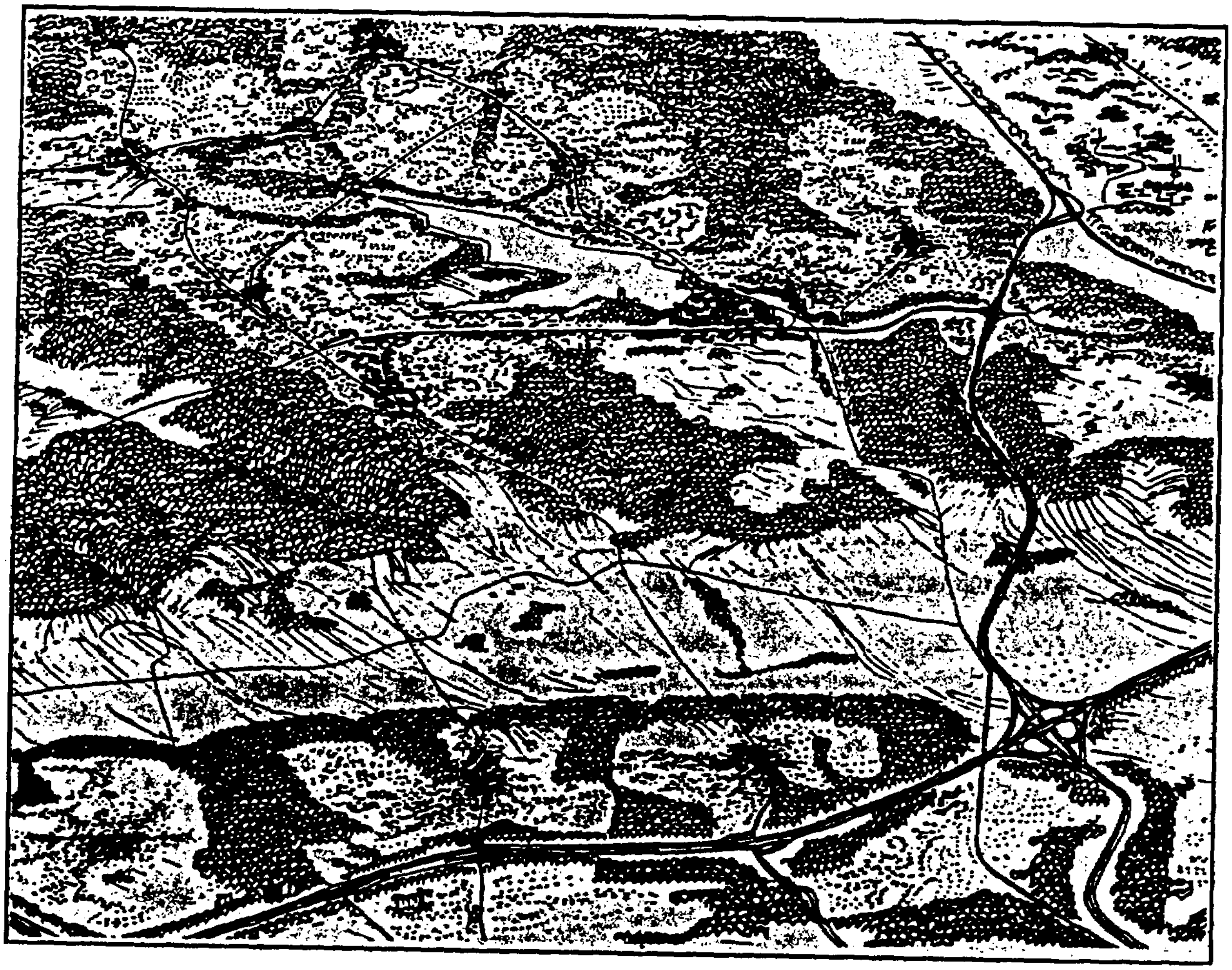
United States
Environmental Protection
Agency

Office Of
Federal Activities
(2252)

EPA 300-B-94-006
April 1994

EPA

Evaluation Of Ecological Impacts From Highway Development



EVALUATION OF ECOLOGICAL IMPACTS FROM HIGHWAY DEVELOPMENT

April 1994

U.S. Environmental Protection Agency
Office of Federal Activities
401 M Street, SW
Washington, DC 20460

EVALUATION OF ECOLOGICAL IMPACTS FROM HIGHWAY DEVELOPMENT

EPA Contract No. 68-C0-0070
Work Assignment 2-06

April 1994

Submitted to:

Jim Serfis
U.S. Environmental Protection Agency
Office of Federal Activities
401 M Street, SW
Washington, DC 20460

Submitted by:

Mark Southerland*
Dynamac Corporation
The Dynamac Building
2275 Research Boulevard
Rockville, MD 20850

*Present address:
Versar, Inc.
9200 Rumsey Road
Columbia, MD 21045

CONTENTS

Table of Tables

Table of Figures

1. Introduction

The purpose of this report is to provide guidance for the analysis of ecological impacts from highway development activities and the evaluation of related ecosystem mitigation measures. This guidance will support NEPA reviewers in providing informed comments for project scoping, EIS review, and 309 analyses regarding the issue of ecological degradation resulting from highway development and similar activities. It is hoped that this report will also be used by the Federal Highways Administration (FHWA) and other federal agencies that do not have land management responsibilities as they consider ecological issues in environmental analyses. Where appropriate, EPA program offices may want to support FHWA and other federal agencies in assessing the environmental risks of their proposed actions and in developing mitigations for these impacts.

This report builds on the guidance provided by the earlier EPA report, *Habitat Evaluation: Guidance for the Review of Environmental Impact Assessment Documents*, and provides specific information on the ecological impacts associated with highway development. A primary focus of this report are the potential mitigations that may implemented during highway planning, design, construction, and operation. Many of the degrading activities and accompanying ecological impacts associated with highway development are also relevant to other construction-based projects such as power generation and industrial or residential development. By providing detailed guidance on both ecological analysis and mitigation, this report should improve the environmental impact assessments for a wide range of development activities.

1.1 Definition of Ecological Impacts

The evaluation of ecological impacts has traditionally been limited to the consideration of individual species, their immediate habitats, and general natural resource categories such as water and air quality. Although this approach has afforded some protection to individual species and their ecosystems, it is inadequate for regional or global biodiversity protection efforts. The need to address the conditions of a wide range of species, and biological diversity in general, requires an ecological approach to analysis that focuses on ecosystems. Therefore, this document defines ecological impacts as any and all changes in the structure and function of ecosystems.

> Ecosystem — a natural environment composed of both living organisms and physical components that function together as an ecological unit.

Ecosystems provide substantial ecological values and services such as fish and wildlife populations, nutrient cycling, water purification, and climate control. All natural areas contain definable units that can be called ecosystems. In general, the natural condition of an environment is preferred because it represents a system that through evolution is most likely to provide the desired values of biological diversity and ecosystem functioning. However, in some cases, managed environments may be needed to promote desired resources, or because natural processes have been altered. An important component of the ecosystem approach to preserving biodiversity and ecological values is the designation of certain ecosystems, or habitats, as "of special concern." For the purpose of this document, ecosystems of concern are defined as those sensitive environments whose degradation or loss results in significant diminution of regional biodiversity (see Council on Environmental Quality 1993). The condition of these ecosystems can be evaluated in terms of both structure and function and should reflect holistic measures of ecosystem health or ecological integrity (see Costanza et al. 1992).

While ecosystem are often classified by broad vegetation-based categories, each ecosystem is unique and must be evaluated in the context of its specific geographic location. At the same time, alteration of an ecosystem by degrading activities must be considered in terms of the impact on the entire landscape. Therefore, an ecosystem perspective is essential for the adequate consideration of ecological impacts. This approach requires that the interactions of ecological components be considered, and that the unique characteristics of each ecosystem be evaluated.

The Council on Environmental Quality (1993) report, *Incorporating Biodiversity Considerations Into Environmental Impact Analysis Under the National Environmental Policy Act*, recommends an ecosystem approach to biodiversity conservation. Therefore, the approach and methods described in this report are consistent with the increased emphasis being placed on preserving biodiversity. As evidenced by the reports of the Office of Technology Assessment (U.S. Congress, OTA 1987) and the National Academy of Sciences (Wilson 1988), awareness of the immense social and intrinsic values of biodiversity has increased greatly in recent years. The diversity of species and genetic strains provides a pool of critically important resources for potential use in agriculture, medicine, and industry; the loss of wild plant and animal species that have not been tested, or in some cases not yet described, would deprive society of these potentials. Access to genetic resources contributes about $1 billion annually to U.S. agriculture through development of improved crops. Livestock and other sources of protein benefit from this access as well. About 25 percent of our prescription drugs are derived from plant materials, and many more are based on models of natural compounds. Native species themselves are essential as foodstuffs and are valuable as commodities such as wood and paper. Marine biodiversity, in particular, plays a major role in meeting the protein needs of the world. At the ecosystem level, biodiversity is essential to the continued provision of important ecological services, such as regulation of hydrologic cycles, carbon and nutrient cycling, soil fertility, and commercially and recreationally important fish and wildlife populations.

1.2 Report Format

The following sections of this report present the specific approaches and methods required for adequate evaluation of ecological impacts from highway development. Section 2 illustrates how the evaluation of ecological impacts meets existing requirements for integrated NEPA analyses. Section 3 discusses the many specific impacts to ecosystems that result from highway development activities. Section 4 provides the basic framework for addressing ecosystem conservation through evaluation of highway impacts. Section 5 presents specific methods for evaluating these impacts, including identifying possible ecosystem assessment endpoints. Section 6 follows with specific mitigation measures that may be applied to address the impacts to these endpoints. Finally, Section 7 provides a summary table of mitigations for highway impacts in different settings. A bibliography is included as Section 8.

2. The Need for Ecological Analysis in Highway Projects

Traditionally, NEPA analyses of ecological resources have emphasized threatened and endangered (and certain commercially important) species, wetlands (and other sensitive aquatic habitats), and protected areas (such as parks and refuges). As the understanding of ecosystem functioning has increased, more comprehensive and sophisticated ecological analyses are possible. The recent Council on Environmental Quality (CEQ) report (1993), *Incorporating Biodiversity Considerations into Environmental Impact Analysis Under the National Environmental Policy Act,* illustrates the increased level of analysis that is now expected from environmental impact assessments. Improved ecological analysis is also the goal of continuing efforts to strengthen the integration of NEPA considerations with other environmental assessment activities (Bausch 1991). Efforts to develop methods for cumulative effects analysis have also been ongoing, and they are expected to culminate in publication of a practitioner's handbook by the end of 1993 (Ray Clark, CEQ, personal communication).

2.1 NEPA Mandate

Section 102(2) of NEPA requires a systematic, interdisciplinary approach that integrates science and environmental design into the decision-making process. In addition, CEQ regulations require integrating NEPA requirements with other environmental review and consultation requirements. Both of these provisions are designed to meet the basic objective of NEPA which is—to integrate environmental quality objectives comprehensively into planning. The ecosystem approach, as embodied in this report, provides the framework for a truly integrated assessment of environmental objectives. Because it requires consideration of the interactions among the full range of ecological resources and focuses on the integrity and functioning of the landscape or regional ecosystem, the ecosystem approach is ideal for integrated NEPA assessments.

2.2 Federal Highway Administration Mandate

There are nearly 4 million miles of roads in the United States. Such a complex system has the potential to alter the natural environment in a myriad different ways, and includes the potential for large cumulative and secondary impacts. The NEPA process offers federal and state highway authorities a unique tool for considering the full range of environmental impacts from highway development.

The FHWA has recognized the importance of environmental assessment in its Environmental Policy Statement (EPS) of 1990, establishing policy to avoid, minimize, and mitigate adverse environmental impacts. The statement gives the environment full consideration along with engineering, social, and economic factors in project decisionmaking and stresses the need to fully integrate environmental considerations into agency policies and procedures. Of particular concern to FHWA is the requirement to consider the possibility of secondary and cumulative impacts of agency actions. Cumulative impacts are defined in 40 CFR 1508.7 (1978) as "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions." To achieve the balanced consideration of these and other impacts, environmental concerns must be addressed in the early stages of planning and throughout project development. The ecosystem approach provides a means of identifying the entire complement of resources and interactions that must be understood to adequately consider cumulative and indirect impacts.

This is especially important when the affected environment is largely undisturbed, while in human-altered systems a targeted resource approach may be equally valid.

This emphasis on integrated assessment of environmental impacts from highway development is also contained in the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA). ISTEA (U.S. Congress 1991) states that

> "It is the policy of the United States to develop a National Intermodal Transportation System that is economically efficient, [and] environmentally sound...

and that

> "... Social benefits must be considered with particular attention to the external benefits of reduced air pollution, reduced traffic congestion and other aspects of the quality of life in the United States."

ISTEA also contains provisions requiring FHWA to work with State highway agencies as never before to preserve and enhance environmental resources while implementing transportation programs. Specifically States are required to "... undertake a continuous transportation planning process... " which includes statewide and metropolitan plans (including long-range plans) consistent with existing plans under the Clean Air Act and Clean Water Act, that consider the

> "... overall social, economic, energy, and environmental effects of transportation decisions."

Projects related to ecosystem conservation that are eligible for federal funding under either the National Highway System or the Surface Transportation Program include the following (emphasis added):

> "... participation in <u>wetlands mitigation efforts</u> related to projects funded under this title, which may include participation in wetlands mitigation banks; contribution to statewide and regional efforts to conserve, restore, enhance and create wetlands; and development of statewide and regional wetlands conservation and mitigation plans, including any such banks, efforts, and plans authorized pursuant to the Water Resources Development Act of 1990 (including crediting provisions)...

> "... Construction, reconstruction, rehabilitation, resurfacing, restoration, and operational improvements for highways (including bridges on public roads of all functional classifications), including ... <u>mitigation of damage to wildlife habitat, and ecosystems</u> caused by a transportation project funded under this title...

> "... Highway and transit safety improvements and programs, hazard eliminations, projects <u>to mitigate hazards caused by wildlife</u>, and railway-highway grade crossings."

