NCHRP PROJECT 25-25 TASK 68

Implementing Measures to Reduce Highway Impacts on Habitat Fragmentation

Prepared for the AASHTO Standing Committee on the Environment

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August 2011

The information contained in this report was prepared as part of NCHRP Project 25-25, Task 68, National Cooperative Highway Research Program, Transportation Research Board.

Acknowledgements

This study was requested by the American Association of State Highway and Transportation Officials (AASHTO), and conducted as part of National Cooperative Highway Research Program (NCHRP) Project 25-25. The NCHRP is supported by annual voluntary contributions from the state Departments of Transportation. Project 25-25 is intended to fund quick response studies on behalf of the AASHTO Standing Committee on Environment. The report was prepared by Mr. Edward Samanns of The Louis Berger Group, Inc. with assistance from Ms. Laura Sliker, Mr. Stephen Parker and Mr. Richard Bolton of The Louis Berger Group, Inc. The work was guided by a task group which included Ms. Frannie Brindle, Oregon State DOT, Ms. Judy Gates, North Carolina DOT; Mr. Paul Wagner, Washington State DOT, Mr. Simon Wray, Oregon Department of Fish & Wildlife; Ms. Debra Nelson, New York State DOT; and Ms. Mary Gray, FHWA. The project was managed by Nanda Srinivasan, NCHRP Senior Program Officer.

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I. Introduction

A. Objective of the Research

The overall objective of the Task 68 research was to document existing techniques and measures used to assess, minimize and mitigate habitat fragmentation impacts during highway facility design. The product of this research is meant to assist state department of transportation (DOT) practitioners, regional environmental coordinators and other transportation and environmental professionals in identifying and recommending habitat fragmentation solutions that are cost effective, can be readily implemented using available technology, provide significant habitat connectivity benefits, and reduce overall transportation project impacts on wildlife.

B. Purpose of this Decision Support Tool

The information gathered as part of this research has been assembled into a Decision Support Tool that can be used to identify potential solutions to the fragmentation of both terrestrial and aquatic (non-fish) resources. Terminology associated with habitat fragmentation and suggestions for ways to integrate consideration of habitat fragmentation into the National Environmental Policy Act (NEPA) process are presented in the decision support tool, as well as a Habitat Fragmentation Decision Guide.

Section III of the decision support tool contains three subsections that present the background, guidance, and potential mitigation solutions that can be adopted to address habitat fragmentation impacts.

Subsection A provides background information on habitat fragmentation and definitions for some of the key terms used in the memo and in the flow charts.

Subsection B presents a flow chart titled General Considerations for Habitat Fragmentation Assessment and Mitigation Needs by Highway Improvement Type which outlines steps to consider prior to selection of habitat fragmentation mitigation solutions for different transportation project types: New construction, Reconstruction and Rehabilitation. The state DOT survey results indicated that these are the most common project types where habitat fragmentation and connectivity issues are addressed. The basic steps in the chart reflect current transportation agency practice as obtained from the state DOT interviews and additional research.

Subsection C provides further guidance for projects that involve new construction that may involve multiple alternate alignments. The section includes a flow chart on Habitat Fragmentation Assessment within the NEPA Planning Process which provides key considerations for conducting a habitat fragmentation assessment within the project scoping, alternatives analysis, and record-of-decision/permitting process. Brief descriptions and potential

sources of additional information are provided for each step in the habitat fragmentation assessment procedure.

A flow chart titled: Conceptual Framework for a Habitat Fragmentation Decision Guide along with descriptive text is provided to explain each step in the process of evaluating potential fragmentation impacts leading to the selection of potential mitigation solutions for each alternative.

This section also presents a summary of Mitigation Solutions for habitat fragmentation in a table format using connectivity solutions and patch (habitat) solutions that have been successfully implemented or used by transportation agencies. A brief discussion of the organization of the summary table and information sources is also provided.

C. Use of Survey Results in Developing the Decision Support Tool

The information and tools presented in this document were developed, in part, based on the results of an on-line survey and subsequent phone interviews. Eight state transportation agencies were interviewed with regards to minimization practices and 7 state transportation agencies were interviewed on avoidance and compensation practices. The survey methods and results are presented in Section II.

Several insights obtained through the survey and interviews of transportation agencies influenced the content of this document and are highlighted below.

- Mitigation for habitat fragmentation is being performed for a variety of highway improvements including new construction, reconstruction, and rehabilitation types of projects.
- Of the 8 states interviewed for avoidance measures, only two states, Texas and Maryland, reported having defined procedures for conducting landscape level habitat fragmentation analysis during the project planning stage. Subsequent research indicated that only five additional states appear to have similar programs.
- Compliance with the Endangered Species Act and Clean Water Act (404 program) appear to be the main drivers for mitigating habitat fragmentation. Improving highway safety by reducing the potential for wildlife-vehicle collisions was another reason provided by some transportation agencies for adopting mitigation solutions.
- Through the interviews, transportation agencies indicated that specific costs for mitigation measures, including long term maintenance, are generally not tracked separately or are not readily available.
- Transportation agencies interviewed indicated that they generally did not implement long term or detailed monitoring programs to determine the effectiveness of mitigation actions.

The survey and interviews revealed several methods that transportation agencies are currently using to address habitat fragmentation. Only a few states were found to have developed a process to assess habitat fragmentation at a landscape level. A general framework is needed during project planning and alternative analysis when avoidance and minimization of impacts are most achievable.

There are many different approaches and scales for which a habitat fragmentation analysis can be performed and each practitioner needs to define the parameters of the adopted method to suit their specific needs. To consider mitigation solutions for any project type requires identifying impacts at the landscape and target species or species group in order to select appropriate mitigation solutions; therefore, this document includes a framework for assessing habitat fragmentation that is applicable and scalable to any project type.

II. State DOT Survey and Interviews

To identify and recommend solutions that provide significant habitat connectivity benefits, and are cost effective and immediately implementable using readily available technology, the following outreach was conducted with State DOTs across the country:

- 8 Minimization Phone Interviews (selected states based on NCHRP Report 615)
- 1 Online Screener Survey (to determine Avoidance & Compensation candidates)
- 7 Avoidance & Compensation Phone Interviews (based on results of Online Screener Survey)

The following section describes the results of this outreach. The online screener survey was run while the minimization interviews were being conducted, and based on the results of the screener survey, interviews were conducted with 7 states that were found to have such avoidance & compensation techniques in place and were willing to discuss them further. The results of the two sets of interviews assisted in the development of the flow chart by identifying key steps and techniques to assess and mitigate the impacts of existing and planned highway development on aquatic and terrestrial habitat fragmentation, based in part on the actual experiences of State DOTs.

A. Minimization Interviews

1. Methodology

Phone interviews were conducted with eight state DOTs to discuss more in-depth their efforts at minimizing habitat fragmentation impacts by providing either terrestrial or aquatic (non-fish) passages or crossings. To aid in selecting states for interview in Task 68, the results of a comprehensive survey conducted in NCHRP Report 615: Evaluation of the Use and Effectiveness of Wildlife Crossings (2008) were used. The survey in Report 615 attempted to capture the number of wildlife crossings per state, province or territory in North America as of 2007. After reviewing the results of the Report 615 survey, the four U.S. states with the highest number of terrestrial crossings and the four states with the most aquatic crossings were contacted to see if they were interested in participating in a telephone interview to discuss these minimization efforts further under NCHRP Task 68. If any of these states were not available, the next state with the highest number of crossings was contacted until a participant could be established. Efforts were also made to maintain regional representation among states when possible.

The states that ultimately participated in Minimization interviews were:

1. Vermont (terrestrial)
2. Arizona (terrestrial)
3. Florida (terrestrial)
4. Idaho (terrestrial)
5. California (aquatic)
6. Georgia (aquatic)
7. Connecticut (aquatic)
8. Minnesota (aquatic)

Interview questions were developed and reviewed by the NCHRP Panel prior to conducting the phone interviews. The intent of the questions was not to examine the state of the science, since this has already been studied, but instead how to insert the science into common practice. The questions were directed at finding out how practitioners are changing or adopting new processes to address minimization of habitat fragmentation, what specifically drives the change, how performance and success are defined, how performance and success are monitored and where the best dollars: results ratios are obtained. The original questionnaire can be found in Appendix A.

2. Results Summary

Summaries of the eight phone interviews are presented below, while the full write-up of each interview can be found in Appendix A. Some issues that were common to all interviews are that cost was reported to be a prohibitive factor in building bigger and better crossings. Land acquisition and topography issues were also found to be common limiting factors in using the desired crossing technique. Agency collaboration was mentioned as an important element by all states, especially during the identification of hotspots and sensitive areas. Pre-construction monitoring was also found to be important in order to establish a baseline for monitoring. In most cases it was found that post-construction monitoring is not usually required and is therefore lacking, unless it is a condition of a permit (associated with a wetland or in the case of aquatics). It was also found that most states do not have separate cost tracking methods for the cost of maintaining crossing structures and fencing.

Literature review conducted throughout this research revealed that the issue of crossings for aquatic species has been rather well addressed through guidance and regulations. Some states indicated during the interviews that while semi-aquatic species most likely benefit from some of the practices applied to fish, non-fish species have not been the main focus in constructing these passages.

Specific to terrestrial species, most states noted that safety is very closely linked with minimizing terrestrial habitat fragmentation. If the minimization of habitat fragmentation can be shown to increase safety to motorists on the roads, the dedication of time, effort and funding to create adequate terrestrial passages is more likely to be widely accepted.

Terrestrial

Arizona Department of Transportation developed a process to address habitat fragmentation with its Wildlife Linkages program. The program included a Workgroup of nine public agencies and nonprofit organizations with the mission “To identify and promote wildlife habitat connectivity using a collaborative, science based effort to provide safe passage for people and wildlife”. Arizona radio tagged hundreds of terrestrial species, including desert tortoise, and monitors their movements in order to identify hot spots both before and after construction of highways in order to determine success based on similar animal movements. Engineers at ADOT understand that each species reacts differently and that crossings are designed for different purposes. While the overall purpose of a crossing is to minimize disruption of habitat connectivity, it has been found that fencing and undercrossing provide the greatest ecological benefit to dollar cost, while also considering safety of motorists.

Florida has a wide variety of terrestrial species to consider in its program, from panthers to crocodiles, while also dealing with the obstacle of constructing crossings at sea level and frequently in wetlands. Fencing has been found to be beneficial, along with underpasses where practical. Florida has also been using Roadside Animal Detection System (RADS) which involves a sensor that activates a notification system to alert drivers when a panther or other large animal steps into the right of way. Florida also uses DNA studies and radio collaring in studying animal populations. Success is determined by whether the target species is using the crossing, the effectiveness of which is monitored by using motion sensor cameras. Success can also be measured by whether there was a reduction in roadkill in the area of the feature.

In contrast to growing states like Arizona and Florida, the Vermont Agency of Transportation (VTrans) has taken a different approach. Vermont has decided to focus on its existing infrastructure, rather than building new roads, via its "Road to Affordability" initiative. VTrans has developed a GIS model for habitat linkage so that they can assess their existing facilities and the few small projects that they do have that involve building new roadways. VTrans advocates for the use of longer and oversized bridge spans when doing bridge replacements. Since Vermont's few highways were built in the 1950's and 60's, wildlife was not monitored at that time to provide a baseline. However, for those crossings which do have baseline data, VTrans uses remote and digital infrared cameras, track beds/pads, visual monitoring, tagging and recapture.

Idaho is in the process of finishing up a very large crossing project, funded by stimulus dollars, which may be the first officially monitored project by the Transportation Department. This project will facilitate wildlife crossing for elk and deer in an area that has been identified as a safety concern due to the high number of collisions between motorists and wildlife. Idaho has also identified linkages and wildlife-vehicle collision locations which are being incorporated into a database. The practice of building bridges and culverts wider to accommodate passage has been found to be the technique that provides the greatest ecological benefit to dollar cost.

Aquatic (Non-Fish)

California's aquatic passages are designed in accordance with California Senate Bill 857, which amended California Fish and Game Code in 2005 to incorporate specific provisions regarding Caltrans' progress in removing barriers to fish passage, superseding the management of non-fish aquatics. However, anadromous fish and other aquatic species that use the same habitat such as amphibians and reptiles will benefit from some of the practices in California. Common practices include the use of culvert baffles, fish ladders and bridges instead of culverts. Caltrans has a Wildlife Crossing Guidance Manual and wildlife crossing website that provides methods for assessing proposed projects that focus on aquatic and semi-aquatic species permeability. Sites are monitored if required following an established mitigation and monitoring plan.

Since 2005, Connecticut DOT (ConnDOT) has incorporated new U.S. Army Corps of Engineers (ACOE) specific culvert crossing criteria into design of both new and replacement culverts. Channel work and rock work, including rock weirs and veins which incorporate natural streambed material back into the environment, have been found to be the most effective practices providing the greatest ecological

benefit to dollar cost. Approximately 1/3 of ConnDOT projects involve the use of in-stream rock weirs or veins for bank or channel stabilization which also adds habitat value. While trout seem to benefit the most from these practices, any species including invertebrates that can utilize the structures will and do benefit. The gradation of natural material creates natural crevices for invertebrates to use. Monitoring is conducted if required by a permit.

For Georgia DOT (GDOT), the most commonly used aquatic habitat sensitive design features are a result of the US ACE (Savannah District) Regional Conditions which require GDOT to look at channel spanning using bridges as part of permit review process. GDOT has found that bridging is the technique that provides the greatest ecological benefit to dollar cost. Generally bridges benefit most species that Georgia deals with including trout, federally protected darters, freshwater mussels, flatwater salamander, bog turtle, and terrapin. But while bridging may be most beneficial it is also the most costly technique. No formal monitoring is performed.

Minnesota DOT's (MnDOT) liaison to the Department of Natural Resources (DNR) reported that MnDOT uses passage benches in bridges and finds them to be very beneficial, even for the local fisherman. They have been successful in showing that wildlife passages can benefit not only wildlife, but humans as well; in this case fishermen have used the benches for safe crossing under bridges. They have also had success with recessed culverts and have the state universities studying both the benches and the culverts to help MnDOT revise their design manual. MnDOT also has a detailed Best Practices Manual, developed with DNR, which directs the early agency coordination process. MnDOT's creation of the DNR-DOT liaison position can also be credited with promoting a successful agency-department relationship and coordination process.

B. Screener Survey for Habitat Fragmentation Avoidance and Compensation

1. Methodology

An online screener survey was developed in accordance with NCHRP guidance and is attached in Appendix B along with a full report of the results. The online screener survey was developed with the intent of identifying states that:

- Regularly use techniques for avoiding habitat fragmentation and habitat connectivity loss as it relates to highway projects;
- Have established methods of compensating for these types of impacts to habitats and wildlife resulting from highway projects;
- Commonly utilize habitat connectivity solutions;
- Are willing to contribute further to this research by participating in a follow-up telephone interview.

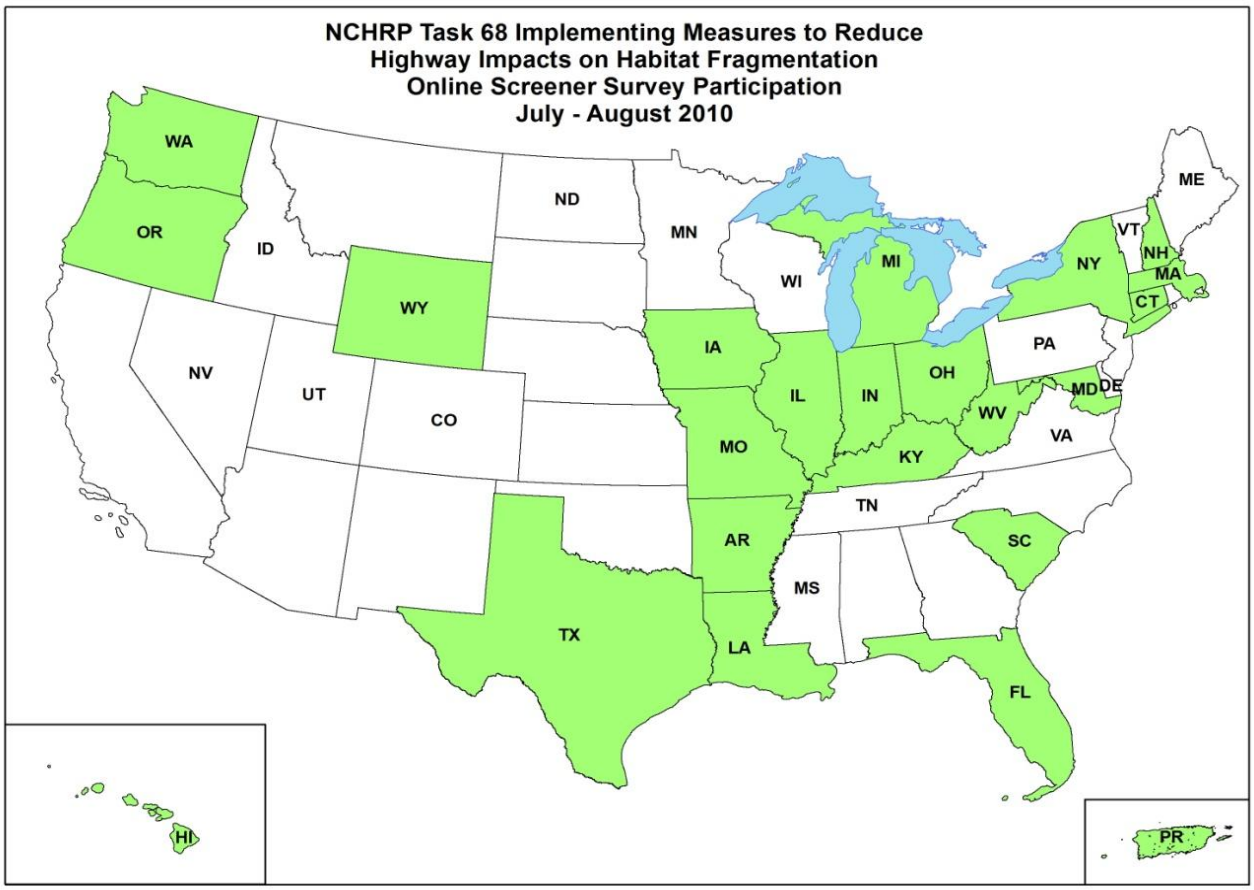
An email was sent to the Environmental Director at each state DOT on July 6, 2010. This email included an explanation of the Task 68 research and a live link to the online screener survey, hosted by *Survey*

Gizmo. It was requested that the states complete the 10- question survey by August 1, 2010. On August 4, a second round of emails was sent out to all State DOTs extending the survey deadline to September 1, 2010. The online survey was officially closed on September 7, 2010. During this two month period, a total of 24 states participated in the online screener survey as shown in Figure 1.

