Ecological Infrastructure: A Framework for Planning and Design
Addressing Landscape Connectivity and Wildlife Resources for Interstate Highway Systems

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Ecological Infrastructure: A Framework for Planning and Design
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This document is a result of a two semester investigation into the subjects of wildlife passage, transportation planning, and landscape ecology carried out through the Landscape Architecture Department of Virginia Polytechnic Institute and State University.

Abstract

For the last century, automobiles and the roads they require have been a dominant force shaping the modern American landscape. An unrivaled interstate highway system connects major metropolitan areas and is the basis of our transportation infrastructure. Unfortunately, many roadways were not planned or designed with wildlife in mind. As long linear features in the landscape, interstates can function as landscape barriers and cause significant impacts to adjacent wildlife populations. While an aggressive transportation system is being carried out, researchers have only marginally demonstrated the relationships between roadways and wildlife. In such cases, twinned interstate roadways have proven to be the greatest obstacle for wildlife resources.

By incorporating ecological design theory into highway planning and design, the transportation community has an opportunity to reassess the short comings of existing highway infrastructure and improve functions of wildlife passage and landscape connectivity. Through system level approaches and analysis applied within an eco-region context, practical solutions can be developed. The following document provides a process for landscape level analysis, wildlife passage structure design and implementation for future planned interstates projects. As a collaborative effort among professional, we can work towards improving interstate highway systems and retain the relationships occurring within the landscape.

The following I-81 design and planning project offers an exceptional opportunity to reassess the inadequacies of the existing interstate infrastructure in terms of landscape connectivity, wildlife resources and public safety, and demonstrate how system level design approaches can give our roadways new shape and form.
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Introduction

Transportation development in the United States creates great challenges for wildlife conservation. The need for humans to have access and mobility has resulted in a national roadway system of more than 4 million miles traversing our diverse landscape and impacting many natural systems (Cook and Daggett 1995). While roadways are important to humans, they can drastically affect the movement of wildlife. As long linear features in the landscape, interstates can function as landscape barriers and have impacts on wildlife habitats that are disproportionate to the area of land that they occupy. The resulting impacts are characterized by the animal-vehicular collisions, the loss of habitat, limited mobility and species isolation.

Viewing this issue from a landscape ecology perspective, it is clear that highways have the potential to undermine social and ecological process through the fragmentation of the landscape. Landscape connectivity or habitat connectivity is often very important for maintaining ecological systems. Without landscape connectivity, wildlife populations as well as other ecological and cultural resources can be segregated.

As we embark into the next millennium, it is paramount that transportation planners have the tools necessary to begin to address the affects posed on wildlife resources and landscape connectivity. A method for addressing the conflict between highway systems and wildlife resources is by incorporating ecological design theory into roadway design. Ecological theory looks to inform human actions by solving environmental issues related to the interactions between organisms and their environment. The challenge is to build ecologically based transportation systems and infrastructure that does not permanently fragment the natural systems that support wildlife populations.

Since road construction is not showing any signs of decline and vehicular travel is only becoming a more integral part of the American culture, it is crucial that solutions are developed to improve highway safety, increase landscape connectivity, and decrease the impact of animal-vehicle collisions on wildlife. One solution for maintaining connectivity across interstate highways is the implementation of animal passage systems in the form of over or underpasses. Researchers have proven their effectiveness for facilitating wildlife across interstate highways in many locations. However, in many cases passage systems have fallen short in addressing broad wildlife diversity, efficient planning integration, and offer little in cultural significance.

Through system level approaches and analysis applied within an eco-region context, we can begin to identify practical and reasonable solutions, develop design guidelines for a wide range of species and purposes, and promote landscape connectivity not only for wildlife but rather for the entire roadway system as a form of ecological infrastructure. A framework to serve as a tool for addressing transportation planning, design, operation and maintenance is essential for the success of such measures. The process and action will
require implementation of structural form on future planned interstates or as retrofits. As a collaborative effort among professional, we can work towards improving interstate highway designs, and retain the relationships occurring within landscape connectivity, promote better understanding, safety and support within the transportation community.

SECTION I
Conflicts Between Wildlife and Interstate Roadways

Many of you have felt the sensation. A momentary panic while driving in the dark as your headlights cast upon a deer, opossum, or raccoon trying to cross the road. Far too many of these critters don’t make it. So many in fact that some biologists believe that animal-vehicle collisions are the primary human source of wildlife mortality in the United States (Lowy 2001). Decades of research have produced estimates that over 1 million vertebrates are killed everyday by motored vehicles in the U.S.

Not only are wildlife populations threatened by high speed traffic, but human safety is a primary concern as well, particularly in areas with vast numbers of mega fauna species such as white-tailed deer, elk and black bear. According to Insurance Institute for Highway Safety, more than 1.5 million traffic crashes involving deer are estimated to occur each year in the United States (2003). These crashes produce at least $1.1 billion in vehicle damage and about 150 fatalities annually (Hedlund et. al. 2003). The only widely accepted method with solid evidence for reducing animal/vehicle collisions is well-designed and maintained fencing, combined with wildlife passage systems where appropriate. By addressing potential wildlife collisions during highway planning, the savings associated with reduced human injury and vehicular damage could offset the cost of mitigation measures.

While roadways are important to humans, they can drastically affect the movement of wildlife. As long linear features in the landscape, roadways have impacts on wildlife habitats that are disproportionate to the area of land that they occupy. Roads and roadides cover approximately one percent of the United States, yet it is estimated that 15-20% of the land is directly affected by roads and vehicles (Forman 2000).

The effects of highways are so detrimental to population connectivity, in fact, studies have shown that gray wolves migrating from Canada to reestablish in Montana stopped when they reached I-90 (Davidson 2003). According to Devlin (1998), in order to determine the actual amount of habitat suitable for wildlife, one must superimpose a map of the US road system on the areas of suitable habitat; almost always, habitat boundaries are dictated by road locations.

Habitat connectivity is very important for maintaining wildlife populations. Without connectivity, small, isolated populations are often driven toward local extinction. Population isolation can result in low reproduction rates, low rates of gene flow, increased
inbreeding, and make populations prone to chance events such as fires or droughts. Connectivity between populations will allow several small populations to function as a group, together functioning more like a larger population (Figure 1-1).

-FIGURE 1-1: Population Dynamic

The roadway barrier affect causes isolation and prevents population interaction through connected favorable habitats. What constitutes a barrier for wildlife? A barrier can be described as any obstacle or obstruction, natural or otherwise, preventing passage. Its magnitude to wildlife depends on the species mobility. Natural barriers such as large bodies of water or topographic features such as canyons can prevent wildlife movement and result in speciation of populations. It is not likely that roadway systems have the capacity to cause complete isolation resulting in speciation. However, a 12 inch vertical concrete curve may function as a barrier for amphibians while not affecting larger more mobile fauna species like deer. This creates a dilemma when trying to determine what size roadway begins to function as a barrier. Research indicates that twinned interstates highways with more than four lanes of traffic pose the greatest threat to wildlife. The barrier affect is compounded with traffic volume, vehicular speed and the presence of structural features such as jersey barriers, sound walls or roadside fencing. With their larger size and high rates of speed, it can be deduced that interstate
highways represent the greatest threat to wildlife. Particularly interstate highways of more than six lanes, can form an almost impassable barrier for many reptiles, amphibians and mammals.

Wildlife have intrinsic desire to survive, feed, reproduce, compete and disperse. The daily and deasonal needs vary among species. However, a desire to move within and between areas of favorable habitat make species venerable to encounters with adjacent road systems (Figure 1-2). This desire to cross should not be prevented but rather designed into the highway road systems as a form of mitigation.

![Figure 1-2: Wildlife Movement Desire](image)

Often when interstate construction occurs, many local fauna will experience population reduction due to habitat isolation. This can expose the reduced population to chance events and lead to local extinction (Figure 1-3). It can be assumed that species are not only subject to the changes in habitat associated with the roadway footprint, but rather the additional conversion of habitat due to increased sprawl or urbanization following roadway construction. Often this landuse change associated parallel with interstate roadway system can serve as additional barriers for many species.
FIGURE 1-3: Population Reduction Curve.

Since road construction is not showing any signs of decline and vehicular travel is only becoming a more integral part of the American culture, it is crucial that solutions are developed to increase landscape connectivity, decrease the impact of mortality on wildlife populations and improve highway safety.

**Wildlife Passage Systems**

Beginning in the 1970s, several countries including Great Britain, the United States, Germany, Netherlands and Canada were looking to reduce vehicular causes of animal mortality by providing linkages between patches of wildlife habitat. Often these linkages were in the form of underpasses or open-span bridges with a series of fences to funnel animal movement. These structures became collectively known as wildlife passage structures. Early research showed that small animals used the culverts or ditches freely while the overpass bridges were more effective in facilitating the movement of larger animals such as deer, elk and sheep (Clevenger 2002).
In North America, most efforts addressing mega fauna have been conducted along mule deer and elk migration routes in Montana and Wyoming, as black bear and panther crossings in Florida, and as wildlife passage structures on the Trans-Canada Highway in Banff National Park. These three regions are world leaders in research and development of passage structures for reducing vehicle-wildlife collisions.

**Current Research**

Before the creation of a series of wildlife crossing structures in Banff National Park, approximately 300 animals, the majority being elk, were killed each year on the Trans-Canada Highway (Clevenger 2002). After construction of the passage structures, elk mortality in the Park declined by 96 percent.

The creation of wildlife overpasses along the Trans-Canada Highway began in the mid 1980s. During the construction, a series of 11 underpasses were built and a 2.4 meter high fence was erected along each side of the highway. By 1997, 11 additional underpasses were completed. In 1996, research began to determine their effectiveness. Early results indicated that the underpasses were very effective for elk, deer and coyotes, but that large carnivores like wolves, black and grizzly bears were reluctant to use them (Clevenger 2002). It was this research that led to the construction of two overpasses.

The researchers used a combination of track path surveys and video surveillance to get details on just what animals were using the structures and how often. As the principle researcher, Clevenger (2002) felt that in many areas, crossing structures were considered effective “if the targeted species use them at least occasionally and/or are used by a large portion of the local fauna.” He felt that consideration must be applied to the affects on local species distribution as well. As an example, 300 elk crossings my not be more significant than 2 grizzly bear crossings. It is difficult to state that a certain number of crossings equal effectiveness.

There are numerous factors that combine to determine the attractiveness of a passage structure for a particular species. For example, elk where influenced by the length of the underpass, while carnivores like wolves and cougars preferred underpasses that where near drainage areas (Clevenger 2002). If vegetation or landform blocked the view to the other side of the highway, deer and sheep were less likely to use the crossing. Small mammals preferred underpasses probably due to increased security.

The question is Do They Work? The simple answer is yes and in some cases better than expected. The Banff National Park study documented 32,518 crossings during the four year study period. The structures are very effective. There are a few problems with their design though. Because the overpasses are typically arched, an animal must climb up into the unknown. These means an animal cannot see to the other side of the road before reaching the summit. According to Clevenger (2002), future designs may use the landscape more effectively to place the overpasses at the bottom of gulleys to give fauna better visibility across the structure.
At the University of Florida, Daniel Smith and his colleagues in the Department of Wildlife Ecology and Conservation developed a computer-based model that identifies ecological hotspots along transportation routes. Hotspots are sections of roads where high quality habitat, statewide transportation planning and vulnerable species intersect. It’s an effort that could help coax species such as the Florida panther, American crocodile and Florida Keys deer back from the brink of extinction.

Road ecologists are now confirming what many mega fauna biologist likely knew all along: That not all roads are equal. In fact, even individual segments of the same road can vary dramatically in how animals perceive, use and cross them. Some stretches of road are simply more important and more deadly than others. From 1976-1999, four out of every five black bears killed on Florida highways died on just five roads around Ocala National Forest north of Orlando (Havlick 2004).

On Big Pine Key, highway traffic was the number one killer of the endangered Florida Key deer. Two Winnebago-sized culverts and an eight foot high barrier fence now usher deer beneath the highway without their need to dodge cars en route.

Scientists had also identified vehicles collisions as the leading cause of death for the rare Florida panther throughout the 1980s. As part of a road expansion project, the highway department installed two dozen wildlife underpasses in key locations along the lethal Interstate 75 corridor in Big Cypress National Preserve. Panther mortality on the highway over the ensuing years dropped to zero (Havlick 2004).