Implementation of such wildlife and ecosystem mitigation measures, as well as upfront, areawide planning, can be facilitated by incorporation of an ecosystem approach into the environmental documentation process for highways. For example, the concepts of corridor preservation and integrated land use planning are best conducted in the framework of ecosystem analysis and management. In many cases, a regional ecosystem approach can help unite transportation planning with the land use and resource management planning process of local and regional communities. The next section discusses the relationship between ecosystem protection goals and the existing FHWA environmental documentation process.

2.3 Relation of Ecosystem Protection Goals to FHWA Guidance

As discussed previously, the FHWA has already developed substantial guidance on the evaluation of effects on natural resources, including cumulative and secondary impacts. In highly urbanized and other disturbed environments, existing environmental documentation activities are adequate for assessing impacts from highway development. However, federal highway assessments involving largely undisturbed natural environments could be improved by placing them in the framework of an ecosystem approach. An ecosystem approach entails application of principles of ecosystem protection (i.e., biodiversity conservation) as described by CEQ (1993). The following six principles of ecosystem protection are already implicit in many of FHWA requirements and policies, and their explicit incorporation in environmental documentation can strengthen highway assessments:

- Evaluate within a regional context. The "logical termini" provision in FHWA regulations and guidance is designed to prevent segmentation of projects and requires the use of a "rational endpoint for review of environmental impacts". This provision requires that an individual highway project cannot be used to force improvements in other highway sections. Application of a regional analysis of highway development, one that considers both the functional utility of the highway and the effects on the larger ecosystem, can help ensure that the best logical termini are chosen. At the same time, use of a regional context for assessment can greatly facilitate the consultation process with other agencies and involved parties. By addressing development within a region, other planning and management activities are more easily incorporated. Incorporation of these plans is a goal of the 1992 FHWA guidance on secondary and cumulative impacts.

- Preserve sensitive communities and ecosystems. FHWA regulations (40 CFR 1502.15) state that the affected environment includes "environmentally sensitive features". Consideration of the variety of different habitat types is essential to protecting the larger ecosystem. Usually, natural resource cooperators are required to point out habitats of concern other than wetlands. An inventory of ecosystem (habitat) types should be conducted earlier in the planning process. This inventory would also serve to identify Section 4(f) lands (i.e., public parks, recreation areas, and wildlife and waterfowl refuges with national, state, or local significance), as required by FHWA regulations.

- Maintain natural habitat structure and ecosystem processes. The 1992 FHWA guidance on cumulative and secondary impacts stresses the need to consider indirect effects, such as those on ecosystem processes. An ecosystem approach that applies strong ecological expertise is the best means of evaluating indirect effects among ecosystem components. Application of an ecosystem perspective can also help identify important indirect effects such as the impact of exotic species.

- Protect rare or ecologically important species. Again, consideration of "environmentally sensitive features" under FHWA regulations requires that assessment extend beyond the traditional categories of listed endangered (and threatened) species and game species to include rare and "keystone" (ecologically important) species. An ecosystem approach would include consideration of the full complement of species in an ecosystem, and would coordinate their protection with the preservation of sensitive habitat types.

- Minimize fragmentation. Adequate consideration of cumulative and secondary impacts as described in the 1992 FHWA guidance necessitates evaluation of effects on habitat connectivity. Changes in the landscape pattern of habitats often result from the cumulative effects of construction projects. By applying an ecosystem approach within a regional perspective, an analysis of both habitat connectivity and habitat pattern can be used to evaluate the impacts of habitat fragmentation.

- Restoration and monitoring. In other than strictly urban settings, highway development will always have impacts. Therefore, the FHWA requirement that projects "minimize adverse effects" virtually ensures the need for mitigation. An ecosystem approach to mitigation could be used to extend existing FHWA methods for creating lost wetland functions to other habitat types. By assessing the contribution of each habitat to the larger ecosystem, ecosystem analysis could identify restoration opportunities for biodiversity conservation, e.g., using highway corridors as preserves for rare plant communities. An ecosystem perspective could also form the basis for mitigation monitoring by focusing restoration of ecosystem functions. It may be possible to adapt routine maintenance of highways to include monitoring of ecosystem impacts with the possibility of modifying the mitigations as necessary.

3. Impacts of Highways on Ecosystems

The construction of highways can have a substantial impact on the degradation and loss of natural ecosystems, especially in less developed areas. Although the actual areas converted by highways, railways, and power line right-of-ways may cover only a small proportion of a region, these areas total 27 million ac nationwide. Perhaps more importantly, the fragmentation of habitats caused by highway development is often severe (Frey and Hexem 1985). Transportation routes can be described as "disturbance corridors" that disrupt the natural, more homogeneous landscape (Barrett and Bohlen 1991). In forested environments, these disturbances can cause (1) dramatic physical disruption to the continuous vegetative community; (2) disruption to the structure and function of habitat; and (3) impacts to resident wildlife, which must negotiate, tolerate, and cope with the habitat barriers. In addition, disturbance corridors created by forest fragmentation alter the natural mix of habitats and species by providing conditions suitable for early successional plants and animals. They replace forest trees with grasses and shrubs, eliminating nesting habitat for forest-interior species. While they provide dispersal routes for certain small mammals, they present barriers to many species.

The scale of both the habitat conversion and habitat fragmentation effects caused by highway development varies with the size of the project. The impacts of projects also vary according to the environmental setting, especially the degree of naturalness in the local and regional ecosystems. In many cases, small individual highway projects may have little or no impact on natural ecosystems. In other cases, large projects can have dramatic impacts on wildland areas (areas that are largely undisturbed by human activity). Evaluations based on only a few species or resources may be adequate for small projects. However, it is important to consider the contribution of small projects to the cumulative impacts on the region. Although individual road segments may cause only minor environmental impact, the combined effect of the entire highway system may seriously degrade the natural environment. In the same way, the cumulative impact of several highway systems can seriously affect entire regions, disrupting migratory pathways and other ecosystem processes. These effects may be augmented, or even overwhelmed, by secondary development, i.e., the land conversions to industrial or residential use that usually accompany road building.

3.1 Highway Development Activities

Highway development consists of four phases of activities: planning, design, construction, and operation. Each of these phases involve a number of specific actions that vary with each highway development project. As described in the introduction, an ecosystem is defined to include all the relevant natural resources affected by highway development projects. These include air quality, water quality, wildlife, wetlands, and all other types of natural communities. The planning and design phases of highway development determine which ecosystems will be affected, while the construction practices and operation and maintenance procedures actually cause the ecosystem impacts.

3.1.1 Planning Phase

The planning phase involves all pre-design activities including the siting of the highway corridor. Planning proceeds from the purpose and need for the project and includes consideration of all various transportation options, potential locations, and possible basic designs. In essence, this phase determines the locations (and sensitive habitats) to be affected by selecting the corridor route. Selection of the highway type and basic configuration and number of interchanges also contributes to identifying the ecosystems to be affected. Both direct destruction of ecosystems and potential degradation based on proximity are determined in this phase.

3.1.2 Design Phase

The design phase involves the siting of the final right-of-way footprint and all aspects of structural design and within design mitigations. By selecting such highway parameters as width, slope, and type of crossing structures (e.g., bridges), this phase actually determines the specific potential impacts on adjacent and nearby ecosystems. While planning determines the general areas where habitat will be destroyed or degraded (areas within the highway corridor), design decides which specific locations will be affected or avoided. For this reason, small-scale mitigations are most important in the design phase.

3.1.3 Construction Phase

The construction phase involves the vegetation removal, earth moving, and road building activities that actually impact sensitive habitats. Although the habitats to be affected and the types of impacts are already determined by the preceding phases and the basic requirement of highway construction, the specific operation of construction activities may determine the severity of impacts such as erosion and disturbance. While vegetation removal is inherent within the roadway footprint, excessive vegetation clearing can be eliminated. In addition to physical destruction of habitat within the footprint, soil erosion and other forms of pollution are the primary impacts in this phase. Mitigations involving both the timing and performance of these activities can dramatically reduce these latter adverse impacts.

3.1.4 Operation and Maintenance Phase

The operation and maintenance phase includes all post-construction activities associated with the built project, including routine vehicle traffic and roadway maintenance, as well as accidents and spills. Routine maintenance activities include the following (Krame et al. 1985):

- Roadway paving and patching.
- Roadside blading and litter collection.
- Vegetation management (including mowing, chemical control, planting, seeding, and fertilizing).
- Cleaning, painting, and repair of roadside structures, including curbs, drains, guardrails, and signs.
- Street cleaning, snow removal, lighting, abrasives, and pavement marking.
- Equipment cleaning and hazardous material handling and storage.

Although similar in nature to construction impacts, the pollution effects of this phase are long term. Best management practices are the principal mitigation measures for these impacts.

3.2 Types of Impact to Ecosystems

A completed highway project necessarily includes impacts from all of the phases described above. Generically, highway development can be said to affect ecosystems, and their values and functions, through the following stressor processes:

- Alteration of topography.
- Vegetation removal.
- Erosion, sedimentation, and soil compaction.
- Dehydration and inundation.
- Acidification, salinization, and warming.
- Contaminant toxicity.
- Noise and visual disturbance.
- Introduction of exotic species.
- Direct mortality from road kills.

These stressor processes can result in the following effects on ecosystems:

- Direct mortality of resident species.
- Physiological stress and decreased reproduction.
- Disruption of normal behavior and activities.
- Segmentation of interbreeding populations.
- Modified species interactions and alien species invasions.

Although highway development shares these effects with other human activities that degrade the natural environment, highways (as well as powerline rights-of-way and other transportation routes) have unique impacts associated with their linear form. Within forested landscapes, highways act as concave corridors, areas that exhibit lower vegetation heights than the surrounding habitat matrix (Gates 1991). In agricultural and some rangeland landscapes where dense vegetation is encouraged along the roadsides, highways may act as convex corridors. These highway corridors may function as (1) specialized habitats, (2) conduits of movement, (3) barriers or filters to movement, or (4) sources of effects on the surrounding habitats (modified from Forman and Godron 1986). Exactly how the corridor will function depends on the condition of the larger landscape, not simply the habitat adjacent to the corridor. For example, a highway corridor in a forested landscape will function differently than a corridor bordered by forest, but which exists within a landscape dominated by agricultural land. Highway development is also unique in its facilitation of secondary development.

The direct, indirect, and cumulative impacts of highway development can be grouped into three general categories:

1. **Destruction** of habitat (resulting in the elimination of certain habitat types and their replacement with non-natural uses or with specialized semi-natural habitats).

2. **Fragmentation** of habitat (resulting in the loss of habitat integrity through the creation of barriers to species and ecological processes).

3. **Degradation** of habitat (resulting in the loss of habitat integrity through disturbance of resident species, contamination with pollutants, alteration of natural processes, and introduction of exotic species).

3.2.1 Destruction of Habitats

The most direct effect of highway development on ecosystems is the destruction of a natural habitat through its "conversion" to a transportation land use or "right-of-way". Although natural vegetation may be preserved within the right-of-way, the original natural characteristics of the land are eliminated within the paved area and adjacent roadsides. The clearing of vegetation (trees, shrubs, grasses) and accompanying leveling operations (that destroy the original topography and soil profile) are the principal changes. In some cases, the natural vegetation may be replanted while in others different species are planted and the habitat values modified. In wetland environments, road construction may require filling and draining operations that destroy wetland habitats. In aquatic environments, flow alteration (via damming or channelization) may eliminate habitat. Dredging, filling, and draining required by road construction also destroy aquatic habitat.

The conversion of forested land to a highway right-of-way entails replacement of natural habitat along the roadway with grassy or shrubby vegetation. These early successional areas provide additional habitat for species such as Brewer's and red-winged blackbirds (Adams and Geis 1981). These and other birds are likely attracted to suitable nesting, perching, or feeding sites. Interstate rights-of-way have also been shown to attract significant populations of small mammals (constituting 17% of wildlife mortality). Trapping data indicate that right-of-way habitat and its accompanying edge are attractive not only to grassland species but also to many less-habitat-specific species. Examples include, in the Southeast—the eastern harvest mouse, white-footed mouse, and meadow vole; in the Midwest—the prairie vole; and in the Northwest—the vagrant shrew, Townsend's vole, and California vole (Adams and Geis 1981). Although certain species benefit, the creation of homogenous modified early successional environments negatively affect regional ecological diversity by replacing complex coevolved systems with common species and simplified systems. In the case of forest environments, this conversion represents a decrease in the structural diversity. Universally, the removal of vertical habitat structure reduces the diversity of species. Structural diversity provides more microhabitats (e.g., nest sites) and allows for more complex species interactions (e.g., avoidance of predation and partitioning of foraging space).

In summary, both the construction of paved roadways and the removal of vegetation from the right-of-way result in the destruction of natural environments and the loss of habitats. The impact of these losses on local and regional ecosystems varies with the habitats destroyed. Although all habitats contribute to ecosystem integrity, those that are rare or play critical ecological roles in the landscape can be designated as "habitats of concern" and given special consideration. A discussion of regional habitats of concern is available in the EPA Office of Federal Activities (OFA) report (Southerland 1993), *Habitat Evaluation: Guidance for the Review of Environmental Impact Assessment Documents.*

3.2.2 Fragmentation of Habitats

In general, highway development rarely eliminates entire habitat types, but instead destroys part of a habitat, leaving other areas intact. In most instances this local habitat destruction is better thought of as habitat fragmentation. Such fragmentation is the principal cause of the loss of "area-sensitive" species (Harris 1984) and is considered the most serious threat to biological diversity (Wilcox and Murphy 1985, Harris 1988). For example, fragmentation on a broad geographic scale has been shown to result in declines of songbird species (Whitcomb et al. 1981). Specifically, studies in Maryland, Michigan, and Oregon have shown that the occurrence of most forest-dependent species is correlated with forest size, and that contiguous forests of 100 to 300 ac are needed by long-distance, insectivorous, neotropical migrants, such as flycatchers, vireos, and wood warblers (Terborgh 1992).

The consequences of habitat fragmentation (Harris and Atkins 1990, Hunt et al. 1987) may include the following:

- Erosion of genetic diversity and amplification of inbreeding (i.e., risk to sedentary species from random variation in demographic and genetic variables when isolated).