2. Results Summary

The results of the online screener survey indicate that the 71% of the 24 states that completed the online survey do incorporate the State Wildlife Action Plan (SWAP), and/or consider natural resource protection, wildlife and/or stream corridors or critical habitat for threatened and endangered species in their statewide or regional transportation planning processes. However, 50% of the planning processes do not contain written objectives such as "maintain habitat connectivity" or "minimize habitat fragmentation". Fifty-eight percent of the states responding have both mechanisms in place to proactively address connectivity rather than reactively mitigate as well as have priority areas for habitat protection/connectivity and/or have state or regional habitat connectivity plans. Sixty-seven percent of states have critical habitat mapping, terrestrial and aquatic wildlife corridors, and/or other information readily available during the transportation planning process.

Figure 1 Online Screener Survey Participation: July-August 2010



Twelve of the states responding confirmed that their state has adopted mitigation strategies for impacts due to habitat fragmentation and loss of connectivity for projects. Those twelve states then indicated that the predominant forms of mitigation that took place were preservation, enhancement and restoration. Nine of these states approximated that there were less than 10 projects that used mitigation for habitat fragmentation in the last ten years.

When considering mitigation for habitat fragmentation and loss of connectivity of habitats, 75% of the states responding said that potential mitigation sites are weighted differently based on connectivity to adjacent habitats. Additionally, 75% of states indicated that regulatory agencies do require post-construction monitoring of compensation mitigation to determine if they are effective or meeting performance goals.

Three quarters of the states that took the online survey volunteered to participate in a telephone interview to examine their Avoidance & Compensation techniques more in-depth. Taking into consideration affirmative answers provided as well as geographical diversity, the following DOTs from seven states and the Commonwealth of Puerto Rico were pursued for Avoidance & Compensation interviews:

1. Oregon
2. Arkansas
3. Indiana
4. New York
5. New Hampshire
6. Maryland
7. Puerto Rico
8. Hawaii

C. Avoidance & Compensation Interviews

1. Methodology

Phone interviews were conducted with state DOTs to explore their efforts at avoiding habitat fragmentation during the regional planning process as well as at the project planning level. The interviews also investigated whether states have methods of compensating for habitat fragmentation and connectivity loss when impacts to habitat were found to be unavoidable, and how those methods work. The interviews were conducted via telephone and lasted, on average, 60 minutes each.

The states were selected for interview by examining the responses to the online screener survey which was conducted in July-August 2010. The results of this survey were reported in the October 1, 2010 Task 2 Memorandum. Selection was based on the number of affirmative responses provided by each state and also whether a state was willing to discuss the topic further, as indicated by their response to that specific survey question. Taking into consideration previous participation in the Minimization interviews as well as geographical distribution, if a state indicated that they were willing to participate in the phone interview, every effort was made to contact that state and set up an interview. However,

some of the states that were originally selected for interview either did not respond or were unavailable to participate and it was necessary to find replacements. Ultimately, only seven states were available to participate in this round of interviews and they are as follows:

1. Oregon
2. Arkansas
3. Indiana
4. New York
5. New Hampshire
6. Maryland
7. Texas

Interview questions were developed and reviewed by the NCHRP Panel prior to conducting the phone interviews. The intent of the questions was to examine the efforts made by states to avoid fragmenting habitat during statewide and regional planning and also at the state DOT project planning level. The questions also looked at what types of mitigation activities state DOTs are involved in and if the compensation is intended to directly address habitat loss, or whether that is indirectly addressed through the process. The questions were somewhat structured around the answers provided by the states in their online screener survey responses, and were adjusted accordingly during the phone interview to be specific to each state's particular strengths or challenges. A copy of these questions can be found in Appendix C of this memorandum.

2. Results Summary

As explained above, the interview questions were grouped into three categories:

- Avoidance during Statewide and Regional Planning
- Avoidance during Project Planning
- Compensation

While a full write-up of each interview can be found in Appendix C, below are some of the highlights from the phone interviews in each of the three categories. When considering each state DOT's current methods for avoiding and/or compensating for habitat fragmentation it is helpful to bear in mind the type of roadway project that is currently the most common in each state. The table below shows the type of projects indicated by the state to be most common at the time these interviews were conducted. A table is also presented at the end of the summary to aid in order to provide an overview of the avoidance and compensation interview results.

Table 1 Common Types of Roadway Projects

State	Most common type of roadway project
AR	Capacity improvements
IN	New alignments, major projects
MD	System preservation/maintenance
NH	Safety and intersection improvements
NY	Safety improvements/maintenance
OR	Preservation/ maintenance
TX	New projects and rehabs

3. Avoidance During Statewide & Regional Planning

Several states are taking positive strides towards avoiding habitat fragmentation at the statewide and/or regional planning level by making a shift towards an ecosystem-based approach.

According to Arkansas State Highway and Transportation Department, connectivity issues are rarely considered at the regional planning level unless listed species are involved. Habitat fragmentation issues are usually handled during the Endangered Species Act Section 7 consultation process between FHWA and the USFWS.

For instance, Indiana Department of Transportation (INDOT) is working with Indiana Department of Natural Resources (DNR) on a habitat-based study that will prioritize areas within watersheds and ecoregions and give INDOT a framework to use towards efforts at avoiding habitat fragmentation at the statewide and regional planning level. The study is based on the Indiana Forest Management Plan.

Maryland State Highway Administration (SHA) uses a Geographic Information System (GIS) tool called "Green Infrastructure" (GI) that was recently developed and is still being introduced throughout the SHA and recently to regional planners and to Metropolitan Planning Organizations for use in their long range planning efforts. The GI assessment includes everything in the undeveloped environment which was mapped in GIS and is now used to screen projects at the statewide level. The GI tool identifies critical areas known as hubs and corridors and, in turn, SHA makes every effort to minimize impacts. Some Maryland counties are also developing their own versions of the tool. The GI Tool utilizes an Eco-logical approach/ systems approach, rather than a species-specific approach.

New Hampshire DOT (NHDOT) is taking a local approach by working with the NH Audubon Society to develop guidelines for considering habitat fragmentation and to implement them in municipalities. NHDOT has been making efforts to get municipalities and regional planning commissions to examine and consider conservation lands in the area before they suggest new roads to be placed on the 10-year plan for funding. They also use New Hampshire's Geographically Referenced Analysis and Information Transfer System (GRANIT) to determine sensitive habitat and areas to avoid during corridor planning and regional planning.

The New York State Comprehensive Wildlife Conservation Strategy identifies the protection of land in large blocks of unfragmented forests, as a conservation priority. However, at this time, most connectivity issues are dealt with on a case-by-case basis.

Oregon has recently published Wildlife Linkages data available for planners to use for consideration of habitat connectivity across highways and major roads. Oregon Department of Fish and Wildlife (ODFW) has recently funded a Habitat Connectivity Biologist position whose sole focus is addressing wildlife movement, habitat fragmentation, and connectivity at a statewide level. The creation of this position was a result of the Oregon Conservation Strategy (OCS) written by ODFW to fulfill the requirements of the congressionally created State Wildlife Grants Program.

Texas Department of Transportation (TxDOT) has developed the Texas Conservation Action Plan (TCAP) which will be put into action in early 2011. TCAP will be the central planning document for natural resources when developing a project. TCAP includes the construction of a detailed mapping database of potential habitats and, listed species and/or records of occurrence based on the NatureServe Ecological System Classification System. The project is in its third year of a 5-year duration. Under a Memorandum of Agreement (MOA) with Texas Parks and Wildlife Department (TPWD), TxDOT provides training on how to use the tool in exchange for access to the data. However, since access is controlled due to concerns with releasing information on rare plants and animals, regional planners must send a request and get information through coordination with TPWD until they can be properly trained on the system. Texas is making a conscientious effort towards an ecosystem-based approach, as demonstrated by their mapping efforts to redefine ecoregions to be more in-line with EPA designations and promote consistency across state boundaries.

4. Avoidance During Project Planning

When it comes to avoiding habitat fragmentation at the project level, nearly all of the states interviewed relied on a strong working relationship and open communication with resource and regulatory agencies to help them identify potential impacts to habitat resulting from highway projects.

Arkansas State Highway and Transportation Department (AHTD) makes an effort to avoid impacts to habitat during the “cursory review” phase where personnel determine if proposed project corridors may potentially impact listed or sensitive species or habitats based on known occurrences. AHTD relies on comments received from USFWS and other natural resource/regulatory agencies following initial review of the NEPA document with regards to habitat fragmentation and/or connectivity.

For Indiana DOT, the earliest stage at which habitat is considered is during the NEPA process at the step that they refer to as “red flag” step, which occurs after scoping/field visits and before meetings with regulatory agencies. Red Flag issues are put into a commitments database, along with recommendations from regulatory agencies and responses. Habitat fragmentation is not generally considered unless it is specifically received as an official written concern from an agency.

Maryland SHA develops preliminary alternatives using their GI Tool and looks at connectivity in the project area, determining what alternatives would have the biggest impact and highlighting more viable alternatives. If impacts cannot be avoided, then efforts are made towards stewardship. The GI Tool is

also used at the project planning level, and can be tailored to individual projects, particularly major capital and high visibility projects. This approach involves intense data collection and analysis of project study area watersheds, and the use of an optimization model for stewardship and/or mitigation opportunities. Maryland SHA also has Concurrence Points in their project development process as well as monthly project review meetings with the resource agencies during which they may express concerns about habitat fragmentation at any time. There are also new MD Department of Environmental Protection (DEP) rules for stormwater management during Environmental Site Design. The rules encourage a move away from ponds and towards more linear designs which will reduce the project footprint and minimize impacts to habitat.

At the project level, NHDOT uses the GRANIT system to help identify natural resources and avoid impacting habitat. Letters are sent out as soon as a project is proposed to agencies and town officials to inquire about the area in which the project may be located to determine if they know of any issues associated with the project area. If a critical issue is identified, a meeting will be held. Natural resource agencies may express concerns about habitat fragmentation at monthly meetings involving the state and federal agencies. When a project comes up, and there are issues regarding natural resources or habitat, it will be presented at these monthly meeting to obtain comments. Meetings may occur several times during the course of design and alignment options may be altered based on comments.

New York State DOT has not had many large projects requiring an alternatives analysis and as a result, have not yet developed a standard procedure to identify potential wildlife habitat fragmentation impacts at this time. However, agencies may express their concerns about habitat fragmentation during the NEPA process or during design phase meetings.

For large-scale planning and projects requiring an Environmental Impact Statement (EIS), Oregon DOT conducts interagency statewide multi-agency forums. Decision points in the process allow for resource agency input. ODOT is also one of the few states interviewed that does include impacts to wildlife resulting from proposed roadway-generated noise in the impact analysis, but only when listed species are involved (e.g., northern spotted owl, bald eagle, etc.).

When it comes to avoiding habitat fragmentation during project planning, TxDOT has found that it is more effective to have all agencies and stakeholders involved as early in the project development process as possible so that they can think about avoidance and compensation in the early stages even if the project design is only 0-20% complete. The issue of fragmentation is discussed during alternatives analysis and is addressed in environmental documents as part of impacts and indirect and cumulative impacts analysis. TxDOT looks for, and expects to see a discussion of fragmentation in these documents. In terms of stormwater management, TxDOT is currently studying things like Permeable Friction Course which is a permeable roadway that allows the roadway to act as a filter. This type of technology can reduce the size of stormwater facilities and associated impacts. TxDOT has always included impacts to wildlife resulting from proposed roadway-generated noise in the impact analysis because they consider impacts at the landscape scale with an eye towards the future.

5. Compensation

The interviews revealed that some states are looking beyond the standard wetland mitigation rules when considering compensation for impacts to habitat and connectivity.

Mitigation is not typically required solely for habitat loss resulting from highway projects in Arkansas unless the land is owned by a state, federal or local government or enrolled in a federal program like the Wetlands Reserve Program.

INDOT has a *Woody Revegetation Program* for any stream crossing, new bridge or bridge replacement, which functions as a banking program. It is based on re-establishing a wooded corridor as close to the structure as possible, based on the riparian corridor upstream and downstream. For each qualifying project, INDOT has a landscape architect look at the potential to do replanting within the right of way. The Woody Revegetation Program is voluntary on the part of INDOT and these projects are audited and the riparian plantings are monitored so that they may be applied as compensatory credit on other projects. Also noteworthy is that INDOT has been funding liaison positions at the U.S. Army Corps of Engineers (USACE), USFWS and the Indiana Department of Environmental Management (DEM) for specific projects for the past three years. It has been shown that liaisons improve review times, communication, and regulatory interpretation.

Mitigation for wildlife habitat fragmented by highway projects is not required at this time in Maryland.

New Hampshire DOT uses a compensatory mitigation ratio table to compensate for impacts from habitat fragmentation. The most common forms of mitigation are preservation, enhancement and restoration. There is also a watershed-based in-lieu fee program run by New Hampshire Department of Environmental Services (DES). The resource agencies have been known to include special permit conditions which specifically address habitat fragmentation/connectivity compensation.

In New York, the amount of mitigation required for habitat fragmentation is based on negotiation with resource agencies. The New York State Department of Transportation (NYSDOT) uses preservation, enhancement, and creation types of mitigation; however, habitat mitigation is not used often enough for any type to be considered common. In general, close proximity/connectivity to adjacent habitats is preferred when considering mitigation for habitat fragmentation and loss of connectivity of habitats. Compensation monitoring includes population sampling (e.g., Indiana bat mist netting), observation of conservation measures (e.g., nest box use, crossing use, planting survival), and road kill surveys. Resource agencies have included special permit conditions which specifically address habitat fragmentation/connectivity compensation.

Compensatory wetland mitigation and mitigation for habitat for listed species are the most common types of compensation that Oregon DOT uses. For listed species, restoration and enhancement are most common. Oregon natural resource agencies do not accept the purchase of bank credits for the mitigation of habitat fragmentation and connectivity loss. There is a mitigation requirement for connectivity at the EIS level, which is project specific.

In Texas, there is a mechanism in place through an existing agreement with resource agencies that allows for mitigation to replace impacts from habitat fragmentation of non-federally regulated resources, but it is not often used. With the new TCAP, TxDOT is looking at ways to implement a more rigorous system for calculating impacts. The most common types of compensation TxDOT uses specifically for habitat mitigation are preservation, enhancement, restoration, creation, and in-lieu fee. There is an expectation that in the near future, in-lieu fee will be more predominantly used as TxDOT is looking at ways to use banking for wildlife impacts. Resource agencies have included special permit conditions that specifically address habitat fragmentation/connectivity compensation in the form of temporary, enforceable conditions in a Section 7 Biological Opinion.

Summary Table

The table below summarizes the results of the avoidance and compensation interviews by major topics for which the states provided information.

Table 2 Results Summary – Avoidance and Compensation Interviews

State	How states avoid habitat fragmentation during Statewide & Regional Planning efforts	How states avoid Habitat Fragmentation at the project planning stage	Mitigation for habitat loss/ fragmentation (requirements and use)	Stream/river crossing protocols that consider aquatic habitat and fluvial process requirements in addition to hydraulic criteria?	Agencies in this state have included special conditions in permits with regards to habitat fragmentation.
Arkansas	Issues rarely considered at this level unless listed species are involved	ID potential habitats during alt. dev. and initial review by DOT personnel. Receive comments from agencies during NEPA review process.	Mitigation is not required for habitat loss unless owned by a state, federal or local gov. or enrolled in a federal program.	No	Not specified
Indiana	A study is being developed to prioritize areas within watersheds and ecoregions	Issues are flagged after scoping/field visits. Agency comments & recommendations received during NEPA process.	Mitigation is not required for fragmentation, but adjacent habitat and connectivity is considered when identifying sites. They are looking to implement a program.	Yes	Not specified
Maryland	Green Infrastructure Tool , IDs critical areas, used to screen projects at statewide level.	GI Tool is used to avoid impacts. Agency input at concurrence points.	Mitigation is not required for habitat fragmentation.	Yes	Yes
New Hampshire	Working with municipalities and promoting awareness, developing guidelines, some GIS use (GRANIT)	Use of GRANIT, town involvement, federal and state natural resource agencies meet at monthly meetings and provide input.	NH compensates for habitat fragmentation using; preservation, enhancement , restoration, ILF.	Yes	Yes

Table 2 Results Summary – Avoidance and Compensation Interviews (Continued)

New York	Reducing fragmentation is identified as a state priority but no maps are available	NY Natural Heritage data is used. Rely on agency comments on NEPA documents or during design phase (for non-NEPA).	NY compensates for habitat fragmentation (infrequently) using; preservation, enhancement, creation.	Yes	Yes
Oregon	Statewide Planning Goal 5 addresses fragmentation and some use of Wildlife Linkages GIS mapping	Agency input during forums and at decision points during the alternatives analysis.	Compensation for listed species habitat at the EIS level only, it is project-specific.	Consider habitat; Yes Fluvial processes; Yes	Not specified
Texas	TCAP GIS mapping of ecoregions can be accessed via coordination with TWPD	Fragmentation is discussed during alt. analysis and addressed in impacts assessments.	Texas has a process for compensating for habitat fragmentation, but is used infrequently. Preservation, enhancement, restoration, creation, ILF.	Yes	Yes

III. Decision Support Tool for Habitat Fragmentation Solutions

A. Habitat Fragmentation Background, Concepts and Terminology

Habitat fragmentation refers to the process of severing previously continuous habitat (or ecosystems) into smaller and spatially separated patches of habitat by human-induced and natural processes. (ELI 2003). Causes of habitat fragmentation include land conversion to agriculture, housing and commercial development, natural resource extraction (e.g. mining, forestry, oil/gas recovery), transportation corridors, utility corridors, and natural disturbances like wildfire, wind, or flooding. Fragmentation results in the reduction in the area of natural habitats that can lead to changes in ecosystem functions and wildlife populations. Suburban and rural development commonly change patterns of habitat continuity of natural forests, grasslands, wetlands, and coastal areas as a result of adding fences, roads, houses, landscaping, and other development activities (Dale et al. 2000).