On average, Florida adds 2,400 kilometers of paved road each year (Havlick 2004). By matching road projects up front with one of the 15,000 hotspots that came from Smith’s model, Florida transportation officials can now make conservation part of routine highway maintenance and development.

Smith’s research is supported by many others in the field of wildlife distribution mapping and movement. Dr. Shelly Alexander from the University of Calgary, combines GIS techniques which merge different layers of geographic information about the landscape, with ground tracking data of wildlife movement, to develop sophisticated models of how different species move through their landscape. According to her research, landscape features can be used to determine where the optimal placement for crossings structures should be. She states that, “it is imperative that we consider the entire system if we are to ensure ecological integrity and long-term viability of wildlife species” (Alexander 2003).

However, despite research identifying hotspots and wildlife movement patterns, much work is still needed in understanding the structural design of crossings, their attractiveness to wildlife species and their practical integration into transportation planning. Forman et. al suggests that innovative overpass structures need to be designed that accommodate certain patterns of vegetation growth, account for length to width ratios according to roadway type, and potentially serve as a complete landscape linkage (2003).
methods for effectively implementing mitigation measures into transportation planning have only been marginally proven over the last few decades. Little attention has been paid to how structural designs may influence transportation users as well.

The need is apparent, to provide a framework for design and planning. The framework should be based on system level mapping and ecological theory that can serve to inform transportation planning when baseline wildlife research data is lacking or when time constraints do not allow for preconstruction empirical research studies. The physical design and form of such actions can inform the process of landscape connectivity to the transportation user and reveal that we are part of a greater ecological system.

**Passage Structures**

Animal passage systems can be designed to facilitate movement of certain wildlife species across highways. According to Jackson and Griffin (2000), the effectiveness of highway mitigation systems has not been evaluated with respect to the vast majority of wildlife. They consider it probable that some species do not require specific design features while others will require careful attention to factors such as placement, size, substrate, noise, temperature, light and moisture. In areas where road and highway density is high, conservation of a particular species may be of less concern than the maintenance of overall habitat connectivity. While it is impractical to design mitigation projects that account for the specific requirements of all species affected by a highway, it may be possible to develop a generalized strategy for making highways more permeable for a larger number of species.

Jackson and Griffin (2000) have identified a variety of highway crossing structures and generalized their application and use. In order to design effective wildlife passage structures, attention needs to be paid to features that affect their utilization. These features include placement, size, light, moisture, temperature, noise, substrate, approach, fencing, human disturbance, and species interaction.

**Placement:** Many feel that placement is the single most important factor affecting the success of a passage structure (Foster and Humphrey 1995). In terms of mega fauna, structure locations that bridge habitat connection zones and/or facilitate large home ranges are more successful. Small mammals, reptiles and amphibians are better served when passage structures are placed at uniform intervals along highways or at ecologically rich areas like riparian zones.

**Size:** It is difficult to determine the critical threshold size for passage structures because preference undoubtedly varies from species to species. For tunnel layouts, the ability of an animal to see the opposite end of a passage structure was positively correlated to use (Rosell et al. 1997). Overpass designs for mega fauna are typically more successful if widths are greater than 50 meters (Jackson and Griffin 2000). Jacobson suggests a minimum underpass openness ration of 0.9 (openness ratio = height x width/length) is needed to accommodate ungulate species (2002).

**Lighting:** Some species are hesitant to enter underpasses that lack sufficient light. Maintenance of natural light with the use of overpasses, large underpasses or open-top grated underpasses may help to address these concerns (Jackson and Griffin 2000).
**Moisture and Temperature:** The presence of moisture and a change in temperature can greatly affect the movement of amphibians, especially species that don’t use riparian areas for migration. Proper drainage is important as well, because many small mammal species will not cross standing water.

**Noise:** Traffic noise can be a problem for some mammals, especially those sensitive to human disturbance. Underpass structures with expansion joints and/or uncovered medians can be quite noisy. Overpass systems that incorporate tree and shrub buffers along the edges blocking the view of traffic appear safer to sensitive wildlife. However, the use of sound walls will effectively reduce traffic noise on both under and overpass systems.

**Substrate and Approach:** Substrate and approach characteristics may affect their use by some species. Forested species, such as black bears, prefer well vegetated approaches for concealment and security (Jackson and Griffin 2000). The presence of cover in the form of rocks, vegetation and logs, may enhance use by a variety of small mammals, reptiles and amphibians (Rosell et. al. 1997). On the other hand, species such as mountain goats and mule deer appear to prefer approaches that provide good visibility (Jackson and Griffin 2000).

**Fencing:** Although some species may utilize underpass or overpass systems without fences, some form of fencing does appear to be necessary for most species. Fences help guide animals to passage systems and prevent wildlife from circumventing the system. Typically an 8’ fence is required for ungulate species.

**Human Disturbance:** In an evaluation of underpasses in Banff National Park, human disturbance either as distance to a town or human activity within an underpass was consistently ranked high as a negative factor affecting use by ungulates and carnivores (Clevenger and Waltho 2000). Passage structures used in coordination with recreational crossings are not recommended if wildlife is the priority.

**Species Interaction:** Use of passage systems by predator species may inhibit use by prey species. It is important to recognize that different species have different requirements. If fence and passage systems are not designed for use by a broad range of wildlife, a project that facilitates passage for one species might constitute an absolute barrier for another.

The features and structural elements of a wildlife passage system can have a significant influence on the overall use by wildlife species. Trial and error design is a thing of the past. Currently a vast array of data and technological advancements are now available to be incorporated into design and development of future passage structures.
Generally speaking there are a variety of structures currently used for wildlife passage. Most fall under the categories of wildlife overpasses, bridges, viaducts, expanded bridges, oversize stream culverts, upland culverts and dry drainage culverts (Jackson and Griffin 2000). A brief description of each follows and is summarized in Figure 1-4.

**FIGURE 1-4: Wildlife Passage Structure Typology**

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<thead>
<tr>
<th>Type</th>
<th>Size</th>
<th>Topo/ Character</th>
<th>Substrate</th>
<th>Expense ($)</th>
<th>Pros</th>
<th>Cons</th>
<th>Species</th>
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<td>Parabolic or Straight</td>
<td>50m, narrowing to 8-35m in center</td>
<td>works best when highway drops below grade</td>
<td>vegetation</td>
<td>1.15 million (Foreman 2003)</td>
<td>less confining, maintain ambient conditions; rain, temp, light.</td>
<td>expensive</td>
<td>Serve a wide variety of wildlife, particularly cervids</td>
</tr>
<tr>
<td><strong>Underpasses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Span Bridges</td>
<td>dependent on road size</td>
<td>highway maintained at grade, at swales or basins</td>
<td>natural or existing riparian zone</td>
<td>expense associated w/ additional length</td>
<td>unconfined passage under</td>
<td>wide variety, particularly predators</td>
<td></td>
</tr>
<tr>
<td>Viaducts</td>
<td>&gt;50m</td>
<td>elevated roadway, spanning valleys or gorges</td>
<td>natural or existing</td>
<td>approx. 42,000/meter (Forman 2003)</td>
<td>riparian zones</td>
<td>excellent passage for riverine wildlife</td>
<td></td>
</tr>
<tr>
<td>Expended Bridges</td>
<td>&gt;50m</td>
<td>extending from riverine to terrestrial ecosystems</td>
<td>natural or existing</td>
<td>approx. 33,600/meter (Forman 2003)</td>
<td>riparian zones to terrestrial ecosystems</td>
<td>excellent passage for riverine wildlife</td>
<td></td>
</tr>
<tr>
<td>Oversized Stream Culverts</td>
<td>&gt;2m height x stream width</td>
<td>typically watercourses bisecting roadway</td>
<td>at least one bottom side serves as a bench for dry passage</td>
<td>approx. 3,630/meter (Forman 2003)</td>
<td>cost effective with high frequency</td>
<td>lack of interior light and vegetation</td>
<td>small mammals, large predators, depends on size</td>
</tr>
<tr>
<td>Upland Culverts</td>
<td>&gt;2m x 2m</td>
<td>uplands</td>
<td>dry natural substrate</td>
<td>approx. 1,880/meter (Forman 2003)</td>
<td>used by upland specific species</td>
<td>lack of interior light and vegetation</td>
<td>upland mammal, reptile and amphibian species, Box turtles, etc</td>
</tr>
<tr>
<td>Dry Drainage Culverts</td>
<td>dependent on stormwater mitigation</td>
<td>swales or drainage basins</td>
<td>dry most of the year, except during periods of storm events</td>
<td>approx. 1,880/meter (Forman 2003)</td>
<td>dual roles as passage and stormwater mitigation</td>
<td>potential danger to wildlife and human safety</td>
<td>small mammal, reptile and amphibian species.</td>
</tr>
</tbody>
</table>

**Species Considerations for Underpasses**

<table>
<thead>
<tr>
<th>Species</th>
<th>Consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ungulates</td>
<td>Openness Ratio of &gt;0.9 = height x width/length (Jacobson 2002)</td>
</tr>
<tr>
<td>Predator species</td>
<td>prefer cover for security</td>
</tr>
</tbody>
</table>
Wildlife Overpasses: The most effective overpasses range in width from 50 m wide on each end narrowing to 8-35 m in the center, to structures up to 200 m wide (Jackson and Griffin 2000). The primary advantages of overpasses are that they are less confining, quieter, maintain ambient conditions of rainfall, temperature and light and can generally serve a wide variety of wildlife. The major drawback is high construction expenses.

Bridges or Open-Span Bridges: Wildlife bridges are large underpasses that provide relatively unconfined passage. The highway is typically maintained on grade allowing natural basins or swales to act as the passage route underneath (Figure 1-5).

FIGURE 1-5: Theoretical Open-Span Bridge

Viaducts: Viaducts are areas of elevated roadway that may span marshes, valleys or gorges. Primarily viaducts provide passage for riverine wildlife, as well as those that use riparian corridors for movement.

Expanded Bridges: Expanded bridges can be characterized by extending from riverine ecosystem to terrestrial ecosystems. Typically in the form of multi-span bridges with highs above or equal to tree line, accommodate a wide variety of species.
**Oversize Stream Culverts:** Where culverts are used to cross stream and small rivers, oversized culverts, large enough to allow for animal passage may be used. The bottom side of the culvert should be characterized by a bench or partially dry substrate (Figure 1-6).

**Upland Culverts:** Not all wildlife readily use stream corridors to travel. Upland culverts maintain a dry substrate and serve to link upland habitats.

**Dry Drainage Culverts:** Placed to conduct water during brief periods of runoff but otherwise dry for most of the year. With some attention to design considerations, these structures can serve dual roles for stormwater management and wildlife passage.

Despite existing structure typologies, design of wildlife crossings that are effective for facilitating animal passage and are practical for use in the transportation systems should be explored. Biologists need to establish the performance standards for such structures based on the characteristics and needs of wildlife. The assistance of designers is needed to provide the technical solutions so that crossing structures more effectively meet the standards identified by biologists. Methodologies that fit within the time-line constraints of transportation planning need to be implemented as well. Given the incredible feats of transportation engineering over the
years, collaborative partnerships between designers, biologists, and engineers should serve as the source for developing practical solutions to wildlife passage as a form ecological infrastructure.

The Challenge

Traditionally, highway impacts on wildlife have been viewed in terms of road mortality and threats to specific populations of animals. Viewing this issue from a landscape ecology perspective, it is clear that highways have the potential to undermine ecological process through the fragmentation of the landscape, affecting many wildlife species as well as severing other human relationships to the landscape.

It is a clear challenge to design highways and passage structures that will effectively mitigate the impact of roadways on animal movement, wildlife population dynamics, and humans. However, much has been learned from projects around the world that can guide new approaches and promote the development of an ecological infrastructure here in the U.S. As a tool for transportation planners, designers, engineers and biologist, a system level framework model can serve to guide future transportation projects. Through system level modeling and analysis applied within an eco-region context, we can begin to identify practical and reasonable solutions, develop design guidelines for a wide range of species and purposes, and promote landscape connectivity not only for wildlife but rather for the entire landscape system.