- Increased probability of local extinction from small population sizes and reduced likelihood of reestablishment (because immigration is inhibited by barriers).

- Extinction of wide-ranging species (e.g., wolves, black bears, panthers, manatees).

- Loss of interior or area-sensitive species (e.g., sharp-shinned hawk, Cooper's hawk, Swainson's warbler, red-cockaded woodpecker).

- Increased abundance of weedy species (regionally distinct communities give way to globally homogeneous ones).

As discussed under the destruction of habitat, highway rights-of-way may be converted to a modified earlier successional habitat depending on the width of the corridor. Both wide and narrow corridors can act as effective barriers to the movement of animals, effectively isolating habitat patches and subpopulations. In addition to the effect of distance, wind-funnelling can prevent the migration and dispersal of invertebrates and plants across corridors (Sheate and Taylor 1990). The many discontinuities associated with roadways and traffic also contribute to the barrier effect, principally the break in microclimate (temperature, humidity, and evaporation), instability of the vegetation (due to mowing and spraying), vehicle emissions (noise, dust, headlight illuminations, car exhaust, increased salinity in soil, vegetation, and ditches), and direct road kills (Mader 1984). In fact, the simple contrast in habitat conditions characteristic of edges often acts as barrier to the distribution and dispersal patterns of both birds and mammals (Thomas, Maser, and Rodiek 1979).

The most obvious barrier effect is direct mortality of animals attempting to cross the highway corridor that result from collisions with motor vehicles. Millions of animals are killed annually on highways (Leedy 1975). Road kills may represent a critical mortality factor for large wide-ranging species that can often avoid direct impacts of other development activities (e.g., key deer in Florida). Annual road-killed animals are significantly correlated with average vehicle speed (Case 1978). In an extensive study of highway impacts on wildlife, Adams and Geis (1981) observed that 76% of road wildlife mortality occurred on interstate highways and that roads appeared to act in a density-dependent manner, predominantly killing those species attracted to roadways. Species killed in greatest numbers included meadowlarks, indigo buntings, field sparrows, red-winged and Brewer's blackbirds, deer mice, several vole species, and rabbits.

Adams and Geis (1981) also found many species reluctant to cross highways. Shrews are a disturbance sensitive group that rarely enter rights-of-way; other sensitive species include the golden mouse, pinon mouse, dusky-footed wood rat, California red-backed vole, and brush mouse. In June surveys, salamanders did not readily cross interstate highways, and were not attracted to right-of-way habitat. Turtles, frogs and toads, and snakes were common road kills. Foxes, raccoons, skunks, and coyotes appeared to shun interstate rights-of-way even though a substantial small mammal food resource is available there. Elk tended to avoid habitat adjacent to interstates and forest roads. Roads did not act as a critical barrier to deer, but roadside hunting and dogs affected deer distribution.

Early field data from Oxley et al. (1974) suggested that small forest mammals were reluctant to venture onto road surfaces where the distance between forest margins exceeded 20 m. Burnett (1992) concluded that while roads may not act as barriers per se to small mammals, they do act as psychological and sociological barriers, effectively inhibiting the movement of dispersers and ultimately gene flow. Mader (1984) extended the roadway barrier effect to wandering insects by determining that forest carabid beetles avoid unstable habitat conditions. He also demonstrated that mice species will adjust their territory boundaries to avoid roadway corridors.

Because the majority of species respond to corridors as an activity filter, reducing activity with distance to the corridor; changes in corridor vegetation can reduce the effectiveness of the filter by softening the edge or creating "pores". Edge permeability increases as the contrast between adjacent habitat decreases (Forman and Godron 1981); even small changes in edge permeability may have large impacts on animal movement across patch boundaries (Buechner 1987).

Both forested and nonforested environments can be disrupted by fragmentation due to highway construction. However, the dense canopy structure of certain shrublands may be most severely impacted by fragmentation. An example is the fragmenting of pocosin wetlands and uplands in the Southeast. Because of the scale at which many pocosin inhabitants move, highway development can effectively isolate much of the pocosin fauna.

Barrier effects are not limited to terrestrial habitats and may have extreme consequences for migratory fish species where highways have diverted streams or constructed impassable culverts. Upstream passage is a particular problem for anadromous fish such as salmon and shad that must travel long distances to reach natal spawning grounds. Passage of anadromous fish at large dams has received considerable attention through research and the construction of fish ladders and lifts (Bell 1991). Ironically, culvert barriers associated with highways often occur at the end of spawning runs just below spawning grounds, thereby negating passage achievements downstream. Even small barriers can act as blockages near the end of the spawning run when the passage capabilities of anadromous fish species may decline. In addition, resident fish can be adversely affected by stream blockages, as in the case of trout, pike, and grayling that migrate upstream and downstream during their lifecycle in search of habitats for spawning, rearing, or shelter.

The success of fish passage is principally dependent on the swimming ability of the fish and the hydraulic conditions of the modified stream segment (Baker and Votapka 1990). Swimming ability varies with the size and species of fish (Bell 1991). Passage problems include:

- Vertical barriers.
- Water velocities that exceed fish swimming ability over prescribed distances.

- Low water depth.
- Icing and debris blockages.

In addition, culverts can limit passage through changes in water temperature, water pollution, and darkness that conflict with behavioral requirements of the fish (Baker and Votapka 1990). Another important factor is the relation of these modifications to annual hydrographic and seasonal time of fish passage for all species of concern. For example, even closely related species may have different spawning times (e.g., brown trout spawn in the fall in Montana where rainbow trout spawn in the spring).

3.2.3 Degradation of Habitats

Degradation of habitats specifically refers to a decrease in the health or ecological integrity of the "intact" habitat. In the case of highway development, this degradation is closely associated with fragmentation and what many researchers call the "edge effect". This edge effect can be viewed as a reduction in habitat integrity at the boundary of a highway corridor caused by disturbance, contamination, or other degrading factors that extend into the natural habitat. In addition to direct toxicity and behavioral effects on resident organisms, this degradation includes the alteration of natural processes such as water flow, fire regime, and species interactions. Biological invaders are a particular problem along roadway corridors that can seriously degrade natural systems by modifying species interactions.

Sheate and Taylor (1990) state that the vulnerability of woodlands to degradation from motorway impacts is dependent upon the size of the woodland; that small woodlands will tend to be susceptible to physical impacts, whereas larger ones will be more vulnerable to qualitative change. Direct edge effects on interior trees include temperature effects of aspect, wind-funnelling "jet" effects, potential root starvation from lowered water tables adjacent to cuttings, increases in evapotranspiration, and susceptibility to wind-blow.

Effects of disturbance associated with forest edges has been well documented for many mammal and bird species. In particular, large, mobile carnivores such as mountain lions and grizzly bears require extensive tracts of undisturbed habitat (Wilcove and May 1986). Ferris (1979) found that bay-breasted warblers, blackburnian warblers, blue jays, and winter wrens avoided forest edges along highways and suggested that noise created by vehicular traffic, rather than vegetation differences, render the forest edge unsuitable for breeding. Recent research indicates that increased edge effects result in less "secure" habitat for nesting birds (Temple 1986) and a much higher incidence of nest predation and parasitism (Wilcove 1985, Laudenslayer 1986).

Because detrimental edge effects may extend 600 m into a forest, Wilcove (1985) concludes that more than 100 ha of contiguous forest are required for forest-interior habitat. Van Der Zande (1980) found empirical support for Veen's (1973) conclusion that disturbance effects greatly exceed right-of-way widths and may extend 500 to 600 m from quiet rural roads and 1600 to 1800 m from busy highways in the Netherlands. Terborgh (1992) estimates that areas as large as 15,000 ha may be needed to provide safe havens from nest parasites such as brown-headed cowbirds that fly up to 7 km in search of host nests.

Pollution

Chemical contamination related to highway development results from air or water pollution during construction and operation and can be a significant cause of habitat degradation, especially in aquatic environments. Although toxic effects may be the most severe, conventional pollutants and other effects may exist in greater frequency and extent. For example, soils are degraded through erosion or soil compaction while elevated temperatures may damage adjacent vegetation. Rivers and streams can be degraded by siltation and salinization from deicing activities. In general, highway construction parallel to streams provides greater opportunities for adverse effects than perpendicular arrangements that result in stream crossings. Underground water sources and their contributions to ecosystem integrity can be degraded by runoff and hazardous material spills that contaminate aquifers. Where highways cross permeable sandstone and limestone, they introduce the possibility of fractures that can contaminate or eliminate water supplies.

During construction, the potential for soil erosion from earthmoving operations is great. Therefore, major efforts at erosion control, sediment trapping, and stream diversions are required. Leakage of hazardous materials, as well as major spills, must also be controlled through catchment basins and recovery methods. During operation, lower levels of contaminants are present (in runoff, soil percolation, and spray), but they represent a major contribution to nonpoint source pollution in many areas. The principal nonpoint source pollutants from highways are sediment, metals (including lead, zinc, copper, nickel, and chromium), toxicants (including pesticides), hydrocarbons, nitrogen, phosphorus, de-icing salt, material from worn brake linings and tires, organic matter, litter, and debris (Linker 1989). Both gaseous and particulate automobile emissions contribute to runoff via atmospheric deposition. Muschack (1990) points out that new highway surfaces that are textured to reduce noise and hydroplaning, keep pollutant particles in contact with the water longer and result in higher contaminant concentrations in the runoff.

Disruption of natural processes

In addition to disturbance and contamination effects, highway development can seriously degrade habitat through the alteration of ecological processes. These processes include natural hydrology, fire regimes, animal migration patterns, and competitor and predator-prey relationships (including the effect of exotic species). By creating barriers to natural water flow, highways can degrade aquatic systems, wetlands, and terrestrial environments. Natural stream flows are usually maintained by the construction of bridges or culverts, although barrier effects and local losses of natural aquatic habitat may result. Wetlands are more problematic. Natural drainage patterns are easily disrupted in the saturated soils characteristic of wetlands (McLeese and Whiteside 1977). If a surface highway runs perpendicular to the path of water transport, even precise construction of drains and channels may not prevent soil compaction from lowering the water table and eventually draining downflow wetlands (Sheridan 1988). On the upflow side, ponded conditions can lead to tree death.

The adverse effects of road building on natural hydrological patterns are especially deleterious for riparian habitats. In arid environments, riparian areas make up 80% of available wildlife habitat and support the majority of endangered species (Johnson 1989). The maintenance of natural flow patterns in perennial and intermittent streams is critical to these unique habitats. Impacts on riparian areas from highway development include the following (Terrene Institute 1993):

- Acceleration of runoff, increasing flood peaks, erosion, and downstream sedimentation.
- Dewatering of riparian areas as gullies are created by concentrated flows.
- Decreased volume and duration of base flows, causing streams (including former perennial streams) to dry up earlier in the year.
- Shifts in plant composition from riparian species to drought-tolerant invaders or upland species.
- Loss of habitat for riparian-dependent wildlife species.

Suppression of fire is a common impact on virtually all human-use lands. Land use practices are the major factor suppression natural fire regimes, although highways may act as unnatural fire breaks in some areas. Many plant communities require a natural periodicity and intensity of fires to maintain their typical species composition. Where highways combine with land use practices to reduce the frequency of fires, the accumulation of flammable material may result in less frequent, intense fires that degrade native habitats.

Natural animal migration patterns, as well as the relationships among competitors and between predators and prey, are an essential part of ecosystem integrity. While some species (such as birds of prey) may benefit from access to a new food source, many less adaptable species are adversely affected by the presence of new competitors or predators. The greatest danger to these processes is posed by the invasion of non-native, or exotic, species. Highways can act as movement corridors for exotic animals, or even provide intentional or unintentional transport in vehicles. Non-native weeds are a particular problem for highway rights-of-way where the inevitable transport by wind and tires is often exacerbated by the intentional planting of exotics. The magnitude of the problem has prompted an interagency white paper for the Federal Coordinating Committee on Science, Engineering, and Technology (FCCSET) that calls for maintaining a Federal Interdepartmental Committee for Management of Weeds (FICMW). The goals of this committee would be to develop a Federal Land Weed Management Policy that would strengthen Federal Agency Manuals, review current agency policies for effectiveness, contribute to national legislative proposals, and create prioritized coordinated treatment efforts (Anonymous 1993).

3.2.4 Cumulative Impacts

As mentioned earlier, highway development differs from other degrading activities in the proportion of its effects that can be attributed to cumulative impacts. The effects of highway development accumulate when different road segments or highway systems overlap in space or time. The principal effect of the cumulative impacts of highway development is increased habitat fragmentation. As habitat patches become smaller and more isolated, species that depend on them become less able to find them and to maintain populations in them. The National Research Council (1986) described these decremental effects as "nibbling". The combined effect of these cumulative impacts may exceed the sum of each impact or even create a qualitatively different effect on the ecosystem. For example, individual highway projects may not affect forest-interior bird species, but when several projects provide enough habitat to sustain brown-headed cowbirds, nest parasitism may completely eliminate forest-interior species from that habitat.

These effects may be augmented, or even overwhelmed, by secondary development, i.e., the land conversions to industrial or residential use that often accompany road building. Capacity improvements, additional interchanges, and new location construction have greater potential for secondary development than upgrades of existing facilities. Creating new access to undeveloped locations can have the greatest impact, if other economic conditions are favorable. In fact, demand for increased capacity often creates a highway that, in turn, increases the influx of secondary development and recreation, thus creating demand for yet more increased capacity (Sheate and Taylor 1990). It is important to note that the promotion of economic development in depressed areas through infrastructure improvement is often the purpose of a highway project.

The FHWA recognized the importance of considering cumulative impacts in its 1992 Position Paper on secondary and cumulative impact assessment. In this guidance, FHWA proposed that environmental assessment focus on the functional relationships of resource with larger systems because of the following difficulties associated with cumulative impacts:

- Secondary and cumulative consequences are triggered by impacts to environmental resources that function as integral parts of a larger system.

- Since the resource functions may be removed in both distance and time, secondary and cumulative consequences to the larger system may likely be "invisible" to normal environmental studies that examine only the immediate influence of an isolated project.

