areas are acceptable when necessary.

**Process**

Appendix A is an ICOET poster presentation that featured some of the problems described above (Tonjes 2005). Some of the deficiencies were able to be corrected while the structures were still under construction, at minimal cost. But many problems were discovered too late. The Wildlife Crossing Design Team described below is overseeing the development of a separate project to correct most of the deficiencies, at considerably greater cost. The roadway projects studied were designed independently by several different engineering firms, so the problems were not limited to one individual designer or firm, but rather reflect a general difficulty in the process of wildlife crossing design.

Bridges and culverts have carried vehicles and water for a long time, and there are well-established standards for building structures to do so. Accommodating bicycles and pedestrians has grudgingly become accepted enough to have generated some guidelines and standards, and accommodating people with disabilities has, with the help of legislative clout, also made it into the design manuals. There is much less guidance for building wildlife crossings. Most wildlife crossing literature is not accessible to transportation professionals who are trying to answer questions about how
particular wildlife crossings should be designed and whether or not they’re worth the money. Existing studies only cover a haphazard combination of structures, roadways, habitats and species. Much more work is needed to make statistically valid generalizations involving the whole range of factors likely to be encountered by engineers. The needs for the wildlife accommodations that were studied in this research were identified during environmental studies that were conducted to comply with the National Environmental Policy Act (NEPA). NEPA applies to all projects with federal funding or permits. In a NEPA study, the locations and design concepts for the roadway and the structures are developed far enough to ensure that they will fulfill their purpose and to evaluate their environmental impacts and the need for any mitigation. When this Preliminary Engineering Study is approved, the project may advance to the detailed Design phase.

Transportation engineers are accustomed to consulting with environmental scientists in Preliminary Engineering, and environmental scientists determined the dimensions of the wildlife passages that would be needed in the structures. But they were not consulted in the Design phase, where the details of the materials and methods to be used in construction are determined.

During the course of this research, other wildlife crossing projects were proceeding through Design. The standard procedure for advancing a project is to send out iterations of plans at pre-determined benchmarks for formal review by each department for conformance of the project to the appropriate standards. But as noted above, wildlife accommodations are not covered by established design standards. The plan review process was too cumbersome to permit the kind of flexible collaboration and problem solving that is needed in the absence of authoritative guidelines; therefore, the projects were becoming stalled when environmental reviewers discovered problems. Attempted solutions would be independently drawn up by a department for the next iteration of plans, and the solutions would conform to standard engineering criteria, but they would create a different set of problems for wildlife, which were not discovered until the next plan submittal, months later.

The FDOT district office finally assembled a multidisciplinary Wildlife Crossing Design Team to convene at the early concept stages so that each discipline’s objectives and constraints could be understood and addressed before a significant investment was made in designs and plan sets. The team convenes first to discuss the requirements and constraints of the wildlife crossing structure and its location. Conceptual sketches are developed and reviewed by all team members, in meetings or informal e-mails, before any plans are drawn up. If one member finds a problem, it can be reviewed and discussed immediately by everyone who might be affected by the problem and who might be impacted by any of the proposed solutions.

Figure 2, right, lists all the disciplines that participate on the team. “PD&E” (Preliminary Engineering) is represented by an engineering project manager and an environmental scientist, but the “Wildlife Biologist” is a consulting wildlife ecologist who has experience in transportation ecology research and specific knowledge of the animals that are supposed to be accommodated. The experience and knowledge of most environmental scientists who work for roadway design firms and of most transportation agency scientists (including the primary author of this paper) are not specific enough to answer detailed design questions of structure size, shape, materials, spacing, substrate, transitions, fencing, moisture, light, noise, etc. that are critical to the functioning of a wildlife crossing. Having specific ecological expertise available to answer these questions as they come up greatly increases the efficiency of the process.

![Figure 2. Wildlife Crossing Design Team Invitation.](image-url)
Stephen Tonjes, MS, graduated from the University of Michigan with a BS in Zoology and from Oregon State University with a MS in Oceanography. He has taught Marine Science at Newfound Harbor Marine Institute/Seacamp, administered Coast Guard bridge permits in Juneau, Alaska and written Biological Opinions for the United States Fish and Wildlife Service in Washington, D.C. He has worked as an Environmental Scientist for the Florida Department of Transportation in east central Florida since 1986, preparing and reviewing environmental documents according to the National Environmental Policy Act (NEPA). He also reviews in-house and consultant design plans, and inspects construction sites and mitigation areas to ensure compliance with environmental permit conditions and with commitments made in NEPA documents. In his spare time, he assists other departments and responds to public inquiries concerning environmental issues related to DOT projects, including gopher tortoises, trees, bats, ground orchids, invasive plants, and lately, wildlife crossings. He has a special interest in communicating usable information on wildlife needs to engineers who design transportation projects, and has presented posters at wildlife conferences and spoken in transportation engineering forums concerning engineering problems, solutions and guidelines for wildlife crossing structure design.

Daniel J. Smith, Ph.D., A.I.C.P., has over 15 years’ experience in the fields of ecology and environmental planning. Previous work includes comprehensive ecological impact assessments, wildlife movement pattern, behavioral and corridor studies, habitat loss/fragmentation, connectivity and landscape change analyses, highway linkage and ecological hotspot modeling, ecopassage siting projects, and development of standards for the design of wildlife crossing structures. Research methods employed include mark-recapture, telemetry, track and road-kill surveys, spatial analyses using Geographic Information Systems (GIS) and landscape genetics. Daniel earned a Ph.D. in Wildlife Ecology and Conservation (2003) and master's degrees in Forest Resources and Conservation (1995) and Urban and Regional Planning (1989) from the University of Florida. He is currently a Research Associate at the University of Central Florida and is a member of the American Institute of Certified Planners, International Association of Landscape Ecologists, The Wildlife Society, Ecological Society of America and Society for Conservation Biology. His primary focus is on understanding spatial patterns of biological phenomena and integrating conservation, transportation and land-use planning.