Defining the Scale

An eco-region or ecosystem based approach should serve as a foundation for decision making and planning. At this systems level, the cumulative effects of highways on the landscape can be determined, and measures can be taken to determine the environmental impacts to important ecological areas. As an overriding principle, the framework employs the following ecosystem ideals.

Ecosystems are interconnected communities of living things, including humans, and the physical environment with which they interact (Bank and Garrett 1995). Healthy and well-functioning ecosystems are vital to the protection of our diverse biological resources, and to sustaining our economies and communities that rely on their products. This approach recognizes the interrelationship between the natural environment, sustainable economies, and emphasizes the integration of planning for the protection and preservation of both. It is goal driven and is based on a collaboratively developed vision of desired future conditions of ecological, economic, and social
functions. It is applied within a geographic region and is context sensitive, defined primarily by ecological boundaries. An example of such an eco-region might be the Southern Florida Everglades, Upper Yellowstone Ecosystem, or the Chesapeake Bay Ecosystem, where geographic boundaries can be drawn around an interacting area of concern. Traditional resource management tends to be site specific, with little consideration of how a proposed action fits into the context of the broader ecosystem, region or landscape. Under the eco-region based approach, the frame of reference and planning objectives are much broader. Although site-specific actions are still necessary, they would be developed and conducted within the broader ecosystem objectives.

**Federal Transportation Regulations and Landscape Connectivity**

Transportation planning and highway construction is a complex process. Principle environmental regulations pertaining to highway construction and expansion projects include a compliance with the National Environmental Policy Act of 1970 (NEPA), the Clean Water Act, Endangered Species Act, Clean Air Act and the Transportation Equity Act for the 21st Century (known as TEA-21, a successor to the Intermodal Surface Transportation Efficiency Act of 1991.)

How can these regulations address landscape connectivity and wildlife resources? Implementing NEPA emphasizes consideration of ecological resources in early planning phases of highway projects, and encourages planning to avoid undesirable ecological impacts. Where impacts are unavoidable, authority is provided for other alternatives to mitigate impacts which affect critical or highly important resources. Mitigation may include reclamation or creation of similar impacted resources, and/or implementation of wildlife passage.

In the U.S., approximately 1300 species are currently on the Endangered Species list and more than five times that number are considered vulnerable to extinction (Defenders of Wildlife 2004). Many are endangered not because of hunting, agriculture or extractive industries, but because of the alarming rate of habitat conversion due to sprawling development. Endangered species can dramatically affect the highway planning process. However, many states have problems justifying habitat and wildlife mitigation that is not associated with listed species, because of no regulatory imperative (Transportation Research Board 2002). The opportunity is to address broader ecological diversity and landscape connectivity at system levels as part of the environmental analysis required by NEPA and ultimately provide measures to avoid, minimize or mitigate those impacts despite the lack of regulatory imperative.

ISTEA and TEA-21 contain the following environmental initiatives that begin to address highway permeability and landscape connectivity.

- Transportation Enhancement: $3 billion allocated for transportation projects to improve communities’ cultural, aesthetic, and environmental qualities.
• Sustainable Communities: Establishes a pilot program to help state and local governments plan environmentally friendly development.

The Transportation Enhancement (TE) initiative under TEA-21 contains one program that has direct benefits for America’s wildlife, which sets aside 10% of Surface Transportation Program (STP) funds for small scale projects that are initiated at the local level and enhance the transportation experience (Defenders of Wildlife 2004). Common examples of TE activities include construction of bike and walking trails and preservation of our scenic or historic resources as they exist in a transportation context. TEA-21 included an expanded list of eligible TE activities, including funding for provision of wildlife habitat connectivity. Recognizing the inherent conflict between wildlife and transportation, this category covers projects such as wildlife crossing, underpasses and overpasses.

Linking Regulations and Planning

Looking at this issue from an integrated system level approach and as a user, one can begin to see the potential for multi-use mitigation where wildlife passage systems can serve dual roles as landscape connectors and for other sociocultural interests. The highway system serves as a barrier not only to wildlife but also to humans. Connecting agricultural units, stormwater mitigation systems, local and scenic trails are part of the greater regional system and should be considered as habitat components as well. The concept of habitat then begins to take a form of not just associated species but rather associated functions. The function of systems and highway infrastructure are combined and not independent of one another. Under current environmental regulations, wildlife can benefit if habitat is integrated into clean water provisions, stormwater mitigation, aesthetic requirements, recreational opportunities and preserved scenic beauty. Landscape connectivity is not just a wildlife obligation but rather a greater visual, social, and functional obligation. This action can become revelatory serving to inform the transportation users and reveal the phenomena of landscape connectivity. By incorporating such approaches, highway planning should not feel restricted in terms of environment obligation but rather consider it as an opportunity to increase the overall quality of highway design and user experience.

Project Area

The land west of the Blue Ridge Mountains is called the Ridge and Valley Region. This region consists of a series of narrow, elongated, forested knobs and ridges, which are parallel to one another. Most of the ridges rise between 3 and 4 thousand feet. Some of the ridges found in this region are the Massanutten Mountain, Shenandoah Mountain, Brushy Mountain, Walker Mountain, and Clinch Mountain. Between the mountains, flat land persist called the Valley of Virginia, or the Great Valley, and all combine to form what is known as the Allegheny Mountains. This line of mountains is also part of the Appalachian Mountain range. The Great Valley is made up of several valleys such as the New River and Roanoke Valleys and the beautiful Shenandoah Valley.
Due to the topographic parameters, vegetation regimes and landuse patterns in the region, designing landscape connectivity across the interstate roadway system should be handled specifically. Viewing the region remotely, it is clear that human habitation, infrastructure, landuse and vegetation regimes take on distinct patterns associated with water courses and topographic limitations. This informs a method of design specific to the Ridge and Valley Ecosystem that would differ from other regions such as the Piedmont or Coastal Plain (Figure 1-7).

The interstate highway system within the Ridge and Valley Region is characterized primarily by the Interstate 81 Corridor, following a northerly and southerly direction along the Great Valley floor between major mountain ranges. The I-81 corridor is bisected by major interstates, I-64, I-77 and the planned I-73 which follow more restrictive routes by crossing major mount ranges. The interstate system in the region takes on three primary characteristics by either following broad valleys, narrow valleys along river courses, or crossing ridge lines with significant elevation change.

According to Virginia Department of Transportation (VDOT) I-81 is one of the busiest trucking corridors in the U.S. With the dramatic growth in passengers and freight traffic, VDOT is working with planning groups to improve traffic flow and public safety. No final decisions have been made about how I-81 will look and function in Virginia's future. However one thing is for sure, lanes will be added and the interstate will be expanded. This offers an exceptional opportunity to reassess the short coming to the existing interstate infrastructure in terms of landscape connectivity, wildlife movement and public safety.
Analysis Tool: Applying New Theory

Scientific research analysis in the area of wildlife passage is limited while an aggressive transportation program is being carried out across the United States. This presents an opportunity for system level modeling that is not subject of time constraints of empirical research or data collection methods. Often when planners or biologists are charged with determining the locations of wildlife mitigation measures, time limits do not allow for preconstruction wildlife distribution and movement studies. In addition, case study analysis shows that empirical studies are primarily conducted when specific species, endangered species, or lands in conservation status are conflicting with proposed highway construction. This presents a few associated issues. First of all, typically empirical studies are single species approaches to a much broader ecological question. For example a black bear study, will not necessarily address the greater biodiversity of a particular area such as the distribution of small mammal, reptiles and amphibian. Secondly, most roadway proposals do not transverse areas in conservation status such as federal and state public lands. Clearly there is an opportunity to begin to address greater ecological diversity and landscape connectivity at eco-region levels encompassing private and public lands alike. This is not to say that empirical studies are no longer necessary. The benefit of empirical studies, when time or funding permits or NEPA requires, is to establish quantifiable data that can be utilized to compare pre and post-construction results which ultimately inform future mitigation measures. Much has been gained from past empirical studies to inform new approaches that better suit general transportation planning. The baseline information has already been proven with the success of wildlife passage structures across the country from the Rocky Mountains to the Florida Everglades. The next priority is to effectively integrate mitigation measures into transportation planning as a standard of practice.

An alternative to empirical studies is a systems level modeling approach which can be integrated into and function as a tool for transportation planning. This approach is grounded in ecological theory and derived from a concept of Convergence. Applying landscape ecological paradigms within an eco-region context, landscape connectivity can begin to take on theoretical form and graphical representation. This exercise requires a utilization of GIS data sets, aerial photography, satellite landuse cover data, GAP analysis and a clear understand of geophysical and biophysical complexity of the ridge valley region of Appalachia. Utilizing such data and knowledge, landscape convergence can be mapped and integrated into highway planning. Landscape convergence can be characterized by mapping biological, geophysical, or infrastructure elements and the system flows associated with those elements. Forman and Godron (1986) describe the concept of peninsular interdigitation where peninsulas of one landscape element type interfinger with those of a second type. The landscape peninsulas create a funnel affect that is indicative of a high frequency of animal tracks (Forman and Godron 1986). Just as spatial patterns emerge from a heterogeneous mosaic view of the landscape, convergence can be identified as areas of funneling social, biological, geophysical or structural flow. For example as a road system emerges from
many directions in the landscape the flow of traffic can be characterized by convergence or as sub-watersheds converge to form a main stream. This concept not only looks at spatial patterns in the landscape, but rather applies function and process to the entire system. In terms of landscape connectivity; trail systems, secondary road systems, water courses, vegetation and topographic patterns can collectively be viewed as a system, described by areas of sinks where convergence occurs.

If one then begins to consider the convergence of habitat units in the same manner, then one can begin to map habitat convergence points (Figure 1-8). The points would suggest areas of rich ecological diversity and potentially address a broad range of associated species within a given site. Foreman (1995) suggests that total species diversity is highest in the central portion of interdigitating peninsulas, where species from differing landscape elements are present. In addition, the highest rate of object flow occurs parallel to peninsula fingers (Forman 1995). Ultimately such an exercise will identify key locations in interstate design that would serve to facilitate landscape connectivity for wildlife resources.
Habitat Convergence Point

* A Primary Ecological Interaction Point

FIGURE 1-8: A Habitat Convergence Point
The following is a comparison of advantages and disadvantages associated with data collection methodologies and analysis for wildlife mitigation measures.

<table>
<thead>
<tr>
<th>Methodologies/ Information</th>
<th>Type of Analysis</th>
<th>Retrofit</th>
<th>New Construction</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing Data</td>
<td>Roadside mortality data. Insurance Data. Past Research Information.</td>
<td>Offers insight on current wildlife crossing locations. Allows for pre and post construction studies. Species Specific (sp sp)</td>
<td>No specific input on existing conditions of new proposal.</td>
<td>Site areas of precedence. Excellent source of background information. Establishes a baseline for action.</td>
<td>Primary mega fauna data and research which is specific to study area.</td>
</tr>
</tbody>
</table>

**FIGURE 1-9: Methodologies for Wildlife Passage Mitigation**

Primary advantages associated with a system level modeling approach include a process that is interdisciplinary and fits within the timeline of transportation planning, is nonrestrictive in terms of adjacent landownership, considers greater ecological communities, is context sensitive and multi-scaled. In addition, the types of analysis tools, such as habitat convergence and remote GIS mapping, are applied at the transportation system scale to unify highway planning and project development.

**Grounded Ecological Theory**

Habitat convergence mapping for wildlife passage systems is grounded in ecological theory, primarily landscape ecology, restoration ecology and road ecology.

*Landscape Ecology* is the study of spatial variation in landscapes at a variety of scales. Broadly interdisciplinary, it includes the biophysical and societal causes and consequences of landscape heterogeneity (Johnson and Hill 2002).
Ecological Restoration is the process of assisting the recovery and management of ecological integrity. Ecological integrity recognizes the critical range of variability in biodiversity, ecological process and structure, regional and historical context, and sustainable cultural practices (Johnson and Hill 2002).

Road Ecology has a primarily foundation in landscape ecology but looks further to explore and address the relationship between the natural environment and the road system (Forman et. al. 2003).

The patterns in the landscape create a virtual ecological footprint (Forman et. al. 2003). Recognizing that it is sensible to lessen the impacts to that footprint is the wisdom that comes from seeing the landscape patterns. The more obtuse and impermeable the highway system, the less connected it is to the landscape in which it is embedded. Applying ecological theory, one overriding principle emerges. Since a large virtual ecological footprint is associated with the physical footprint of roads, planners and designers need to be concerned with the broad landscape rather than the one-dimensional road corridor (Forman et. al. 2003). In order to make these landscape associations apparent, methods of spatial measure and terminology are described.