Roadway impacts to the natural environment are well-documented, but it has only been in the last two decades that extensive research into the role of transportation projects on habitat fragmentation and connectivity has been performed. This research has led to a new and growing understanding of both the effects of roadways on landscape processes and larger ecosystems, and methods to assess, minimize and compensate for unavoidable impacts. Habitat fragmentation in general is a threat to biological diversity in the United States (Wilcove et al 1998). For transportation projects, the potential changes, or impacts, to landscapes can vary in significance by project, ecosystem and species. Some of the potential effects of habitat fragmentation include (Gunderson, et al. 2005):

- Reduction in genetic exchange/loss of species population
- Reduction in species diversity/distribution
- Increase in wildlife-vehicle collisions
- Reduction in habitat quality (water quality, noise, plant community change/invasive plants)
- Loss of habitat connectivity

Clevenger and Huijser (2011) provide a concise overview of the mechanisms for these impacts. Key terms and concepts associated with habitat fragmentation which are used in the habitat assessment process and in this decision support tool are explained here since there are several uses of these or similar terms in the practice. Figure 2 also provides a schematic to clarify some habitat fragmentation terms and concepts.

- **Connectivity**- the degree of connectedness across a defined landscape that facilitates or impedes species movement among terrestrial and aquatic habitats (Taylor et al, 1993; Tischendorf and Fahrig, 2000).

- **Patch**– a relatively homogeneous type of habitat that is spatially separated from other similar habitat and differs from its surroundings (Forman, 1995; McGarigal and Marks, 1995).

- **Core**-a patch of habitat which supports a population which can serve as a source for other habitat patches regardless of connectivity (Baur, et al, 1995; Porej et al, 2004).

- **Island**- a patch of habitat separated by natural or artificial means from other patches of the same habitat (Fernández-Juricic and Jokimäki, 2001; Jennersten et al, 1992).

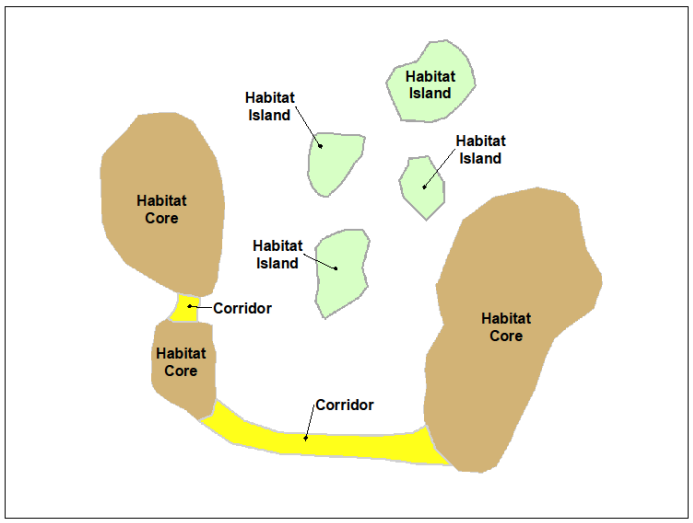
- **Corridor** -a land feature that connects core areas allowing species movement and connection between areas of natural habitat enabling the ecological network to function. Corridors can be continuous strips of land or stepping stones that are patches of suitable habitat (Beier and Noss 1988; Bennett, 1990; Forman, 1995; Dramstad et al, 1996; Fischer et al, 2000).

- **Landscape Scale** - a larger area of land containing a variety of habitat patches or landscape elements which depicts the extent and function of existing networks. A landscape is not necessarily defined by its size; rather, it is defined by an interacting mosaic of patches relevant to the phenomenon under consideration (at any landscape scale) (Forman, 1999; Harris et al, 1996; Turner, 1989).

- **Target (focal) species** –individual or group of species chosen to represent the movement and habitat needs of wildlife species in the study area. Target species should include: (a) species narrowly dependent on a single habitat type, (b) area sensitive species, and (c) species most sensitive to barriers (Majka, D., J. et al, 2007).

- **Habitat Networks or Linkages** (Terrestrial/Aquatic) - a functionally interconnected chain of natural habitats across a landscape that contains core areas, corridors, and buffer zones that are relatively close to each other, thereby allowing for the movement of species between and within the network elements (Davidson, 1996; Opdam, 2002; Marcott, 2006; Kallimanis, 2008).

Figure 2 Conceptual Illustration of Habitat Patches as Cores, Corridors and Islands



The following section provides a framework for assessing habitat fragmentation impacts and mitigation needs for different highway improvement types. Section C provides an overview of the key elements of habitat fragmentation analysis within the context of the NEPA process.

B. Assessing Habitat Fragmentation and Mitigation Needs Based on Highway Improvement Type

Based on the transportation agency interviews, habitat fragmentation impacts are addressed for different highway improvement types. Figure 3 provides a general framework that outlines key components for assessing habitat fragmentation for different highway improvement types. Highway improvement types addressed in Figure 3 are defined below (FHWA, 1997).

1. New Construction - this action involves the construction of a new highway facility where nothing of its type currently exists.

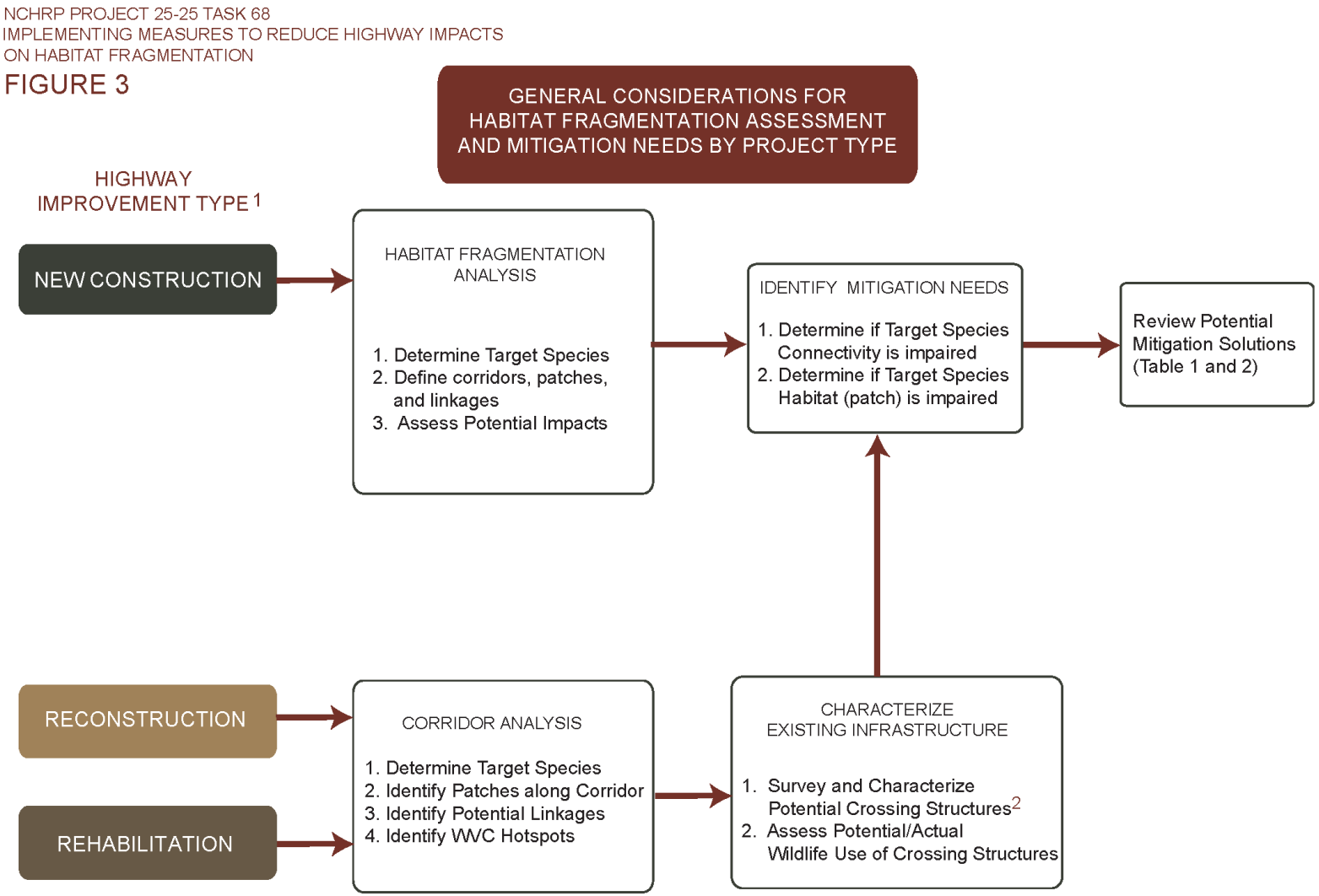
2. Reconstruction – this action involves a major change to an existing highway within the same general right-of-way corridor. This may include capacity improvements or may involve making substantial modifications to an older highway's horizontal and vertical alignment in order to eliminate safety and accident problems.

3. Resurfacing, Restoration, Rehabilitation (3Rs) – these actions primarily serve the preservation and extension of the service life of existing facilities and on safety enhancements. The types of improvements may include resurfacing, pavement, structural and joint repair, minor lane and shoulder widening, minor alterations to vertical grades and horizontal curves, bridge repair, and removal or protection of roadside obstacles.

New construction projects involve a new roadway alignment that can be more complex and require a larger investment of time to complete a landscape level analysis of habitat fragmentation impacts, often as part of a NEPA study. The process depicted in Figure 3 is simplified to show only the basic steps that should be performed prior to determining the need and type of mitigation required. Similar to reconstruction and rehabilitation projects, the process begins with the analysis of the baseline conditions and the identification of potential impacts for alternatives, prior to the step of identifying mitigation needs for either connectivity or patch impacts. Once the nature of the potential impacts is defined, potential mitigation solutions can be reviewed and evaluated (Tables 3 and 4).

The basic difference between new construction and reconstruction/rehabilitation improvements is that the latter occurs along an established transportation corridor where initial impacts to wildlife habitat and connectivity occurred with the original construction. The process to define habitat fragmentation and identify target species can be much simpler for these projects since the project corridor is established, and the existing structures (culverts, underpasses, overpasses, bridges) and potential wildlife crossings are in place. For instance, if a reconstruction/rehabilitation project involves the replacement of a single culvert or reconstruction of a single bridge, then a landscape level assessment of habitat fragmentation is not necessary. In this case the practitioner may only need to define the target species or wildlife species group, assess types of structures and current use by wildlife, and identify the mitigation need. The practioners can then proceed directly to the list of mitigation solutions for connectivity to begin evaluating mitigation options (Tables 3 and 4). The complexity of the assessment process depends on the project scope, target species and other issues. The level of effort and complexity of analysis may increase depending upon site and project specific conditions.

Figure 3 General Considerations for Habitat Fragmentation Assessment and Mitigation Needs



1. Definition of Highway Improvement Type per FHWA.
2. Crossing structures include culverts, underpasses, overpasses and bridges.

Unique to reconstruction/rehabilitation projects is the opportunity to survey and characterize the physical features of existing structures and assess their functional potential for wildlife passage (Figure 3). Examples of procedures to evaluate existing structures are available. Several states have prepared manuals for the assessment of existing culverts for aquatic wildlife passage. While the manuals focus primarily on fish and not aquatic mammals, the principals for documenting and evaluating existing structures for the passage of aquatic wildlife are applicable. Similar manuals or guidelines for evaluating existing structures for use by terrestrial wildlife have not been identified through the literature review.

Figure 4 is a schematic of a *Habitat Fragmentation Assessment within the NEPA Process* that provides a conceptual framework for conducting a landscape level habitat fragmentation analysis within the NEPA process. Section C includes a more detailed discussion on the information needs and process to conduct an analysis and define project impacts. A conceptual decision guide is described in the following section that is designed to facilitate the selection of mitigation solutions for connectivity and patch impacts. The information contained in these sections represents a general conceptual approach that can be scaled to apply to any size of highway improvement project. It is not a comprehensive approach and it is not an NCHRP policy statement.

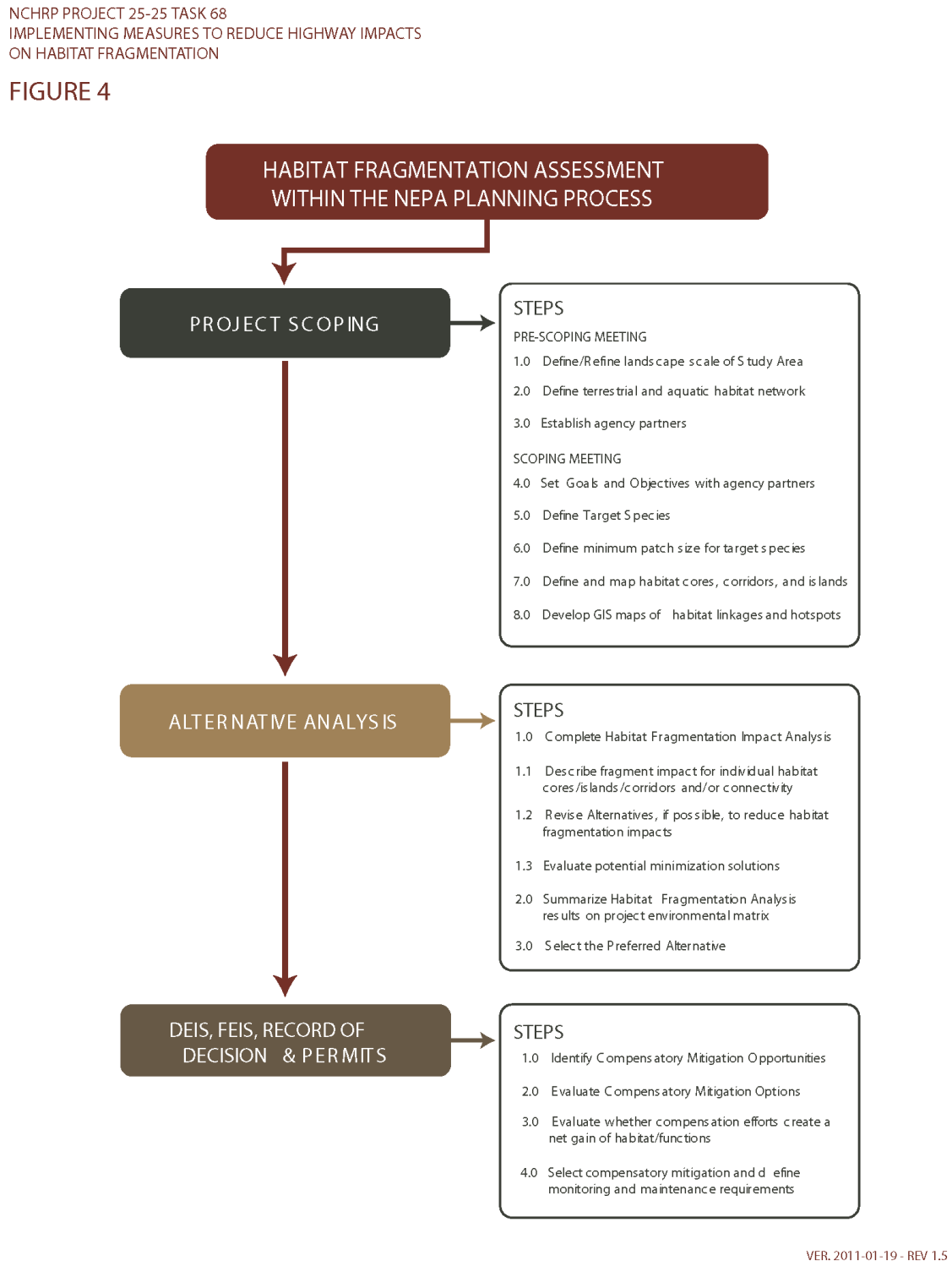
C. Habitat Fragmentation Assessment within the NEPA Planning Process

The incorporation of habitat fragmentation assessments into transportation planning and the project scoping phase of a project is one example of a method to address broader ecosystem level concerns for habitat fragmentation and connectivity, and is consistent with the recommendations in the National Academy of Sciences report "*Assessing and Managing the Ecological Impacts of Paved Roads*" to address ecological effects of roads on a broader scale (Gunderson et al, 2005). In addition, through the surveys of transportation agencies for avoidance measures, it was clear that most avoidance actions are conducted at the beginning of the project development, and that several State DOTs utilize GIS-based systems to prioritize fragmentation avoidance. Integrating habitat fragmentation into project planning provides greater opportunity for the avoidance of potential impacts to critical habitats and connectivity points within a landscape, and allows for advanced planning for minimization and mitigation solutions in coordination with regulatory and resource agencies. To address the process of avoidance and provide information sources useful to the implementation of habitat fragmentation and connectivity assessments, an example flow chart (Figure 4: Habitat Fragmentation Assessment within the NEPA Planning Process) was prepared to illustrate potential steps involved and their likely placement within the NEPA process. A discussion of each step in the process is provided below along with references and links to additional information. It should be noted that this is an example framework only that is presented strictly for informational purposes; other valid methods may be employed to accomplish similar results.

1. Project Scoping

For habitat fragmentation assessments conducted under NEPA, the Project Scoping phase is the initial opportunity to evaluate the project location within the context of the regional landscape and habitat fragmentation issues. The evaluation process begins with the assembly of existing information prior to

Figure 4 Habitat Fragmentation Assessment within the NEPA Planning Process



the agency and public scoping meetings (pre-scoping meeting steps 1 through 3) so that key elements for the landscape and resource information can be collated and provided to agency partners. Through the scoping meetings, several decisions relative to habitat fragmentation assessment would be resolved (steps 4 through 8) prior to conducting the baseline habitat fragmentation analysis during the Alternatives Analysis phase.

Pre-Scoping Meeting

Prior to the Scoping Meeting it will be useful to assemble information that can be used to guide discussions of habitat fragmentation with the objective of refining the landscape scale of the study area, defining target or focal species, and setting objectives for habitat fragmentation analysis. The following steps serve as illustrative steps for practitioners to follow or amend per their specific needs.

Step 1: Defining/Refining a landscape scale for the study area.