LITERATURE CITED


Appendix A. ICOET 2005 Poster Presentation.
DESIGN CONSIDERATIONS AND EFFECTIVENESS OF FENCING FOR TURTLES:
THREE CASE STUDIES ALONG NORTHEASTERN NEW YORK STATE HIGHWAYS

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ABSTRACT

In northeastern New York State, as in many places, aquatic turtle road mortality is high, and the toll disproportionately consists of breeding females. There is evidence that excessive road-mortality results in population declines near roads, and regional declines in heavily-roaded landscapes. In northeastern New York, turtle road mortality is concentrated along short lengths of road, referred to as road-kill hotspots. Inexpensive but effective and durable fencing, combined with subterranean passageways through culverts, could provide a mitigation tool to apply at hotspots to reduce road-kill while maintaining population connectivity. I report on the design, cost, durability, and effectiveness of three roadside wildlife barriers along state highways that are intended to prevent turtle trespass onto roads. Effectiveness of fencing was measured via pre-installation and post-installation monitoring of road-kill (using a before-after control-intervention (BACI) design). The impact of fence installation on nesting behavior was also measured, including effects on nest predation and nest microclimate. I also collected radio-tracking data on common snapping turtles (Chelydra serpentina) to investigate whether existing tube culverts provide habitat connectivity between the two sides of a highway, when above-ground connectivity is impeded by fencing. I conclude that inexpensive and easy-to-install fencing is effective at reducing aquatic turtle road-kill, but occasional inspection and repair is necessary to insure long-term functioning. Habitat connectivity can be maintained via culverts or bridges. Depending on the design, installation of fencing may have no effect or may positively affect nesting success. When combined with an effective process to identify the road segments that are the most severe hotspots for nesting turtle mortality, wildlife fences designed for turtles can be an effective and relatively inexpensive measure to conserve aquatic turtle populations within a roaded landscape.

INTRODUCTION

There is presently a recognized need for practical but effective roadside barriers and passageways for turtles, to prevent these animals from crossing roads while maintaining adequate connectivity between the landscape on both sides of a roadway. This is particularly critical at hotspots of road mortality, which are often located along causeways (Langen 2009, Langen et al. 2009). Moreover, since freshwater turtles near roads are frequently breeding females seeking nesting sites along roadside verges (Steen et al. 2006), barriers may need to be designed such that they do not imperil turtle breeding success.

There has been little research focused on developing and testing barriers for turtles. Such research is essential for improving the design, installation, and maintenance of economical wildlife barriers that successfully function to reduce mortality while maintaining connectivity and avoiding reductions in nesting success. There is a need for critical evaluation of the various barrier designs that are currently in use, including their effectiveness at preventing turtle trespass onto roads, secondary impacts on nesting and habitat connectivity, cost, durability, and ease of installation and maintenance.

Specifically, the design considerations of wildlife barriers for turtles must include:

- Location
- Cost (materials, labor)
- Motorist Safety
- Impacts on Right-of-Way Management
- Durability & Maintenance Needs
  - Including ‘ownership’ of maintenance duties
- Public Buy-in
  - Perceived value of reducing road-kill
  - Aesthetics
- Effectiveness at Preventing Road-kill
- Impacts on Nesting Success
- Impacts on Predation Risk (including harvest by humans)
- Impacts on Population Connectivity
In northeastern New York, barriers consisting of low fencing have been installed at road-kill hotspots along three causeways. Two were designed and installed by this author and colleagues, and one was designed and installed by the New York State Dept. of Transportation (NYSDOT). This author and colleagues are currently evaluating the three wildlife barriers for functionality, durability, and secondary impacts. In this paper, I will review some of the findings of this ongoing project, with the objective of providing road managers with information on how to reduce turtle trespass on roads in their regions, and to provide researchers with suggestions on the most critical applied research needs for improving the functionality and practicality of wildlife barriers for turtles.

BACKGROUND

There are three major considerations for effective mitigation of turtle road mortality using barriers and passageways:

1. **location** – where to place barriers to most effectively reduce road mortality,
2. **barrier design** – how to provide an effective barrier for preventing turtle trespass onto the roads, and
3. **passageway design** – how to maintain connectivity between the two sides of the road despite the presence of an effective barrier.

Location and design considerations must include effectiveness at reducing road mortality or maintaining population connectivity, materials & labor costs, durability, and effects on motorists' safety. Good general reviews are found in Jackson & Griffin 2000, Evink 2002, Bank et al. 2002, Luell et a. 2003, Forman et al 2003, Bissonette & Cramer 2008, Langen 2009 and Glista et al. 2009. Additional online sources include the USGS-sponsored *Wildlife & Roads* website (www.wildlifeandroads.org), and the *Infra Eco Network Europe* (www.cbm.slu.se/iene). For this paper, I will focus on barrier design.

Structural mitigation using roadway barriers for turtles has two purposes: to prevent animals from entering the roadway, and to guide animals to safe passageways for crossing to the other side of the road. Without appropriate passageways, roadway barriers can eliminate habitat connectivity between the two sides of a road. Short-term gains in population viability due to reduced road mortality may be offset, in the long-term, by reduced population viability that is the consequence of lost connectivity (Forman et al. 2003). Jaeger and Fahrig (2004) show that barriers lacking safe road-crossing alternatives can be detrimental to populations when the per capita risk of mortality due to road-crossing is low, and highly beneficial where the risk is very high.