Habitat convergence mapping is derived from the proceeding ecological paradigms. A key principle for understanding convergence methodology embraces the notion of the landscape mosaic, where patch-corridor-matrix models can be used for analyzing the structure, function and change of a landscape as a specific object (Forman 1995). Primary measures for landscape elements includes edge effect, boundary crossing frequency, stepping stone dispersal, matrix connectivity, network connectivity, gamma index, alpha index and patch-corridor-matrix shape, size and type (Forman and Gordon 1986).

The spatial hierarchy of landscape patterns are formed by patches (predominate individual structural features), corridors (links between patches), and matrix (the major encompassing landscape element). The edge condition can be characterized by change in landscape structures such as from grassland to forest or land to water. The edge affect creates habitat typology and is important to associated wildlife species, known collectively as edge species. The interior portion of patches or matrix serves as specific habitat types for interior species. Corridors or small patches can serve as stepping stones for species to move among favorable habitat types. Understanding the habitat requirements of species associated with landscape structure is important for determining habitat convergence.

The patch-corridor-matrix model is easily delineated in plan view but lacks certain levels of input in the vertical dimension, particularly in regions with varying topography. This vertical dimension is very important in understanding wildlife movement and dispersal as well as landuse patterns. For example, in the Ridge and Valley Region of Virginia, openland is associated with landuse practices resulting from soil type and forgiving topography. Large tracks of forest land are typically associated with land that is too steep or inaccessible to cultivate as profitable agricultural land. This begins to inform the reasons certain patterns exist in the landscape and
will continue in their relative form. When topography limits what private enterprise can build, the status of the land then begins to inform potential opportunities for mitigation measure adjacent to a roadway system. For example, a stream gorge with 40% slopes covered in woody vegetation will likely remain within a few successional states of woody stemmed plants for many decades to come. The slope is not stable enough or it is not economically feasible to clear and covert to agricultural or developed land. There are always exceptions. However, this premise begins to highlight how mitigation measures can be effectively implemented without the need to purchase land adjacent to a roadway. In some instances, particularly when reconnection is a priority, the purchase or easement of adjacent land will be necessary and needs to be addressed specifically.

In addition, game trails in mountainous regions typically correspond to topography limitations rather than just vegetation patterns. These wildlife trail systems typically flow routes of least resistance such as along water course, ridge lines or across contour of slopes. Habitat convergence mapping employs landscape structure patterns (vegetation regimes) as well as topographic influences to wildlife movement. A theoretical graphical example of how habitat convergence mapping occurs is demonstrated.
FIGURE 1-10: Theoretical Habitat Convergence Mapping

Links and Nodes Associated with Topography

Theoretical Roadway and Species Movement Associated with Vegetation

Two Habitat Convergence Points Identified for Wildlife Mitigation Efforts

Topography and Water Courses

Added Vegetation Cover

Topological Nodes Combined with Vegetation Regime and Roadway
It is also important to note that the interstate highway system functions as a corridor for many wildlife species. The edge effect is pronounced in the margins of road right-of-ways and serves as habitat for a variety of fauna, particularly small mammals. However, road surface and traffic volume function as barriers between right-of-way margins.

A quantifiable method of determining the capacity of fauna to move through the landscape is by calculating the gamma and alpha indexes. These measures can apply value to habitat convergence points valuing areas of priority for wildlife mitigation. The gamma index is the ratio of the number of links (corridors) in a network to the maximum possible number of links in that network (Forman 1995).

\[ \gamma = \frac{L}{L_{\text{max}}} = \frac{L}{3(V - 2)} \]

\( L = \) number of links \( V = \) nodes or areas of intersection

The alpha index is the measure of circuitry, the degree to which nodes are connected in the network (Forman 1995).

\[ \alpha = \frac{(L - V + 1)(2V - 5)}{2V - 5} \]

\( L = \) number of links \( V = \) nodes or areas of intersection

Together, connectivity and circuitry, as by the gamma and alpha indices, indicate the degree of network connectivity (Forman 1995). Merely the graphical exercise begins to suggest what system flows are occurring within the landscape. However, these measures are only abstract based on the scale from which data is drawn. Elevation change, direction of links and linear distance of links are not considered. In addition to the measure of landscape patterns, topographic patterns should be measured as well. Utilizing the gamma and alpha indices in the same manner based on topographic limitations, the topological network connectivity can also be measured. Combining both the network and topological network connectivity, a designer can discriminate between many possible routes of habitat convergence ultimately informing mitigation locations. However, it is important to note that utilizing this approach for habitat convergence mapping will only give informative value within a site specific context and when scale is maintained across the study area, because determining links and nodes is primarily a qualitative exercise.

Considering the notion of boundary crossing frequency and landscape stepping stones, one can add an additional measure of how wildlife can move through the landscape. Boundary crossing frequency is a measure of the number of boundaries (edges) per unit of length that an object (animal) crosses while moving through the landscape (Forman 1995). The higher the boundary crossing frequency the more spatial heterogeneity exists in the landscape, often demonstrating the use of rest spots or stepping stones for species. The benefit for understanding boundary cross frequency is that it can be used for calculating any number of routes between two points as well as serve to compare a straight route to a route that uses corridors (links) in the network.
The gamma and alpha indices, and boundary crossing frequency are excellent methods for training individuals to understand the movement of wildlife species in the landscape as well as convey a foundation for habitat convergence mapping.

Highlighting the notion of quantitative versus qualitative data, habitat convergence modeling is primarily a qualitative exercise that recognizes the most obvious areas of convergence based on geophysical and biophysical elements in the landscape. It looks to function as an exercise that can be preformed with limited training as well as fit into the time restraints of transportation planning. The discretion of measure should be subject to evaluation by wildlife professionals, primarily the state wildlife agency. In addition, a transportation department should only use the habitat convergence technique in general transportation planning. When endangered species or federally protected lands are a concern of proposed highway actions, legal requirements and environmental issues will require a more intensive investigative approach or study that should be handled specifically. This is not say, that habitat convergence mapping is not grounded in solid research data. Rather on the contrary.

A potential starting point to identify key associated species by geographic location is the utilization of GAP Analysis. As a collaborative effort between US Geological Survey, Virginia Department of Game and Inland Fisheries and the Conservation Management Institute, GAP Analysis provides the habitat, species, and land management information necessary to protect and manage biodiversity in Virginia (2002). Primarily the project identifies species richness and associated habitat “gaps” between protected and private land status. Predicted terrestrial wildlife species diversity maps are produced based on existing vegetation and landuse regimes at a scale of 1:100,000. By utilizing species diversity distribution, fauna groups can be prioritized for mitigation measures on proposed or existing sections of interstate roadway projects. Habitat convergence mapping and passage structure typology should correspond to selected fauna groups identified by Gap Analysis, if this approach is used.
Habitat convergence mapping assigns high value to habitat nodes, characterized by sinks in the natural landscape matrix or by primary corridors associated with interior species. If this node or corridor corresponds as an intersection with the roadway, habitat convergence points are defined and should be further enhanced. Utilizing the theory of ecotones, habitats convergence point can be managed or designed as unique habitat elements attracting a wide variety of species. Examples of natural ecotones might include a hillside seep wetland or other habitats based upon particular lithology and associated vegetation. These habitats, while small, form important parts of a mosaic landscape. Instead of considering only one community parcel, habitat convergence models attempt to address the maximum number of natural communities associated with a given site. Habitat convergence modeling will be further demonstrated in the ensuing Interstate 81 design study.
Once modeling and landscape connections have been determined, it is important to consider form and specific function of mitigation measures. Many of the current passage structure used across the country are specific engineered solutions resulting from performance standards determined by biologist, such as an underpass openness ratio or overpass minimum width. This presents a clear opportunity to incorporated design theory into structural form which could reveal the process actions and convergence phenomena, demonstrating a deeper meaning and understanding of landscape connectivity. This premise acknowledges that the success of integrating ecological infrastructure is more than just building an engineered structure and facilitating wildlife across interstates. It informs and reveals a deeper understanding of ecological process and connectivity to the transportation community, whom ultimately influence future sustainability and environmental policy.

**Integrated Design Theory**

Eco-revelatory design is landscape architecture intended to reveal and interpret ecological phenomena, processes and relationships (Brown et al. 1998). Landscape architects construct nature and in doing so, they shape and intervene in interactive geophysical, biological and cultural systems. Revelatory design ideals can serve to inform ecological infrastructure, by not only guiding the design of landscape forms and functions, but also by creating experiences for the observer. Designing landscape forms can direct vision and interpretation; they emphasize, they accentuate, they reveal.

“According to the Eco-Revelatory Design Committee, eco-revelatory design strategies have to do with how we see and experience as well as with what we see and experience (1999). Designers envision and plan new uses of landscapes, out of which arise deeper caring for the interactive life and processes within them. They preserve, restore and introduce signifying features in landscapes that speak for natural and cultural processes that might otherwise remain invisible. They expose processes customarily hidden.”

This design philosophy tends to be more immersive and reflective than conventional interpretation devices but relies on a viewer or an observer not an actor within the processes which occurs. The richness of eco-revelatory design lies within the innovative means of telling the story, the landscape of interacting systems and processes rather than a landscape of static structure. In terms of wildlife passage structures, forms can be characterized as constructed ecologies, where entirely new systems are made to connect or reconnect into greater ecological processes both human and natural (Ware 2004). The range of design responses in this category forms both a conventional understanding of constructing an ecology as well as re-configuring dynamic processes. Constructed ecologies can go beyond the mere landscape function and employ a formal experience to focus attention on a place and its particular qualities. This revelatory exercise allows the transportation participant to engage in the roadways ancient landscape histories, its recurring natural cycles and processes, and reveal things which were almost invisible to a not informed culture. This awareness will not happen over night, but depends on the experience of a dynamic place by an engaged transportation users over time.
Framework Model

In order to achieve the complexity of integrating ecological infrastructure into interstate roadway planning, a framework of decision making, key areas of focus and project role is provided (Figure 1-12).

Ecological Infrastructure Framework Model

FIGURE 1-12: Ecological Infrastructure Framework
The framework model comprises of five major subsets addressed independently yet inform by one another. This process is only complete once every subset has been concluded and works toward common goals that complies with the other subsets, therefore maintaining complete cohesion between planning and design. The process is goal driven within the context of the eco-region.

Transportation planning can be characterized by a series of steps that include project concept, project development, construction, operation, and maintenance. Planning results in project concept that continues through project development which is typically informed by environmental studies and engineering studies. The following system level model speaks to address the issues and decisions conceived during project development. It is imperative that the consideration of the ecological systems are included early in the project development stage and correspond with assessment of environmental, sociocultural, and engineering studies (Figure 1-13). This systems level approach employs a body to professionals in varying disciplines to study and design passage systems that can employ single or multiple uses. The integration of stormwater management, scenic vista, trail systems and wildlife passage can collectively be studied and achieved as a form of ecological infrastructure.
Goals associated with environmental, sociocultural, and engineering studies should include the following.

Environmental Studies:

- Conduct habitat connectivity studies based on habitat convergence theory to determine where passage structures are needed. Locate mitigation routes as needed based on associated wildlife needs.
- Retrofit existing and new highways with wildlife passage structures. Consider the full range of options from at-grade, non-structural approaches to land bridges.
• Consider all bridge and culvert locations as opportunities for dual purpose mitigation.
• When planning, designing and building wildlife crossings, ensure the future viability of habitat on either side through land acquisition and easement, or as landuse limitation.
• Conduct post-construction monitoring on the effectiveness of passageways.
• Where appropriate incorporate revelatory design elements to inform motorist of actions.

Sociocultural Studies:
• Conduct historical and cultural resource studies informed by state, county or municipal comprehensive planning.
• Identify existing or key future pedestrian trails, local cultural features and scenic byway routes that may correspond with mitigation measures and serve as a form of mixed use passage.
• Apply for Surface Transportation Funds provided by the Transportation Enhancement (TE) initiative under TEA-21.

Engineering Studies:
• Conduct cost engineering analysis and typology analysis for desired mitigation routes and procedures.
• Focus on dual purpose infrastructure that may serve to mitigate stormwater and secondary road systems as well as wildlife resources.
• Program structure maintenance and operation.