This section guides the user through the considerations used in the selection of a landscape level study area that is scaled appropriately to the particular project. The project may range from a new roadway alignment with multiple alternatives, to a capacity and safety improvement at an existing interchange, to a simple rehabilitation or preservation project along an existing roadway. When setting the landscape scale for any project size, the following items should be considered:

- **Define the landscape scale as broadly as possible:** Prior to attending a Scoping Meeting with agency partners, the initial landscape scale should be set to encompass a landscape area that encompasses all potential areas that could be affected by the project. For larger projects, the extent of the study area should include project limits as defined in the Project Need statement or Statewide Transportation Improvement Plan (STIP). Wildlife movements extend beyond typical transportation project study areas. In its broadest sense, the landscape scale study area should reasonably include the project limits where the roadway design will result in traffic volume increases extending out to encompass habitats that could be affected (fragmented) by the construction of the alternative(s). A project study area encompassing all reasonable alternatives should be considered.

- **Utilize available Geographic Information Systems (GIS) database information and aerials:** The use of GIS is integral with the mapping and spatial analysis associated with habitat fragmentation assessments. Typically, states and most federal agencies have GIS database sources that are publicly available and are potentially useful to provide base map information. An example of an on-line source includes the USGS Landcover Database for all of North America (http://landcover.usgs.gov/landcoverdata.php), and the University of Oregon's Library system which maintains links to a national clearinghouse for state and federal GIS data (http://libweb.uoregon.edu/map/map_section/map_Statedatasets.html). Data sources that are useful in assessing the study area landscape include:

    - Digital Aerial photographs
    - Wetland and Land Use Cover mapping

  - Topography and soils
  - Watershed or Hydrologic Unit Code (HUC) boundaries
  - Natural Lands, Parks, Wilderness Areas, Wildlife Refuges, National Forests, Forest Reserves, Recreational Areas, and other managed or protected natural areas.
  - Land ownership, land use zoning and urban growth zones

- **Review pertinent information sources:** Most federal and state agencies have a variety of natural resource databases, inventories and other information sources that can be used to initially identify regionally significant ecosystems, wildlife species of concern, critical habitats and habitat corridors. This information is useful in defining potential target species, species at risk, and key landscape features and objectives for maintaining or improving habitat connectivity. Examples of information to review include:
  - Watershed Management Plans
  - State Wildlife Action Plans (http://www.wildlifeactionplans.org)
  - Natural Resource Management Plans
  - State Natural Heritage Database
  - State or Federal Resource Agency Data
  - County or local community tax maps/property ownership data
  - NatureServe (http://www.natureserve.org)

In addition to these information sources, locations of known concentrations of wildlife-vehicle collisions, or hotspots, should be incorporated into the baseline information. Hotspot data may not be readily available but methods to collect and analyze the data are available and are discussed in Bissonette and Cramer (2008).

- **Determine the Watershed Boundaries:** Aquatic resource networks are defined in part by watershed boundaries and resources within individual networks should be tracked based on the watershed level. Using watersheds as a landscape unit is also recommended for consistency with other regulatory programs, including the US Army Corps of Engineers (USACE) and US Environmental Protection Agency (USEPA) use of a watershed approach in reviewing Clean Water Act related impacts and compensatory mitigation. Most aquatic resource impacts would also be regulated under this program. Hydrologic Unit Codes (HUC) at the 11-digit to 14-digit level is typically used by USACE. When defining the watershed limits for the study area, the boundaries should encompass the outermost project traffic nodes and all of the adjacent HUCs. If HUC data at the 11-digit or 14-digit level is not available, then watershed limits can be developed using a Digital Elevation Model (DEM) and the Strahler stream order hierarchy (Strahler, 1957), or GIS based tools.

Resources that can be consulted for more information concerning this step include:

- www.virginiadot.org/vtrc/main/online_reports/pdf/07-r14.pdf
- www.floridahabitat.org/wildlife-manual/transportation
- www.wsdot.wa.gov/NR/rdonlyres/7337015A-40F0-4DAE
- Majka, D., J. Jenness, and P. Beier. 2007. Corridor Designer: ArcGIS tools for designing and evaluating corridors. Available at http://corridordesign.org

Once the initial landscape level study area map is prepared, the terrestrial and aquatic habitat networks should be prepared prior to the project Scoping Meeting.

Step 2: Define Terrestrial and Aquatic Habitat Networks

The identification of habitat networks (or linkages) can be accomplished using current high resolution aerial photo coverage combined with available GIS databases (topography, natural heritage data, land use, etc) as available. Delineation of the terrestrial and aquatic habitat networks consists of delineating linked habitats, or patches, distributed along and among definable natural corridors. The linkages may be physical and/or could be linked based on a species' use of the habitat. An example of a physical linkage is a stream and its associated forested riparian corridor. On the other hand, neo-tropical migrant bird species may use physically separated habitat (e.g. mature forest patches made up of certain species/age composition). Species movement between and use of separate patches creates the connectivity or network. Information obtained in Step 1, such as Critical Habitats, protected lands and heritage database locations, should be utilized to develop the habitat network map for the landscape study area. Patch refinement is discussed further in Step 6.0. Incorporating knowledge of potential target species and their use of habitats in the study area can be used at this stage to initially define networks for these species.

The habitat network map is a very useful figure and can be used in agency meetings. Some states are developing habitat (patch/corridor) network or "linkages" mapping as part of a State Wildlife Action Plan (SWAP) or similar plans and should be referenced or adopted as appropriate. Resources that provide additional information useful to define habitat networks include:

- www.environment.fhwa.dot.gov/integ/case_texas.asp/
- www.aot.state.vt.us/TechServices/EnvPermit/Documents/Wildlife_Linkage_Habitat_Report_5_15_06.pdf
- www.azconservation.org/projects/natural_infrastructure/data_sources
- http://restoretherockies.wordpress.com/

Step 3: Establish Agency Partners

Habitat fragmentation analysis requires the direct input from resource and regulatory agency partners to properly frame the assessment process, beginning with the establishment of the landscape scale of the study area through to the establishment of appropriate mitigation strategies. Agency partners often can provide data sources and expertise to guide the fragmentation impact analysis process. Their "buy-in" to the evaluation process is essential so that critical decision points and project schedules can be maintained while also meeting the overall project purpose and need. Examples of typical agency partners include State wildlife resource agencies and the U.S. Fish and Wildlife Service.

The *Wildlife and Roads Decision Guide* (http://www.wildlifeandroads.org/decisionguide) developed under NCHRP 25-27 provides relevant guidelines that assist in determining the agency partners.

Scoping Meetings

The objectives of a scoping meeting with the agency partners include:

1. Identify target species and define minimum patch size requirements for target species, particularly through coordination with resource agency partners.
2. Solidify the limits of habitat networks and define components of the habitat networks.
3. Create working habitat linkage maps that can be refined as field work progresses.
4. Compile input and supporting documentation of existing conditions.

The identification of target species habitat, minimum patch sizes, species life history details and other noteworthy habitat qualities for targeted species is predicated on resource agency coordination. The habitat networks and study area limits will likely need some refining to accommodate the home range and/or dispersal distance of particular target species. Critical information gleaned from resource agency coordination during this step is key to forming the framework and assumptions for future analysis of fragmentation, including impacts analysis and mitigation decision-making. This process begins with the project scoping meeting and ideally would be completed before the alternatives analysis so as to inform the decisions made during the alternatives development.

Step 4: Set Goals and Objectives with Agency Partners for Habitat Fragmentation Reduction

At the onset of coordination with Agency partners, the project team should establish a set of reasonable goals and objectives for the habitat fragmentation assessment process, with the overall objective of not increasing the effects of habitat fragmentation and connectivity loss due to project construction. The goals and objectives should be reviewed and amended periodically as additional project information is obtained. Some considerations for developing goals:

- avoidance of impacts to habitat corridors;
- minimizing impacts to habitat corridors;
- maintaining habitat integrity to the greatest extent possible;
- replacement/mitigation of habitats lost;
- target species goals

Clevenger and Ford (in Beckmann et al, 2010) discusses ecological functions of wildlife corridors that can be considered in the development of goals and objectives such as:

1. Reduced mortality and increased movement (genetic interchange) within a population
2. Meeting biological requirements such as finding food, cover, and mates
3. Dispersal from maternal or natal ranges and re-colonization after long absences
4. Redistribution of populations in response to environmental changes and natural disturbances (e.g., fire, drought);movement or migration during stressful years of low reproduction or survival
5. Long-term maintenance of meta populations, community stability, and ecosystem processes

Step 5: Define Target (Focal) Species

Through coordination with agency partners, target species for the habitat fragmentation assessment should be identified. Obtaining early consensus on the number and types of species to be evaluated is essential to maintaining a streamlined process. Once a target species has been identified, it is important

to become familiar with its lifecycle requirements, especially any habitat specific attributes. These attributes can align with minimum patch size thresholds and habitat connectivity needs.

Step 6: Define Minimum Patch Size for Target Species

The minimum patch size is an area threshold for a particular habitat that is sufficient to sustain a population of a given species. "Particular habitat" is a quality dependent variable associated with the life cycle/habitat needs of the target species. The user should clearly describe and define the minimum patch size of the target species based on available references and input from federal and state resource agencies, non-government organizations and regional expertise. The minimum patch size will also aid in the planning for mitigation of patch impacts at a later stage.

Step 7: Define and Map Habitat Cores, Corridors and Islands

The main objective of this step is to structure an assessment of landscape connectivity and identify habitat networks common to both existing and proposed conditions so that comparisons can be made during the alternatives analysis phase.

The key objectives include:

1) To identify the baseline habitat network components; Cores, Corridors , and Islands
2) To describe or depict the level of connectivity through each habitat network.
3) To assign a functional score to these features

Using the definitions adopted for the project-specific habitat assessment, the habitat networks are divided into respective cores, corridors and islands. The identification of cores, corridors and islands is directed by the target species and the assumptions which guide the user's delineation of these features should be documented and accompany any maps or figures.

The functional assessment of cores, corridors and islands is more subjective. The assumptions which guide the user's delineation of these features, particularly any qualitative scoring of these features, should be explained and accompanied by maps or figures. There are many methods for qualitatively scoring network components, though some simple metrics are presented here which relate back to basic fragmentation factors: size, shape, and location/configuration (ELI 2003).

Federal and state wildlife agencies may have their own preferred metrics that can be incorporated in to the process. Examples of scoring methods can be reviewed at the following sites:

- www.virginiadot.org/vtrc/main/online_reports/pdf/07-r14.pdf
- www.floridahabitat.org/wildlife-manual/transportation
- www.wsdot.wa.gov/NR/rdonlyres/7337015A-40F0-4DAE-9408-D2D88FD32B6C/0/SR167study1.pdf

Step 8: Develop GIS Maps of Habitat Linkages

At this step the practitioner should refine the maps which were created in Step 1. The practitioner should incorporate resource agency feedback and identify the most functionally intact components of each habitat network. Information gleaned from resource agency coordination during this step is key to forming the framework and assumptions for future impacts analysis and mitigation decision making. Completion of this step before the alternatives analysis is necessary since this information will support the determination of critical areas to avoid impacts and opportunities for minimization and compensation of potential impacts.

A toolkit of free software and accompanying instructions for developing, identifying, and assessing habitat linkages is available on-line at www.corridordesign.org. This information has been used in the development of conservation plans for the Southern Rockies Ecosystem Project. Reviewing and drawing upon the experience of the Southern Rockies Ecosystem Project website (http://restoretherockies.wordpress.com/) is highly recommended.

2. Alternatives Analysis

Following the completion of the project scoping, development of the baseline habitat network, and a landscape level assessment of habitat fragmentation, an assessment of project alternatives can be performed. At this point in a typical project timeline the alternatives have been identified and initial efforts to avoid critical habitats and habitat fragmentation impacts can be incorporated in the initial alignment selections using the habitat network mapping. The impact analysis is also predicated on having an understanding of the habitat features of the target species and familiarity with the qualities of habitats present along each alternative. The GIS mapping and modeling process does not supplant the need for gathering field data to support mapping and model assumptions: knowledge of field conditions is implied throughout the assessment process.

The level of effort and detail required for this assessment is dependent upon the size and complexity of the project (culvert replacement versus new alignment), complexity of the project landscape (urban vs. rural), number of target species, requirements for data collection through field work, and other factors. The three main steps of this process, as outlined in Figure 4, are discussed in turn below.

Step 1.0: Complete Habitat Fragmentation Impact Analysis

The objective of this step is to assess the direct and secondary impacts of each proposed alternative within a habitat network for each individual target species or species group. The impact assessment requires design information for each alterative including the roadway alignment, profile, lane and right-of-way width, limit of construction, anticipated culvert and/or bridge locations, and stormwater facilities and conveyances. Operational details that assist in addressing potential impacts include changes in traffic volumes, noise levels, and estimated annual salt loads. Landscape disturbance processes that influence and maintain some habitats and species requirements suitability, such as periodic flooding, wild fire, landslides and sediment loads, can also be altered by transportation projects. In certain circumstances, project designs could influence these natural processes and result in a change to the habitat networks.

Step 1.1: Describe Impact on Individual Cores, Islands, Corridors and Connectivity

The potential direct impacts of each alternative can be quantified for each target species by overlaying the project features with the habitat network maps. Quantitative estimates of direct impacts to habitat acreages and connectivity changes (corridor impacts) can be documented for each alternative. As part of this process, opportunities for impact avoidance and minimization can be identified for further evaluation.

Methods for the assessment of secondary impacts on wildlife (habitat degradation and functional loss) are not well established, are typically based on professional opinion and agency coordination, and mostly qualitative. Methods to estimate the acreage of effect and the degree of effect will vary by species and habitat types. Determining an appropriate level of mitigation, if any, to offset secondary impacts may be difficult to quantify and require a more subjective approach. Procedures for selecting appropriate mitigation measures for secondary impacts are also poorly defined. Procedural guidance on assessing secondary impacts is provided in the NCHRP 25-25 Task 11 *Indirect and Cumulative Impacts Analysis* (Stanley 2006). The report includes a flow chart for assessing secondary impacts within the NEPA planning process as well as case studies.

Step 1.2: Revise Alternatives to Avoid Impacts

The objective of this step is to determine if potential impacts identified in Step 1.1 can be avoided through the alteration of the project design. The evaluation process and outcomes should be documented for each alternative. The evaluation should account for other potential impacts that may be imposed by a change in the alignment that avoids a habitat fragmentation impact, including cost considerations. Cost considerations should include potential changes that increase or decrease costs for roadway construction, residential/commercial displacements, wetland or other mitigation requirements, and other relevant items that would influence the decision for altering a proposed alignment.

Step 1.3: Identify Potential Minimization Solutions

The objective of this step is to initially identify and evaluate potential minimization steps that could reduce connectivity impacts. These initial minimization solutions would focus on improving or maintaining permeability through the transportation corridor using structural approaches such as underpasses, overpasses and crosswalks. The Wildlife and Roads website (http://www.wildlifeandroads.org/) provides a complete decision guide for selecting appropriate measures to reduce wildlife-vehicle collisions that includes a variety of wildlife crossing structures. Using this reference, potential solutions can be identified, evaluated and either adopted as a means to minimize potential impacts or determined to be inappropriate for location.

Resources that provide further guidance on minimization solutions for this step include:

- http://www.wildlifeandroads.org/decisionguide/
- http://www.corridordesign.org/designing_corridors/linkage_designs/mitigating_barriers

- http://www.dnr.state.mn.us/waters/watermgmtsection/pwpermits/gp2004_0001_manual.html
- http://www.dem.ri.gov/programs/benviron/water/permits/fresh/wetbmp.htm

Step 2.0: Summarize Habitat Fragmentation Analysis Results on Project

At this step a comparative analysis of the refined impacts of each alternative can be completed. The impacts should reflect the avoidance and minimization steps considered in Steps 1.2 and 1.3. One approach is to utilize an environmental matrix that allows for side by side comparisons of each alternative by topic. For habitat fragmentation, the comparisons would be based on the project specific features of the habitat networks and target species, including estimates of affected acreage (direct and indirect) of cores, island and corridors, functional scores for connectivity gain/loss, or other metrics adopted in Step 1. This information would assist the project team in selecting a preferred alternative and identify mitigation needs.

Step 3.0: Select Preferred Alternative

Based on the analysis of potential environmental, social and land use impacts the preferred alternative that satisfies the projects purpose and need can be selected. Once selected, refinement of approaches to minimization impacts can be completed. The preferred alternative considering habitat fragmentation may or may not be the preferred NEPA alternative. The identification of potential mitigation options can also be conducted during the alternatives analysis process, but the final selection and evaluation of solutions is often completed following the identification of the preferred alternative and is discussed in the next section.

3. DEIS, FEIS, Record of Decision & Permit Documentation

As noted above, once the preferred alternative is identified and habitat fragmentation impacts are quantified then the evaluation of mitigation solutions that compensate for those impacts can be completed. Identifying mitigation opportunities should be initiated as early in the project planning phase as possible. Advanced planning and agency coordination to identify opportunities is encouraged as part of the *Ecological Approach* (Brown, 2006). Mitigation projects themselves have been evaluated within EIS and EA documents as a part of the transportation project such that the entire action is comprehensively addressed. The process is presented here simply for the ease of review and discussion. Once mitigation is identified, evaluated as feasible and deemed appropriate by the project sponsor and agency partners, the elements of the mitigation plan can be incorporated into the commitments of the Record of Decision (ROD) and permit documents.

The process generally includes the following steps:

1) Identification of mitigation opportunities
2) Evaluation of mitigation options
3) Evaluation of whether mitigation efforts result in a net gain in habitat function
4) Selection of mitigation; defining of monitoring and maintenance requirements

Step 1: Identification of mitigation opportunities

Mitigation opportunities can be identified as early as the Scoping Meeting and should include a robust list of sites and actions that can each be evaluated independently. Mitigation could include preservation, enhancement, restoration or creation of habitat. Incorporating structures designed to facilitate wildlife passage and habitat connectivity could also serve as mitigation. This effort typically occurs once the approximate extent of and nature of impacts is known and a screening study can be conducted around the anticipated mitigation needs.

Step 2: Evaluation of mitigation options

Once the mitigation opportunities are identified, each option can be evaluated to determine if it is physically feasible, has impacts to other resources (T&E habitat, cultural resources, etc.), is cost effective, and is acceptable to agency partners and other stakeholders. As the number of options is reduced through the evaluation process, ongoing coordination with agency partners is critical to assure that the remaining options are considered suitable for the meeting the project needs, or if additional options need to be considered.