Most research on design and effectiveness of structural wildlife barriers for prevention of road crossing has focused on large mammals or amphibians (reviewed in Evink 2002, Bank et al. 2002, Bissonette & Cramer 2008). Evink (2002) reported on several projects in North America and Europe that involved structural barriers to prevent road access by turtles. Designs included mesh wire fencing, prefabricated plastic walls with a small overhang, and prefabricated galvanized steel walls with a small lip (see page 32 of Evink 2002 for illustrations). Banks et al. (2002) and Luell et al. (2003) reported on use in Europe of roadway barriers for reptiles and amphibians constructed of prefabricated galvanized steel walls, cement walls, and silt-screen type plastic sheeting affixed to the bottom of existing fences. Unfortunately, in these reviews there are few details about the design specs of these barriers, or on their actual success at reducing road-mortality. A Spanish publication does provide detailed specifications on affixing fine mesh fencing strips to the bottom of existing roadway barrier fences to reduce reptile mortality, but does not evaluate this techniques’ effectiveness at reducing road mortality (see pages 81-84 of Ministerio de Medio Ambiente 2006).

Guyot and Clobert (1997) reported that fencing (fine mesh wire fencing, 40 cm aboveground and 10 cm into the soil, affixed to ‘sheep fencing’) was successful at minimizing road-kill of the tortoise *Testudo hermanni* along a newly-constructed highway in France. Apparently only 5 tortoises were found road-killed on the 4 km fenced segment of highway over four years post-construction, but there was no pre-fence treatment period or control site with which to compare this road-kill density.

The Paynes Prairie State Preserve (located in Alachua County, Florida) is a wetland complex bisected by U.S. Highway 441, a 4-lane divided highway with a daily traffic volume of 11,000 vehicles. In 1998 there were 2,411 herpetofauna road kills recorded along a 2.8 km causeway (see also Smith and Dodd 2003). As reported in Dodd et al. (2004), in 2001 the Florida Department of Transportation (FDOT) constructed a 2.8 km concrete barrier (1.1 m height) with a 15 cm overhanging lip at 9-11 m from the pavement on both sides of the highway, at a cost of $4 million. Connectivity was maintained by 8 passageway structures 44 m in length underneath the road (two 2.4 x 2.4 m wet box culverts, two 1.8m x 1.8m dry box culverts, four 0.9 m diameter tube culverts). A second barrier type, fabricated of corrugated metal guardrail sheets was also constructed along one 300m segment of highway guardrails. An analysis of pre and post construction road mortality surveys and culvert monitoring indicated that turtle mortality was reduced by 98%, and four species of turtles (including *Chelydra serpentina*) were detected using the culverts as passageways. The concrete wall was judged
The Lake Jackson Aquatic Preserve (located in Tallahassee, FL) is bisected by a 1.8 km stretch of 4-lane highway bearing 21,000 vehicles/d. Turtle road mortality was extraordinarily high at this road segment (1300 turtles/km/y of 10 species, Aresco 2005a, see also Aresco 2005b). In 2000, Aresco installed a 700 m barrier consisting of woven vinyl erosion control ‘silt-fencing’ with pre-attached wooden stakes that was 40 cm in height plus an addition 20 cm buried. A 3.5 m diameter, 47 m long corrugated metal tube culvert passed under the road. Based on road-kill surveys before and after barrier installation, risk of mortality for road crossing turtles, and the numbers intercepted at the fence, Aresco (2005a) estimated that the barrier reduced turtle road mortality by 98%; there was however a small amount of additional mortality associated with the fence due to predation by raccoons or thermal/dehydration stress of turtles pacing along the barrier. Many more turtles would have succeeded in climbing over the barrier and trespassing onto the road, but the researcher intercepted them before the act. Turtles did use the culvert as a passageway, but many turtles were carried across the road by the researcher. The effective life of the barrier was 18 months, and required frequent repair. This study recommends that a barrier of the silt-fence design only be used as a temporary measure until a more durable barrier structure is installed.

Ruby et al. (1994) tested 13 different barrier designs for Gopherus agassizii in experimental enclosures (see also Fusari 1985). These included various types of metal and wood barriers between 30 cm and 100 cm height. They also tested propensity of the tortoise to enter culverts. Ruby et al. (1994) provides exhaustive details on the behavioral reaction of tortoises to the different barrier and passageway designs, and on the costs and durability of the designs. They concluded that 1 cm mesh metal hardware cloth with a height of 65-70 cm and buried in the soil 15 cm was best in terms of effects on animal behavior, durability, cost, and other factors. Larger mesh sizes were discouraged, because tortoises attempted to push themselves through these. Various other studies have also recommended this barrier design, or similar 1 x 2 cm mesh vinyl-coated metal fence (Boarman & Kristan 2006).

Boarman & Szaki (1996) reported that fencing reduced Gopherus agassizii road mortality by 93%. Boarman et al. (1997) provided details on fencing used along a major highway crossing the Mojave Desert in California. The design was the same as recommended by Ruby et al. (1994), and barrier fencing was also affixed to vehicle gates to access property along the route. Metal tube culverts at regular intervals under the road (installed for storm-water drainage) were 1-3.6 m diameter and 48-63 m long. Radio-tracking data, road surveys, and other survey methods indicated that the barrier and passageway system was successful at reducing road mortality and that tortoises regularly used the culverts to access habitat on the other side of the highway. A few other studies based on direct observation of turtles or radio-telemetry also indicated that barrier fencing and standard culverts under highways are effective at preventing road access while maintaining habitat connectivity (Boarman & Kristan 2006).

Woltz et al. (2008) experimentally tested four heights of barriers (0.3 m, 0.6 m, 0.9 m) constructed of corrugated plastic sheeting. All Chrysemys picta and 80% of Chelydra serpentina were unable to scale the 0.3 m barrier, and no turtle scaled the 0.6 m barrier.