Conducted during the project development stage, formation of an interdisciplinary team to conduct the environmental, sociocultural, and engineering studies will increase the efficiency and effectiveness of implementation. Only by integrating project level decisions with system wide studies can the transportation agencies address the larger connectivity needs of wildlife and human culture.

Conclusion
For the last century, automobiles and the roads they require have been the dominant force shaping the modern American landscape. There are more cars per capita in the United States than in any other nation in the world (White, P.A. and M. Ernst 2003). An unrivaled interstate highway system connects major metropolitan areas and is the basis of our transportation infrastructure. Unfortunately, many roadways were not planned or designed with wildlife in mind. Viewing this issue from a landscape ecology perspective, it is clear that highways have the potential to undermine social and ecological process through the fragmentation of the
landscape. However, science and engineering have converged with solutions, and several states are retrofitting existing roads to protect biodiversity as a form of ecological infrastructure. While wildlife crossings are not a universal remedy, they can go a long way toward restoring connectivity where roads have fragmented habitat. The current I-81 expansion offers an exceptional opportunity to reassess the short coming to the existing interstate infrastructure in terms of landscape connectivity, wildlife resources and public safety, and demonstrate how system level design can give our roadways new shape and form.

FIGURE 1-14: Project Diagram
SECTION II

So why did the chicken cross the road? Because we built him a 2 million dollar wildlife overpass. This was one of the first questions a colleague asked at a presentation. This brings light to the subject matter. If we lose our sense of humor in our professional careers then we have lost too much.
Project Study: Interstate 81 Planning and Design Exercise

The Interstate 81 project demonstrates the theories and science embodied in Sections I of this document. Principles and actions are informed by thought and theories attained through literature view and academic scholarship. I approached this subject of ecological infrastructure as a way of combining my wildlife management background with my master’s work in landscape architecture. I have a deep passion for our wildlife resources, but yet like many rely on modern conveniences and a superb highway infrastructure to carry out my day to day life. The national roadway system is vital to our nations grow and progress. We rely on our roadway systems more than ever, however at some ecological consequences. This subject of wildlife passage is a proactive way to readdress the construction of roadways not as an obligation but rather as an opportunity.

In order to demonstrate the full potential of such a study, the process of design and planning should choose the site, rather than choosing an arbitrary site for academic demonstration. Meaning to make this project potentially viable, the actions of planning and design are informed under a practical eco-region management scheme and physical wildlife resource data. Applying process and methodologies ground in landscape ecology will serve as the foundation for analysis and mapping studies. Some question might arise in how does one integrate such a complex program into transportation planning? How might the qualities of a site or sites choose the project? The following study is a demonstration of integrating wildlife passage systems into general transportation planning as a form of ecological infrastructure. The context of the study is in bound within eco-region management objectives and performed as part of the environmental studies under transportation planning (see Figure 1-14).

The following graphic was conceived as diagrammatic way of looking at of the wildlife passage issue. The roadway footprint is at the center of debate, while the overall shape suggests a similarity to a modern car.

![Diagram 2-1: Primary Objective](image-url)
For the context of this study, environmental studies will be performed under a transportation scenario illustrated above.
**General Problem**
Primarily concerned with the animal/vehicular interface resulting from projected Interstate 81 roadway expansion:

**Underlying Issues:**
- mortality, dispersal and movement of wildlife
- wildlife population isolation
- barrier affect: diminishing landscape connectivity
- Motorist safety

**Goals**
- Increase interstate roadway permeability
- Reconnect landscape process via facilitating wildlife passage
- Promote motorist safety and awareness

**Solutions and Methods**
- Utilize system level mapping applied under eco-region planning objectives

Habitat Convergence Mapping
- Advantages: Process that is interdisciplinary and fits within the timeline of transportation planning, is nonrestrictive in terms of adjacent landownership, considers greater ecological communities, is context sensitive and multi-scaled. In addition, the types of analysis tools, such as habitat convergence and remote GIS mapping, are applied at the transportation system scale to unify highway planning and project development.

**Results**
- Mitigation locations and strategies determined based on HCM and landscape analysis.

**Implementation**
- Performed during roadway expansion and/or construction.

During the study a set of steps or process recommendation emerged. The following flowcharts demonstrate a process for integrating wildlife passage into transportation planning. Later the project study is performed utilizing the recommendations.
Process Flowchart for Wildlife Passage Planning

Three Important Questions to Consider:
1. At what level do we consider wildlife passage a legitimate option?
2. Where to locate passage systems based on methodology?
3. What type of structure and at what frequency?

(1) At what level do we consider wildlife passage a legitimate option?

Develop Eco-Region Management Goals

Within Geophysical Boundaries

Identify areas of critical habitat coverage for mitigation measures

Approaches (see the following "Scaled Decisions" Flowchart)
- Biodiversity (Gap Analysis: mammal diversity, amphibian diversity, etc.)
- Endangered Species (Listed Species for the Region)
- Single Species (Empirical Studies: black bear, deer, etc.)

Determine: wildlife communities or species to focus mitigation efforts.

Determine: factors influencing selected conservation effort.

At Regional Scale Informed by Wildlife Professionals
- identify corridors
- habitat islands
- wildlife communities
- general wildlife conservation goals

How does the roadway footprint fit into the context of eco-region management goals?
- the magnitude of the existing roadway (twinned 4+ lanes, greatest concern)
- public safety concerns
- associated species concerns
- budget constraints
- projected roadway projects

Resources at an eco-region scale will determine the degree of intervention for wildlife passage mitigation.

(2) Where to locate passage systems based on methodology?

Three Principle Methods: (see: Analysis Tools in Section II)
1. Empirical Research Studies
2. System Level Landscape Modeling, Analysis and Mapping
3. Available Information

Design Project Example: System Level Modeling, Analysis and Mapping

Perform Environmental, Sociocultural and Engineering Studies under Project Development during Transportation Planning

Environmental Studies

Habitat Convergence Mapping

(Continued)
(Continued From System Level Method)

Habitat Convergence Mapping (HCM)

Criteria based on selected fauna group or taxa

(see flowchart: Species Criteria for HCM)

Example: Biodiversity Approach (GAP Analysis)

Determine Objectives: Perform mapping and analysis exercise to determine habitat convergence points for selected fauna groups under the eco-region management objectives.

Method: The goal is to create an understanding of the geophysical and biophysical complexity of the landscape and how fauna groups use and interact with that landscape.

Existing Data Assessment:

GIS Data Layers by County or Region:

- Roads
- Proposed roads
- Buildings
- Water courses
- Topography
- Properties and boundaries

Landcover Information:

- Landuse
- Zoning
- Vegetation cover

Aerial Photography:

- Satellite imagery
- Flyover DRG

Deer road kill data by County:

State Police crash report information, typically organized by County:

Wildlife Species Information:

- Threaten and endangered wildlife distribution - VDGIF
- Gap Analysis - CMI
- Virginia Outdoor Plan - DNR

Driving Survey: photo and visual assessment exercise for roadway projects.

Objective: Determine habitat convergence points that will serve the highest mammal diversity along projected interstate roadway expansion in Montgomery County, VA.

Process: Habitat convergence mapping assigns high value to habitat nodes, characterized by habitat sinks in the natural landscape matrix where wildlife can converge. By considering the roadway has infinite possible points to cross, habitat convergence points identify the wildlife movement node or sink that corresponds as an intersection to the roadway.

Key components of HCM: The location of wildlife passage is a key decision for achieving objectives. Rather than selecting locations based mainly on road-kill and tracking data (single species approaches), crossing structures are likely to be most effective long term if located to fit overall patterns of the landscape and to coincide with or create effective zones of landscape connectivity. According to Forman (2000), inexpensive structures placed at the right location (optimal habitat for crossing) will likely be more effective than costly structures placed in suboptimal habitat.

Process Steps and Guidelines
(Continued from Process Steps and Guidelines)

− Clarify Criteria and Approaches at Varying Scale.

Regional and County Scale: 1:500,000
(1) Understand landuse process - how landuse directly affects species diversity and associated habitats.
(2) Understand how landuse influences on landuse directly influencing species diversity composition.
(3) How we see the landscape? Design for wildlife and their behavior.
(4) Determine budget constraints (estimated 7 million for project example).

County Scale: 1:50,000
(1) Eliminate areas for mitigation based on density of developed areas. Develop criteria associated with your study area.
(2) Determine important landscape features (see Species Criteria for HCM).
(3) Balance human and landscape with important ecological zones identified at the county scale.
(4) Account for long term success and potential life cycle of project.
(5) Refine regional analysis criteria for study area: Piedmont vs Ridge Valley vs Tidewater

Site Scale: 1:10,000
(1) Map potential wildlife circulation and convergence points associated with roadway footprint.
(2) Determine most appropriate crossing locations based on landscape level analysis.

− Wildlife passage structure locations determined at a graphics level. Suggest site visits and follow up for further construction detailing.

(3) What type of structure and at what frequency?

− Two Methods: Number of crossing structures per linear distance. General roadway permeability

− (Better) Number of crossing structures based on landscape level analysis.

Structure frequency, size, and typology based on system level analysis and mapping (informed by existing landscape features)

− No one-size-fits all solution exists for wildlife crossing structures. Inevitably, species vary in their comfort level with and adjust to different structure types and designs.
− Wildlife crossing structures should be built to last long term. Accommodating changes in species, their demographics, animal behavior, habitat conditions, and nearby human activities is important for sustained effectiveness.

(1) Determine structure typology by topographic influences at roadway footprint. Over verse under. Due to construction cost associated with overpasses, limiting this measure is crucial and should only correspond to the very best locations for maintaining landscape connectivity. Such as areas corresponding to primary ridgelines or ridgelines corresponding to major mountain ranges and connected habitat corridors.

(2) Frequency should be maximized in mitigation zones identified at the County level. Distance between structures will correspond to key convergence areas. Recommend distance between structures should at a minimum equal to distances associated with sub-watersheds crossing roadway footprint. This maximizes opportunities for dual purpose mitigation where stormwater systems can function as wildlife passage structures.

(3) Size of structure should correlate to desired species use. Deer and other large fauna in the region will require an openness ratio of at least 0.9. Bigger is better, however with budget limitations, increased frequency of structures will improve overall roadway permeability for general wildlife species.
Scaled Decisions: Scale of associated habitats or areas for mitigation focus.

What level of conservation is appropriate for your area or region?

Eco-Region Scale → Determine Conservation Goals for Wildlife Communities

Managing for:
- Biodiversity (Utilize GAP Analysis or BOVA)
- Endangered Species (Listed or Critical Species)
- Single Species (Conservation effort for blackbear, florida panther, etc.)
- General Species (Urban wildlife or suburban deer/vehicular interface)

- At Regional Scale Prioritize Conservation Areas and Set Management Goals for Associated Species or Communities.
- Should Correspond with State Conservation Mandates or Recommendations by Wildlife Professionals.

Species Criteria for Habitat Convergence Mapping

Objective: Determine Species Mapping and Design Criteria

Grounded in Landscape Ecology Theory

Once project areas and appropriate habitat for selected species or taxa have been determined, utilize the following factors to develop criteria.

- Landscape level features influencing movement in favorable habitat.
  - Virtual wildlife roadways
    - visual signals - security, protection, predation
    - smell signals - following pervious animal movement routes and/or scent warnings
    - touch signals - ground substrate, vegetation
  - Watercourses
    - Concerned with watersheds crossing roadway footprint.
    - Primary movement routes
      - directly correlates to topographic influences and creates edge conditions
      - rivers vs streams
      - 3rd order vs 1st and 2nd order
      - prioritize largest watersheds for a given site
    - Watercourse size
      - the larger the watershed the greater the overall ecological influence
  - Topography
    - routes along contour
      - aspects - northern facing slopes are more ecologically rich in central Appalachia
    - vegetation associations with topography
  - Vegetation
    - contiguous vegetation cover
      - edge affect - margins between cover types
  - Human Infrastructure
    - build environments
      - roadways - parallel versus bisecting roadways

Criteria of landscape features should be specific to the study area and fauna groups previously selected. Mapping bisecting landscape features to roadway footprint suggests the potential for wildlife crossing areas.
Implementing Project Conceptions

The preceding process flowcharts offer guidance and incite for the implementation of wildlife passage systems. The following Interstate 81 study emphasizes components demonstrated in the process recommendations as well as reinforces realistic application for transportation planning. To understand the project and how it evolves, one must reflect on the, “The three important question to consider for wildlife passage planning.”