Step 3: Evaluation of mitigation efforts-do they result in a net gain in habitat function

The preferred mitigation options should be further evaluated to determine if the proposed action will result in a net gain in habitat function (i.e., improved connectivity or increase in patch size) for the target species. Comparisons of the mitigation options with proposed impacts are made to assess suitability of the proposed mitigation to offset or compensate for impacts.

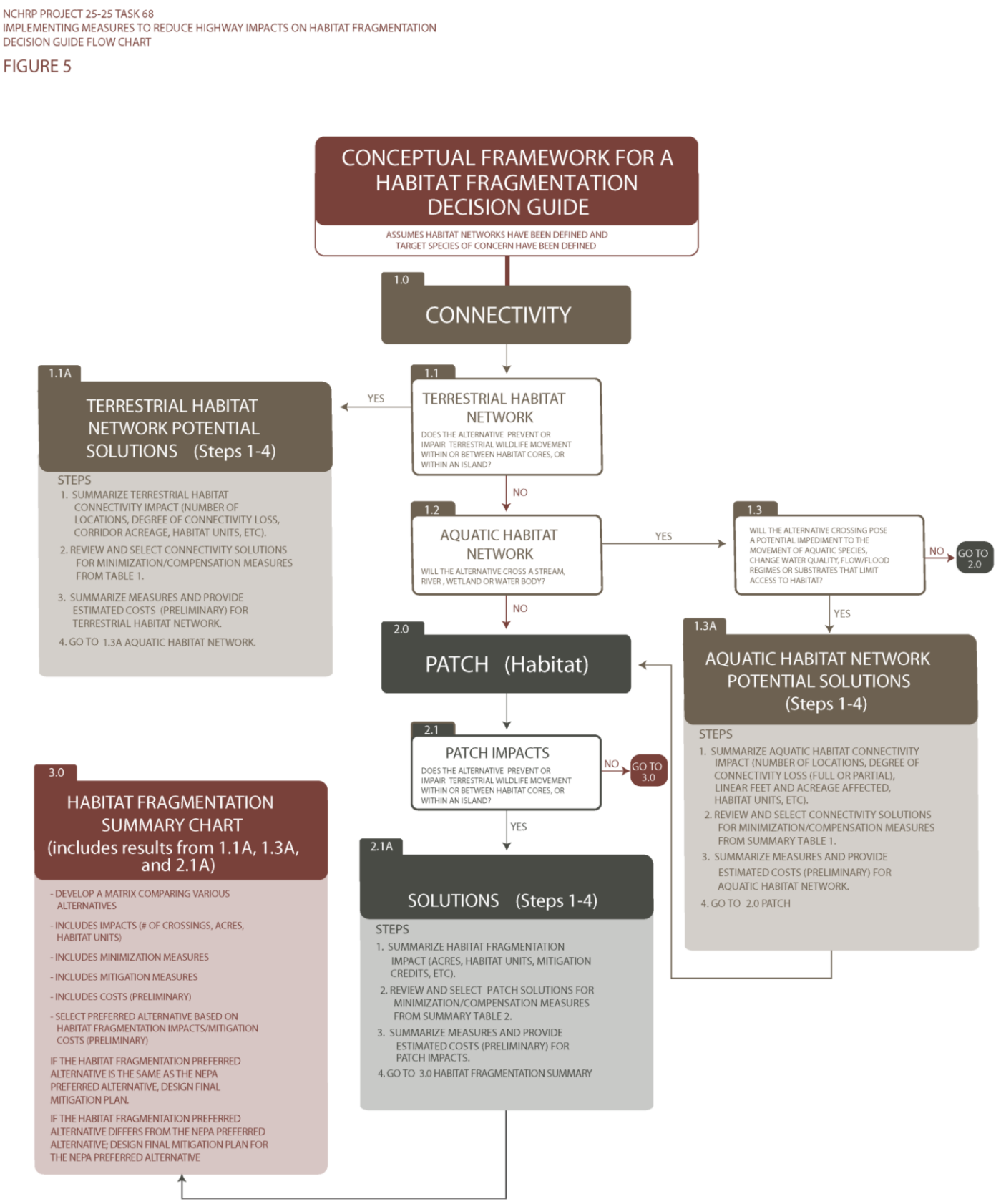
Step 4: Selection of mitigation and defining of monitoring and maintenance requirements

Once mitigation for the project is defined and advanced for further study, monitoring and maintenance requirements should be also be defined. These latter steps are important as they become part of the mitigation plan and incorporated into the ROD and permit documents. These measures also define long term budgetary commitments for the project sponsor, as well as serve as the means to determine if the mitigation goals and objectives for the project are being satisfied or if remedial action is necessary.

4. Conceptual Habitat Fragmentation Decision Guide Flow Chart

The Conceptual Framework for a Habitat Fragmentation Decision Guide (Figure 5) is described in this section. The premise of the conceptual Decision Guide is that the project impacts will dictate the types of mitigation solutions available, and that the solutions need to be tailored to the project. The Decision Guide is a series of basic questions to categorize habitat fragmentation impacts for a project during the NEPA Alternatives Analysis process. The Decision Guide leads to a series of potential solutions based on an affirmative answer to the sequence of questions. The questions require the practitioners to address whether the project alternative will impact a terrestrial habitat network, an aquatic resource network, or habitat patch. The process can be repeated for each alternative. The information is then summarized in a final matrix to assist in the selection of a preferred alternative based on several factors.

Figure 5 Conceptual Framework for a Habitat Fragmentation Decision Guide



There are several prerequisites that support the use of the decision guide, namely:

1) The habitat network within the study area has been defined;
2) Target species have been defined;
3) The minimum patch size for target species have been defined;
4) Habitat cores, islands and corridors are mapped.
5) Habitat fragmentation analysis has been completed.

Each question in the guide requires the user to consider potential project impacts (both direct impacts and impairments to functions) to habitat cores, islands and connectivity (corridors). The analysis will require specific project information (as defined in the project scoping phase) which should be developed on a per project basis for specific project settings and target species. The process can also be used in an iterative process to compare alternatives and refine alignments. A description of each main element within each numbered box on the flow chart (Figure 5) is provided below.

Box 1.0 Connectivity

The guide begins with the assessment of connectivity impacts to habitat networks (Box 1.1). Habitat networks, as defined in Section C above, consist of both terrestrial and aquatic resource networks.

Box 1.1 Terrestrial Habitat Network: Does the alternative prevent or impair terrestrial wildlife movement within or between habitat cores, or within an island?

The practitioners will determine the potential of the project alternative to prevent or impair terrestrial wildlife movement within or between cores (along a corridor), or within an island. Direct impacts to habitat cores, habitat islands or impairment impacts should be assessed throughout the length of the entire alternative. The practitioner should assess the number of impacts, the acreage of direct impact and the affects of impairment. An affirmative answer leads the practitioners to a list of potential mitigation solutions (Box 1.1A). A negative answer (lack of terrestrial habitat network impacts) directs the practitioner to Box 1.2 Aquatic Habitat Network.

Box 1.1A Terrestrial Habitat Network Potential Solutions (Steps 1-4)

Box 1.1A describes a 4 step process to develop a preliminary minimization/mitigation strategy and preliminary cost estimate for the alternative under consideration.

Step 1. Summarize terrestrial habitat connectivity impact (number of locations, degree of connectivity loss (full or partial), corridor acreage, habitat units, etc).

All Terrestrial Habitat Network impacts for the alternative should be considered collectively. The measure of impact such as number of corridors, corridor acreage, habitat units, or other measures may be used to quantify the impact of the entire project alternative. The quantitative analysis will serve as the baseline measure of habitat and connectivity loss. Mitigation will be designed to offset the baseline impact. Natural systems may require 3 to 5 years or longer before developing and becoming fully functional. Mitigation ratios may exceed a 1 to 1 ratio of mitigation to impact. Factors that determine mitigation ratios typically include the degree of functional loss (full or partial) that are lost by the impacted habitat type, duration of time required for re-establishment of a habitat type and function,

and some measure of rarity of the habitat type. Agencies may provide input on the mitigation ratio that will be required.

Step 2. Review and select terrestrial connectivity solutions for minimization/compensation measures from summary table of connectivity mitigation solutions. The mitigation solutions for connectivity impacts can be reviewed and assessed for applicability to the project impacts based on species group, opportunity, effectiveness and cost.

Step 3. Summarize measures and provide estimated costs (preliminary) for Terrestrial Habitat Network.

A summary of Terrestrial Habitat Corridor avoidance, minimization, and mitigation measures should be prepared. The number of crossings, acreage, habitat unit totals, and a preliminary estimate of costs for the measures should be totaled. This will be carried into the summary prepared in Box 3.0 Habitat Fragmentation Summary Chart.

Step 4. Go to 1.2 Aquatic Habitat Network

Once the terrestrial habitat network is evaluated for the alternative the practitioner is directed to evaluate connectivity impacts to the aquatic habitat network.

Box 1.2 Aquatic Habitat Network: Will the Alternative cross a stream, river, wetland or water body?

The first question directs the practitioner to assess if an alternative will cross part of an aquatic habitat network (stream, river, wetland or waterbody). If there are no crossings (and no impacts) then the practitioner is directed to 2.0 Patch. If the project crosses part of an aquatic habitat network then the practitioner is directed to Box 1.3 to assess if the crossing has the potential to become a barrier or impair connectivity.

Box 1.3. Aquatic Habitat Network: Will the alternative crossing pose a potential impediment to the movement of aquatic species, or change water quality, flow/flood regimes or substrates that limit access to habitat?

The practitioner will determine the potential of the project alternative to prevent or impair aquatic species movement within or between cores (along a corridor). Direct impacts to cores or impairment of connectivity should be assessed throughout the length of the entire alternative. The practitioner should assess the number of impacts, the acreage of direct impact and the effects of impairment. An affirmative answer leads the practitioner to a list of potential mitigation solutions (1.3A). A negative answer (lack of aquatic habitat network impacts) directs the practitioner to 2.0 Patches.

Box 1.3A Aquatic Network Potential Solutions

Box 1.3A describes a 4 step process to develop a preliminary aquatic habitat network minimization/mitigation strategy and preliminary cost estimate for the alternative under consideration.

Step 1. Summarize aquatic habitat connectivity impact (number of locations, degree of connectivity loss (full or partial), linear feet and acreage affected, habitat units, etc).

All Aquatic Habitat Network impacts for the alternative should be considered collectively. The measure of impact such as number of corridors, corridor acreage, habitat units, or other measures (stream mitigation impact units) may be used to quantify the impact of the entire project alternative. The quantitative analysis will serve as the baseline measure of aquatic habitat and connectivity loss. Mitigation will be designed to offset the baseline impact. Mitigation ratios have been discussed in Terrestrial Habitat Networks (1.1b).

Step 2. Review and select aquatic connectivity solutions for minimization/compensation measures from summary table of connectivity mitigation solutions. The mitigation solutions for connectivity impacts can be reviewed and assessed for applicability to the project impacts based on species group, opportunity, effectiveness and cost.

Step 3. Summarize measures and provide estimated costs (preliminary) for Aquatic Habitat Network.

A summary of Aquatic Habitat Corridor avoidance, minimization, and mitigation measures should be prepared. The number of crossings, acreage, habitat unit totals, and a preliminary estimate of costs for the measures should be totaled. This will be carried into the summary of developed in Box 3.0 Habitat Fragmentation Summary Chart.

Step 4. Go to Box 2.0 Patch

Once completed, the practitioner is directed to continue the process to assess for impacts to Patch (2.0).

Box 2.0 Patch (Habitat) Patches include cores and islands. A core is a patch of habitat which supports a population which can serve as a source for other habitat patches regardless of connectivity. An island is a patch of habitat separated by natural or artificial means from other patches of the same habitat. Section 2.0 is an assessment of impacts to habitat patches (cores and islands) for target species.

Box 2.1 Patch Impacts: Does the alternative have the potential to impact/impair a habitat core/island or reduce core/island patch size?

The practitioners will determine the potential of the project alternative to impact or impair habitat for target species. Direct impacts to habitat cores/islands (reduction in size or elimination) or impairment impacts should be assessed throughout the length of the entire alternative. The practitioner should assess the number of cores/islands that are impacted, the acreage of direct impact and the effects of impairment. An affirmative answer leads the practitioners to a list of potential mitigation solutions (2.1.b). A negative answer (lack of patch impacts) directs the practitioner to the summarization step for the alternate at 3.0.

Box 2.1A Patch Impact Potential Solutions (Steps 1-4)

Potential Solutions (Box 2.1A) describes a 4 step process to develop a preliminary minimization/mitigation strategy and preliminary cost estimate for the alternative under consideration.

Step 1. Summarize patch impacts for target species (acreage of core and/or island habitat, degree of impairment (full or partial), habitat units, etc).

All patch impacts for the alternative should be considered collectively. The measure of impact such as the acreage of cores and islands impacted, habitat units, or other measures may be used to quantify the impact of the entire project alternative. The quantitative analysis will serve as the baseline measure of habitat and connectivity loss. Mitigation ratio determinations were discussed previously in Section 1.1.A.

Step 2. Review and select patch solutions for minimization/compensation measures from summary table of patch mitigation solutions. The mitigation solutions for patch impacts within the table can be reviewed and assessed for applicability to the project impacts based on species group, opportunity, effectiveness and cost.

Step 3. Summarize measures and provide estimated costs (preliminary) for Patch.

A summary of core/island avoidance, minimization, and mitigation measures should be prepared. The number of crossings, acreage, habitat unit totals, and a preliminary estimate of mitigation costs for the measures should be totaled. This will be carried into the summary of 3.0 Habitat Fragmentation Summary Chart.

Step 4. Go To 3.0 Habitat Fragmentation Summary

Results from the Patch analysis as well as terrestrial and aquatic habitat networks should be totaled as part of Box 3.0 Habitat Fragmentation Summary Chart.

Box 3.0 Habitat Fragmentation Summary Chart (includes results from 1.1A, 1.3A, and 2.1A)

For each alternative a summary of Habitat Fragmentation impacts, avoidance and minimization measures should be prepared. For each alternative the summary will include Terrestrial Habitat Network impacts/mitigation (1.1A); Aquatic Habitat Network impacts/mitigation (1.3A) and Patch impacts/mitigation (2.1A) should be totaled.

<u>Develop a comparative matrix for all alternatives</u>. The comparative matrix should include but not be limited to:

- impacts (# of crossings, acres, habitat units)
- minimization measures
- mitigation measures
- costs (preliminary)

<u>Select preferred alternative based on habitat fragmentation impacts/mitigation costs (preliminary).</u> Alternatives should be compared to determine the least damaging alternative. Impacts, minimization measures, and mitigation measures should be considered in the comparison. Preliminary costs are also a factor in determining the preferred. If the preferred alternative based on habitat fragmentation analysis is the same as the NEPA-preferred alternative, the practitioner should design final mitigation plan as part of the permitting of the project.

In some cases the NEPA-preferred alternative may differ from the preferred identified by the habitat fragmentation analysis. A final mitigation plan will be developed for the NEPA-preferred alternative

after the Record of Decision and simultaneously with permitting. Designing mitigation plans will be developed as part of Task 4.0.

5. Circumstance/Context Based List of Selected Mitigation Solutions

Tables 3 and 4 present a list of mitigation solutions developed from the interviews with transportation agencies, reports and literature. Table 3 lists mitigation solutions specific for connectivity, and Table 4 lists mitigation solutions specific for patch. Because the table reflects projects that, for the most part, have been constructed and have demonstrated effectiveness through monitoring, the solutions are considered to have immediacy of implementation, are cost-effective for specific situations, and have been accepted by resource agencies as mitigation measures. Each mitigation solution included has at least one project example.

The tables are organized by types of solutions. Table 3 lists solutions to address connectivity impacts and Table 4 lists solutions to mitigate for patch impacts. Within each table, the mitigation solutions are further listed by size of structure followed by the species group that it serves. Each solution is also supported by one or more project examples with the corresponding reference. Design considerations, mitigation cost and other relevant factors are included when available.

As described previously, the review and selection of potential mitigation solutions for habitat fragmentation should be preceded by an analysis of potential project impacts, or in the case of some reconstruction and rehabilitation projects, opportunities to restore connectivity due to past impacts. With an understanding of the type of fragmentation impact (connectivity or patch) and the target species that the mitigation solution should serve, practitioners can quickly find and review information pertaining to one or more mitigation options. Further evaluation to address the project-specific feasibility and effectiveness of any mitigation solution is required prior to advancing the mitigation solution into project design plans.

A brief description of the main components of the table and relevant information sources are provided below.

Type of Solution

The tables are organized by the type of solution for either connectivity (Table 3) or patch (Table 4). As noted, the solutions represent mitigation solutions that have been implemented before and are supported by examples. For connectivity (Table 3) the solutions are organized into three general approaches: 1) Shift Alignment; 2) Install structure; and 3) Retrofit structure. Each addresses different approaches to facilitate wildlife passage. Under Install Structure further divisions are made to present more specific approaches based on type and size of structure.