Griffin (2006) conducted behavioral experiments in enclosures to test whether Chrysemys picta could scale a 46 cm high, 2 x 4 cm mesh wire fence that had affixed to the top a 10 cm or 15 cm wide strip of aluminum flashing. Of the 4 turtles out of 177 that managed to climb the fence up to the flashing, none could progress further or escape. Two of 55 turtles tested in similar barriers without aluminum flashing succeeded in scaling the fence and escaping.

THREE TURTLE BARRIERS ALONG NORTHEASTERN NEW YORK HIGHWAYS

State Highway 68 at Upper & Lower Lakes State Wildlife Management Area

Two wildlife barriers for turtles were built along causeways on NYS Highway 68 (AADT = 5200 vehicles/d) at Upper and Lower Lakes State Wildlife Management Area (ULL SWMA) in St. Lawrence County, New York State. ULL SWMA protects a major wetland complex that has large populations of three turtle species (Common Snapping Turtle Chelydra serpentina, Painted Turtle Chrysemys picta, Blanding’s Turtle Emydoidea blandingii), one of which is of which is a very high conservation priority (Blanding’s Turtle). The objectives of the two wildlife barrier projects were to experimentally test the effectiveness of some low-cost designs for turtle barriers, and to reduce turtle road mortality at two major road-kill hotspots. To inform the public about the function of the two wildlife barriers, a parking pull-off with an informational kiosk was installed at a public access area located along NYS 68.
ULL SWMA Causeway Barrier 1

This wildlife barrier spans a short causeway that had been a previously localized turtle road-kill hotspot (Fig. 1). Barriers were placed on both sides of the road, for a road centerline length of 225 m; 20 m 'wings' were included at the end to reduce the risk of animals going around the end of the fence. Connectivity between the two roadsides was maintained by a partially submerged 1.3 m diameter water-equalization culvert. Several different designs and materials were used along the length of the barrier, which was installed by a NYSDOT work crew in 2006.

![Fig. 1. Causeway Barrier 1 location at Upper and Lower Lakes WMA. The red dashed line indicates the length of the barrier. The inset shows the location relative to Causeway Barrier 2.](image)

Evaluation of the effectiveness at reducing road-kill was done by comparing four years of pre-construction monitoring and four years (and continuing) post-construction monitoring. Monitoring was done by repeatedly walking the road segment during four years previous to construction (weekly, and more frequently during the nesting period) and four years post-construction. Two comparable 'control' segments were also monitored, thus the monitoring design was used a BACI design (before-after, control-intervention).

To assess connectivity, during one season adult Common Snapping Turtles were radio-tagged, and their movements tracked after being relocated into the water body on the opposite side of the road to where they were captured. The objective was to determine whether a water-equalization culvert would be used to cross under the road (see Fig. 2).

In addition, for one year we monitored turtle nests along the barriers, and compared the nests to roadside turtle nests and nests constructed away from roads. We measured the soil temperature and humidity of nesting sites along the turtle barrier. We also measured the rate of nest lost due to predation.

*Design of Barrier:* The site of the barrier was an elevated section of road with a steep verge. The east side, which included wire and wooden fence designs, was offset 6.5 m from the road. The length was 212 m, plus additional 7 m and 12 m wings on the ends of the barrier, oriented 45 degrees away from the road. The west side barrier, which was exclusively wire fencing, was 3 m from the road. The length was 213 m, plus additional 9 m and 12 m wings on the ends of the barrier, oriented 45 degrees away from the road. Wire fencing was used on each side to connect the fence to the water-equalization tube culvert (Fig. 2).
**Wooden Barrier:** The wooden barrier design was a fence consisting of three boards (each 1 inch x 10 inches x 10 feet or 2.5 cm x 25 cm x 3 m) set on each other with 1 inch (2.5 cm) gap between them (Figure 3a). The gaps were intended to allow water flow. The boards were affixed using decking screws to 4 x 4 inch (10 x 10 cm) treated wooden posts that were set 4 feet (1.3 m) into the ground. A reflector was placed on every fifth post. About 5 inches (13 cm) of the lowest board was buried into the ground. Fine mesh (0.6 x 0.6 cm) metal fencing pieces were affixed (using a staple gun) to the gaps in the boards, after it became evident that frogs and snakes were crossing through the fence via the gaps. The total intended height of the barrier above the soil was 2 feet (0.6 m), but at installation it was actually 20 inches (60 cm).

Site preparation required use of a backhoe and trencher (Figure 4). It proved to be extremely difficult to dig the trench and post-holes, because the fill of the causeway, below a superficial layer of soil, was rock, including large boulders. These site conditions may be typical of causeways.

![Fig. 3. NYS Highway 68 turtle barrier just after installation. (a) Wooden barrier. (b) Vinyl coated metal barrier. Both barriers are 2 feet high.](image_url)
Because of concerns by the NYSDOT engineer that the wooden barrier was a potentially-dangerous ‘fixed object’, this design was only used where a guardrail was present at the roadside. The wooden barrier design was not used on the west side, because the verge was too steep and narrow to use a back-hoe, and manual digging was impossible. Two sections of wooden fence were installed: a 29 m and a 79 m section.

During the first year, there were problems with water undercutting sections of fence after rainstorms. We had to regularly patrol and fill these holes. One year later, there were occasional problems with undercutting, but the soil had mostly stabilized. Now in the fifth year, plant roots and natural compaction have stabilized the soil, and undercutting is not a problem.

After the first year, a few boards warped and became un-nailed. Some could be repaired, and some replaced. In the second year, a couple more boards warped and needed repair or replacement.