4. Ecosystem Approaches in Highway Development

The emerging disciplines of landscape ecology and ecosystem management are providing new insights into potential approaches for assessing ecological impacts, including those from highway development. Although this research has not yet produced definitive methods for ecological impact assessment, some general principles for ecosystem (or biodiversity) conservation are becoming accepted. The recent report of the CEQ, *Incorporating Biodiversity Considerations into Environmental Impact Analysis Under the National Environmental Policy Act* (1993), provides the following eleven general principals of ecosystem management:

1. Take a "big picture" or ecosystem view.

2. Protect communities and ecosystems.

3. Minimize fragmentation.
   Promote the natural pattern and connectivity of habitats.

4. Promote native species.
   Avoid introducing non-native species.

5. Protect rare and ecologically important species.

6. Protect unique or sensitive environments.

7. Maintain or mimic natural ecosystem processes.

8. Maintain or mimic naturally occurring structural diversity.

9. Protect genetic diversity.

10. Restore ecosystems, communities, and species.

11. Monitor for biodiversity impacts.
    Acknowledge uncertainty.
    Be flexible.

4.1 Categories of Highway Development

Each of these principles has implications for assessment and mitigation of ecological impacts caused by highway development. However, the applicability of each principle will vary with the conditions surrounding individual highway projects. For example, fragmentation will likely be less important in highly urbanized settings. Therefore, it is useful to consider assessment of the ecological impacts of four distinct categories of highway projects:

- Urban
- Suburban

- Rural
- Wildland.

4.1.1 Urban

Highway development in urban settings may have little impact on sensitive habitats, or natural ecosystems of any kind. Often, road construction affects only previously developed areas and may not have even indirect effects on natural habitats. However, in some instances, urban highway construction will have substantial impacts on natural water bodies or other habitats existing within the urban matrix. Destruction of these habitats can occur if new roadways are built on any of the few remaining natural areas. Fragmentation is of lesser importance, because natural habitats are usually already isolated by urban development. The principal impact of highway development in the urban setting is habitat degradation. River habitats running through urban areas may receive greater loadings of pollutants from runoff during construction or normal operation of the highway. Other impacts include adverse effects on urban trees and wildlife. Direct mortality of certain species may increase through road kills, and air pollution may damage terrestrial vegetation. Deposition of airborne contaminants may also degrade aquatic vegetation and fisheries. Because of the extensive development in urban areas, cumulative and secondary development impacts from highway development are usually minor.

4.1.2 Suburban

As in urban areas, highway development in suburban settings can still adversely affect vegetation and wildlife that are well adapted to human-altered habitats. Perhaps more important are the impacts on species less adapted to urban conditions, which try to move among pockets of natural habitat within the suburban matrix. For this reason, fragmentation can have a severe impact on suburban habitat. While high levels of ecosystem functioning are rare in urban environments, suburban areas may maintain substantial habitat integrity if a considerable undeveloped area remains and natural habitats are connected in a planned or de facto system of natural areas or greenways. Creation of additional highways can sever remaining migration corridors and further isolate species. Pollution from air emissions and roadway runoff are important, as are the higher levels of roadkills. The introduction of weedy or pest species is a special problem in suburban areas, where native species are surviving in unnaturally small habitat areas. Cumulative impacts of highway development in suburban areas can be severe, and secondary development often follows road construction and other infrastructure improvements in this high growth setting.

4.1.3 Rural

Rural areas are characterized by less land conversion to residential, commercial, and industrial uses. Additional highway development may have a greater proportional impact on rural areas than on suburban or urban areas, although this is reduced in heavily agricultural regions. In most rural environments, significant areas of natural habitats remain. Although they may be fragmented by cultivated fields, grazing pastures, and commercial timber lands, natural habitats are more likely to be impacted by highway development in rural settings than in suburban or urban ones. Except in areas of monotypic cropland and timberland, rural areas contain a greater variety of species than do urban and suburban settings. Many rare and regionally important species may be at risk. Destruction and degradation of these habitats usually accompany any highway development that is not confined to existing agricultural land. Degradation of hydrological processes, as well as nutrient and energy cycling functions are more important in rural environments. Fragmentation is perhaps the most important impact, serving to sever migration routes that continued across agricultural lands and other undeveloped regions. Cumulative impacts may be a major factor in rural environments where highway development is provided as a stimulus to secondary development and ultimately local economic enhancement.

4.1.4 Wildland

Wildlands are landscapes largely undisturbed by human activity. Highway development in wildland areas differs substantially from that in rural, suburban, and urban settings. Rather than contributing to the cumulative impacts of a suite of development activities, highways are often the only major impact on wildland habitats. Where secondary development does follow highway development (as in second home development), alterations to the natural habitat are almost always severe. The intricate ecosystems found in wildlands possess far more sensitive species and maintain a larger suite of natural functions than in previously developed areas. In addition to water, nutrient, and energy cycling, fire regimes in wildlands can be disrupted by highway development. Destruction of habitat (where virtually all areas are sensitive), fragmentation of habitat (where contiguous natural areas are the rule), and degradation of habitat (where species are more sensitive to disturbances such as noise) are all important factors in wildlands.

4.2 Approaches and Ecosystem Protection Goals

The following table illustrates approaches to attaining ecosystem protection goals within each of the four different categories of highway development. With the exception of urban environments, most of the goals are applicable to virtually all highway development projects. The specific approaches may differ among categories, and are not limited to the examples given below.

Table 1. **Approaches to Meeting Ecosystem Protection Goals Within Four Categories of Highway Development**

Ecosystem Protection Goals	Categories of Highway Development			
	Urban	Suburban	Rural	Wildland
1. Big picture		Maintain landscape integrity	Protect watersheds	Protect regional ecosystems
2. Protect ecosystems		Protect remnant communities	Maintain local ecosystem integrity	Preserve remote habitat
3. Minimize fragmentation		Maintain greenways	Maintain riparian corridors	Maintain contiguous habitat
4. Promote native species	Plant native species	Control exotic pests	Limit spread of exotic invasions	Control population growth of edge species
5. Protect rare and keystone species		Protect remnant populations	Protect endemics and migratory species	Protect habitat interior species
6. Protect sensitive environments		Protect wetlands and riparian zones	Preserve riparian and forest corridors	Maintain contiguous habitat and unique environments
7. Maintain natural processes		Limit high runoff and stream flows	Maintain nutrient cycling through natural hydrology	Maintain natural fire regimes and species interactions
8. Maintain natural structural diversity		Maintain diversity of natural vegetation	Maintain diversity of landscape pattern	Maintain structural components of interior habitat
9. Protect genetic diversity			Maintain dispersal routes	Maintain movement among subpopulations
10. Restore	Plant trees and natural vegetation	Restore riparian areas	Restore grazed and logged lands	
11. Monitor	Monitor restoration	Monitor landscape pattern changes	Monitor watershed dynamics	Monitor loss of interior species

These four categories of ecosystem approaches can serve to focus assessments related to highway development impacts. Once the appropriate goals have been identified, specific ecosystem endpoints and evaluation methods can be developed. In the area of wetlands impact assessment, considerable progress towards this end has been made and Bedford and Preston (1988) conclude "(1) that scientifically sound bases exist for setting assessment boundaries in terms of distribution of wetland resources, (2) that landscape-level measures of function can be identified, and (3) that qualitative relationships to landscape variables can be described for hydrologic and water quality functions." The current challenge for assessment of highway development impacts to ecosystems is to develop quantitative measures of impact for all natural habitats.

5. Evaluation of Ecological Impacts

FHWA mandates clearly require consideration of direct, cumulative, and secondary highway impacts on ecosystems. This can be accomplished by using the ecosystem approach presented in the CEQ biodiversity document (1993) and discussed in this report. The steps required for habitat impact assessment are basically those of traditional FHWA assessment with the incorporation of a landscape perspective and the identification of specific ecosystem endpoints. In addition, many of the same analytical tools currently used in environment assessment can be modified to include the improved land pattern analysis that can be achieved by using geographic information system (GIS) technology.

Evaluation of ecological impacts from highway development requires both scoping and analysis. Included in scoping are the determination of the appropriate scale of analysis, the setting of specific ecosystem goals or endpoints, and the gathering of information. The analysis phase involves consideration of the impacts on individual ecosystem endpoints and quantification of specific effects where possible.

5.1 Determining the Appropriate Scale

Scale is a central issue in the ecosystem approach. The appropriate boundary for highway impacts is one that ensures adequate consideration of all resources that are potentially subject to non-trivial impacts. For some resources, that boundary can be very large. Hydrologic and atmospheric transport of emissions and surface runoff can affect distant reaches of the watershed. In addition, barriers to migration may affect populations on the regional scale. At the other end of the spectrum, habitat protection also includes identifying and avoiding small sensitive areas, such as rare plant communities. Determining relevant boundaries for assessment is guided by informed judgment, based on the resources potentially affected by an action and its predicted impacts. Although in some cases ecological impacts may be limited to the highway corridor (e.g., 300 feet in width), impacts will often extend to the watershed or ecological region (via indirect and cumulative impacts of additional road construction and secondary development).

Separate jurisdictions and competing missions may make it initially more difficult for federal and state highway departments to engage in cooperative ecosystem management with other agencies. However, clear benefits are to be gained from sharing expertise, technical capabilities, and information; such sharing will lead to improved environmental decisionmaking. Highway agencies need not sponsor regional ecosystem planning efforts to benefit from them, however inclusion of transportation planning into regional land use planning should be done as early in the process as possible. Early consideration of ecological issues in the highway development process may be the most important factor in ensuring the environmental success of projects.

5.2 Establishing Ecosystem Goals and Endpoints

In order to consider ecological impacts from highway development, it is important to establish concrete operational goals for the maintenance of ecosystem integrity. Although the general goal of ecosystem protection is to protect or restore the diversity of natural organisms and natural ecosystem processes, there is no one objective that will apply to all situations. Because they may represent important social choices, the establishment of goals and objectives must be undertaken with care. For example, the federal and state highway agencies should involve not only the public, but other agencies that may be responsible for managing the affected natural resources. This will help identify those instances where other parties have developed operational goals and objectives relevant to habitat conservation.

General objectives for the protection of ecosystems, and biodiversity, can be developed by applying the relevant guiding principles outlined in this report. For example, measures to minimize landscape fragmentation, or to preserve old growth forests, can be assumed to benefit biodiversity without quantifying the specific biodiversity goal to be achieved. Highway agencies may have to limit their biodiversity objectives to such general guidelines if more specific objectives cannot be identified.

Ultimately, ecosystem endpoints must be selected based on biodiversity conservation principles. These endpoints should be quantifiable environmental attributes for which a baseline can be established and subsequent monitoring done. A wide variety of objectives and measurement approaches are potentially useful. For example, Noss (1990) has delineated a hierarchical approach that incorporates elements of ecosystem composition, structure, and functioning at four levels of organization: regional landscape, community-ecosystem, population-species, and genetic. Incorporation of these individual indicators, or endpoints, will depend on the ecological resources present, the impacts involved, and the available information.

The following table is an attempt to define categories of ecosystem endpoints that should be used in environmental assessments of highway development. One or more categories have been defined for each of five general principles of ecosystem protection (derived from the original 11 principles). Specific endpoints for each category are described in the next section.

Table 2. Ecosystem Endpoints Associated with Ecosystem Protection Goals for Use in Environmental Assessment of Highway Development

Ecosystem Protection Goals	Ecosystem Endpoints
Focus on ecosystems. Address the needs of the region.	• Consistency with regional plans. • Integrity of regional ecosystem.
Protect sensitive communities and ecosystems.	• Area of sensitive communities. • Status of sensitive communities.
Maintain native diversity and natural processes.	• Native species diversity. • Native structural habitat diversity. • Status of hydrology, nutrient and energy cycling, fire regime, and keystone species interactions.
Protect sensitive species.	• Number of sensitive species. • Status of sensitive species populations.
Minimize fragmentation.	• Habitat connectivity. • Habitat patch distribution. • Number of contiguous habitat areas affected.

5.2.1 Ecosystem Endpoints

The categories of ecosystem endpoints defined in the table may be thought of as "assessment endpoints" in the terminology of Suter (1990), and the more specific indicators discussed below as "measurement endpoints." The designation of sensitive habitats or species is critical to endpoint selection. In the context of impact assessment, the term "sensitive" applies to both ecologically valuable species and habitat, and to those vulnerable to impact. Rarity is often a good indicator of vulnerability, but the following characteristics are also indicative of vulnerability:

- species requiring high survival rates rather than high reproduction rates may be more at risk (given that impact is on survival rather than on nesting or other reproductive parameters) (Mertz 1971).

- species whose intrinsic rates of increase fluctuate greatly are most likely to go extinct, even with high average population sizes and high birth rates (Goodman 1987).

- communities with vulnerable keystone (*sensu* Paine 1969) predators or mutualists may be more vulnerable; similarly, the presence of exotic species may dramatically increase the vulnerability of communities.

As discussed previously, the selection of specific ecosystem endpoints, or indicators, is dependent on the resources of concern and the data available. In addition to Noss's (1990) comprehensive list of biodiversity indicator types, EPA's Environmental Monitoring and Assessment Program (EMAP) is developing a wide range of specific indicators of environmental condition (Hunsaker and Carpenter 1990). These indicators range from population abundances to community indices (e.g., Karr's Index of Biotic Integrity for fish communities) to landscape-level indicators such as the following:

- Abundance or density of key physical features and structural elements.
- Habitat proportion (cover types).
- Patch size and perimeter-to-area ratio.
- Fractal dimension (amount of edge).
- Contagion or habitat patchiness.

Research into ecological indicators is continuing and promises to provide a diverse toolbox of methods for determining environmental change and identifying habitat impacts. As new indicators are developed, they can be incorporated into analyses focusing on the following categories of ecosystem endpoints:

Consistency with regional plans.

CEQ (1981) guidance on the "forty most asked questions" (46 Federal Register 18026) states that environmental assessments must identify and evaluate conflicts with land use plans (all formally adopted documents for land use planning, zoning and related regulatory requirements, even if proposed).

Placement of the highway corridor may conflict with land uses assigned to specific areas in regional plans. Each such instance should be identified and discussed in detail.

Integrity of regional ecosystem.