1. At what level do we consider wildlife passage a legitimate option?
2. Where to locate passage systems based on methodology?
3. What type of structure and at what frequency?

Question 1: At what level do we consider wildlife passage a legitimate option?

Interstate 81 Roadway Expansion Project: Developing a Scope

By developing eco-region management goals for Interstate 81 in Virginia, we can set program objectives for the Ridge/Valley region. In order to develop these objectives, one must first consider the wildlife resources present in the region and their relationship to the interstate. In many areas, the land adjacent to I-81 functions as habitat barriers between major mountain ranges to the north and the south. By utilizing GAP Analysis, three contiguous forested corridors have been identified bridging the vegetation regimes not typically found along the interstate corridor. Interesting, predicted mammal, reptile and amphibian diversity is highest in the three corresponding areas. Under the eco-region management goals, habitat zones associated with highest species diversity along the I-81 corridor will serve as the selected fauna groups for conservation objectives. As the interstate is expanded or upgraded, future actions should be planned to accommodate wildlife passage in these areas corresponding of highest species diversity.

This is a biodiversity approach to eco-region objectives. It would be reasonable to develop additional objectives for endangered species locations or single species such as for black bears or seasonal migratory amphibians. Local wildlife professional knowledge should serve to inform regional objectives.

The future I-73 corridor joins the I-81 corridor form Roanoke VA to Christiansburg VA. In the near future, traffic volume is predicted to increase and the existing four lane interstate is projected to be upgraded with increased lanes and roadway infrastructure. As the three contiguous forest corridors along I-81 persist in Southwestern Virginia, the combined interstate section between Christiansburg and Roanoke, VA., has the highest predicted mammal diversity in the state. These habitats are produces of topography,
vegetation and landuse. In addition, Montgomery County rests on the eastern continental divide between to major river systems, the New River and forks of the Roanoke River. All these factors combine to influence the habitat composition directly influencing mammal diversity.

**Project Objectives: Under the Eco-Region Context**

- Identify wildlife passage locations for predicted roadway expansion on combined I-81 and I-73 through Montgomery County, VA.
- Design and plan within a seven million dollar budget.
- Utilize an approach that fits into the time line of transportation planning.

![Land Cover Class for Virginia](data.png)

The I-81 corridor is highlighted in red and the three contiguous forest connection zones identified by a state wildlife biologist are marked by white arrows.
FIGURE 2-2: Predicted Mammal Diversity for Virginia (data layers provided by Conservation Management Institute)

The darker shades of red and orange represent habitat compositions for mammal species predicted by county. The highest diversity areas correspond to the forest connection zones identified early. From an eco-region management perspective, these areas should be prioritized for conservation efforts and wildlife passage mitigation.
The taxa diversity varies among forest connection zones. This suggests different mitigation or management objectives of each forest connection zone. For example, the mammal diversity is highest for the middle white arrows. This indicates that corresponding interstate expansion will address mammal diversity for that locale.
The eastern half of Montgomery County corresponds to one of the forest connection zones identified earlier and highest predicted mammal diversity for the region. Any planned interstate expansion will address wildlife passage for the county, under eco-region management objectives.
FIGURE 2-5: Interstate 81 Corridor through Montgomery County

The highlighted interstate corridor presents the linear site for wildlife passage studies. The county has been identified for highest predicted mammal diversity, but how does one narrow down specific areas for mitigation. First, one must identify the landscape features affecting habitat composition which correlates to highest species diversity. The following has been inventoried for the county; topography, road system, landuse and species diversity.
FIGURE 2-6: Elevation Change for Montgomery Co.
FIGURE 2-7: Mammal Diversity for Montgomery Co.
FIGURE 2-8: Landuse/Land Cover for Montgomery Co.

The bright green areas represent various forest cover types. The pink and grays are developed areas and infrastructure, while the light green is open or agricultural land.
For Montgomery County, forest cover, significant elevation change and mammal diversity all are directly related. The forested land is a direct result of land use. Meaning the forested areas primarily occur on steep slopes with unforgiving topography. Mountainous areas have little agricultural value and have not been maintained as open land. In addition, predicted mammal diversity is highest in these corresponding forested areas.
FIGURE 2-10: Interstates 81 and future I-73.
FIGURE 2-11: Project Study Area

The project study area for Montgomery County is highlighted. The roadway expansion for the combined I-81/I-73 is to occur through the eastern portion of the county (see Figure 2-9). The project area is highlighted in orange.
FIGURE 2-12: Major Forest Connection Zone.

The primary forest connection zone through Montgomery Count has a direct relationship to the I-81 corridor.
FIGURE 2-13: Treatment and Analysis

Conclude that areas in green are to serve as a focus for wildlife passage studies and mitigation.
Following discussions with VDOT highway maintenance crews, approximately 250 deer are picked up annually along the interstate roadway. Since highway safety is an ever growing concern, addressing wildlife passage and optional exclusion fencing should be set as a priority. Interestingly, these high roadkill areas correspond to highest mammal diversity as well.
FIGURE 2-15: County Scale Convergence One

From a wildlife ecology perspective, these river systems, prioritized for recreation and wildlife diversity associated with riparian zones function as major wildlife movement and dispersal corridors. For Montgomery County, a level of mitigation should be considered for the areas in yellow based on ecological significance of riparian zones.
FIGURE 2-16: County Scale Convergence 2

By addressing the forest cover zones with high species diversity as well as the major river systems for the county, it can be concluded that these areas in yellow represent a starting point for wildlife passage location studies.
Addressing Question 1

As the Process Recommendations Section began, the question was entertained, "at what level do we consider wildlife passage a legitimate option?" As pointed out earlier, an eco-region or ecosystem based approach should serve as a foundation for decision making and planning. At this broad scale defined by geophysical boundaries, the cumulative affect of the highways on the landscape can be determined and measures can be taken to determine potential environmental impacts to important ecological areas. These potentially important impacted areas, identified by wildlife professionals as vital wildlife corridors and/or habitats via GAP Analysis serve as a foundation for determining general areas to conduct landscape level analysis for mitigation measures. For Montgomery County, it can be deduced that the highest predicted mammal diversity, landuse, forest cover and topography have direct correlation to one another. This notion begins to suggest how landscape composite can influence ecological processes and how wildlife may move among favorable habitats.

It can be concluded that wildlife passage is a legitimate option for the I-81 and I-73 highway expansion. Determining the level of intervention is the challenging part. Construction budget constraints will typically limit project size, however by utilizing Gap Analysis and establishing objectives and budgets at the eco-regional level, the transportation department can gain the most rewards in light of cost restraints. The following is a summary of conclusions and positions attained determining the scope of the study project.

- Interstate 81 expansion project: The I-73 corridor joins the I-81 corridor form Roanoke VA to Christiansburg VA. Traffic volume is predicted to increase and the existing four lane will be upgraded with increased lanes.
- Three contiguous forest corridors along the I-81 corridor persist in Southwestern Virginia. These areas correspond with highest amphibian, reptile, and mammal diversity, and are considered areas of priority for wildlife mitigation measures. Recognizing that eastern Montgomery County and the combined interstate expansion project correspond to habitat areas predicted to have highest mammal diversity, it is reasonable that this area will take precedence for wildlife passage location studies.
- Major river systems are prioritized for recreation and wildlife diversity associated with riparian zone. Literature suggests a cost efficient method for mitigation is by extending the link of bridges to span over adjacent terrestrial habitats.
- Interstate roadway sections not corresponding to high species diversity such as areas adjacent to roadways with minimal development and agricultural land should include stormwater culvert upgrades or any complementary system upgrades that can serve dual roles and facilitate wildlife movement (see Sketch Studies).
- Concern to improve highway safety and reduce animal vehicular collisions, proposal of extensive fencing and/or animal exclusion devices must include the implementation of passage structures to maintain viable wildlife populations.
Question 2: Where to locate passage systems based on methodology?

Three wildlife passage implementation methods where identified earlier; empirical studies, system level landscape analysis and mapping, and available information. These methodologies were determined through case study analysis and literature view. A summary of each follows.

“Available information” speaks to the notion of utilizing existing case studies and literature to suggest wildlife passage implementation. This approach lacks validity for most situations. Meaning wildlife passage structures built in southern Florida will offer great incite into project planning but offer little in actually determining structure locations in areas such as mountainous Appalachia. Design and implementation of passage structures should be context specific to the region or locale based on the present biographic and physiographic landscape features. Mimicking structure design and location of sites out of context to the region will not likely achieve objectives.

Performing empirical wildlife research studies such as track surveys, remote camera surveillance, or telemetry studies is a time consuming approach that only measures the existing roadway system and a limited species sample. The method is ideal for single species approaches where specific species or endangered species are of concern. For example, a bear study will not give any evidence towards the relationship between roads and other fauna groups. For general transportation planning, often there is not legal imperatives present to warrant such studies, so ultimately wildlife passage is not even considered an option.

An alternative is system level analysis and mapping that can be included in general transportation planning, fit into the time line of project development, and primarily address objectives determined at an eco-region management scale. The method is grounded in landscape ecology and looks to improve existing or proposed highway infrastructure by the evaluation of current and future landscape features. Performed during interstate project development, a multi-disciplinary team can employ system level approaches to design and implement passage systems not only for wildlife but for other uses as well. The integration of stormwater management, scenic vistas, pedestrian trail systems, utilities and wildlife passage can collectively be studied and achieved as a form of ecological infrastructure.

Ideally as part of project development, environmental, sociocultural and engineering studies should be conducted in unison. The following example study addresses how the environmental studies may be executed. A technique for doing such analysis and mapping utilizes habitat convergence theory.

Process for Habitat Convergence Mapping:

One of the most compelling questions associated with the implementation of passage structures is where to locate mitigation measures. Convergence mapping and structure design is landscape architecture for wildlife. The primary objective is to perform a
mapping exercise to determine habitat convergence points that will serve the broadest range of wildlife species for the I-81 expansion project through eastern Montgomery County. The method employed is habitat convergence mapping. The goal is to create an understanding of the geophysical and biophysical complexity of the landscape and how fauna groups use and interact with that landscape. The process for HCM assigns high value to habitat nodes, characterized by habitat sinks in the natural landscape matrix where wildlife can converge. By considering the roadway has infinite possible points to cross, habitat convergence points identify the wildlife movement node or sink that corresponds as an intersection to the roadway footprint. The location of wildlife passage structures is a key decision for achieving objectives. Rather than selecting locations based mainly on road-kill and tracking data (single species approaches), crossing structures are likely to be most effective long term if located to fit overall patterns of the landscape and to coincide with or create effective zones of landscape connectivity. According to Forman (2000), inexpensive structures placed at the right location (optimal habitat for crossing) will likely be more effective than costly structures placed in suboptimal habitat.

Earlier under the process recommendations flowchart, process guidelines were developed for habitat convergence mapping and will be executed in the following mapping exercises.