Metal Fencing Barrier: The metal fencing barrier consisted of a base of 2 foot high (0.6 m) vinyl-coated over galvanized steel welded-wire metal fencing (Fig. 3b). The fencing was affixed to metal posts (salvaged steel sign posts) using heavy-duty, ultraviolet light-resistant cable ties (three per post). The posts were spaced 6 feet (2 m) apart, and driven into the ground using a post-hole driver. A reflector was placed on every tenth post. When installing the fence, a trench a few inches was dug, and the bottom of the fence buried. Installation was fast (around 20 m / hr for a team of 5 men) and not difficult.

During the first year, a 1 foot (30 cm) high section of fine mesh (0.6 cm x 0.6 cm) coated wire fencing was placed at the bottom and secured using u.v.i.l. resistant cable ties, to prevent hatchling turtles or frogs from passing through the fence. This was determined to be inadequate, and in the second year, the fine mesh coated wire fencing was used to the full 2 foot (60 cm) height on the barrier along the east side of the road. On the west side, uncoated galvanized fencing of the same mesh site was used, and the fence was raised to a height of 3 feet (1 m), including a small overhang that was fabricated by bending the wire (Fig. 5).

During the first year, there were problems with water undercutting sections of fence after rainstorms. We had to regularly patrol and fill these holes. One year later, there were occasional problems with undercutting, but the soil and mostly stabilized. Now in the fifth year, plant roots and natural compaction have stabilized the soil, and undercutting is not a problem.

There was little other maintenance: in five years the cable-ties have held up, and the fence on the east side of the road is undamaged. On the west site, the uncoated fine-mesh fencing has been damaged in places (cut or torn), and has needed repairs (see Fig. 5). However, the integrity of the fence remains good. In 2009, we trimmed the uncoated fence back to 2 foot (60 cm) height (the height of the vinyl-coated metal fence), while leaving a sort inward-facing lip at the top to prevent overtopping by turtles.

**Evaluation of the Experimental Barrier Designs:** The wooden barrier was hard to install, and required extensive maintenance. Inflexibility in placement of the posts, because boards were precut to fit, presented challenges when the location of a post happened to be a site with large buried rocks. To install this barrier, large machines (e.g. backhoe) was needed. It was difficult to maintain a level placement of the fence given the topography, but the fence had to be level to provide an effective barrier; much time was spent in site preparation to get everything properly aligned. The wooden barrier design could not be easily used to create guiding ‘wings’ to a culvert. There were concerns about this design being a hazardous ‘fixed-object’ near the roadway. In theory, one could inset the wooden barrier into the bank of the verge (as was done in Woodbridge, New York), but the nature of the rocky fill precluded this at our site. The cost of materials was comparable to the metal fence (under $10/m), but it required minimally three times the labor.

The vinyl-coated metal design was somewhat less effective than the wooden barrier, because it was easier for some animals to climb. Slight design modifications can remedy that problem. Installation of the metal fencing was much easier than the wooden fence. The flexibility in placement of the metal posts was a significant advantage at a rocky
site. The ability to easily bend or curve the fencing to conform to contours or to intercept features (e.g. culverts) was a significant advantage. The black color and open partially-transparent structure of the mesh made this design much less visually obtrusive than the wooden barrier. Moreover, the vinyl-coated metal fence was a better design for reducing road-mortality for other herpetofauna taxa (frogs, snakes). The cost was comparable to the wooden fencing (under $10/m for materials).

Either fence design requires yearly maintenance, including inspection for repairs, refilling under-cuts (perhaps unnecessary after the second year), and mowing of vegetation along the fence. Mowing is necessary to prevent damage to the fence, but also is necessary to provide a cleared area for turtles to place their nests. I remain unsure about the reasonable expected lifetime of the fencing – we expect it will be around a decade, but will continue to monitor and maintain the fences to assess the durability of barrier designs.

ULL SWMA Causeway Barrier 2

This wildlife barrier also spans a causeway that is a previously localized road-kill hotspot (Fig. 6). Barriers were placed on both sides of the road, for a road centerline length of 550 m; 20 m ‘wings’ were included at the end to reduce the risk of animals going around the end of the fence (Fig. 7). The distance of the barrier from the pavement was 4 m. Connectivity between the two road-sides was intended to be provided by a culvert, but during barrier construction it was discovered that the culvert had collapsed; presently there is no functioning passageway along the barrier. The design of the barrier was 60 cm high, 2.5 x 2.5 cm mesh vinyl-covered wire fencing affixed to standard light fence posts. The fencing was affixed to posts using heavy-duty, ultraviolet light-resistant cable ties (three per post). The base of the fence was buried 5 cm into the ground. The barrier was completed in 2010, and was installed by high-school student work crews under the supervision of NYSDOT employees and Clarkson University students. Evaluation of the effectiveness at reducing road-kill was done by comparing six years of pre-construction monitoring and one year (and continuing) post-construction monitoring.

![Fig. 6. Causeway Barrier 2 location at Upper and Lower Lakes WMA. The red dashed line indicates the length of the barrier. The inset shows the location relative to Causeway Barrier 1.](image)

![Fig. 7. ULL SWMA Causeway Barrier 2 constructed of vinyl-coated wire fence.](image)
Monitoring was done by repeatedly walking the road segment during six years previous to construction (weekly, and more frequently during the nesting period) and the one year post-construction. One comparable ‘control’ segments were also monitored, thus the monitoring design was used a BACI design (before-after, control-intervention).

**State Highway 3 – Tupper Lake Causeway**

Fencing intended to prevent turtle trespass onto a roadway was installed by contractors using NYSDOT design specifications along a long causeway on NYS Highway 3 (AADT = 2300 vehicles/d) at Tupper Lake in Franklin County, New York State (Fig. 8). The causeway spans a major wetland complex that has large populations of two turtle species (Common Snapping Turtle *Chelydra serpentina*, Painted Turtle *Chrysemys picta*). The objective of the wildlife barrier project was to reduce turtle road mortality at this previously-localized major road-kill hotspot. NYSDOT installed the wildlife barrier to meet regulatory conditions that were part of the permitting process for a major road reconstruction project along the road segment. To inform the public about the function of the wildlife barrier, a parking pull-off with an informational kiosk was installed near one end of the barrier.