Table 3 Summary of Connectivity Solutions

TABLE 3 : CONNECTIVITY SOLUTIONS

SOLUTION		SPECIES GROUP	REGION	MITIGATION TYPE	TIMING OF SOLUTION/ EVALUATION	IMPACT REDUCTION BENEFITS	COST RANGE	DESIGN CONSIDERATIONS	SOURCE(S)	
SHIFT ALIGNMENT - Prevent or reduce impact through alteration to the proposed road alignment such that the connectivity function can be maintained										
	Examples:	•Multi-species	VT	Minimization	Project Planning/ Alternatives Analysis			• Shift road alignment at least 100 ft away from edge of Missisquoi River and restore area to functional riparian habitat	Austin, J.M., M. Ferguson, G. Gingras, and G. Bakos. 2003. Strategies for restoring ecological connectivity and establishing wildlife passage for the upgrade of Route 78 in Swanton, Vermont: an overview. IN: Proceedings of the 2003 International Conference on Ecology and Transportation, Eds. C.L. Irwin, P. Garrett, K.P. McDermott. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 253-259.	http://escholarship.org/uc/item/50q5q4m7
INSTALL STRUCTURE - Provide overpass, underpass, or at-grade cross to facilitate wildlife passage over, under or across the roadway										
Overpass : grade separation structure designed to allow wildlife to cross over an intersecting highway or railroad, usually covered with vegetation	Overpass	Carnivores/large herbivores/small - medium sized mammals/flying animals/reptiles & amphibians	ALL	Minimization/ Compensation	Project Planning/ Alternatives Analysis	Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs	>$1 million	•Minimum Size >40 m wide (NCHRP, 2008), Recommended 100 m wide (Clevenger and Huijser, 2011) •Width required increases with length of overpass (width to length ratio should be >0.8) •Designed to resemble natural habitat •Soil depth of 5-8 feet to support plants •Minimum Fence / Berm Hieght of 8 feet (sound and light attenuation)	Bissonette, J.A. and P.C. Cramer. NCHRP Report 615: Evaluation of the Use and Effectiveness of Wildlife Crossings. Transportation Research Board of the National Academies, Washington D.C., 2008. Clevenger, A.P. and M.P. Huijser. 2011. Wildlife Crossing Structure Handbook; Design and Evaluation in North America. U.S. Department of Transportation, Federal Highway Administration. Report No. FHWA-CFL/TD-11-003	http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_615.pdf http://www.cflhd.gov/programs/techDevelopment/wildlife/documents/01_Wildlife_Crossing_Structures_Handbook.pdf
	Examples:	•Ungulates/multi-species	Alberta	Minimization/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs	$1,688,993/overpass (2007); IN CONSTRUCTION - $3,290,000 - $3,760,000 for Lake Louise Area of Park including traffic control & detour; fencing $69/m (2007 $) (Huijser et al. 2008)	•52-m wide x 70 m long overpasses (Huijser et al. 2008) •Openness ratio =5.41 (Clevenger and Waltho 2005) •Planted with native grasses/shrubs/white spruce (Gloyne and Clevenger 2001) •Lake Louise overpass - 60m wide across 2-lane road (Huijser et al. 2008)	Clevenger, A.P. and N. Waltho. 2005. Performance Indices to Identify Attributes of Highway Crossing Structures Facilitating Movement of large Mammals. Biological Conservation 121(3): 453-464	http://biology.ucf.edu/~rnoss/papers/Clevenger%20and%20Waltho%202005.pdf
									Gloyne, C.C. and A.P. Clevenger. 2001. Cougar (Puma concolor) use of wildlife crossing structures on the Trans-Canada Highway in Banff National Park, Alberta. Wildlife Biology 7: 117-124.	http://www.wildlifebiology.com/Downloads/Article/326/En/7_2_gloyne.pdf
									M.P. Huijser, P. McGowen, A.P. Clevenger, and R. Ament. 2008. Wildlife-vehicle collision reduction study: best practices manual. Report to Congress. U.S. Department of Transportation, Federal Highway Administration.	http://www.fhwa.dot.gov/environment/fconnect/wvc/index.htm
Underpass : passages that allow for wildlife to cross underneath the roadway	*Bridge underpass* : structure (>20') including supports, erected over a depression or obstruction and having a floor for carrying traffic or other moving loads	Carnivores/large herbivores/small - medium sized mammals/flying animals/reptiles & amphibians, *aquatic animals*	ALL	Minimization/ Compensation	Project Planning/ Alternatives Analysis	Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		•Location in the landscape influences effectiveness •Light in the underpass will increase openness and therefore, may be helpful for some species •Underpass width of 20 foot minimum, > 40 foot recommended •Underpass height 10 foot minimum, >15 foot recommended •Eliminate motor and all-terrain vehicle use from area surrounding underpass, minimize human use and disturbance of the underpass •Design roadway drainage and direct runoff away from the underpass structure	Bissonette, J.A. and P.C. Cramer. NCHRP Report 615: Evaluation of the Use and Effectiveness of Wildlife Crossings. Transportation Research Board of the National Academies, Washington D.C., 2008. Clevenger, A.P. and M.P. Huijser. 2011. Wildlife Crossing Structure Handbook; Design and Evaluation in North America. U.S. Department of Transportation, Federal Highway Administration. Report No. FHWA-CFL/TD-11-003	http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_615.pdf http://www.cflhd.gov/programs/techDevelopment/wildlife/documents/01_Wildlife_Crossing_Structures_Handbook.pdf
	Examples:	•Bighorn sheep	AZ			Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		•Openness ratios: = 75, 28, 56 (highest was most successful)	Bristow, K. and M. Crabb. 2008. Evaluation of Distribution and Trans-highway movment of desert bighorn sheep: Arizona Highway 68. Final Report 588. Arizona Department of Transporation.	http://www.azdot.gov/TPD/ATRC/publications/project_reports/PDF/AZ588.pdf
		•Mountain goat	MT			Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		•Openness ratio = 25-57 •12-28 feet h x 90 ft w x 44 ft through •8-ft fencing	Singer, F.J., W.L. Langlitz, and E.C. Samuelson. 1985. Design and construction of highway underpasses used by mountain goats. Transportation Research Record. 1016:6-10	abstract only

Table 3 Page 2 (Continued)

		•Florida panther/alligators	FL			Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		•Openness ratio = 0.92-1.12 •Underpass has 22.3 m median opening •3 m high fence	Foster, M.L. and S.R. Humphrey. 1995. Use of highway underpasses by Florida panthers and other wildlife. Wildlife Society Bulletin 23(1): 95-100	http://www.jstor.org/pss/3783202
		•Multi-species	NC			Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		•Openness ratio = 2.48-4.03 •3 m high fencing ≥800 m from underpasses (continued through underpasses to other side) •One underpass has a stream	McCollister, M.F. and F.T. Van Manen. 2010. Effectiveness of Wildlife Underpasses and Fencing to Reduce Wildlife-Vehicle Collisions. Journal of Wildlife Management 74(8): 1722-1731.	http://onlinelibrary.wiley.com/doi/10.2193/2009-535/abstract
		•Elk	AZ			Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs	$1.5 - 2 million/underpass; video/cameras -$7000	•Openness ratios - 12.3 and 5.5 •Minimize length or add atrium •Avoid areas with human disturbance •Some underpasses with streams	Dodd, N.L., J.W. Gagnon, S. Boe, A. Manzo, and R.E. Schweinsburg. 2007. Evaluation of Measures to Minimize Wildlife-Vehicle Collisions and Maintain Permeability across highways: Arizona Route 260. Final Report 540. Arizona Department of Transportation.	http://www.azdot.gov/TPD/ATRC/publications/project_reports/PDF/AZ540.pdf
		•Mountain lions, multi-species	Alberta			Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs	$675,597-965,139 (2007) - 12m w x 30m l underpass; IN CONSTRUCTION - Lake Louise area - $2,350,000 (2007) incl traffic control & detour (16-25m w underpass); fencing $69/m (2007 $) (Huijser et al. 2008)	•Open span /creek=3m h x 11 m w (Phase 1 &2) •12m w x 5 m high underpass (Phase 3A) (Huijser et al. 2008) •Openness ratio =0.4-1.25 minimize human disturbance/use (Clevenger and Waltho 2000)	Gloyne, C.C. and A.P. Clevenger. 2001. Cougar (Puma concolor) use of wildlife crossing structures on the Trans-Canada highway in Banff National Park, Alberta. Wildlife Biology 7: 117-124.	http://www.wildlifebiology.com/Downloads/Article/326/En/7_2_gloyne.pdf
									M.P. Huijser, P. McGowen, A.P. Clevenger, and R. Ament. 2008. Wildlife-vehicle collision reduction study: best practices manual. Report to Congress. U.S. Department of Transportation, Federal Highway Administration.	http://www.fhwa.dot.gov/environment/hconnect/wvc/index.htm
									Clevenger, A.P. and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14(1): 47-56.	http://www.transwildalliance.org/resources/20088416534 5.pdf
		•Multi-species	Ontario	Minimizaton/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs	bridge =$1.2 million;	•81 m open span bridge	Gartshore, R. G., M. Purchase, R.I. Rook,and L. Scott. Bayview Avenue Extension, Richmond Hill, Ontario, Canada Habitat Creation and Wildlife Crossings in a Contenious Environmental Setting: A Case Study (September 2005). Pages 55-76 IN Proceedings of the 2005 International Conference on Ecology and Transportation, edited by C. Leroy Irwin, Paul Garrett, and K.P. McDermott. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2006.	http://www.icoet.net/ICOET_2005/proceedings/2005ICOETProceedingWeb.pdf
		• Large herbivores, carnivores, small & medium-sized mammals	MT	Minimization/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs	$435,340 (2007$); fencing $27-42/m (Huijser et al. 2008)	•Open span bridge •12m w x 30 m l (height unknown) (Huijser et al. 2008)	M.P. Huijser, P. McGowen, A.P. Clevenger, and R. Ament. 2008. Wildlife-vehicle collision reduction study: best practices manual. Report to Congress. U.S. Department of Transportation, Federal Highway Administration.	http://www.fhwa.dot.gov/environment/hconnect/wvc/index.htm
									Huijser, M.P., T.D.H. Allen, and W.Camel. 2010. US 93 Post-Construction Wildlife-Vehicle Collision and Wildlife Crossing Monitoring and Research on the Flathead Indian Reservation between Evaro and Polson, Montana. Annual Report. Montana Department of Transportation.	http://www.mdt.mt.gov/research/docs/research_proj/wildlife_crossing/phaseII/annual_report_oct10.pdf
		•Multi-species	VT	Minimization/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		•500-ft wide bridge span over wetland/upland habitat complex	Austin, J.M., M. Ferguson, G. Gingras, and G. Bakos. 2003. Strategies for restoring ecological connectivity and establishing wildlife passage for the upgrade of Route 78 in Swanton, Vermont: an overview. IN: Proceedings of the 2003 International Conference on Ecology and Transportation, Eds. C.L. Irwin, P. Garrett, K.P. McDermott. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 253-259.	http://escholarship.org/uc/item/50q5q4m7
	Culvert - covered with embankment around entire perimeter	Carnivores/small - medium sized mammals/flying animals/reptiles & amphibians, aquatic animals	ALL	Minimization/ Compensation	Project Planning/ Alternatives Analysis	Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		•Location in the landscape influences effectiveness •Light in the underpass will increase openness and may be helpful for some species •Design underpass to minimize the intensity of noise and light coming from the road and traffic. •Revegetation will be possible in areas of underpass closest to the entrance, as light conditions tend to be poor in the center of the structure.	Bissonette, J.A. and P.C. Cramer. NCHRP Report 615: Evaluation of the Use and Effectiveness of Wildlife Crossings. Transportation Research Board of the National Academies, Washington D.C., 2008. Clevenger, A.P. and M.P. Huijser. 2011. Wildlife Crossing Structure Handbook; Design and Evaluation in North America. U.S. Department of Transportation, Federal Highway Administration. Report No. FHWA-CFL/TD-11-003	http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_615.pdf http://www.cflhd.gov/programs/techDevelopment/wildlife/documents/01_Wildlife_Crossing_Structures_Handbook.pdf

Table 3 Page 3 (Continued)

	Box culvert - culvert with a square or rectangular cross-sectional profile having 4 sides, including a bottom.										
	Examples:	CLASS 1: Small; ≤1.5 m (5 ft)	Some medium-sized mammals, aquatic animals, small mammals, reptiles & amphibians	ALL	Minimization/ Compensation	Project Planning/ Alternatives Analysis	Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs				
			●Spotted salamander/mole salamanders	MA	Minimization		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		●Bury drift fence 6-10 cm (Jackson and Tyning 1989) ●Tunnels 200 m apart (FHWA Critter Crossings website); or 200 ft. apart (Jackson 2003). ●Min. 2 ft. x 2ft concrete culverts, open grate top and soil bottom (Jackson 2003) ●Culvert wingwalls and min. 18-inch high vertical walls extend 100 to 200 feet in length (Jackson 2003)	Jackson, S.D. and T.F. Tyning. 1989. Effectiveness of drift fences and tunnels for moving spotted salamanders under roads. Pp. 93-99 In T.E.S. Langton (ed.) Amphibians and Roads. proceedings of the toad tunnel conference. ACO Polymer Products, Shefford, England. Jackson, Scott. 2003. Proposed Design and Considerations for Use of Amphibian and Reptile Tunnels in New England. Department of Natural Resources Conservation, University of Massachusetts Amherst. FHWA Critter Crossings Website	http://www.umassextension.org/NREC/Images/stories/linked_content/pdf_files/amphibians_and_roads.pdf http://www.umass.edu/nrec/pdf_files/herp_tunnels.pdf http://www.fhwa.dot.gov/environment/wildlifecrossings/salamand.htm
			●Otter, beaver, muskrat, herps	VT	Minimization/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		●Concrete wetland box culverts min. 4' wide ●Open grate, trapezoidal cast concrete amphibian tunnels	Austin, J.M., M. Ferguson, G. Gingras, and G. Bakos. 2003. Strategies for restoring ecological connectivity and establishing wildlife passage for the upgrade of Route 78 in Swanton, Vermont: an overview. IN: Proceedings of the 2003 International Conference on Ecology and Transportation, Eds. C.L. Irwin, P. Garrett, K.P. McDermott. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 253-259.	http://escholarship.org/uc/item/50q5g4m7
			●Santa Cruz long-toed salamander	CA	Minimization/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		●Five 32cm h x 47cm w and one 21 cm h x 23 cm w tunnels constructed of non-abrasive cement polymer with slots along top ●Entrances screened with wire mesh (5cm x 10 cm) to reduce predator access ●Permanent fencing 40 cm h, curved	Allaback, M.L. and D.M. Laabs. 2002-03. Effectiveness of road tunnels for the Santa Cruz long-toed salamander. Transactions of the Western section of the Wildlife Society 38/39:5-8.	http://www.tws-west.org/transactions/Allaback%20Laabs.pdf
			● Small & medium-sized mammals	MT	Minimization/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs	$70,932 (2007 $); fencing $27-42/m (Huijser et al. 2008)	●Concrete box culverts, 1.2m w x 1.8m h x 27.5m l (Huijser et al. 2008) ●Openness ratio =0.08	M.P. Huijser, P. McGowen, A.P. Clevenger, and R. Ament. 2008. Wildlife-vehicle collision reduction study: best practices manual. Report to Congress. U.S. Department of Transportation, Federal Highway Administration. Huijser, M.P., T.D.H. Allen, and W.Camel. 2010. US 93 Post-Construction Wildlife-Vehicle Collision and Wildlife Crossing Monitoring and Research on the Flathead Indian Reservation between Evaro and Polson, Montana. Annual Report. Montana Department of Transportation.	http://www.fhwa.dot.gov/environment/hconnect/wvc/index.htm http://www.mdt.mt.gov/research/docs/research_proj/wildlife_crossing/phaseII/annual_report_oct10.pdf
		CLASS 2: Medium ; >1.5 m (5 ft) to 2.4 x 2.4 m (8 ft)	Large carnivores, small & medium-sized mammals, reptiles & amphibians, aquatic animals, some flying animals	ALL	Minimization/ Compensation	Project Planning/ Alternatives Analysis	Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs				
			●Multi-species	FL	Minimization/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		●2.4x2.4m submerged culverts ●1.8x1.8m dry culverts ●Openness ratio <0.6 ●Concrete barrier wall 1.1 m h, 15.2 cm overhanging lip; wall runs 2.8 km e and 2.5 km w	Dodd, C.K., W.J. Barichivich, and L.L. Smith. 2005. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation 118: 619-631.	http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V5X-4BG8TPH-1&_user=10&_coverDate=08%2F31%2F2004&_rdoc=8&_fmt=high&_orig=browse&_origin=browse&_zone=rslt_list_item&_srch=doc-info(%23toc%235798%232004%239988199994%2349830062FLA%23display%23Volume)&_cdi=5798&_sort=d&_docanchor=&_ct=15&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=c2e64825118ceaaf42f6be78c3ed58de&searchtype=a
		CLASS 3: Large - 2.4 m x 6.1 m (8x20 ft) or 3.1 x 3.1 m (10x10ft) to open span bridges	Large herbivores, large carnivores, small & medium-sized mammals, reptiles & amphibians, aquatic animals, some flying animals	ALL	Minimization/ Compensation	Project Planning/ Alternatives Analysis	Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs				

Table 3 Page 4 (Continued)