Once the boundary of the appropriate regional ecosystem is identified (e.g., the Greater Yellowstone area or the Chesapeake Bay Watershed) the impact of the project on this ecosystem should be identified and discussed in at least qualitative terms.

Area of sensitive communities.

Distinct local ecosystems and vegetative communities should be identified; where these habitats are natural or ecological significant it should be so indicated. The areal extent of each community should be determined and the absolute and relative decrease in area (acres) calculated for highway land conversion impacts. As an example, sensitive habitats in the southeastern coastal plain include streams and rivers, riparian areas, wetlands, bottomland hardwoods, scrub habitat, old-growth pine forest, and contiguous upland hardwood forest. These and habitats of concern for other regions are described in *Habitat Evaluation: Guidance for the Review of Environmental Impact Assessment Documents* (Southerland 1993).

Status of sensitive communities.

In addition to determining areal impacts to distinct local ecosystems and vegetative communities, adverse effects to remaining habitat areas should be determined. These include changes in the seral stage, loss of habitat features (e.g., caves, cliffs, slopes, springs, and seeps), and decreased community vigor through contaminant toxicity (e.g., needle loss in conifer stands caused by acid precipitation).

Native species diversity.

Single species diversity indices have often been used to justify the creation of additional edge habitat. However, these increases in diversity simply reflect the replacement of local organisms with species adapted to disturbed or edge habitats. The invading species are usually common species that do not contribute to regional biodiversity. Measures of diversity should be limited to native species adapted to the intact natural habitat of the area. Numerical indices that use multiple metrics (e.g., Karr's Index of Biotic Integrity) are often preferable to single metrics such as species richness.

Native structural habitat diversity.

Creation of modified roadside areas, stream channels, and wetlands usually results in the simplification of structural diversity, including the loss of critical microhabitats (e.g., snags and down material). These changes should be identified and quantified. The U.S. Fish and Wildlife Service Habitat Evaluation Procedures (HEP) provides a method for describing habitat features important to wildlife (USDOI 1980).

Status of hydrology, nutrient and energy cycling, fire regime, and keystone species interactions.

Highway development frequently alters surface and subsurface water flows. Changes in rates and total volumes should be quantified and their effects on nutrient and energy cycling described. Quantitative systems cycling studies may be possible in some instances. Disruption of natural fire regimes should be described. Effects on ecological important species, such as top predators, major migratory populations, essential prey populations, and dominant plant species, should be evaluation in terms of ecosystem impacts.

Number of sensitive species.

Both rare and ecologically important species should be identified and counted. This include federal and state endangered and threatened species, species of special concern, migratory species, as well as keystone ecological species (i.e., those that control species composition of communities through strong predatory, competitive, or symbiotic relationships). The number of exotic species invading the area due to highway development should be included as a negative factor in the assessment.

Status of sensitive species populations.

In addition to the number of different species, the demographic status of each sensitive species (including genetic composition) should be evaluated. Changes in age class distribution, sex ratios, and subpopulation migration can be measured.

Habitat connectivity.

Fragmentation caused by highway development results in reduced connectivity of habitats. Connectivity of single habitat types, or general classifications such as contiguous forest, can be measured using pattern analysis (e.g., fractal geometry) and GIS techniques.

Habitat patch distribution.

Another measure of the fragmentation of the landscape is habitat patch distribution. The composition of different habitat types and habitat sizes may be as important as connectivity for species movement and maintenance of metapopulations. Again using GIS techniques, quantitative measures of patch distribution can be obtained.

Number of contiguous habitat areas affected.

A simpler method of measuring fragmentation is to calculate the number of contiguous habitat areas affected by highway development. Once habitat block sizes of interest (e.g., forest stands) are selected, the number and proportion affected can be determined.

5.3 Gathering Ecosystem Information

Successful application of an ecosystem approach to evaluating ecological impacts requires sufficient ecological information. It is important that information be collected on the distribution and status of the ecosystems or habitats that could be impacted by the proposed action to establish a baseline of existing conditions. Assessment of potential impacts at the ecosystem level will aid in the protection of the majority of the animals, plants, and microorganisms. Information on species populations and communities that are rare, sensitive, or otherwise in need of special protection (e.g., small, endemic populations confined to localized areas) is essential as well.

Agencies should begin by assembling information from existing sources. The recently instituted National Biological Survey (Larson 1993) should improve access to biodiversity information, assess existing information, and improve and standardize information management. Many federal and state agencies have already developed inventories of the distribution of biota and the ecological conditions in areas under their jurisdiction. The following are several potentially useful sources of ecological information.

- National Biological Survey (202-208-3733).
- Natural Heritage Program Network (703-841-5300).
- Fish and Wildlife Information Exchange (703-231-7348).
- Regional Natural Resource Plans.
- Resource Agency Management Plans.
- Regional Land Use Plans (such as Coastal Zone Management Plans).
- Local Zoning and Growth Plans.

Detailed discussions of the information available in the state Natural Heritage Programs, the Gap Analysis program of the U.S. Fish and Wildlife Service, state biodiversity inventories, and the cooperative multi-state Fish and Wildlife Information Exchange are available in *Incorporating Biodiversity Considerations Into Environmental Impact Analysis Under the National Environmental Policy Act* (CEQ 1993).

5.4 Analysis of Impacts

Once the necessary background information has been obtained, the potential direct, indirect, and cumulative impacts of highway development on ecosystems can be determined. This task requires the careful evaluation of the effects of the proposed action and each alternative on attaining ecosystem goals and objectives. Ecological analyses should consider both the factors causing the destruction, fragmentation, and degradation of habitats and the general principles for ecosystem protection. A wide range of techniques can be used to evaluate these ecological impacts, including checklists, matrices, mathematical models, and cartographic displays. No one technique is suitable for all situations, although geographical analysis is of special importance in evaluating ecological impacts.

In addition to direct effects, CEQ guidance requires that indirect effects be considered:

> "EIS must identify all the indirect effects that are known, and make a good faith effort to explain the effects that are not known but are "reasonably foreseeable." (NEPA Section 1508.8(b)). The agency has the responsibility to make an informed judgment, and to estimate future impacts on that basis, especially if trends are ascertainable."

Highway agencies seeking to consider ecological impacts in their project-level environmental analyses must address the same problems faced in other cumulative impact analyses. A basic problem is the disparity between administrative and ecological boundaries, that is, differences between the scope of the project decision and the scale of potential impacts in both time and space. There are also difficulties in estimating possible future actions on the same resource, and the additive or synergistic effects of multiple stresses. The use of an ecosystem approach can help address this issue (see section 5.5).

5.4.1 Analytical Approach

As described in *Habitat Evaluation: Guidance for the Review of Environmental Impact Assessment Documents* (Southerland 1993), the following considerations should be central to any process of ecological impact evaluation:

- Apply an **ecosystem-level perspective** that considers the full range of interactions among ecological components.

- Assess the **cumulative effects** that arise from the additive and synergistic impacts of several degrading activities occurring over time or space.

- Analyze the true **effectiveness of mitigation** measures in conserving natural habitats and their ecological values.

Traditionally, environmental assessments have focused on the following subject areas related to ecological resources:

- Geological Resources
- Noise
- Air Quality
- Water Quality
- Aquatic Environments
- Terrestrial Environments
- Endangered Species
- Wetlands
- Designated Natural Areas.

The consideration of aquatic and terrestrial environments has principally focused on economically or recreationally important species of fish and wildlife. In some cases, these environments have been subdivided into land use or vegetation based classes. Rarely, however, have the variety of natural habitats in project areas been accorded the attention given to wetlands or designated natural areas (e.g., parks, wild and scenic rivers, and recreation areas). By definition, an ecosystem approach to the evaluation of ecological impacts from highway development will consider all habitats in terms of their ecological importance, and therefore not exclude important environments that do not have official designations. Similarly, this approach requires consideration of the full range of species of ecological importance, not only listed endangered and threatened species.

The *Habitat Evaluation* report (Southerland 1993) provides useful information on the status and trends of habitats, and the likely habitats of concern, in each region of the United States. A review of that report and related material can facilitate the identification of sensitive habitats and other ecological resources. Subsequently, the functions and values of the habitats and resources of concern should be characterized by selected ecosystem endpoints as discussed in the previous sections. Lastly, the impacts to these impacts are analyzed. In summary, the following three basic steps can be used to incorporate landscape-scale considerations into both regional-level and site-level environmental assessments of highway development:

Step 1. Classification and mapping of sensitive habitats.

Step 2. Characterization of habitats in terms of ecological values and functions.

Step 3. Comparative methods for quantifying different degrees of impact to these habitats.

5.4.2 Classification and Mapping of Habitats

There are two principal systems for classifying natural resources: taxonomic ecosystem classification and regionalization. Taxonomic classification systems attempt to develop definitions for different ecosystem types, irrespective of their location (Pfister and Arno 1980). This approach is similar to the traditional classification techniques of species taxonomy and uses a dichotomous key rather than a map. Regionalization of ecological resources is a map-based approach that defines geographical areas of similarity based on ecosystems, or ecosystem-determining factors.

Robert Bailey of the U.S. Forest Service and James Omernik of the EPA Environmental Research Laboratory in Corvallis, OR have developed comparable, but conceptually different, ecoregion maps of the conterminous United States. Bailey's (1980) map is hierarchical, drawing on different factors for delineating regions at different levels (e.g., Divisions versus Provinces). His classifications are principally climate driven, but use soils, landform, and vegetation at successive levels. Omernik (1987) uses an overlay approach that determines the homogeneity of areas by the coincidence of different factors, including vegetation, hydrology, soils, etc. Omernik's maps have been refined in many states to provide finer resolution for assessing water resource quality, while the U.S. Forest Service is incorporating local scale ecoregions into Bailey's classification to facilitate forest management.

On the relatively fine scale of individual highway projects, vegetation is still the best indicator of ecosystem type. However, azonal areas (such a riparian zones) are still poorly represented in vegetation-based classifications. Kuchler's (1964) potential natural vegetation (PNV) units is the only organized description of major above-ground terrestrial ecosystem diversity that describes the entire United States in reasonable detail (Department of Agriculture, 1978), although NASA and cooperating agencies are developing new vegetation maps from remote sensing data (Janetos, personal communication). In terms of ecosystem classifications, the new EMAP initiative at EPA is developing a classification of ecosystem types for each of their major natural systems, including those for forests (developed by the Society of Foresters) and for deserts and grasslands (developed by the Society of Range Management). In addition, statewide natural community classifications have now been completed for each state Natural Heritage program (Larry Master, The Nature Conservancy, personal communication). There is now good agreement among state classifications on a regional basis, resulting in about 150 to 300 ecosystem types per state. More general vegetation types are in use by the natural resource agencies and range from designations such as oak-hickory and spruce-fir associations to simple hardwood forest, conifer forest, and rangeland categories.

Given the advancement of these efforts, and the many sophisticated habitat classification programs at local levels, it is now reasonable to expect a good delineation of habitat types and areas for major highway development projects. Analysis of these data require graphic overlay capabilities that are greatly enhanced by the use of GIS.

GIS — Geographic Information Systems

A geographic information system (GIS) is a collection of computer hardware, software, and geographic data that can capture, store, integrate, edit, retrieve, manipulate, analyze, synthesize, and output all forms of geographically referenced information. GIS approaches using remote sensing and existing data, such as U.S. Geological Survey quad sheets, are also being used in states to develop statewide land use maps for planning (Turner 1990). Many more examples of GIS for planning are occurring on local scales as its power for determining spatial patterns is realized. GIS can be used to analyze the spatial relationships between species ranges and land use patterns, and to identify adequate buffer areas and potential habitat corridors for the maintenance of ecosystem integrity. For ecological evaluation, mapping of individual habitat areas is essential. Only through GIS or other graphical methods can the areas of habitat impacted and the changes in landscape patterns be quantified.

Current GIS approaches to assessing the impacts of highway development use photographic imagery (usually low level aerial) to delineate vegetation using the Anderson Level I, II, or III classifications. In addition to accurate measures of habitat area, this imagery provides perimeter-to-area ratios and other measures of habitat fragmentation and isolation. Some analysts are hoping to use the gap analysis program data developed by the U.S. Fish and Wildlife Service that correlates Landsat Thematic Mapper vegetation imagery with ecosystem types and vertebrate distributions (Idaho Cooperative Fish and Wildlife Unit 1991). Even more promising is the use of GIS in highway planning that has grown since McHarg (1969) advocated map overlay methods to determine the suitability of land for highway development. The anticipated rapid growth of highway systems in North Carolina has prompted the State to create a Center for Geographic Information and Analysis to provide the locational data on natural resources needed for effective highway planning (Fred Skaer, FHWA, personal communication).

5.4.3 Characterization of Habitat Values and Impacts

Once habitat areas have been classified and mapped, potentially impacted areas need to be characterized in terms of ecosystem values and functions. Traditionally, habitat characterization per se has been limited to wetlands. Others considerations have focused on individual species and water quality.

Species Characterization

In the ecosystem approach to ecological evaluation, analysis of impacts to individual species continues to play an important role. To adequately consider the role of individual species in ecosystem protection, current analyses conducted for endangered and threatened species and for species of economic and recreational important need only be extended to other rare and ecologically important species. In each case, predicted mortality from road kills, contaminant toxicity, and habitat alteration should be evaluated, as well as indirect effects on population status, behavior, and movement patterns.

The important factor in species analysis is identification of the sensitive species. The number of federally and state listed threatened and endangered species is very small; however, many more species can be included if consideration is expanded to include U.S. Fish and Wildlife candidate (category 2) species and state species of concern. The best approach is to survey the species list of each major animal group (e.g., invertebrates, amphibians, reptiles, birds, and mammals) for rare species, species threatened by other stresses, migratory species, and keystone species (such as raptors). Potentially sensitive plant species can be identified through rare species lists and plant community analyses that identify dominant vegetation layers, important food source plants, and species critical to nutrient cycling. Plants and animals associated with special or unique habitats (such as cedar glades, shale barrens, talus slopes, cliffs, and caves) should also be included. Special attention should be given to symbiotic species such as butterflies and their host plants.

In the urban setting, fewer species will be present, but consideration should extend to the full range of "urban" wildlife that increase as more edge is created around fragmented woodlots and wetlands (such as raccoon, opossum, muskrat, squirrel, woodchuck, cottontail, chipmunk, meadow vole, American toad, robin and cardinal, and deer).