Fencing was installed on both sides of the road, for a road centerline length of 1330 m; 20 m ‘wings’ were included at one end to reduce the risk of animals going around the end of the fence. Connectivity between the two roadsides was provided by a wide-span bridge and a culvert. There were three gaps in the fence (100 m, 20 m, 14 m) associated with property inholdings (a residence and a tavern) along the causeway. The design of the barrier is 0.6 m high, 5 x 10 cm mesh 12 gauge vinyl-covered wire fencing affixed to an existing steel guide rail posts (Fig. 9). The fencing was affixed using heavy-duty, ultraviolet light-resistant cable ties (three per post). The base of the fence was flush with the road decking, and the top of the fence was flush with the guardrail (box beam). The barrier was completed in 2008 by contractors.

Evaluation of the effectiveness at reducing road-kill was done via two years of post-construction monitoring. Monitoring was done by repeatedly walking the road segment (weekly, and more frequently during the nesting season) during two consecutive years, two years post-construction. Two comparable ‘control’ segments were also monitored. The location of any road-kill or living turtle on or near the roadway was georeferenced, as was any nest constructed alongside the road or fence. We placed six temperature sensors (Dallas Electronics ibutton thermochrons) into the soil at sites where turtles nested along the Tupper Barrier, to measure this critical microclimatic attribute.

**FINDINGS TO DATE**

At the only barrier for which we have adequate pre-construction and post-construction data, ULL SWMA Causeway 1, there was a significant reduction in road-kill of turtles post construction of the barrier as compared to two contemporaneously monitored ‘control’ road segments (ANOVA: Period X Treatment $F_{1,516} = 5.0, P = 0.007$). The effectiveness of this barrier over time has seemed to increase. This is probably due to the addition of a small overhang in the second year of installation, and the stabilization of the soil at the base of the barrier due to root growth, which prevented undercutting.

Data from 2010 and the current 2011 season indicate that the other two barriers (ULL SWMA Causeway 2, Tupper Causeway) are also very effective at reducing road mortality. Most residual road-kill occurs at the end of the fence, or in the case of the Tupper Causeway additionally at the three gaps. We also...
observed that some small juvenile Common Snapping and Painted Turtles were able to pass through the 5 x 10 cm mesh size used at the Tupper Causeway Barrier.

Radio-telemetry of 8 Common Snapping Turtles at the ULL SWMA Causeway 1 demonstrated that these turtles used a 1.3 m diameter water-equalization culvert under the road (see Fig. 2) to move from one side of the road to the other.

Each barrier has held up well, and only requires modest levels of repair each year. This is despite severe seasonality, including heavy snowfall in winter. Snowplow operators report that the barriers do not interfere with snow removal. Most damage to the fences was caused by people intentionally cutting a section of fence to (presumably) make it easier to cross it. Some cable ties have had to be replaced.

The one significant maintenance challenge is vegetation management. The turtle fences do interfere with mowing using conventional equipment. We cut vegetation using hand-held brush-mowers (weed-whackers). This was labor intensive. Unfortunately, if turtles are to nest behind the barriers, vegetation has to be kept short during the nesting season. There is a research need to determine how to best provide suitable nest site alternatives to the roadside when wildlife barriers are present. Options might include mowed segments along the barrier (see Fig. 10), annually plowed soil patches adjacent to the fence, or natural or constructed nesting habitat elsewhere.

Turtle nest predation was significantly less frequent along the ULL SWMA Causeway 1 Barrier than along the roadside or a turtle nesting site distant from the road (survival analysis (Mantel-Cox Model) $\chi^2 = 47.2$ $P < 0.0001$). A caveat is that this was done one year after construction of the barrier, and nest predation may become more frequent along a barrier over time as predators learn to associate it with the presence of nests.

Nests constructed behind the vinyl-coated metal and wooden barriers had similar soil humidity and temperature as nests constructed at other sites away from paved roads, but were much cooler than roadside nests (Fig. 11). The Tupper Lake Causeway soil temperatures were very high, and similar to other roadside nest sites (Fig. 12). Note that in laboratory incubation studies, sustained temperatures greater than 31 C are fatal to embryos. We do not know, however, the effect on egg viability of the very high temperatures recorded in soils around roadside turtle nests. The temperature differences are great enough in terms of average temperature and daily temperature variation that egg development, including sex determination, duration of incubation, and possibly egg viability (Ewert 2008, Janzen 2008), are likely to differ between roadside nests and nests along barriers installed 4 m distant from the road. This may be an additional justification for constructing barriers at sites where turtles migrate to roadsides to nest.

![Fig. 10. Common Snapping Turtle nesting along ULL SWMA Causeway Barrier 1.](image)
CONCLUSIONS

I conclude that wildlife barrier fencing that is constructed of 2.5 x 2.5 cm mesh vinyl-coated steel fencing (or similar mesh sizes) is effective at significantly reducing turtle road trespass and road-kill at hotspots of turtle crossing. Fencing should be at least 60 cm high, and ideally have a small lip at the top. Fencing can be affixed to standard light-duty fence posts, using ultraviolet light-resistant cable ties. Wildlife barriers using this design are unobtrusive, inexpensive and easy to install, but require annual repairs and vegetation management. Connectivity can be maintained between the two roadsides if suitable large culverts (at least 1 m diameter) or bridges are present to provide passageways. Turtles will nest behind wildlife barriers if vegetation is kept low. The microclimate at nests located along fences is comparable to other nest sites, and nest predation risk does not appear to be elevated. Nests constructed along barriers installed 4 m distant from the roadway (e.g. the ULL SWMA Causeway barriers) will have a microclimate similar to nests constructed at natural sites distant to roads, whereas nests constructed at barriers installed immediately adjacent to the roadway (e.g. Tupper Lake Causeway) will have much higher temperatures, which is likely to affect embryo development. The impacts of microclimate at roadside nests on nest viability is a critical research question, given that turtles so frequently are attracted to roadsides to nest.