			●Florida panther	FL	Minimization/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		●Openness ratio = 1.2 ●2.4 m h x 7.3 m w, 14.6 m l	Land, D. and M. Lotz. 1996. Wildlife crossing designs and use by florida panthers and other wildlife in southwest Florida. In G.L. Evink, P.A. Garrett, D. Zeigler, and J. Berry, eds. Proceedings of the International Conf. on Wildlife Ecology and Transportation. June, 1996. Tallahassee, FL. FL DOT FL-ER 58-96.	http://www.icoet.net/downloads/96paper26.pdf
			●Mountain lions; multi-species	Alberta	Minimization/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs	$217,156-241,285 (2007 $) (4x7); $173,725 (2007 $) (2.5x3); IN CONSTRUCTION - Lake Louise area 3-4m w and h $940,000 incl traffic control & detour; fencing $69/m (2007 $) (Huijser et al. 2008)	●Metal culvert= 4m h x 7 m w, concrete box culvert= 2.5m h x 3m w; all crossings with dirt substrate (Phase 1&2) (Gloyne and Clevenger 2001) ●Metal culverts 3.5m h x 4.2m w x 96m l & 4m h x 7m w x 56 l, openness ratio =0.15-0.5 (Clevenger and Waltho 2000)	Gloyne, C.C. and A.P. Clevenger. 2001. Cougar (Puma concolor) use of wildlife crossing structures on the Trans-Canada highway in Banff National Park, Alberta. Wildlife Biology 7: 117-124.	http://www.wildlifebiology.com/Downloads/Article/326/En/7_2_gloyne.pdf
										Clevenger, A.P. and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14(1): 47-56.	
										M.P. Huijser, P. McGowen, A.P. Clevenger, and R. Ament. 2008. Wildlife-vehicle collision reduction study: best practices manual. Report to Congress. U.S. Department of Transportation, Federal Highway Administration.	http://www.fhwa.dot.gov/environment/hconnect/wvc/index.htm
			●Black bear	FL	Minimization/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		●Openness ratio- 1.22 ●2.4m h x 7.3 m w x 14.3 m l ●3 m fence with barbed wire - 0.6 km to west, 1.1 km to east; bury fence	Roof, J. and J. Wooding. 1996. Evaluation of the S.R. 46 wildlife crossing in Lake County, Florida. 7 pp. In G.L. Evink, P. Garrett, D. Zeigler and J. Berry (eds.) Trends in Addressing Transportation Related Wildlife Mortality, proceedings of the transportation related wildlife mortality seminar. State of Florida Department of Transportation, Tallahassee, FL. FL-ER-58-96.	http://www.icoet.net/downloads/96paper27.pdf
Arch culvert - a culvert section forming an arc of a circle and having a natural substrate for its base (bottomless)											
	Examples:	CLASS 1: Small; ≤1.5 m (5 ft)	Some medium-sized mammals, aquatic animals, small mammals, reptiles & amphibians	ALL	Minimization/ Compensation	Project Planning/ Alternatives Analysis	Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs				
		CLASS 2: Medium; >1.5 m (5 ft) to 2.4 x 2.4 m (8 ft)	Large carnivores, small & medium-sized mammals, reptiles & amphibians, aquatic animals, some flying animals	ALL	Minimization/ Compensation	Project Planning/ Alternatives Analysis	Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs				
		CLASS 3: Large - 2.4 m x 6.1 m (8x20 ft) or 3.1 x 3.1 m (10x10ft) to open span bridges	Large herbivores, large carnivores, small & medium-sized mammals, reptiles & amphibians, aquatic animals, some flying animals	ALL	Minimization/ Compensation	Project Planning/ Alternatives Analysis	Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs				
			● Some large herbivores, carnivores, small & medium-sized mammals	MT	Minimization/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs	$223,076 (2007 $); fencing $27-42/m (Huijser et al. 2008)	●Metal arch underpass (Huijser et al. 2008) ●7-8m w x 5m h x 18.3-21.9 l (Huijser et al. 2008) ●Openness ratio = 1.6-1.9 (Huijser et al. 2008)	M.P. Huijser, P. McGowen, A.P. Clevenger, and R. Ament. 2008. Wildlife-vehicle collision reduction study: best practices manual. Report to Congress. U.S. Department of Transportation, Federal Highway Administration.	http://www.fhwa.dot.gov/environment/hconnect/wvc/index.htm
										Huijser, M.P., T.D.H. Allen, and W.Camel. 2010. US 93 Post-Construction Wildlife-Vehicle Collision and Wildlife Crossing Monitoring and Research on the Flathead Indian Reservation between Evaro and Polson, Montana. Annual Report. Montana Department of Transportation.	http://www.mdt.mt.gov/research/docs/research_proj/wildlife_crossing/phaseii/annual_report_oct10.pdf
Round/elliptical culvert - a culvert unbroken (entire in cross-section											
	Examples:	CLASS 1: Small; ≤1.5 m (5 ft)	Some medium-sized mammals, aquatic animals, small mammals, reptiles & amphibians	ALL	Minimization/ Compensation	Project Planning/ Alternatives Analysis	Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs				

Table 3 Page 5 (Continued)

			•Herps/sm mammals	Ontario	Minimizaton/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs	Migration study - $71,000; 5 amphibian tunnels=$360,000; monitoring - $14,500/year	•Round pipes: two concrete 1.2m diameter, two corrugated steel 1.2m diameter •One 1m x 1.7m elliptical concrete •Openness ratio = <0.6 (0.04-0.05)	Gartshore, R. G., M. Purchase, R.I. Rook,and L. Scott. Bayview Avenue Extension, Richmond Hill, Ontario, Canada Habitat Creation and Wildlife Crossings In a Contenious Environmental Setting: A Case Study (September 2005). Pages 55-76 IN Proceedings of the 2005 International Conference on Ecology and Transportation, edited by C. Leroy Irwin, Paul Garrett, and K.P. McDermott. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2006.	http://www.icoet.net/ICOET_2005/proceedings/2005ICOETP roceedingWeb.pdf
			•Herps, small mammals	FL	Minimization/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		•Round 0.9m culverts •Openness ratio <0.6 •Concrete barrier wall 1.1 m h, 15.2 cm overhanging lip; wall runs 2.8 km e and 2.5 km w	Dodd, C.K., W.J. Barichivich, and L.L. Smith. 2005. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation 118: 619-631.	http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V5X-4BG8TPH-1&_user=10&_coverDate=08%2F31%2F2004&_rdoc=8&_fmt=high&_orig=browse&_origin=browse&_zone=rslt_list_item&_srch=doc-info(%23toc%235798%232004%2399881994%2349830 0%23FLA%23display%23Volume)&_cdi=5798&_sort=d&_docanchor=&_ct=15&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=c2e64825118ceaaf42f 6be78c3ed58de&searchtype=a
			•Small mammals	Alberta	Minimization/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		• 0.3 m dia metal drainage culverts •Vegetative cover important	McDonald, W. and St Clair, C. C. (2004). Elements that promote highway crossing structure use by small mammals in Banff National Park. Journal of Applied Ecology, 41: 82–93.	http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2664.2004.00877.x/full
			•Red-sided garter snake	Manitoba	Minimization		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs		•Drift fencing •Pipes 6-12 inches; 20 cm polymer concrete channel covered by slotted iron gate	Carcnet website	http://www.carcnet.ca/english/tunnels/snake_mortality.php
		CLASS 2: Medium; >1.5 m (5 ft) to 2.4 x 2.4 m (8 ft)	Large carnivores, small & medium-sized mammals, reptiles & amphibians, aquatic animals, some flying animals	ALL	Minimization/ Compensation	Project Planning/ Alternatives Analysis	Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs				
			•Bats	Wales	Minimization		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs	Bat tunnel installation = $180,000 (unsure if per tunnel or total)	•2.2 m and 1.8 m - diameter corrugated steel ellipitcal culverts installed on flight path/hedgerow lines •Funnel leading to tunnels was planted to help continue hedgerow corridor effect	Wray, S., D. Wells., W. Cresswell, and H. Walker. Design, Installation, and Monitoring of Safe Crossing Points for Bats on a New Highway Scheme in Wales. Pages 369-379 IN Proceedings of the 2005 International Conference on Ecology and Transportation, edited by C. Leroy Irwin, Paul Garrett, and K.P. McDermott. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2006.	http://www.icoet.net/ICOET_2005/proceedings/2005ICOETP roceedingWeb.pdf
			• Some large herbivores, carnivores, small & medium-sized mammals	MT	Minimization/ Compensation		Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs	$70,932 (2007 $); fencing $27-42/m (Huijser et al. 2008)	•Elliptical culvert; 2m w x 1.5m h x 27.5m l (Huijser et al. 2008) •Openness ratio =0.11 (Huijser et al. 2008)	M.P. Huijser, P. McGowen, A.P. Clevenger, and R. Ament. 2008. Wildlife-vehicle collision reduction study: best practices manual. Report to Congress. U.S. Department of Transportation, Federal Highway Administration. Huijser, M.P., T.D.H. Allen, and W.Camel. 2010. US 93 Post-Construction Wildlife-Vehicle Collision and Wildlife Crossing Monitoring and Research on the Flathead Indian Reservation between Evaro and Polson, Montana. Annual Report. Montana Department of Transportation.	http://www.fhwa.dot.gov/environment/fhconnect/wvc/index.htm http://www.mdt.mt.gov/research/docs/research_proj/wildlife_crossing/phaseII/annual_report_oct10.pdf
		CLASS 3: Large - 2.4 m x 6.1 m (8x20 ft) or 3.1 x 3.1 m (10x10ft) to open span bridges	Large herbivores, large carnivores, small & medium-sized mammals, reptiles & amphibians, aquatic animals, some flying animals	ALL	Minimization/ Compensation	Project Planning/ Alternatives Analysis	Maintain connectivity between core habitats; maintain biodiversity; reduce WVCs				
	At-grade crossing		Large herbivores, reptiles & amphibians	ALL	Minimization		Reduce WVCs				
		Examples:	•Mule deer	UT	Minimization	n/a	Reduce WVCs	4-lane crosswalk - $28,000/2-lane crosswalk =$15,000; fencing	•2.3 m high fence •1 m fence at funnel •Cattle guard lines on road surface	Lehnert, M.E. and J.A. Bissonette. 1997. Effectiveness of highway crosswalk structures at reducting deer-vehicle collisions. Wildlife Society Bulletin 25(4):809-818.	http://www.jstor.org/pss/3783727

Table 3 Page 6 (Continued)

At-grade crossing: designated areas for wildlife to cross the roadway		•Mule deer	WY	Minimization	n/a	Reduce WVCs	Utilized a deer-sensing warning system	•Warning signs 300 m e & w of migratory route crossing •2.4 m high fence	Gordon, K.M., M.C. McKinstry, and S.H. Anderson. 2004. Motorist response to a deer-sensing warning system. Wildlife Society Bulletin 32(2): 565-573.	http://www.jstor.org/pss/3784997
		•Mule deer	West US	Minimization	n/a	Reduce WVCs	Temporary/seasonal warning signs; 6.5 -km strech of rd - $1,740 (lg signs=$400; small signs=$90; lights=$40)	•Signs at mile intervals in migration corridors	Sullivan, T.L., A.F. Williams, T.A. Messmer, L.A. Hellings, S.Y. Kyrychenko. 2004. Effectiveness of temporary warning signs in reducing deer-vehicle collisions during mule deer migrations. Wildlife Society Bulletin 32(3): 907-915.	http://www.jstor.org/pss/3784815
		•Amphibians	ME	Minimization	n/a	Reduce WVCs	Temporary/seasonal warning signs	• Use standard roadway sign material • Signs deployed seasonally to avoid "sign fatigue"	Maine Department of Inland Fisheries and Wildlife	http://www.maine.gov/ifw/atv_snowmobile_watercraft/news_events/pressreleases/2009/07-10a-09.htm
		•Ungulates	All	Minimization	n/a	Reduce WVCs	Animal detection system; cost- $9,000 - 350,000; Cost of installation: $3,000 - 60,000	•Overview of implemented systems throughout North America/Europe	Huijser, M.P. and P.T. McGowen. 2004. Overview of animal detection and animal warning systems in North America and Europe. IN: Proceedings of the 2003 International Conference on Ecology and Transportation, Eds. Irwin CL, Garrett P, McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 368-382.	http://escholarship.org/uc/item/2cc2s81w
RETROFIT STRUCTURE - modify an existing structure or roadway corridor to better facilitate wildlife passage over, under or across										
Add ROW fencing to direct wildlife towards an existing structure	***Examples:***	•Moose	Quebec	Minimization		Reduce WVCs; maintain access between core habitats	Approx. $617,000; maintenance Approx: $12,780	•Bridge underpass w/1.5 m high electric fence •Openness ratio of existing bridge underpass = 4.87 (23 l x 16 w x 7 h) •Also included an at-grade crossing	LeBlond, M., C. Dussault, J.P. Ouellet, M. Poulin, R. Courtois, and J. Fortin. 2007. Electric Fencing as a Measure to Reduce Moose-Vehicle Collisions. Journal of Wildlife Management 71 (5): 1695-1703	http://www.jstor.org/pss/4496252
		•Desert Tortoise	CA	Minimization		Reduce WVCs; maintain access along corridor		•0.9-1.5 m diameter corrugated steel pipe •1.4m diameter concrete, 3-3.6 x 1.8-3m concrete box culverts •Openness ratio = <0.6 •24 km long fence, 45 cm high, buried, mesh/hardware cloth	Boarman, W. I. and M. Sazaki. 1996. Highway Mortality in Desert Tortoises and Small Vertebrates: Success of Barrier Fences and Culverts. Pp. 169-173 In G.L. Evink, P. Garrett, D. Zeigler and J. Berry (eds.) Trends in Addressing Transportation Related Wildlife Mortality, Proceedings of the Transportation Related Wildlife Mortality Seminar. State of Florida Department of Transportation, Tallahassee, Florida. FL - ER - 58 - 96	Discussed IN : http://fishandgame.idaho.gov/cms/wildlife/manage_issues/collision/amphibRep.pdf
		•Turtle	NY	Minimization	Project Planning Post-construction	Reduce WVCs; maintain access between core habitats	$15,250 for 2000 meters of fencing	•50 x 100mm 12 ga. PVC coated fencing or mesh •Plastic UV resistent cable ties	Langen, Tom and John Faige. 2011 Design Considerations, Construction and Effectiveness of Fencing for Turtles. : Northern New York State Highway Traspostation Case Studies. New York State Wetlands Forum. April 2011.	
		•Herps	FL	Minimization	n/a	Maintain access between core habitats	Low (until permanent design can be implemented)	•0.6 m temporary erosion control fence, buried 20 cm (0.4m above ground) •Metal drainage culvert -3.5 m diameter x 46.6 m long •Openness - 0.2	Aresco, M.J. 2005. Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a North Florida lake. Journal of Wildlife Management 69 (2): 549-560.	http://www.jstor.org/stable/3803725
		•Lg herbivores	MT	Minimization/ Compensation	Project Planning	Reduce WVCs	Estimated costs from Huijser et al 2008 - jumpouts = $6,425-13,241; wildlife guards - $30,840	•Bridge underpass w/ 8' fence w/ jumpouts (6-8'h) & cattle guards at fence ends (Craighead et al. 2010)	Craighead, L. A. Craighead, and L. Oechsli. 2010. Bozeman Pass Post-Fencing Wildlife Monitoring Project. Montana Department of Transportation.	ftp://161.7.16.40/research/OTHER/BOZEMAN_PASS/FINAL_REPORT-10-18-10.DOC.
									M.P. Huijser, P. McGowen, A.P. Clevenger, and R. Ament. 2008. Wildlife-vehicle collision reduction study: best practices manual. Report to Congress. U.S. Department of Transportation, Federal Highway Administration.	http://www.fhwa.dot.gov/environment/fhconnect/wvc/index.htm
	Examples:	•Mountain lions	CA	Minimization/ Compensation	Post-construction	Maintain access between core habitats	$1.4-1.6 million (revegetation/fence reconfig)	•Bridge underpass, pavement removal, re-vegetation •$53 million (land acquisition) to restore patches on either side of crossing	Koelle, Alexandra. Cougar Corridors: Restoring the Missing Link in California's Chino Hills. The Road-RIPorter - Quarterly Newsletter of Wildlands Center for Preventing Roads. Spring 2003. Vol 8. www.wildlandscpr.org	http://www.wildlandscpr.org/files/uploads/RIPorter/rr_v8-1.pdf
		•Bobcats/ocelots	TX	Minimization	Project Planning	Maintain access between core habitats		•Box culverts modified with "catwalks" - 18- x 12- inch concrete elevated walkways through the length of culvert and along wing walls.	Hewitt, D.G., A. Cain, V. Tuovila, D. Shindle, and M.E. Tewes. 1998. Impacts of an expanded highway on ocelots and bobcats in southern Texas and their preferences for highway crossings. Page 126-134, In Evink, G.L., et al eds. Proceedings of the International Conference on Wildlife Ecology and Transportation.	http://www.icoet.net/downloads/98paper16.pdf

Table 3 Page 7 (Continued)

Retrofit underpass structure with ledges or pathways to facilitate passage		•Small mammals	MT	Minimization/ Compensation	Project Planning	Maintain access between core habitats		•Round culverts - added 25" w shelves to culverts & vole tube •Culverts 3 & 4' diameter (material unknown) •Added vole tube (similar to gutter drainage pipe)	Foresman KR. 2004. Small mammal use of modified culverts on the Lolo South project of Western Montana - an update. IN: Proceedings of the 2003 International Conference on Ecology and Transportation, Eds. Irwin CL, Garrett P, McDermott KP, Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 342-343.	http://escholarship.org/uc/item/7cw8043j
		•Small mammals	CO	Minimization/ Compensation	Project Planning	Maintain access along corridor	$17 to $20 per linear foot	•Wooden ledges (2.54 x 15.24 cm cedar planks, 1.83 m l attached end to end), glued blocks of wood (5x10.16cm, 30.48 cm l) to culvert wall at 1.83 m intervals with Liquid Nails •Ramps same size as planks, attached at ends •All culverts openness ratio <0.6	Meaney, C., M. Bakeman, M. Reed-Eckert, and E. Wostl. 2007. Effectiveness of ledges in culverts for small mammal passage. Report No. CDOT-2007-9. Final Report. Colorado Department of Transportation, Denver, CO.	http://www.coloradodot.info/programs/research/pdfs/2007/smallmammal.pdf
Alter landscape : designing and managing habitats alongside roads with the aim of reducing collisions and/or facilitating safe passage across the roadway	***Examples:***	•Pygmy owl	Mexico/SW	Minimization	Project Planning	Reduce WVCs		•Plant/maintain lg trees close to roadway and in median •Drop road surface below surrounding elevations	Flesch, A.D. and R.J. Steidl. 2007. Association Between Roadways and Cactus Ferruginous Pygmy-owls in Northern Sonora, Mexico. Final Report for Arizona Department of Transportation, Environmental Planning Group, Tuscon, AZ.	http://aaronflesch.com/Publications/Reports/Flesch%20and%20Steidl.%20%202007.%20%20Pygmy-owls%20and%20roadways%20Final%20ADOT%20Report.pdf
		•Royal terns	FL	Minimization	Project Planning	Reduce WVCs	10-day pole installation = $5,900 (materials + labor) (1994 $)	•Installed 122, 3m long silver-colored metal poles, 5.1 cm diameter, attached vertically, 3.7m apart on both sides of bridge	Bard, A.M, H.T. Smith, E.D. Egensteiner, R. Mulholland, T.V. Harber, G.W. Heath, W.J.B. Miller, and J.S. Weske. 2002. A simple structural method to reduce road-kills of royal terns at bridge sites. Wildlife Society Bulletin 30(2):603-605.	http://www.jstor.org/pss/3784522