HCM: Testing and Applying Methods – Part 1
Utilizing satellite imagery and GIS layers:
Objective: Assess Montgomery County remotely to determine potential locations for wildlife passage mitigation.
Method: HCM focusing primarily on landuse and landcover patterns adjacent to interstate footprint.
FIGURE P1-1: Study Area

The arrow indicates the interstate corridor identified previously as having the habitat components to support high mammal diversity. It is clear from the aerial view the relationship between the forested zone and I-81.
FIGURE P1-2: I-81 Corridor through Forested Zone in Montgomery County

The interstate corridor is highlighted. From this perspective, landscape patterns of forest and openland can be delineated.
FIGURE P1-3: Satellite Imagery with Topographic Overlay

The map demonstrates the relationship between extreme topography and landcover. Forested sections have a direct association to major ridges and steep mountain topography.
FIGURE P1-4: Forest Cover and Potential Associated Wildlife Movement Patterns

The green arrows suggest contiguous/undisturbed sections of forest land. It is reasonable to conclude that these vegetation patterns are produces of landuse do to steep topography and will encourage wildlife movement and/or dispersal from a broad perspective.
FIGURE P1-5: Primary Watershed

The major streams are highlighted demonstrating watersheds associated with roadway footprint. Since watercourse are known to be primary routes of movement for wildlife, the stream crossing locations along the roadway will potentially serve as valuable landscape connections.
FIGURE P1-6: Ridgeline Relationships

The orange arrows represent primary ridgelines and their association with watercourses. These major topographic features encourage animal dispersal in a linear direction either by following ridgelines or contours.
FIGURE P1-7: Existing Buildings

A 200 foot buffer is applied to existing buildings to emphasize the developed areas.
FIGURE P1-8: Minimal Development

Areas bound in black represent patterns of minimal development and human infrastructure. Despite the locale comprising entirely of private land, these patterns suggest relationships between landuse and potential valuable undisturbed areas.
FIGURE P1-9: Combination Map

Combining layers begins to suggest potential relationships of landscape features and how wildlife might move or easily disperse through the landscape.
FIGURE P1-10:  Convergence Points

The circular rings suggest areas for potential wildlife mitigation measures. The size of the rings, based on a level of qualitative judgment, indicates a degree of prior or potential future high success.
FIGURE P1-11: Overall Objective

The green graphic reinforces the overall object of maintaining or improving the landscape connectivity across the interstate footprint.
FIGURE P1-12: Large Scale Convergence Points

The points indicate areas to focus site scale investigation measures for wildlife passage. The scale and data layers used are appropriate for a quick assessment at a county level, but offer little in site specific implementation. The next step is to reduce scale and begin to apply convergence theory at a site specific context or utilize more refined data layer information.
HCM: TESTING AND APPLING METHODS – PART 2

Objective: Determine opportunities and constraints along I-81 corridor through Montgomery Co.
Method: Utilizing aerial photography, existing roadway and stream data layers.

Interstate 81 Corridor Analysis, Montgomery Co.

![Map showing different mitigation efforts](image)

FIGURE P2-1: Study Area through Montgomery County

The roadway sections in green have been determined as primary areas for wildlife mitigation focus.
Beginning in the central portion of the county, closer inspection of interstate footprint is performed for areas designated for primary mitigation focus. In order to completely understand the opportunities and constraints for roadway sections, scale must be reduced.
FIGURE P2-3: Opportunities and Constraints

The areas in red represent existing roadway obstructions for wildlife such as median jersey barriers, sound walls and/or cliff areas due to an excessive cut in the topography. The areas in green represent only a four lane roadway with no additional obstruction. The blue arrows represent watercourse crossing locations at roadway footprint.
FIGURE P2-4: Opportunities and Constraints

Refer to the reference key or Figure P2-1 to maintain orientation. Areas in dark gray are excluded due to existing infrastructure crossing the interstate footprint, such as the secondary roadway indicated above.
FIGURE P2-5: Opportunities and Constraints
FIGURE P2-6: Opportunities and Constraints
FIGURE P2-8: Opportunities and Constraints
Conclusion

Utilizing such a method narrows down potential areas for mitigation implementation. It can be assume that roadway expansion will not improve any of the current conditions identified on the existing roadway footprint. However, this method does identify key areas for opportunities as the roadway is expanded. Generally speaking for the context of this study, the criteria for analysis are not limiting enough. Specific areas for wildlife passage have not yet been determined. With an estimated budget constraint of seven million dollars,
it is not likely that passage structures can be implemented in all areas of opportunities previously identified. This notion suggest, limiting areas and developing discriminatory criteria.

HCM: TESTING AND APPLYING METHODS PART 3
Developing treatment options by utilizing USGS Quad Map, aerial photography and roadway survey.
Objective: Perform HCM exercise identifying passage mitigation locations with highest possible long term success.

Process is informed by landscape features, wildlife behavior, existing infrastructure, topography and landuse. Assumes maximum budget of seven million dollars for structures and adjacent land easement or acquisition. By performing a driving survey combine with the knowledge attained through the earlier studies, site specific locations for wildlife passage are determined. Roadway sections corresponding to secondary road systems, obstructive infrastructure or topographic limitations are excluded for potential mitigation treatment. From Christiansburg east to the Montgomery County line, two areas of focus are identified. These sites will be termed Site I and Site II. The objective for each site is to map potential wildlife circulation referenced to the roadway footprint and identify passage structure locations.

FIGURE P3-1: Analysis Map and Site Reconnaissance
Site I Analysis and HCP Mapping

FIGURE P3-2: Site I Analysis
FIGURE P3-3: Site I Analysis with Aerial Photo
For the ridge/valley region, watercourses function to connect watersheds and serve as excellent opportunities for underpass locations due to fill requirements for maintaining roadway elevation. Vegetation regimes and/or matrix inform movement routes for associated wildlife species. Topography encourages animal movement associated with ridgelines bisecting or running parallel to roadway. Considering that watercourses, routes along contour and contiguous ridgelines function as primary movement routes for wildlife and by combining an understanding of landuse and vegetation patterns, site specific passage locations can be determined. By studying the analysis map and making site visits, four locations where determined to offer the best opportunities for mitigation measures.
FIGURE P3-5: Structure Options for Site One.
Propose one overpass and three underpasses for Site I. Notice how each measure fits to accommodate landscape features previously mentioned. Despite being an intuitive exercise, site one exhibits four exceptional locations for passage structures, based on final site visits. It is not reasonable to think that the actual physical location of a passage structure can be determined by only using remote or GIS data layers.

Due to current landuse behavior, the private land adjacent to proposed actions exhibits little human activity. The terrain is quite steep and has little agriculture, forest produce or development value. The acreage adjacent to proposed mitigation locations should be purchased or attained through conservation easement. Even if land acquisition is not attainable, due to the terrain future development affecting passage structure performance is not likely to occur.

Site II analysis and mapping is performed in the same way.
Site II Analysis and HCP Mapping

FIGURE P3-8: Site II Analysis
FIGURE P3-9: Site II Analysis with Roadway Photographs
Site II Analysis and HCP Mapping

FIGURE P3-10: Structure Options for Site II
Propose one overpass and two underpasses for Site II. One underpass location should be combined with pipeline easement to serve dual purposes.
HCM: TESTING AND APPLYING METHODS – CONCLUSION

The desired outcome of HCM methodology is only as good as the available data used in analysis. This highlights the notion of site reconnaissance and the importance of actually seeing the detail to inform mitigation strategies. The remote HCM analysis method is valuable for determining general site locations, however the same landscape features such as topography, vegetation regimes, water courses and landuse, can be applied as a visual exercise upon site visits. An analogy can be applied to game hunting. When a game hunter, enters the hunting grounds an assessment of the landscape determines where he or she will wait or look for game to pass. The way topography, watercourses and vegetation combine to inform where game will be traveling is a similar exercise executed by designers for determining wildlife passage location.

The follow is a list of guidelines to follow while performing HCM studies. These recommendations are derived from performing the latter HCM studies.

All Scales
1. Understanding landuse process at regional scale, county scale and site scale: How does landuse, topography, and species diversity relate.
2. How do we see the landscape? “A Forest” The forester sees timber value, the wildlife biologists sees forest habitat, the arborist sees tree health. This highlights the notion of how different disciplines see objects differently in the landscape. For the context of habitat convergence mapping, it is helpful to view the landscape with bare feet. The mere idea implies that we now feel the landscape under us differently than we are accustomed. Now if you walk from one point to another the decisions of where you might put your feet are different than a train of thought with shoes on. For HCM, this idea demonstrates that it is imperative to understand selected wildlife movement behavior for the sites identified under the eco-region management goals.

County Scale
1. Eliminate areas for mitigation based on high densities of development, likely future development and adjacent roadways along the interstate highway.
2. Determine the most important landscape features for wildlife movement in your area.
   - watercourses – the associated riparian areas
   - landcover makeup – homogeneity vs heterogeneity
   - topography – landcover influences, parallel vs bisecting ridge lines, routes along contour near roadway elevation.
   - Landuse and property boundaries.
3. Balancing human use vs important ecological zones
4. Concentrate effort on sites with high future success
   - potential for development
   - existing infrastructure
   - highway safety concerns
5. For mountainous regions consider design and location for both upland and riparian associated species. Most species utilize both.

Site Scale
1. Map potential wildlife circulation referenced to the roadway footprint. For the ridge/valley region.
   - Watercourses function to connect watersheds and serve as excellent opportunities for underpass locations due to fill requirements for maintaining roadway elevation.
   - Vegetation regimes and/or matrix should inform movement routes for associated wildlife species. Interior verse edge species.
   - Topography influences: Determine opportunities associated with ridgelines bisecting or running parallel to roadway, vegetation regime or landuse associated with topography.
   - Ridgelines, routes along contour and contiguous ridgelines function as primary movement routes for a wide range of species.
   - Combining landuse and vegetation patterns can further inform likely wildlife movement routes.

2. Decide appropriate structure location and general typology based on available budget and convergence mapping.

Question 3: What type of structure and at what frequency?

Combined with the knowledge attained through literature view, HCM analysis and sketch studies, the following general recommendations were developed.

Structure frequency, size, and typology.
- No one-size-fits all solution exists for wildlife crossing structures. Inevitably, species vary in their comfort level with and adjust to different structure types and designs.
- In order to sustain effectiveness, wildlife crossing structures should be built to last long term, accommodating changes in species, their demographics, animal behavior, habitat conditions, and nearby human activities.

1. Determine structure typology by topographic influences at roadway footprint. Over verse under. Due to construction cost associated with overpasses, limiting these measures are crucial and should only correspond to the very best locations for maintaining landscape connectivity. Such as areas corresponding to primary ridgelines/corridors or topography corresponding to major mountain ranges.

2. Frequency should be maximized in mitigation zones identified at the County level. Distance between structures will correspond to key convergence areas. Recommend distance between structures should at a minimum equal to distances associated with sub-watersheds crossing roadway footprint. This maximizes opportunities for dual purpose mitigation where stormwater systems can function as wildlife passage.

3. Size of structure should correlate to desired species use. Deer and other large fauna in the region will require an openness ratio of at least 0.9. Bigger is better, however with budget limitations, increased frequency of structures will improve overall roadway permeability for general wildlife species.
Section III
Wildlife Passage Structure Sketch Studies

The following structure design and sketch studies are performed as part of the design process. There are many unanswered questions about structure typology and achievable performance. To gain an understanding of how structures might be improve from existing paradigms, it is crucial to critique current structure typologies in use as well as build an understanding of structure characteristics in section, plan and profile.

The following figures 6-1 thorough 6-4, are sketches that represent typical examples of existing passage mitigation measures currently in use. When considering structure design and intent, many questions arise. What improvements can be made? How and what aesthetic is revealed to the motorist? How is animal behavior incorporated into design? How can the surrounding landscape improve structure performance? At what point does a passage structure become an actual landscape connector verses looking and functioning like a “livestock fencing measure?” These are but a few questions relating to current passage structure design. The sketch exercise begins to speak to improving passage structure design and performance.
The structure is not located to complement surrounding topography. The arch, a product of engineering for positive drainage and ease of construction, doesn’t allow passing wildlife to see across the structure as they approach. The structure surface comprises of a natural substrate at a fairly uniform depth. Vegetation such as heat tolerant grasses and shrubs are planted randomly, requiring at a minimum seasonal maintenance.
FIGURE 3-2: Bridged Roadway Underpass

Single-span roadway bridges are excellent alternatives to culverts which require massive filling of a swale or gulch. Natural vegetation and substrate is maintained underneath. This is characteristic of western stream crossings that deal easily with highly variable seasonal stream flows and washing debris. The drawback is this application is much more expensive than conventional culvert crossings.

Concrete underpasses are widely used in the Southeastern States, particularly in areas with high densities of black bear. Their appearance is characterized by massive amounts of fencing with little or no vegetation associated with the structure. The typical height is approximately 6’ with entrance widths varying from 15’ to 40’. This livestock fencing look doesn’t complement the natural surrounding where these structures are found.

FIGURE 3-3: Box Culvert Underpass
If large animals get trapped within the interior of fencing, it is crucial that escape routes are provided. The one-way gate and earth ramp are two solutions for escape measures. It relies on an animal’s natural response to flee and run along straight sections of fencing. Research has shown that earth ramps are more frequently used by deer and antelope in the western states (Jacobson 2002.) Animals respond to the earth ramps because they function and appear more like natural features in the landscape.