Thus, there is a critical research need to examine the long-term consequences of turtle fences on nesting behavior and nest success. This research should be done in parallel with research on methods of creating new suitable nesting habitat that is used by turtles. In addition, there is a need to develop vegetation management methods and best practices for maintaining turtle barriers.

Using partnerships that collaborate on installation and maintenance of the wildlife barrier help develop community interest and ‘ownership’ in the project. Press releases and informational kiosks also are important for providing information to the public on the function and value of the wildlife barriers. This is essential for sustaining long-term maintenance of the wildlife barrier.
MANAGEMENT IMPLICATIONS

Low vinyl-coated galvanized steel fences fabricated with a small overhang should be seriously considered as a mitigation measure wherever hotspots of turtle mortality occur, since such fences are effective at reducing turtle road mortality. For such fences, the materials costs and installation and maintenance labor requirements are reasonable relative to other activities associated with road management. Ideally, such barriers will be used in conjunction with wet culverts or other passage structures, to maintain population connectivity between the two sides of a roadway. Research priorities should include evaluating the success of nests constructed along roadway barriers, and methods of constructing high-quality nesting areas to provide an alternative to roadside nesting.

ACKNOWLEDGEMENTS

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BIOGRAPHICAL SKETCH

Dr. Tom A. Langen is an Associate Professor of Biology at Clarkson University. Dr. Langen conducts research on assessment and mitigation of the environmental impact of roads. His research projects have included the impacts of winter road management in the Adirondack Park of New York State, predictive modeling of hotspots of road mortality of amphibians and reptiles, design and functioning of wildlife barriers and passageways for turtles, and the impact of highways on habitat connectivity in Costa Rican National Parks. He has ongoing collaborations on road ecology with the New York State Depts. of Environmental Conservation and Transportation, Costa Rican National Park Service, and the National University of Costa Rica. He leads professional development workshops in Latin America and North America on the environmental impact of roads and other infrastructure.

LITERATURE CITED


Ministerio de Medio Ambiente. 2006. La fragmentación del hábitat en relación con las infraestructuras de transporte en España.


ABSTRACT

Watercourses are the backbone of the Swiss ecological network. They are habitat and migration axis not only for aquatic organisms but also play an important role for terrestrial animals. These natural corridors are often interrupted by unadapted culverts along transport infrastructure. Most of the existing culverts were designed looking at hydraulic needs only, rarely considering animal needs.

The Swiss Association of Road and Transportation Experts (VSS) has been integrating environmental issues in their road standards for more than 10 years. The new VSS-Standard on fauna friendly culverts (SN 640 696) was written by a team of engineers and biologists. The standard sets design specifications to insure all new culverts are appropriate for aquatic and terrestrial fauna. The standard discusses also the retrofitting of existing roads as this is the most common situation. Specifications distinguish new and retrofitted culverts. The standard distinguishes 6 terrestrial fauna categories and 5 aquatic fauna categories, for which design elements may be different. The specialty of this standard is a sustainable development approach, integrating a cost/benefit analysis. Several flow charts guide planners towards the most cost-effective solution using criteria from structural engineering, fauna specifications as well hydraulic and maintenance aspects. The goal is to offer clear technical solutions which are also most cost-effective. This guarantees not only an ideal effectiveness of measures, but as well aims a cost minimization. The paper proposes to present this new standard and the approach it is based on.

INTRODUCTION

Watercourses represent the backbone of the ecological network in Switzerland with a total length of more than 61’000 km (Gewiss, 2011). Their continuity is not only important for the aquatic fauna and its diversity but also for many terrestrial animals that follow the riverine habitat as natural corridors between vaster habitat. This dense network intercedes often with the transport infrastructure network which totals more than 76’000 km (BFS, 2011). At these intersections bridges or culverts are needed. Many of these are not adapted for the passage of fish or terrestrial animals and create unnecessary barriers or hazards (see Fig. 1), as animals will then attempt to climb over roads or railway with the consequential mortality. Illustrative are beaver roadkills, a significant mortality factor for this species.

Figure 1. Two examples of culverts creating barriers. On the left the outfall is too high for most fish. Both examples are missing dry ledges for the passage of terrestrial animals. Photo courtesy of Antonio Righetti.
The Swiss Association of Road and Transportation Experts (VSS) is responsible for setting building standards for roads and railway in Switzerland. A review of standards on culverts identified a number of knowledge gaps (Rieder et al, 2006). The only existing specifications for culverts were hydraulic. Engineers till recently had no guidelines on how to design culverts or bridges that could guarantee the continuity of the riverine ecosystem. A research project was launched in 2006 in order to define design specifications that would meet all of the needs of the Swiss fauna (Righetti and al. 2008). Based on the results of the research project a team of engineers and biologists wrote a new standard SN 640 696 on fauna friendly culverts (VSS, 2011).

METHODOLOGY

A literature search was done on existing specifications concerning culvert design and different fauna species. It was decided to differentiate minimal dimensions between the needs of different fauna categories, when this permitted to economize on culvert size by identifying properly the target species concerned by the culvert. For fish different experts were consulted in order to describe minimal necessary crossing conditions. A team of engineers and biologist then gathered to draw up design specifications meeting both hydraulic and faunisitic requirements.