Table 4 Summary of Patch Solutions

SOLUTION		SPECIES GROUP	REGION	APPROACH TYPE	TIMING OF SOLUTION	IMPACT REDUCTION	COST RANGE	DESIGN CONSIDERATIONS	SOURCE(S)	
SHIFT ALIGNMENT		**All**	**All**	**Avoidance, Minimization**	**Project Planning, Design**		**N/A**	**Constraints analysis required to assess alternate alignment impacts**		
ROWLANDSCAPING TO ENHANCE HABITAT CORE/HABITAT ISLAND WIDTH	***Examples:***	Butterflies	IA	Compensation				Restore roadsides to native prairie vegetation & restrict use of herbicides/mowing	Ries, L., D.M. Debinski, and M.L. Wieland. 2001. Conservation Value of Roadside Prairie Restoration to Butterfly Communities.Conservation Biology 15(2): 401-411.	http://www.clfs.umd.edu/biology/faganlab/pdf/RiesEtAl2001.pdf
REDUCE ROAD CORRIDOR WIDTH TO MINIMIZE IMPACT		**All**	**All**	**Avoidance, Minimization**	**Project Planning, Design**	**Minimize patch disturbance; potential to maintain functions**	**N/A**	**Constraints analysis required to assess alternate alignment impacts**		
HABITAT PATCH EXPANSION (RESTORATION, REHABILITATION, ENHANCEMENT)	***Examples:***	Herptiles	Ontario	Compensation	Project Planning		$330,000 (wetland construction costs) (Total project $10 million)		Gartshore, R. G., M. Purchase, R.I. Rook,and L. Scott. Bayview Avenue Extension, Richmond Hill, Ontario, Canada Habitat Creation and Wildlife Crossings in a Contenious Environmental Setting: A Case Study (September 2005). Pages 55-76 IN Proceedings of the 2005 International Conference on Ecology and Transportation, edited by C. Leroy Irwin, Paul Garrett, and K.P. McDermott. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2006.	http://www.icoet.net/ICOET_2005/proceedings/2005ICOETProceedingWeb.pdf
		Amphibians		Compensation	n/a				Petranka, J.W., E.M. Harp, C.T. Holbrook, and J.A. Hamel. 2007. Long-term persistence of amphibian populations in a restored wetland complex. Biological Conservation 138: 371-380	http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V5X-4P127CC-2&_user=10&_coverDate=09%2F30%2F2007&_rdoc=1&_fmt=high&_orig=search&_origin=search&_sort=d&_docanchor=&view=c&_searchStrId=1642866832&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=579ca5b1aa4d7bb62ace16a57af79c0d&searchtype=a
		Herps	CA	Compensation	n/a				De Weese, J.M. 1998. Vernal Pool Construction Monitoring Methods and Habitat Replacement Evaluation. Pages 217-223 in: C.W. Witham, E.T. Bauder, D. Belk, W.R. Ferren Jr., and R. Ornduff (Editors). Ecology, Conservation, and Management of Vernal Pool Ecosystems – Proceedings from a 1996 Conference. California Native Plant Society, Sacramento, CA.	http://vernalpools.org/proceedings/deweese.pdf
		Fender's blue butterfly	OR	Compensation	n/a				McIntire, E.J.B, C.B. Schultz, and E.E. Crone. 2007. *Designing a Network for Butterfly Habitat Restoration: Where Individuals, Populations, and Landscapes Interact.* Journal of Applied Ecology 44: 725-736	http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2664.2007.01326.x/pdf
		Fender's blue butterfly	OR	Compensation	n/a				Schultz, C.B. 2001. *Restoring resources for an endangered butterfly.* Journal of Applied Ecology 38: 1007-1019	http://onlinelibrary.wiley.com/doi/10.1046/j.1365-2664.2001.00659.x/pdf
		Bats	ALL	Compensation/ Minimization	Project Planning	Retrofit bridges to provide roosting habitat			Keeley, B.W. and M.D. Tuttle. 1999. Bats in American bridges. Pages 174-179 IN Evink, G.L., et al eds. Proceedings of the International Conference on Wildlife Ecology and Transportation.	http://www.icoet.net/downloads/99paper21.pdf
		Multi-species	CA	Compensation	n/a				Queheillalt, D.M. and M.L. Morrison. 2006. Vertebrate use of a restored riparian site: a case study on the central coast of California. Journal of Wildlife Management 70(3): 859-866	http://onlinelibrary.wiley.com/doi/10.2193/0022-541X(2006)70%5B859:VUOARR%5D2.0.CO;2/abstract
HABITAT PRESERVATION/CONSERVATION EASEMENTS	***Examples:***	Herps	CA	Compensation					Mead, D.L. Determination of Available Credits and Service Areas for ESA Vernal Pool Preservation Banks. Pages 274-282 *in* : C.W. Witham, E.T. Bauder, D. Belk, W.R. Ferren, Jr. and R. Ornduff (Eds). Ecology, Conservation, and Management of Vernal Pool Ecosystems - Proceedings from a 1996 Conference. California Native Plant Society, Sacramento, CA. 1998.	http://www.vernalpools.org/proceedings/mead.pdf
CONSERVATION BANK/WETLAND BANK CREDIT PURCHANSE	***Examples:***	Multi-species	ALL	Compensation						http://www.fws.gov/endangered/esa-library/pdf/ImperiledWildlifeFinalDec2005.pdf http://www.loafercreek.com/ http://www.fws.gov/endangered/landowners/conservation-banking.html
		Multi-species	CA	Compensation		Preserve large tracts of habitat elswhere			DiGregoria, J., E. Luciani, and S. Wynn. Integrating Transportation Conservation with Regional Conservation Planning. In Proceedings of the 2005 International Conference on Ecology and Transportation, edited by C. Leroy Irwin, Paul Garrett, and K.P. McDermott. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2006.	http://www.icoet.net/ICOET_2005/proceedings/06IPCh5-101-110.pdf
IN-LIEU FEE PROGRAM	***Examples:***	Multi-species	NY	Compensation					Spierto, T.J., S.A. Lazazzero, and P.L. Nelson. 2003. Strawberry Island Phase III Erosion Control and Wetland Habitat Restoration: a case study in the successful application of in-lieu fee mitigation. Pages 129-139 In 2003 Proceedings of the International Conference on Ecology and Transportation, edited by C. Leroy Irwin, Paul Garrett, and K.P. McDermott. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2003.	http://escholarship.ucop.edu/uc/item/99w4k3r2;jsessionid=CA3ED2D3F5361BCC4B6A2F78C53B7426

Table 4 Page 2 (Continued)

		Multi-species	NH	Compensation	Pre or Post Construction	Preservation of habitat cores, corridors, some wetland enhancement and restoration.	In 2010, 15.91 acres of impact offset with $2,012,688 in contributions. Avg. $126,505 per acre.	Program goals include preservation of large, unfragmented tracts of habitat and protection of linkages between aqautic resources. Fees fund projects on a watershed basis.	2010 REPORT OF THE ACTIVITY OF THE NEW HAMPSHIRE DEPARTMENT OF ENVIRONMENTAL SERVICES AQUATIC RESOURCE MITIGATION FUND PROGRAM	http://www.nae.usace.army.mil/regulatory/mitigation/nh.htm
ENVIRONMENTAL MITIGATION PROGRAM		Multi-species	CA	Compensation		Preservation of habitat cores, corridors, wetland enhancement and restoration.		1/2 cent sales tax to fund transportation projs - including EMP - purchasing land for mitigation ahead of time.	Fairbanks, J. Transnet's Environmental Mitigation Program. Page 126 IN Proceedings of the 2005 International Conference on Ecology and Transportation, edited by C. Leroy Irwin, Paul Garrett, and K.P. McDermott. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2006.	http://www.icoet.net/ICOET_2005/proceedings/2005ICOETProceedingWeb.pdf

In Table 4, Patch solutions are more direct, though fewer examples were identified by DOTs and in the literature. The list of solutions includes:

1) Shift Alignment
2) ROW Landscaping
3) Reduce Road Corridor Width
4) Habitat Patch Expansion
5) Habitat Preservation
6) Conservation/Wetland Bank Credit Purchase
7) In-Lieu-Fee Payment

Project examples were not available for each of these approaches; however, some elements that represent avoidance and minimization measures are common practice and included though not specific examples or project information is available.

Species Group

The wildlife species group or target species that may utilize or benefit from a solution is presented with the corresponding solution. This is perhaps the second most important consideration in evaluating suitable habitat fragmentation solutions for a project. Many of the solutions address a wide range of species, though project examples that discuss specific species are also presented. It should be noted that many species have specific behavioral traits that influence their use of a passage or overpass and the selected design needs to address these species-specific needs.

Region

The region/State to which the approach or example project is suitable is provided. Most solutions can be applied throughout the nation to address common species such as deer, though certain species (i.e. cougars, moose) have well defined ranges that restrict the regions in which the solutions would be applied.

Mitigation Type

The mitigation solution has been classified based on its anticipated type of mitigation, i.e. avoidance, minimization or compensation. In some circumstances, the solution can be a minimization or compensation action depending the location (on-site = minimization; off-site location = compensation).

Timing of Solution/Evaluation

The evaluation and adoption of a solution can occur at different stages in the project development and this section suggests the appropriate timing to adopt a mitigation solution. Mitigation solutions that are avoidance and minimization approaches should be considered at the project planning stage, whereas compensation solutions can be considered at the project development/permitting stage. Exceptions occur such as efforts to identify advance mitigation opportunities for projects that are in keeping with the FHWA *Ecological* approach.

Impact Reduction Benefits

This section summarizes some of the expected benefits of the mitigation solution that addresses habitat fragmentation impacts. Most connectivity solutions are expected to reduce wildlife-vehicle collisions and maintain biodiversity and genetic exchange within the target species population. While the expected effectiveness of the solution can be stated for WVC reduction based on on-going research, actual results are dependent upon site specific variables.

Cost Estimates for Mitigation Solutions

This section presents available cost information for the construction of mitigation solutions. The values sometimes include maintenance cost. Through the interviews and literature search it was clear that data for design, construction and maintenance cost for mitigation solutions is not readily available. Only a few states have started tracking environmental mitigation costs for stormwater, noise abatement, wetlands and streams separately from construction costs. A survey of state tracking methods for environmental mitigation by Wisconsin DOT in 2008 revealed that several states had initiated programs to better track project investments in environmental mitigation (WisDOT and CTC Associates, 2008). Since 2003, Washington State DOT has conducted surveys of environmental mitigation costs for a sample of projects every three years (WSDOT 2009).

Huijser et al. (2009) used estimated construction and maintenance costs in 2007 dollars for 13 large ungulate mitigation measures to determine cost benefit values. This data utilized project construction and maintenance cost data summarized from various sources and was presented in Appendix I of their report. This data was incorporated into Table 3 for connectivity solutions. Other data was included as available.

Mitigation solutions for patch impacts due to habitat fragmentation were similarly lacking project specific cost information. Habitat enhancement and restoration cost information was derived from related wetland mitigation and other habitat improvements. These cost range widely depending upon the site location, land cost, type of restoration activity and many other factors. The cost of mitigating for wildlife habitat impacts was addressed by the Environmental Law Institute (ELI) in 2007 (ELI 2007) and served as a source for cost information for some measures.

ELI gathered cost information for wetland compensation projects that include preservation, enhancement, restoration, creation, in-lieu-fee programs and wetland bank credits from a variety of sources for a target year of 2003. ELI estimated average wetland compensation costs reported by Corps Districts ranged from a low of $15,000 to a high of $150,000 per acre in 2003 (ELI 2007). In-lieu-fee and wetland bank credit costs varied widely across the nation. In-lieu-fee costs ranged from a low of $3,000 to a high of $129,000 per acre, and wetland bank credit purchase costs ranged from $6000 to over $150,000 per wetland acre.

Design Considerations

This section presents information relevant for the design, placement and effectiveness of the mitigation solution obtained from the source information for the referenced project. This section is not expected to address all of the design considerations for the implementation of a mitigation solution.

Sources

Information sources for the project examples are presented along with internet links to the papers or document referenced.

Effectiveness of Mitigation Solutions

The ecological, economic and social issues created by habitat fragmentation by highways are well documented in a variety of sources. The *Wildlife-Vehicle Collision Reduction Study: Report to Congress* (FHWA 2008; online at: http://www.fhwa.dot.gov/publications/research/safety/08034/08034.pdf) provides an overview of the extent and serious implications of wildlife-vehicle collisions (WVC). The average cost of a single WVC with a deer was estimated to be over $6,600, with an estimated total annual cost of $8,388,000,000 for all WVCs. A breakdown of the estimated cost for WVCs is presented in Table 3. These costs do not address the additional and harder to define economic and social costs related to the effects of habitat fragmentation such as reduced or altered ecological functions, effects on plant and wildlife productivity, changes in biodiversity, and human safety.

Table 5: Summary of Estimated Costs
Wildlife-Vehicle Collision for a Deer, Elk, and Moose

Description	Deer	Elk	Moose
Vehicle repair costs per collision	$1,840	$3,000	$4,000
Human injuries per collision	$2,702	$5,403	$10,807
Human fatalities per collision	$1,671	$6,683	$13,366
Towing, accident attendance and investigation	$125	$375	$500
Monetary value animal per collision	$2,000	$3,000	$2,000
Carcass removal and disposal per collision	$50	$100	$100
Total	$8,388	$18,561	$30,773

Source: Wildlife-Vehicle Collision Reduction Study: Report to Congress (FHWA 2008).

The analysis of cost effectiveness for a mitigation measure attempts to determine if the investment is worth the cost in terms of the measures performance. Based on the data in Table 3 reducing WVCs has a direct economic return; however, practioners need to understand if the return offsets the cost of implementing and maintaining the measures required to achieve that goal, and which measures may achieve that goal with the least cost. Unfortunately, cost-benefit analyses for mitigation measures are rare (Huijser et al, 2009).

The NCHRP Report 615 (2008) report examined the research priorities for the evaluation of wildlife crossings and discussed the need for the development of procedures for estimating the cost-benefit and effectiveness of crossing structures to reduce wildlife-vehicle collisions. Information regarding the cost

effectiveness of various mitigation solutions to offset habitat fragmentation impacts has only recently been compiled to address wildlife permeability (connectivity). These measures, such as underpasses or overpasses, typically require large investments in highway infrastructure. A summary of the estimated cost-benefit of measures to reduce Deer-Vehicle Collisions (DVCs) and improve wildlife permeability was assembled as part of the *Wildlife-Vehicle Collision Reduction Study* (FHWA 2008) and is presented in Table 6. In general, under and over passes and fencing were found to be cost-effective methods to reduce DVCs.

Table 6: Summary Cost-Benefit of Mitigation Measures for Five DVCs per Km per Year

Mitigation measure	Cost ($/km/yr)	% DVC Reduction	Benefit ($/km/yr)	Balance ($/km/yr)
Standard warning signs	$18	0%	$0	-$18
Enhanced wildlife warning signs	$249	?	?	?
Seasonal wildlife warning signs	$27	26%	$10,904	$10,878
Animal detection systems (ADS)	$31,300	82%	$34,391	$3,091
ADS linked to on-board computer	?*	82%	$34,391	?
On-board animal detectors	$2,225*	?	?	?
Vegetation removal	$500	38%	$15,937	$15,437
Deer reflectors and mirrors	$495	0%	$0	-$495
Deer whistles	$23.5*	0%	$0	?
Carcass removal	$250*	?	?	?
Population culling	$2,508	50%	$20,970	$18,462
Relocation	$10,260	50%	$20,970	$10,710
Anti-fertility treatment	$61,702	50%	$20,970	-$40,732
Fence (including dig barrier)	$3,760	87%	$36,488	$32,728
Boulders in right of way	$2,461	?	?	?
Long bridges	$781,250	100%	$41,940	-$739,310
Long tunnels or long bridges	$1,500,000	100%	$41,940	-$1,458,060
Fence with gap and warning signs	$3,772	0%	$0	-$3,772
Fence with gap and crosswalk	$5,585	40%	$16,776	$11,191
Fence with gap and ADS	$9,930	82%	$34,391	$24,461
Fence with underpasses	$5,860	87%	$36,488	$30,628
Fence with overpasses	$26,485	87%	$36,488	$10,003
Fence with under- and overpasses	$7,510	87%	$36,488	$28,978

Assumes 1 km with 5 DVCs per year.

* Costs not in dollars/km/year, but in a different unit; see text.

? = Unknown or uncertain.

Source: *Wildlife-Vehicle Collision Reduction Study: Report to Congress* (FHWA 2008).

Huijser et al (2009) presented a method for calculating the cost-benefit of thirteen mitigation measures (structures and other methods aimed at reducing wildlife-vehicle collisions) for large ungulates. The method incorporates cost factors such as construction and maintenance cost of structures and devices over their useful lifetime. The authors also address the effectiveness of types of approaches in terms of the percentage reduction in wildlife-vehicle collisions attributed to different approaches. This

information was incorporated into Table 3 where appropriate to address estimated costs of mitigation solutions.

Similar studies of the cost effectiveness of patch-based mitigation approaches to reduce the effects of habitat fragmentation are not available, though the literature for assessing the success of wildlife habitat restoration and wetland mitigation in meeting performance standards is readily available.

While the long-term cost benefits and savings from reducing WVCs using different approaches alone is compelling, additional benefits and savings from habitat fragmentation impact reduction may be achieved. The value of the benefits derived from maintaining ecosystem services, biodiversity, aesthetics, and recreation use attributable to habitat fragmentation reduction are not as well defined as for WVCs and can be an area for further research.

IV. Conclusions

As illustrated in the Decision Support Tool, there are several steps in the processes of habitat fragmentation assessment and the evaluation and selection of appropriate mitigation solutions. These steps are based on information obtained through surveys of DOT staff actively engaged in assessing and mitigating habitat fragmentation impacts, and through a review of literature documenting both the assessment process and implementation of mitigation solutions. The tool is designed to illustrate a conceptual framework to assist practioners in thinking through the data collection, coordination and analysis steps to address key issues and questions related to habitat fragmentation. The practioners are then directed to examples of solutions to mitigate connectivity and patch (habitat) impacts. Assessing the effects of habitat fragmentation and evaluating appropriate mitigation solutions can be a complex undertaking that can require interdisciplinary experts in the fields of biology, ecology, hydrology and engineering. Practioners are encouraged to adopt a team approach when engaging in this type of assessment and in the selection of locations for mitigation solutions, especially when addressing connectivity.

The Decision Support Tool also provides references to research papers, reports and methods for further review by practioners. New research papers and reports are regularly published on related topics; the Decision Support Tool should be supplemented by new findings and approaches to habitat fragmentation assessment and mitigation solutions, especially on the species level.

Several areas of further research were identified that could improve the decision process for the evaluation and adoption of mitigation solutions. There are few cost-benefit analyses for mitigation measures available (Huijser et al, 2009) and few transportation agencies track costs for mitigation measures and long term maintenance. Related to the costs of mitigation is a lack of long term or detailed monitoring programs to determine the effectiveness of mitigation actions. In addition, the monetary value derived from maintaining ecosystem services attributable to habitat connectivity and patch mitigation are not well defined. There is a need for further research and documentation of construction, maintenance and monitoring costs of mitigation solutions that can be paired with measures of effectiveness to aid transportation agencies in selecting cost effective solutions in the future.

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