**Fencing: A serious dilemma!** What height is appropriate? At what aesthetic cost? At what monetary expense? Probably cannot be eliminated, but can size and use be reduced?

Typically to exclude deer and bear from entering the roadway, 8’ height fencing is the standard. This application is very expensive to build and maintain. If passage systems are better located where landscape features suggest, then potentially the need from massive fencing systems can be reduced. In addition, personal experience suggests that an 8’ fence is not necessary. Deer and other larger mammals will not jump a fence if they cannot see through it. The average deer head height is only about 3.5’. Deer prefer to jump obstructions only if they absolutely have to. For example, I have seen deer walk a few hundred yards out of their way to walk through an open gap on a 4’ height fence to reach a corn field. I am suggesting that a fence height of 5’ will probably divert deer
movement as well as an 8’ fence, particularly if the deer cannot easily see through it. In addition, if a bear wants to climb a fence regardless of height, they will. Using lower fence heights will have less of a visual impact on the landscape and minimize the need for designing elaborate escape routes. Visual impact can be further reduced by utilizing materials that blend into the landscape as well as incorporating natural landform and vegetation buffers.

**About Roadways and Design Elements**

![Typical Roadway Sections](image)

**FIGURE 3-5: Typical Roadway Sections and Roadway Conditions in Plan**

Twinned roadways can take on many forms in section and profile. Often these roadways are subject to the constraints of topography. It is important to understand how the surrounding landscape can inform the integration of passage systems.
FIGURE 3-6: Bridge Profiles for Wildlife Overpasses
FIGURE 3-7: Overpass Structures in Profile

FIGURE 3-8: Overpass Structures in Plan
FIGURE 3-9: Questions about Overpass Profile

- **How thickness of overpass be reduced?**
  - Make multi-span, increase posts no.
  - Use material that allows for thin profile.

- **What are benefits associated within profile?**
  - Less obtuse.
  - Visual impact, less visual infrastructure.
  - No difference for wildlife.
  - Perception of extending organic layers over.

- **What is surface substrate?**
  - Rock, increased drainage, but lacks organic material.
  - Soil, highly erodable, provides nutrients for vegetation.
  - Concrete, long life span, lacks organic material.
  - Combination, allows plant material to grow in specific location.
  - Effective drainage.
  - Lowers maintenance.
OVERPASS CROSS SECTION STUDY

- Any concave section will block view of roadway below.
- Will increase comfort level for crossing wildlife.

FIGURE 3-10: Overpass Cross Section Study
FIGURE 3-11: Designing the “Thin” Overpass
The parabolic structure in plan as well as profile suggests a true connection to the landscape versus an obtuse cubic structure. Combined with appropriate vegetation, material aesthetic and thin profile, the structure can demonstrate a revelatory experience to the motorist by extending the perception of a continued organic landscape. An overpass structure should do more than just direct animal
passage but rather serve as a reminder of connecting ecological process. The phenomena is celebrated at such structure junctions, conveying an environmentally sound roadway design.

![Typical Overpass Cross Section Diagram](image)

FIGURE 3-13: Overpass Section with Planter Box

Landform or margin planter boxes can further enhance the wildlife's perception to cross by blocking and/or directing the animal's line of site. The planter box allows for planting of wood stem vegetation in available growing spaces, but eliminates interior maintenance needs such as mowing. The area between the planter boxes should be made up of a thin sandy soil substrate preventing the growth of woody stem plants yet encouraging the growth of drought tolerant grasses.
FIGURE 3-14: Overpass Landform Study

- Having a slight crown across the overpass allows for a natural transition to existing topography.
- Exposes wildlife to disruptive traffic.
- Promotes wildlife to enter structure.
- Elevated viewing point across structure.
Conclude that a parabolic shaped overpass with a concave deck is ideal for wildlife passage. The shape allows animals to see across the structure as well as encourages the sensation of a threshold at the center or mid-point of the structure. The parabolic shape combined with landform extending from existing topography enhances the funnel affect to draw wildlife across. In addition, overall structural material use is reduced, compared to a cubic structure, while not lowering the performance.
FIGURE 3-16: Underpass Structure Study
FIGURE 3-17: Underpass Structure Study

- For underpass culvert systems, minimum openness ratio ≥ 0.9
- How to reduce length?
- How to increase natural light?
- How to increase perception of openness?

EQUAL LIGHT PENETRATION
LESS MATERIAL USE
FIGURE 3-18: Underpass Roadway Study

- Total culvert length reduced for joined roadway.
- Less light penetration for joined roadway.
- Split roadway uses more culvert material.
- Split roadway allows for smaller culverts due to reduce individual culvert lengths & openness ratio.
FIGURE 3-19: Topographic Opportunities
Conclude that underpasses, typically made from modified precast concrete culvert systems, are very cost effective ways to increase roadway permeability. Shapes can vary considerably from box to arch to round structures. Research indicates that overhead shape is not that crucial to wildlife. However, openness ratio and bottom substrate are critical design considerations for wildlife. For wildlife in the region, an openness ratio of 1.0 is sufficient. A dry bottom substrate is required for many species, which can be achieved by incorporating a channel in the floor of the structure or by simply eliminating the floor to form a “bottomless culvert.” A major consideration for prey species is the amount of ambient light allowed to enter the underpass structure. This can be maximized by flaring the opening towards the ends of the structure. The approach should be enhanced with the appropriate use of vegetation to create a funneling yet secure environment.

Wildlife Passage Schematic Designs

The following design schematics are modeled to fit in Site I of the I-81 Study. Drawing from sketch study conclusions, the parabolic and underpass structure represent ideal typologies that could be incorporated in the study area.
FIGURE 3-21: Parabolic Passage Structure
FIGURE 3-22: Parabolic Overpass

Located where the roadway footprint is characterized by cutting through topography, the intent of parabolic overpass is to facilitate mobile wildlife across the projected six land interstate at the strategic location in Site I. The main ridgelines as bisecting with the roadway, offer the best opportunities based on habitat convergence phenomena. The overpass structure is considered a minimal size, but the shape along with evergreen screening combines to offer the most benefit within the practical limits of cost engineering. By narrowing at the center, calculable loads are reduced further narrowing the center profile and reducing material usage. The hourglass shape further encourages wildlife to pass by focusing the transition space at the center of the overpass verses at the entrances. By adjusting landform combined with appropriate vegetation, site lines are directed and wildlife are encouraged to cross. The profile suggests that the landscape continues without interference from the roadway cut, which ultimately informs motorists of actions. In order for structures to suggest a revelatory experience, it is key that structural form and material use remains consistent throughout implementation and differ from those forms regularly experience by overhead roadway crossings.
FIGURE 3-23: Box Culvert with Graduated Ends
FIGURE 3-24: Box Culvert with Graduated Ends

The structure represents a method for maximizing benefits at an economical cost, to be installed along watercourses or at upland locations that require a section of filling to construct the roadway. The recommended underpass represents the minimum threshold size for such a structure to be used for all fauna groups present in the region. The structure meets the minimum openness ratio, but has additional feature to improve performance. The canalled floor, graduated ends, and sky lit center, address factors influencing wildlife behaviors, visual and auditory senses. Vegetation planted along structure openings further disrupts the view of traffic for wildlife, but also serves as a consistent planting pallette to unify structure intent for passing motorist.

To address the suggestions developed during the underpass schematic design, 3-D models were created. 3-D modeling serves as an exceptional tool to attain deeper understanding of design considerations.
FIGURE 3-25: Box Culvert Underpass with Graduated Ends

The object of the graduated end is to reduce material use costs and encourage entry, yet maintain performance compared to larger underpasses. The interior portion of the structure has a sufficient openness ratio of 2.5. The graduated ends allow wildlife to approach, hidden from passing motorist. In addition the graduated ends function as noise barriers from passing vehicles. Combined with approach fencing, the entrance allows for ample amounts of ambient light to enter and should usher sensitive wildlife under the roadway. However, I do question whether or not some wildlife may be sensitive to the obtuse/concrete opening. The graduated ends may give the sensation of a chamber closing down around approaching wildlife.

Conclusion

Given the incredible feats of transportation engineering over the years, collaborative partnerships between designers, biologists, and engineers should serve as the source for finding practical design solutions to wildlife passage as a form ecological infrastructure. The most effective mitigation measures need not be the most expensive nor the most difficult to achieve. Developing eco-region management objectives, executed under a wildlife passage framework model should serve as a foundation for planning and design. Applying landscape ecology theories and performing habitat convergence mapping is key for determine structure locations. While wildlife crossings are not a universal remedy, they can go a long way toward restoring connectivity where roadways have fragmented the landscape.
SECTION IV

Closing

For the last century, automobiles and the roads they require have been the dominant force shaping the modern American landscape. There are more cars per capita in the United States than in any other nation in the world (White, P.A. and M. Ernst 2003). An unrivaled interstate highway system connects major metropolitan areas and is the basis of our transportation infrastructure. Unfortunately, many roadways were not planned or designed with wildlife in mind.

Transportation development in the United States creates great challenges for wildlife resources. The need for humans to have access and mobility has resulted in a national roadway system of more than 4 million miles traversing our diverse landscape and impacting many natural systems (Cook and Daggett 1995). While roadways are important to humans, they can drastically affect the movement of wildlife. As long linear features in the landscape, interstates can function as landscape barriers and have impacts on wildlife habitats that are disproportionate to the area of land that they occupy. The resulting impacts are characterized by the animal-vehicular collisions, the loss of habitat, limited mobility and species isolation.

Viewing this issue from a landscape ecology perspective, it is clear that highways have the potential to undermine social and ecological process through the fragmentation of the landscape. Landscape connectivity or habitat connectivity is often very important for maintaining ecological systems. Without landscape connectivity, wildlife populations as well as other ecological and cultural resources can be segregated.

As we embark into the next millennium, it is paramount that transportation planners have the tools necessary to begin to address the effects posed on wildlife resources and landscape connectivity. A method for addressing the conflict between highway systems and wildlife resources is by incorporating ecological design theory into roadway design. Ecological theory looks to inform human actions by solving environmental issues related to the interactions between organisms and their environment. The challenge is to build ecologically based transportation systems and infrastructure that does not permanently fragment the natural systems that support wildlife populations.

One solution for maintaining connectivity across interstate highways is the implementation of animal passage systems in the form of over or underpasses. Researchers have proven their effectiveness for facilitating wildlife across interstate highways in many locations. While wildlife crossings are not a universal remedy, they can go a long way toward restoring connectivity where roads have fragmented habitat. However, in many cases passage systems have fallen short in addressing broad wildlife diversity, efficient planning integration, and offer little in cultural significance.
Through system level approaches and analysis applied within an eco-region context, we can begin to identify practical and reasonable solutions, develop design guidelines for a wide range of species and purposes, and promote landscape connectivity not only for wildlife but rather for the entire roadway system as a form of ecological infrastructure. A framework to serve as a tool for addressing transportation planning, design, operation and maintenance is essential for the success of such measures. Utilizing approaches such as habitat convergence mapping will enable transportation planning to determine critical passage structure locations when baseline wildlife research information is lacking. The process will require landscape level analysis, structure typology design and implementation on future planned interstate or retrofit projects. As a collaborative effort among professional, we can work towards improving interstate highway designs, and retain the relationships occurring within landscape connectivity, promote better understanding, safety and support within the transportation community.

The current I-81 expansion project offers an exceptional opportunity to reassess the short coming to the existing interstate infrastructure in terms of landscape connectivity, wildlife resources and public safety, and demonstrate how system level design can give our roadways new shape and form.

Despite existing structure typologies, design of wildlife crossings that look to improve performance and are practical for use in the transportation systems should be explored. Biologists need to establish the performance standards for such structures based on the characteristics and needs of wildlife. The assistance of designers is needed to provide the technical solutions so that crossing structures more effectively meet the standards identified by biologists. Given the incredible feats of transportation engineering over the years, collaborative partnerships between designers, biologists, and engineers should serve as the source for developing practical solutions.

Although positive actions are occurring, they are happening slowly. By broadening our view of environmental responsibility, the proactive transportation community can reassess the design of our most significant infrastructure undertaking, our interstate roadway system. Rather than reacting to legal imperatives, creative actions that address roadway infrastructure not as an obligation but rather as an opportunity will serve our Nation's wildlife and cultural resources in the future.
Cited References:


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