Aquatic Habitat Characterization

Traditional water quality analysis can be extended to include rigorous assessments of aquatic habitat. The FHWA Technical Advisory T6640.8A addresses impacts to major streams, rivers, reservoirs, and springs. More specifically, the FHWA reference manual for Assessing Water Quality Impacts from Highway Maintenance Practices (Krame et al. 1985) prescribes a Habitat Evaluation Method which classifies impacts. The habitat assessment has three basic goals:

(1) Assess the resource value of the undisturbed habitat of the nearest receiving water downstream of the expected impact.

(2) Predict what effects the expected disturbance might have on the habitat in terms of habitat loss, alteration, or displacement.

(3) Assess the value of the disturbed habitat and determine if the difference in resource values constitutes a significant impact.

The method is based on the principles set forth in the Habitat Evaluation System (HES) as adapted by the U.S. Army Corps of Engineers (COE, 1980) from the Fish and Wildlife Service Habitat Evaluation Procedure (HEP). The HES operates on three basic assumptions: (1) the presence or absence, and abundance and diversity, of animal populations in a habitat or community is determined by basic biotic and abiotic factors that can be quantified; (2) if the necessary habitat requirements for a species are present, then a viable population will be, or could be, supported by that habitat; and (3) general habitat characteristics can be used to indicate the quality of a habitat and its ability to support fish and wildlife populations.

The HES method determines the quality of a habitat type using functional curves relating habitat quality to quantitative biotic and abiotic characteristics of the habitat (i.e., a habitat quality index is on the ordinate ranging from 0-1 for every parameter; a curve based on a particular measurement endpoint is used to quantify the effect). Habitat size and quality are combined to assess project impacts. The general HES method, which is applied to each specific habitat type, is as follows:

Step 1. Determine habitat type or land use areas.

Step 2. Derive habitat quality index (HQI) scores for each habitat type or land use category. Score and weight specific variables based on importance to habitat quality. Calculate an aggregate score.

Step 3. The area of a given habitat type is multiplied by the aggregate HQI to obtain a Habitat Unit Value (HUV).

Step 4. An HUV is projected for the impact of future maintenance activity based on estimated changes in habitat type due to such influences as channel dredging, sediment loading, and addition of toxic materials.

Step 5. Calculate the impact: HUV after practice - HUV before practice = impact.

Step 6. The significance of the impact on the resource value of the habitat is evaluated and possible mitigation requirements examined.

This evaluation requires data from streams and lakes on basic chemical, physical, and biological features of the receiving water bodies. Key variables required for streams include fish species association, sinuosity index (SI), total dissolved solids, turbidity, chemical type, and benthic diversity (aquatic macroinvertebrates); additional variables for lakes include spring flooding index, mean depth, shoreline development index, total fish standing crop, and sport fish standing crop.

This approach to aquatic community characterization is similar to that being used by EPA's Office of Water to develop biological criteria in support of the water quality standards program (EPA 1990). Biological criteria research has developed several powerful methods for characterizing aquatic communities (e.g., the Index of Biotic Integrity, see Karr 1991). These methods are based on the presence, relative abundance, and condition of several species within an aquatic community and provide substantially better measures of habitat composition than traditional richness and evenness indices of diversity. Although existing methods are most applicable to stream ecosystems, technical guidance is being developed for other waterbodies (e.g., lakes, rivers, estuaries, and wetlands) (Southerland and Stribling, in press). Application of new biocriteria methods, as well as modifications of HEP procedures (e.g., Pennsylvania's computer-based PAN HEP), should greatly increase the ability to characterize aquatic and other habitats.

Qualitative methods for characterizing aquatic habitats include assessing potential impacts to waterbodies whose value have been recognized by official designations, such as Wild and Scenic Rivers (as required by FHWA guidance). Unfortunately, too few rivers have been designated as wild and scenic to affect many projects. There are a much greater number of sensitive river segments in the National Rivers Inventory and even more in the American Rivers' Outstanding Rivers List (Southerland et al. 1991). Outstanding Resource Waters are also identified in state 305(b) waterbody assessment reports to EPA (U.S. EPA 1993). A review of the rivers and streams included in these lists should be a minimum requirement for characterizing aquatic habitats in the project area.

Wetlands Characterization

Wetlands have also generated substantial research into methods for characterizing habitat. The Wetlands-FHWA Technical Advisory T6640.8A requires analysts to identify all wetlands using the National Wetlands Inventory (NWI) maps, Soil Conservation Service (SCS) soil surveys, and field surveys, as needed, to delineate wetland boundaries according to the current jurisdictional wetlands manual (U.S. Army COE Environmental Laboratory 1987). Analysts may also designate certain wetlands as exceptional resource value wetlands, including wetland special areas outside the highway corridor that may be subject to indirect and secondary impacts (West Virginia DOT 1992). Impact factors include the size and proximity of the wetland, and the relationship of the wetland to its water source.

General wildlife diversity-productivity scores can be determined for specific wetlands using 10 criteria (Golet 1976, U.S. Army COE and Minnesota Environmental Quality Board 1988). These criteria include 3 based on vegetational community composition, 3 on wetland structure, 2 on wetland hydrology, 1 on adjacent land use, and 1 on water chemistry. More commonly, the Wetland Evaluation Technique (WET) developed for FHWA can be done to determine a functional assessment (Adamus et al. 1987). Wetland functions of concern include nutrient removal/transformation, sediment/toxicant retention, sediment stabilization, floodflow alteration, groundwater recharge, production export, aquatic diversity, and wetland-dependent bird habitat diversity. WET II analysis can be used to develop a rating value for wildlife with a high rating designating floodplain wetlands, large and vegetationally diverse wetlands, and moderate-size wetlands that are oases or complexes with some interspersion (U.S. DOT and Michigan DOT 1991). Individual functions of wetlands such as plant and wildlife support, flood protection, and water quality should be determined and mitigation designed to replace lost values. FHWA has developed specific design criteria for replacing these functions when creating wetlands (Marble 1990). Another approach is to apply HEP to wetland characterizations. The use of HEP analyses is being reviewed for use in wetland mitigation banking programs for highway development in North Carolina (McCrain 1992).

Terrestrial Habitat Characterization

Characterization of terrestrial habitats can follow the same models used for aquatic and wetlands habitats. In particular, the Habitat Evaluation Procedure (HEP) of the U.S. Fish and Wildlife Service and the Wildlife-Habitat Relationships (WHR) of the U.S. Forest Service and certain state wildlife agencies have been applied to multispecies terrestrial communities (Schroeder 1986, O'Neil et al. 1991, Short and Williamson 1986). As with wetland and stream habitat evaluation methods, subjective values can be attributed to terrestrial environments. Following a Forest Service protocol, community importance values can be assigned based on 9 characteristics: diversity of plants and animals, density of plants within each community, canopy height, amount of each community in the state, number of game animals per community, geologic age and degree to which the community is a relic, moisture requirements of each community, "the relative degree of insularity in the discontinuous phase within climax communities of lower sensitivity", and degree of ecological succession. Each factor can then be weighted on a scale of 2 to 10 and summed for the habitat type. (De Waal Malefyt et al. 1976).

Where detailed characterization of terrestrial habitats is not possible, qualitative methods of designating sensitive areas can be applied. FHWA has existing guidance on the inventory of section 4(f)/6(f) lands including state parks, national recreation areas, community parks, existing and proposed National Wildlife Refuges, trails, and other lands acquired or developed with Land and Water Conservation Fund assistance. These and other natural areas, such as local greenways, private preserves, and certain national forest, should be identified and their place in the landscape described. Other areas that are more disturbed should also be considered as they may be successfully functioning natural ecosystems of local importance. Even these human-altered areas are becoming increasingly valuable (and vulnerable) as others like them are eliminated by urbanization.

Existing designations for identifying sensitive habitats can be taken from national forest management prescriptions (MP), e.g., wilderness (MP 5), areas emphasizing management for species intolerant of disturbance (MP 6.1), and areas emphasizing semi-primitive non-motorized recreation in a natural setting

(MP 6.2). Other possible designations include special botanical areas (defined as state natural heritage program and national forest management plan (MP 8) areas emphasizing preservation of unique ecosystems), areas of national significance, and research areas. Many other federal and state designations have been developed that should be included in terrestrial habitat characterization. Many of these designations are compiled in the EPA report, *Targeting Priority Natural Resources: A Review of National Lists* (Southerland et al. 1991). Twenty-five lists are included comprising over 5,000 terrestrial sites. Many more state designated sites may be found on lists that are not yet centrally compiled.

Landscape characterization from remotely sensed data is especially valuable in classifying vegetation as a means of selecting sensitive habitats. The Anderson Level II Land Cover Mapping from USGS provides division of forest habitat in deciduous, evergreen, and mixed categories; additional data on local species associations can provide the more specific vegetation associations needed for habitat designations related to ecosystem protection goals. For example, remote habitat may be given special consideration as it supports species intolerant of disturbance (e.g., bear, turkey, bobcat, fisher, warblers, woodpeckers, thrushes, gnatcatchers, and flycatchers). To evaluate forest fragmentation, the pattern of forests larger than 200 ac can be determined (because smaller areas do not support forest-interior species).

Riparian areas are a habitat type of special interest because of their inherent wildlife value and importance for landscape connectivity. The FHWA authority (Floodplains-FHPM 6-7-3-2 Location Hydraulic Study in 23 CFR 650) "... to avoid or minimize highway encroachments with the 100 year floodplain, where practicable, and to avoid supporting land use development which is incompatible with floodplain values," can be used to protect riparian habitat that provides ecosystem services within the floodplain. Areal measures of the regulatory floodway and 100-yr floodplain (high to moderate risk) and flood hazard areas (low to moderate risk) are already incorporated into environmental assessments of highway development. In a similar way, existing analyses of geomorphology, surface geology, groundwater, soil associations, and hydrology can be used to delineate ecological regions and their unique watershed values.

In a similar vein, other existing analyses conducted in environmental assessments of highway development could be expanded to consider landscape units as functioning ecological systems. For example, evaluation of impacts to the aesthetic and visual character of the site (using visual unit boundaries of 1/2 mi for 30 sec of visual experience at 55 mph) could be modified to encompass landscape ecology principles. In addition, air quality considerations focused on compliance with national ambient air quality standards (NAAQS) could be expanded to include vegetation effects not in the standards.

5.4.4 Comparative Methods

Ultimately the analysis of ecological impacts from highway development must make a clear and concise comparison of the impacts of each alternative on each ecosystem endpoint. As pointed out in Section 4, the suite of ecosystem endpoints of greatest concern varies with the category of highway development, i.e., urban, suburban, rural, and wildland. Similarly, the type and degree of impact may vary with each category. In most cases, however, the methods for measuring the impacts are the same.

The simplest method for comparing impacts is to develop a checklist for each ecosystem endpoint. This may be expanded into matrices that directly illustrate impact degree across endpoints and alternatives. Where more complex relationships between impacts and endpoints can be measured, modeling approaches may be used. Finally, spatial measures of impact can best be compared using graphic methods. In essence, the comparison of impacts is a table of alternatives vs. ecosystem endpoints that includes in each cell a qualitative or quantitative measure of predicted impact. Where possible, these cells should summarize all potential direct, indirect, and cumulative impacts on the ecosystem endpoint.

To arrive at such a summary table, individual analyses may be required for the impacting activities occurring during each of the four phases of highway development: planning, design, construction, and operation. Within each phase, the relative importance of the following stressor processes can be evaluated:

- Alteration of topography.
- Vegetation removal.
- Erosion, sedimentation, and soil compaction.
- Dehydration and inundation.
- Acidification, salinization, and warming.
- Contaminant toxicity.
- Noise and visual disturbance.
- Introduction of exotic species.
- Direct mortality from road kills.

Qualitative measures may be limited to a description of impacts to individual ecosystem endpoints. For comparison purposes, this requires summarization of the magnitude, duration, and frequency of impacts in an ordinal scale such as high, moderate, or low impact. Where possible, numerical measures of impact should be derived. The simplest measure for sensitive habitats is areal extent. The number of acres destroyed or degraded can be determined by overlays of corridor siting or construction design drawings with habitat maps. More complex measures of impact are required to describe fragmentation and indirect effects. Because of edge effects, forest habitat degradation may be more accurately described by perimeter-to-area ratios for individual forest blocks. Distance to adjacent habitat types can also be measured. Lastly, numerical measures of habitat interspersion and connectivity can be given. Although there is no consensus or standardized protocol for quantifying edge effect, both vegetation measures and animal behavior analyses can be used to define edge width. Accurate evaluations of fragmentation impacts require an adequate means of quantifying edge length and width (Yahner 1988).

A simple comparative analysis was conducted by Bohm and Henry (1979) for highway development through a valued forest area surrounding Paris. They set up an algorithm for eliminating extreme alternative choices *a priori* by using two conflicting criteria: the number of forest ac lost and the number of driving miles required. They set bounds on the extreme amounts of forest loss per acre that would be acceptable (e.g., 10 ac per mile and 100 ac per mile). Where estimates of route impacts fell below or above these thresholds the route alternative would be eliminated. Although these kinds of comparisons can be constructed for any number of possible tradeoffs, the interactions among multiple scenarios rapidly increases the difficulty of the analysis.

Methods developed for the selection of transmission line routes can be adapted for highway corridor selection in the planning stage, and provide an illustration of possible ways of standardizing differing impacts. De Waal Malefyt et al. (1976) attempted to quantify such important factors as number of unique vertebrates, number of endangered vertebrates, areal extent of each community in the state, degree of stress, and degree of negative impact from construction by measuring the total length of sensitive areas crossed by the transmission route. These sensitive areas included steep slopes, lakes, stream, marshes and wetlands, forest, and specific areas of ecological sensitivity. They applied a screening process that produced a regional sensitivity survey of the 23,000 m2 area and identified habitats of endangered fauna, geographically isolated biotic communities or those of limited extent, and research natural areas. Two criteria were used to assign impact levels to areas with the greatest sensitivities. First, impacts to biotic communities (based on floral composition) were described in acre-years per mile (as a measure of area and time needed to recover the natural composition). Community impacts were assigned levels 1 to 5 and then were refined with 6 characteristics: areal extent, revegetation potential, floral density, support for vertebrates, and importance to protected species and stability. The second criterion measured the geographic range of human-interest animals and identified critical habitat areas. Impact levels of 1 to 5 were assigned to each community based on potentially impacted area. The sum of these areas within each link of the transmission corridor equaled total impact; the vector sum of all links equaled the route impact. This kind of acre-year analysis incorporates both spatial and temporal impacts into a single unit analysis that can be adapted to the evaluation of ecological impacts from highway development.