It was decided to address separately the design of new culverts in the case of a new infrastructure and the retrofit of existing culverts during maintenance programs. Thus minimal dimensions given differ between the two situations, as new culverts should provide optimal conditions, but retrofitting, which faces more technical constraints, seeks only to address minimal requirements.

The technical and economical practicability of the design was also an important aspect in setting the specifications. It was decided that culverts under a diameter of 1 m are too difficult to retrofit successfully. In such cases either the project should be abandoned or, if the ecological corridor is important, a new culvert should be built. Flow charts for decision making were drawn to ensure that cost and benefit of measures always stayed in equilibrium.

RESULTS

Designing New Culverts in the Context of New Infrastructure

The most important aspect of the standards was setting requirement for aquatic and terrestrial organisms. It was decided to break down the requirement to a rather detailed scale, as the ecotypes of watercourses encountered vary enormously. By adjusting design requirements to the specific needs of the set of species encountered, culvert design can be fitted without overscaling. This means, however, that before designing a proper culvert the stream crossed must be assessed and target species identified.

For fish the following categories were distinguished: Leaping abilities from low to high, swimming speeds and size of fish. Hydraulic design must meet the requirements of the target species in the stream. Baffles may be needed to reduce speed or provide the necessary water depth (see Fig. 2). Generally culverts should try to keep a natural substrate or use a roughened channel. The minimal necessary water depth was identified as 0.1 m for species such as the Minnow (Phoxinus phoxinus), Soufie (Leuciscus soufia) and stone loach (Nemacheilus barbatula) to over 0.3 m for species such as Barbel (Barbus barbus) and Grayling (Thymallus thymallus).

![Figure 2. Principles for the hydraulic design of fish friendly culverts. Drawing courtesy of Antonio Righetti.](image-url)
For terrestrial animals culverts and bridges must provide a dry passage, thus ensuring a certain continuity to the riparian habitat (see Fig 3). Bridges should be designed to avoid any disruption of the riparian habitat. Culverts should provide dry ledges. For culverts classes were also made among the terrestrial animals, with a distinction between amphibians, reptiles, small rodents, otter, marten family and fox, badger and beaver.

**Table 1. Requirements for new culverts for terrestrial animals.**

<table>
<thead>
<tr>
<th>Fauna Categorie Requirements</th>
<th>Otter</th>
<th>Reptiles</th>
<th>Small Rodents</th>
<th>Martens</th>
<th>Amphibians</th>
<th>Beaver, Fox, Badger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal width of dry ledge</td>
<td>1 m</td>
<td>0.6 m</td>
<td>0.4 m</td>
<td>0.6 m</td>
<td>1 m</td>
<td>1 m</td>
</tr>
<tr>
<td>Minimal clearance above dry ledge</td>
<td>1.5 m</td>
<td>0.75 m</td>
<td>0.4 m</td>
<td>0.75 m</td>
<td>0.75 m</td>
<td>1.5 m</td>
</tr>
</tbody>
</table>

**Retrofitting Existing Culverts in the Context of Maintenance Programs**

Design of dry ledges for existing culverts makes a balance between minimal species requirements and hydraulic constraints. Therefore dimensions given are smaller.

**Table 2. Requirements for terrestrial animals when culvert retrofitting.**

<table>
<thead>
<tr>
<th>Fauna Categorie Requirements</th>
<th>Otter</th>
<th>Reptiles</th>
<th>Small Rodents</th>
<th>Amphibians</th>
<th>Beaver, Fox, Badger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal width of dry ledge</td>
<td>0.2 m</td>
<td>0.4 m</td>
<td>0.4 m</td>
<td>0.4 m</td>
<td>0.6 m</td>
</tr>
<tr>
<td>Minimal clearance above dry ledge</td>
<td>0.6 m</td>
<td>0.4 m</td>
<td>0.4 m</td>
<td>0.6 m</td>
<td>0.6 m</td>
</tr>
</tbody>
</table>

The standard, after giving basic dimensions also shows different possible designs, thus giving the engineer a palette of choices that can used in different situations. Dry ledges can be made of wood, concrete or stone.
Finally flow charts guide the engineer through the situations he may meet when building a new culvert or retrofitting an existing one. The flow chart in Figure 4 shows situations when a retrofit is not possible or reasonable (grey boxes). Retrofitting is not feasible for culverts under 1m diameter, for hydraulic reasons. If the stream goes seasonally dry, or basic maintenance is not possible or the slope is too important, a retrofit is also evaluated as unreasonable from a cost/effectiveness perspective (grey boxes). Questions guide the engineer through these aspects.

CONCLUSIONS

This new standard has made road and rail engineers much more conscious of the different functions culverts must fulfill. New culverts no longer should create artificial barriers. A long way remains before the many existing culverts are retrofitted. This depends on maintenance budgets and identified priorities. This new standard completes the VSS set of standards on fauna and traffic covering wild game to amphibians. It is an important step in minimizing fragmentation.

BIOGRAPHICAL SKETCHES

Marguerite Trocmé received her Bachelor of Science in Biology in 1983 then a master in environmental engineering at the Federal polytechnic school of Lausanne (EPFL) in 1985. After working for the World wildlife fund, she became responsible for environmental project reviewing at the federal office for environment in 1989. Since 2008 she is responsible for the environmental standards at the federal road office.

Antonio Righetti received a Masters in Botany and Zoology at the University of Berne, and opened a consulting firm specialising in vegetation mapping, impact studies and in recent years the conception of many fauna passages and efficiency controls. From 2002 to 2010 Mr. Righetti worked also for the Federal Office of Environment responsible for setting up the national ecological network. He is a member of the VSS technical commission on fauna and environment since 2005.

REFERENCES


Figure 4. Flow chart for culvert retrofit. Courtesy Antonio Righetti.