While it is important to quantify impacts, care should be taken not to compare acreages lost among habitats of different values. In most cases, unique natural areas should be evaluated separately with all ecological functions explicitly considered.

The following table illustrates potential ecological effects that might be identified for a hypothetical set of highway development alternatives. In this hypothetical example, a new highway project has been proposed and two possible alignments are evaluated (along with the no action alternative). The project is planned for a rural area with substantial areas of both agricultural and natural habitats. The natural habitats are predominately upland forest (including old growth stands and wilderness areas) with a few wetlands.

Table 3. Hypothetical Comparison of Effects of Alternatives on Ecosystem Endpoints

	ALTERNATIVES		
ECOSYSTEM ENDPOINTS	**No Action Alternative**	**Alternative 1**	**Alternative 2**
Consistency with regional plans.	Does not provide transportation level of service.	Opens planned agricultural area to urbanization	No conflicts with local growth plan or state highway plan
Integrity of regional ecosystem.	No change	Loss of old growth and disturbance of wilderness degrades core natural area in region	No effect on core area and only minor effects on ecosystem services
Area of sensitive communities.	No change	Loss of 100 ac of old growth forest and 10 ac of wetland	Loss of 10 ac of old growth and 50 ac of second growth forest
Status of sensitive communities.	No change	Edge created along 50 mi of adjacent old growth forest	Edge created along 10 mi of old growth forest
Native species diversity.	No change	Introduction of exotic weeds	Includes exotic weed management program
Native structural habitat diversity.	No change	Loss of canopy in adjacent old growth forest along edge	Loss of canopy in adjacent old growth forest along edge
Status of hydrology, nutrient and energy cycling, fire regime, and keystone species interactions.	No change	Reduction of subsurface flow to adjacent wetlands	No change in hydrology
Number of sensitive species.	No change	Local extinction of wetland species	No change
Status of sensitive species populations.	No change	Nest parasite reduce reproductive success of forest interior birds	Loss of some foraging area for forest species
Number of contiguous habitat areas affected.	No change	Disturbance radius (10 mi) intersects 2 wilderness areas	No change
Habitat connectivity.	No change	Severs 5 parcels of old growth forest	Severs secondary growth area only
Habitat patch distribution.	No change	Only small open patches created	Only small open patches created

5.5 Evaluation of Cumulative Impacts

The evaluation of cumulative impacts to ecosystems from highway development is an essential part of any environmental impact assessment. Fortunately, the ecosystem approach to ecological impacts analyses recommended above incorporates the basic principles needed for evaluating cumulative impacts. Nonetheless, it is valuable to review the following crucial steps involved in cumulative effects analysis:

1. Defining the goals of the assessment.
2. Setting the spatial and temporal boundaries of the study.
3. Establishing an environmental baseline for assessing impacts.
4. Selecting the impact factors to be included in the study.
5. Identifying the role of impact thresholds in the study.
6. Analyzing the impacts of the activity (alternatives) relative to the baseline.
7. Recommending mitigation and monitoring based on the cumulative effects.

These steps closely parallel the evaluation approach presented in this report. Of greatest importance, is the need to set spatial and temporal boundaries based on the resource of concern, i.e., the ecosystem. In addition, the enumeration of these steps highlight the additional information needed to conduct cumulative effects analysis as part of the evaluation of ecological impacts from highway development. Specifically, cumulative effects analysis requires an environmental baseline against which to compare ecosystem condition (no. 3), identification of other related actions potentially affecting ecosystems (no. 4), and thresholds of significant cumulative impact (no. 5).

Cumulative impacts to ecosystems must be measured against a baseline condition. Depending on the timeframe of concern, there may be a need for both historical and future baselines derived from trends in ecosystem change. One of the special problems associated with highway development is the accumulated effect of individual components of the highway system and the secondary development that often follows. In assessing cumulative impacts to ecosystems, special emphasis should be given to including development activities that reduce the areal extent of habitat types. Lastly, thresholds of significant impact must be set. Because ecosystems are affected in some way by virtually all activities, the cumulative effects analysis problem can become intractable unless significant levels of change are defined.

A number of specific methods have been developed for cumulative effects analysis. Narrative procedural guidance has been developed from reviews of existing methods (e.g., Horak et al. 1983, Lane and Wallace 1988) and additional conceptual frameworks have been proposed by Westman (1985) and Bedford and Preston (1988). Mathematical representations of the cause and effect relationship have included flow diagrams, networks, and matrices (e.g., Stull et al. 1987). More quantitative statistical and modeling approaches based on analysis of historical patterns of impacts have also been developed (e.g., Gosselink et al. 1990). One of the most useful approaches involves map overlay methods that range from general landscape suitability ratings (McHarg 1969) to individual habitat patch preservation priorities (Scott et al. 1987). The recent advancements in GIS technologies have greatly increased the sophistication of current map overlay approaches.

The synoptic approach to cumulative impact assessment recently developed by EPA for wetlands (Leibowitz et al. 1992) provides a practical framework that could be adapted to any habitat type given adequate data. The approach rests on the selection of synoptic indices (actual functions and values within the particular environmental setting of interest) and landscape indicators (actual data used to represent the indices). By associating a parameter of concern (such as integrity of interior forest songbird populations) with a measurable indicator (such as forest patch size), the cumulative impacts within the landscape can be determined. These synoptic indices can then be compared across landscape subunits (e.g., counties, watersheds, or ecoregions) to promote better decision-making and highway planning.

For many situations, assessment of cumulative impacts on the regional scale, so important to understanding threats to ecosystems, poses major difficulties. Frequently the region-specific data necessary for such assessments are lacking, particularly within the time and resource constraints often involved in preparing environmental analyses (Irwin and Rodes 1992). This emphasizes the need for federal agencies to cooperate in developing regional baseline information. Even for small projects, it should always be the objective of the environmental document to analyze impacts at the largest relevant scale, based on the affected resources and expected impacts.

FHWA recognizes the importance of regional analysis and has taken a significant step toward improving the consideration of cumulative impacts by publishing an 8-step framework for incorporating secondary and cumulative impacts considerations into the highway development process (FHWA 1992):

1. Conduct area-wide planning early in the process and look for links with programmed development and resource management plans.

2. Where planning information is not available, use historical data and trends information as an indicator of future development patterns.

3. Determine recent and expected changes in development and resources as a measure of susceptibility of resources.

4. Relate information on trends in development to geographic scope of the project.

5. Incorporate the time period defined by the project design life in the analysis of impacts.

6. Assess the impact of all planned and potential development in areas influenced by the project over its life.

7. Estimate the contribution of the highway project to projected development based on project features that promote or facilitate development.

8. Develop mitigations that are reasonable and related to project impacts. Recognize that measures to address future development are often beyond the control of highway programs and require that highway proponents work with local agencies to incorporate environmental protection provision in all planned development.

6. Mitigation Measures for Ecological Impacts of Highways

CEQ guidance requires that mitigation measures be considered even for impacts that are not themselves "significant" once the proposal as a whole is considered to have significant effects (46 Federal Register 18026, 1981). In the case of highway development impacts, these measures must include both specific design alternatives (that could decrease pollution emissions, construction impacts, and aesthetic intrusion) and other mitigation activities such as relocation assistance and possible land use controls that could be enacted. To adequately consider ecological impacts of highway development, mitigation measures should be developed within the ecosystem framework and should consider the possible impacts of the mitigation itself.

6.1 Ecosystem Approach to Mitigation

Mitigation for ecosystem protection should address the cumulative impacts of all activities within the landscape (which, depending on the scale of the project, may vary from small watersheds to areas exceeding several thousand acres) to ensure that ecosystem integrity and health are maintained. The preservation of individual habitat areas is important but not always sufficient to maintain the ecological integrity of the greater ecosystem. In addition, the size, diversity, distribution, and connectivity of key habitat tracts must be conserved to provide for the natural diversity characteristic of the larger eco-complex or region. The two most important methods for maintaining the integrity of fragmented habitats are (1) the provision of buffer areas, and (2) the creation of habitat corridors. Buffers represent the principal method of avoiding impacts to sensitive areas, and habitat corridors provide the best means of mitigating habitat isolation. The most common means of creating both buffer areas and corridors is the preservation of natural habitat along streams, steep slopes, and other sensitive areas.

<u>Habitat Buffers</u>. The preservation of a sensitive habitat includes both the avoidance of direct conversion of the area and the maintenance of adequate buffer areas so that edge effects and other negative impacts do not affect the sites. For example, highway corridors through forests can be "feathered" to avoid some edge effects (Gates 1991). Additional areas adjacent to the corridor can be cut to create successional bands of vegetation parallel to the corridor opening; this reduces predation rates at the edge and minimizes the barrier effects. However, a wider edge results in less forest interior. Research into the impacts on benthic invertebrate communities indicates that buffer strips between roadways and streams of at least 30 m are required to prevent alteration in invertebrate diversity and ecological structure (Erman et al. 1977). These buffer strips serve to maintain the riparian canopy and to stabilize the stream channel.

<u>Habitat Corridors</u>. Mitigation of habitat fragmentation involves the maintenance or restoration of habitat "connectivity" (Norse 1990). One way to address the fragmentation caused by highway construction is to reduce the effective width of a highway corridor and decrease the barrier effect. In addition to reducing the number of lanes or roadside area, providing wide, densely vegetated medians can facilitate movement of some species across the highway. However, road kills due to collisions remains problematic. For those species that cannot cross highways of any size, fragmentation must be addressed by the provision of habitat corridor underpasses. Corridors have been used successfully in wildlife management for 50 years (Harris and Atkins 1990). Corridors provide for the movement of animals, serve as a population source, contain whole communities, and withstand natural disturbance events, but they also provide for contamination transmission (Csuti 1991). Unfortunately, because edge

effects reach 200 to 600 m into the forest (Pace 1990), optimal corridors widths cannot be achieved with highway bridges and must be addressed when siting the highway.

Although the development of specific mitigation plans must be based on a thorough understanding of the site conditions, certain basic principles of ecological management should be followed when mitigation measures are developed. The following general mitigation principles apply to ecosystem protection efforts:

1. Base mitigation goals and objectives on a landscape-scale analysis that considers the needs of the region.

2. Mimic natural processes and promote native species.

3. Protect rare and ecologically important species and communities.

4. Minimize fragmentation of habitat and promote connectivity of natural areas.

5. Maintain structural diversity of habitats and, where appropriate, species diversity to promote the natural variety of the area.

6. Tailor management to site-specific environmental conditions and to the unique impacts of the specific degrading activity.

7. Monitor for ecological impacts and revise mitigation plans as necessary.

6.2 Mitigations for Each Phase of Highway Development

The first priority in developing mitigation plans for ecosystem degradation should be avoidance of the impact. This is usually a siting issue, i.e., locating all construction activities at a distance from the habitats of concern. The ecosystem is adequately preserved if all possible impact scenarios are accounted for. Barring this solution, effective management measures must be implemented to ensure the protection of the habitats of concern. Failing effective management, mitigation falls to the restoration of habitat, which is often problematic, or finally to compensation.

In the case of highway development, different mitigation measures can be applied at each of the four phases: planning, design, construction, and operation and maintenance. The earlier phases provide opportunities for avoiding sensitive areas during route selection, while the latter phases require mitigation measures for pollution reduction. In the following sections, specific mitigation measures for each of the four phases of highway development are discussed. At the end of each section, a figure provides examples of mitigation measures that may be applicable in that phase.

6.2.1 Planning Phase

The planning phase involves all pre-design activities including the siting of the highway corridor. This is the most important opportunity for mitigation of highway impacts because it allows for consideration of the full range of landscape-level factors. The principal mitigation measure in the planning phase is avoidance of sensitive areas during the selection of the corridor route. Because the route selection is only constrained by the purpose and need of the project, alternative transportation options can also be considered in this phase.

As soon as the purpose and need for a project has been developed, environmental considerations and potential mitigations should be enter into the highway development process. Incorporation of these concerns early in the planning process is the best way of avoiding irreconcilable conflicts. Consideration of alternative transportation options (such as railways and bikeways, or traffic management) should be viewed as initial "mitigation" opportunities before the type of highway is selected. While the range of alternative transportation options may be greater in the urban and suburban settings, these alternatives should be considered for all categories of highway projects. The planning phase is also the best place to consider effects such as reductions in the carbon sink caused by vegetation removal and its implications for global warming.

The next opportunity for mitigation is corridor selection. This is a critical step, especially in wildland and rural settings, because it offers the greatest range of options for avoiding sensitive habitats. For large highway projects, corridor selection itself is worthy of an EIS, even though the actual roadway alignment will be selected at a later time. In the case of Appalachian Corridor H (West Virginia DOT 1992), a corridor selection process based on a width of 2000 ft was used as a means of considering the many valued natural resources within the project area. The only way to avoid habitat fragmentation and impacts to contiguous forest and remote habitat is to mitigate in the planning phase. The vulnerability of many wildland habitats means that even the most conscientious design and construction phases cannot mitigate adverse impacts from a nearby corridor.

An important component in the consideration of corridor impacts is the likelihood and extent of future secondary development. Again, these impacts can be especially devastating to wildland habitats. In devising planning phase mitigation for secondary development, the analyst should look at existing land use within potential corridors, and project possible future land use (forest, agricultural, and urban) based on current land use plans and controls. This requires consideration of state planning regions and local growth centers. It is only in the planning phase that conflict between ecosystem protection and economic development can be resolved. Traditionally, environmental assessments have been limited to identifying which alignment alternatives have the lowest potential for direct support of base floodplain development. This approach should be expanded to include development on all sensitive lands, and mitigation encouraged in the form of appropriate applications of local zoning restrictions.

The final opportunity for mitigation during planning is the selection of the highway alignment (usually a corridor of 150 to 300 ft). This is the step where specific sensitive habitats can be avoided to the extent practicable given the general corridor route. The mitigation goal is to avoid ecologically sensitive areas and limit encroachments to fringe takings rather than severances. To date, this has included avoiding wetlands, large forested or vegetationally diverse tracts, raptor nests, and major wildlife travel corridors, as well as minimizing construction parallel to streams with important fisheries. As before, these considerations should be extended to all sensitive habitats. Mitigations for secondary development can also be implemented at this step by reducing the number of interchanges and other means of highway access. Any measures to minimize the amount of new highway construction in the alignment selection process will mitigate against adverse impacts and secondary development.

Specific mitigations in the planning phase include the following:

- Avoid impacting sensitive habitats for which there are few mitigation possibilities (e.g., special botanical areas).
- Avoid fragmentation of forest cover or other contiguous habitats.
- Utilize existing non-forest lands and transportation corridors.
- Route near existing edges of forests rather than bisecting them.
- Minimize the length and width of right-of-way through or along a forest to reduce creation of edge.
- Avoid or minimize construction of rights-of-way through remote habitat.
- Compensate for unavoidable loss of habitat through in-kind restoration or mitigation banking programs.
- Compensate for unavoidable direct loss of wildlife habitat by increasing the carrying capacity through habitat improvement methods such as planting/harvesting/managing food species, and providing access to water supplies.
- Compensate for unavoidable loss of sensitive habitats for which there are no mitigation possibilities (e.g., special botanical areas) by identifying and preserving areas of similar or greater value.
- Control the indirect effect of human access to sensitive areas through management policies.

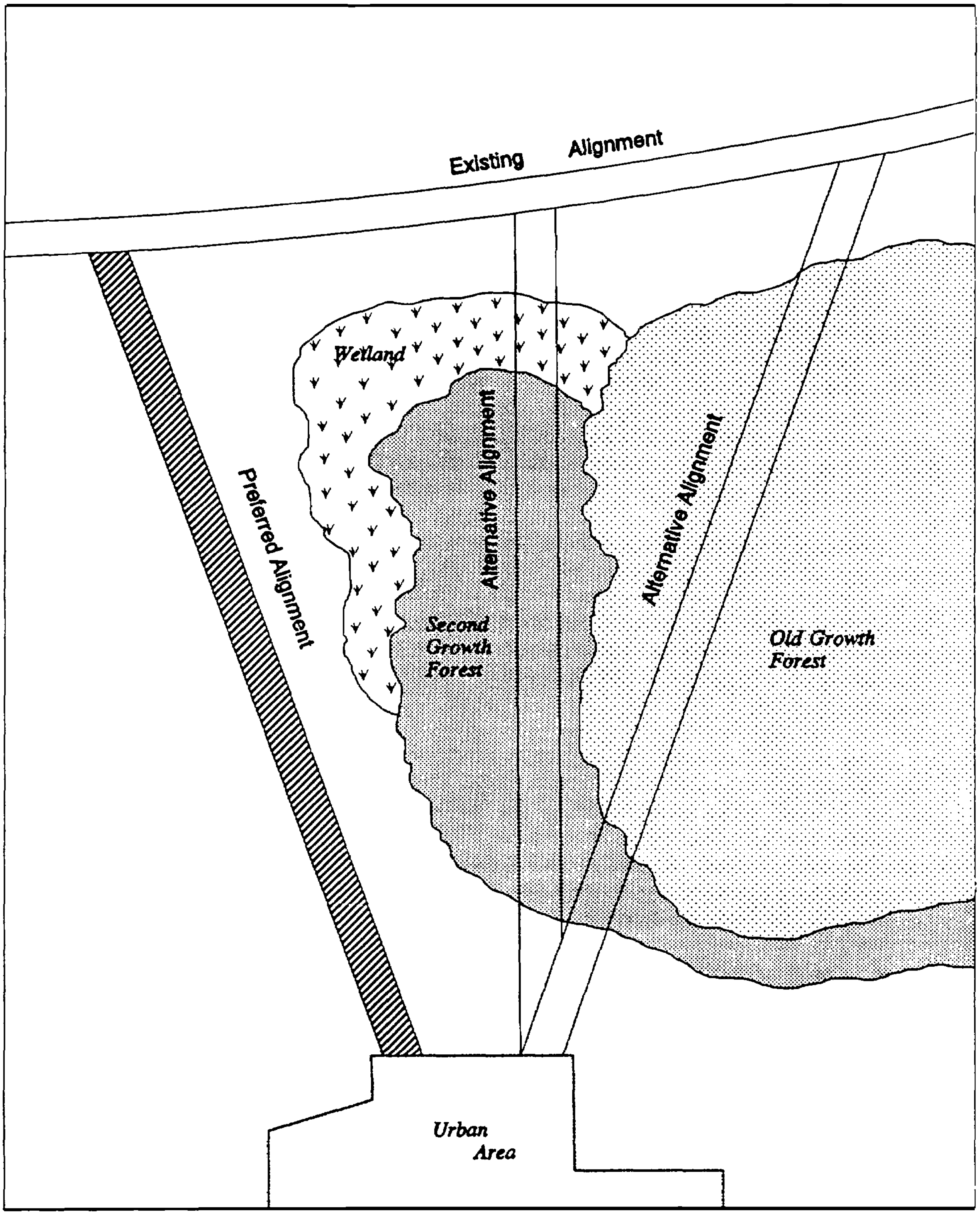


Figure 1. Mitigations in the Planning Phase

6.2.2 Design Phase

The design phase involves the siting of the final right-of-way footprint and all aspects of structural design and within design mitigations. This phase also provides several important mitigation opportunities including both site-scale avoidance of sensitive habitats and structural modifications to the highway design that may reduce impacts of fragmentation or off-site effects. Design of corridor width, median type, roadside vegetation, and location of borrow areas can all contribute to the minimization of ecological impacts. Specific structural mitigations, such as bridges, underpasses or tunnels, and fencing, have considerable potential for enhancing habitat conservation goals.

Once the highway project has been planned (both corridor and alignment selected) many of the opportunities for avoiding sensitive habitats have been removed. However, certain site-level changes in the roadway footprint can be made in the design phase and these changes can minimize effects which can not be avoided. These include limiting impingement on adjacent habitats (through lane adjustments and bridge design), minimizing barrier affects (through the use of bridges and water conveyance), and reducing pollution impacts (through noise walls, curb design, and catchment basins). The unique problem of road kills can be addressed through combinations of fencing and underpasses. At the same time, the design phase provides the opportunity for incorporating substantial restoration or habitat creation activities within the right-of-way (mitigation banking may be better considered under the planning phase).

Avoidance of sensitive habitats through highway design is progressively more important in suburban, rural, and wildland settings. Essentially, the strategy is to reduce the roadway "footprint." Reliance on existing roadway alignments is a primary means of doing this. It may also be accomplished by reducing the roadbed elevation to minimize shoulder width; by shifting the alignment (e.g., to avoid pothole wetlands); or by widening the median to encompass small communities or wetlands. A reduced footprint also allows for a larger buffer zone between the roadway and sensitive habitats, especially stream and wetlands.

Even though sensitive habitats may not be directly altered, nearby highway construction usually entails negative impacts associated with a "barrier effect." Designs to ameliorate the effect of highway barriers should be based on an understanding of the functioning of habitat patches, corridors, edges, and the landscape matrix in the project area (Gates 1991). Mitigations for nearby wetlands include use of minimal practical slopes and median widths; maintenance of existing surface and subsurface hydrology; and provision of passageways through and around structures for movement of biota. Burnett (1992) recommends the following mitigation measures for barrier effects in forests:

- Construct narrow roads.
- Leave the canopy intact.
- Incorporate sub-road tunnels
- Build long bridges (as opposed to culverts or tunnels) over gullies and waterways.

Although the provision of underpasses for animal movement is still being researched, it can generally be said that long bridges are preferable (although this entails higher costs). Barrier effects have been demonstrated for reptiles and amphibians, and some small mammals. Certainly, the fall and spring migrations of amphibians are problems in certain areas. In some cases, successful migrations can be facilitated with short-term traffic management, but roadway tunnels may be the preferred solution (Daly 1993). Solid concrete median barriers pose an additional problem and it has not been determined whether passageways in these barriers would be beneficial for smaller species (Adams and Geis 1981). Hunt et al. (1987) recommend using a variety of tunnel sizes, because new tunnels are predominately used by feral predators. Many species also require regeneration of native vegetation around tunnel entrances before they will use them.

The U.S.H. 53 project in Washburn and Douglas Counties, Wisconsin is an innovative example of mitigation for animal migration across a highway (U.S. DOT and Wisconsin DOT 1991). In this project, the highway corridor passed through an important wolf migration pathway. In order to minimize adverse impacts on the wolf population, significant lengths of "wolf shift" zones (areas with a wide, forested median) were proposed. Although this wide median constitutes the minimal feasible barrier to wolf migration, passage would still be adversely affected. To mitigate for this impact, full control of access through this section of the project (with no new private accesses allowed) was proposed. It was believed that the benefit of precluding secondary development in the project area (thereby preserving this dispersal corridor) would exceed the adverse effects of the highway. In addition, to ensure that wolves or other large animals such as deer or bear would not be restricted by the expressway, fencing would be installed only adjacent to farms with domestic herd animals.

Road kill mortality is another important factor affecting a wide variety of species. Fencing is a common solution, although the reduction in deaths must be weighed against increasing the barrier effect, especially for long stretches of exclusive fencing (Leedy 1975). Research into the use of box-type underpasses by mule deer crossing under interstates with big game fencing (8 ft high) indicates that vehicle-deer collisions can be reduced by over 90% (Ward et al. 1980). However, results indicate that elk and pronghorn do not significantly use underpasses. All three species were twice as likely to avoid roads when people were walking nearby than when traffic was present. While fencing solutions may help resolve deer-human conflicts, Povilitis (1989) feels that road kill problems are fundamentally a land use issue (because conflicts arise when deer occupy wooded areas finely interspersed over land) that needs to be mitigated in the planning phase.

Another impact from highway development that can be mitigated with barrier design is noise and visual disturbance. FHWA noise abatement criteria (currently 67 dBA for parks and 55 dBA for wilderness) could be based on threshold levels of substantial increase above ambient levels, not predetermined levels. Noise abatement measures (usually entailing substantially higher costs) include creating noise barriers of concrete, stone, wood, or earth; shifting the centerline away from sensitive receptors; and depressing the roadway below the level of sensitive receptors. Van Der Zande (1980) has shown that highway disturbance is especially severe in open field habitats, and that it cannot be eliminated by simply placing walls or trees along the roadside, since these features only partially reduce the disturbance. Where effects might be reduced by constructing the road below ground level, the benefits must be balanced against the tendency of this practice to worsen hydrological impacts.

Perhaps the most severe barrier effect that can be remediated within the design phase is blockage of fish migration. As stated earlier, the retention of natural habitat and maintenance of normal stream flow are best achieved by constructing bridges that do not impinge on the stream environment. However, culverts are considerably more economical; therefore it is important to set threshold conditions where it is appropriate to use culverts in place of bridges. Ideally, a culvert installation should not change the conditions that existed prior to that installation, i.e., the cross-sectional area should not be restricted by the culvert, the slope should not change, and the roughness coefficients should remain the same. Changes in these parameters could alter velocity and sediment transportation capacity of the stream and adversely affect fish passage (Baker and Votapka, 1990). Successful culvert design involves matching the velocities of the fish's swimming zone in the culvert to the swimming capacity of the "design fish." It is important to include the full assemblage of native migratory fish in these design considerations. Culvert options include bottomless and buried pipe arches, and box, circular, and squash culverts. Criteria for culverts that provide successful fish passage are as follows:

1. Natural stream bottom.
2. One large culvert, or two with one specifically for passage.
3. Corrugated surface, especially for larger culverts.
4. Diameter must pass maximum flow and debris (50 yr flood at static flow and 100 yr flood at headwater depth).
5. Design for increased flows from urbanization.
6. Design for stream velocity.
7. Maximum acceptable velocity and depth.
8. Allow for delay in passage only during 5% peak flow (as a cost saving) because it does not affect fish.
9. Use larger pipe over baffles.
10. In high gradient streams, provide resting pools and bank protection above and below.
11. Locate culvert where stream is straightest, do not cut off meanders.
12. Carefully install riprap.
13. No concrete aprons at openings.
14. Outlet pool with tailwater control (2x diameter and 2 ft deep).
15. Complete rehabilitative work before rediverting stream back (armor embankment but use natural vegetation rather than armoring on streambank).

In addition to providing for safe passage of fish and other animals, highway design can mitigate impacts to natural hydrological patterns. These patterns of water flow are critical to the functioning of adjacent wetlands and maintaining the integrity of riparian areas. Problems related to road design and their effects on riparian areas can be divided into four categories (Terrene Institute 1993): stream crossings (culverts, fords, and bridges), wet meadow crossings, road alignment, and road drainage. Culverts designed for fish passage should also be sized for minimal impact on flood height and duration. Placement of the bottom of the culvert at the natural channel level, and alignment of the structure with the natural stream direction and gradient, serve to facilitate natural hydrology as well as fish passage. Where there is not a single natural channel, multiple culverts should be placed over the width of the drainage area. Another option is to use french drains under the roadbed to maintain existing subsurface flows. Although culverts should be designed to pass expected high flows, structures that detain water and sediment above the road (such as an upstream dike) can ameliorate erosion and other deleterious effects.

More specific designs related to water flow can also help mitigate the impact of pollution runoff from highways. Potential design mitigations (many of which are in standard water quality specification manuals) include the following:

- Stabilize cut and fill slopes, shoulders, and median with perennial vegetation or non-erosive materials such as riprap or geotextiles.

- Omit the use of curbs for delineation and stormwater runoff control where possible. Consider leaving gaps in continuous curbs to allow transport of pollutants from the highway.

- Establish permanent discharge points for stormwater, including directing stormwater runoff over vegetated surfaces, using wet or dry detention basins, or using infiltration systems to retain runoff.

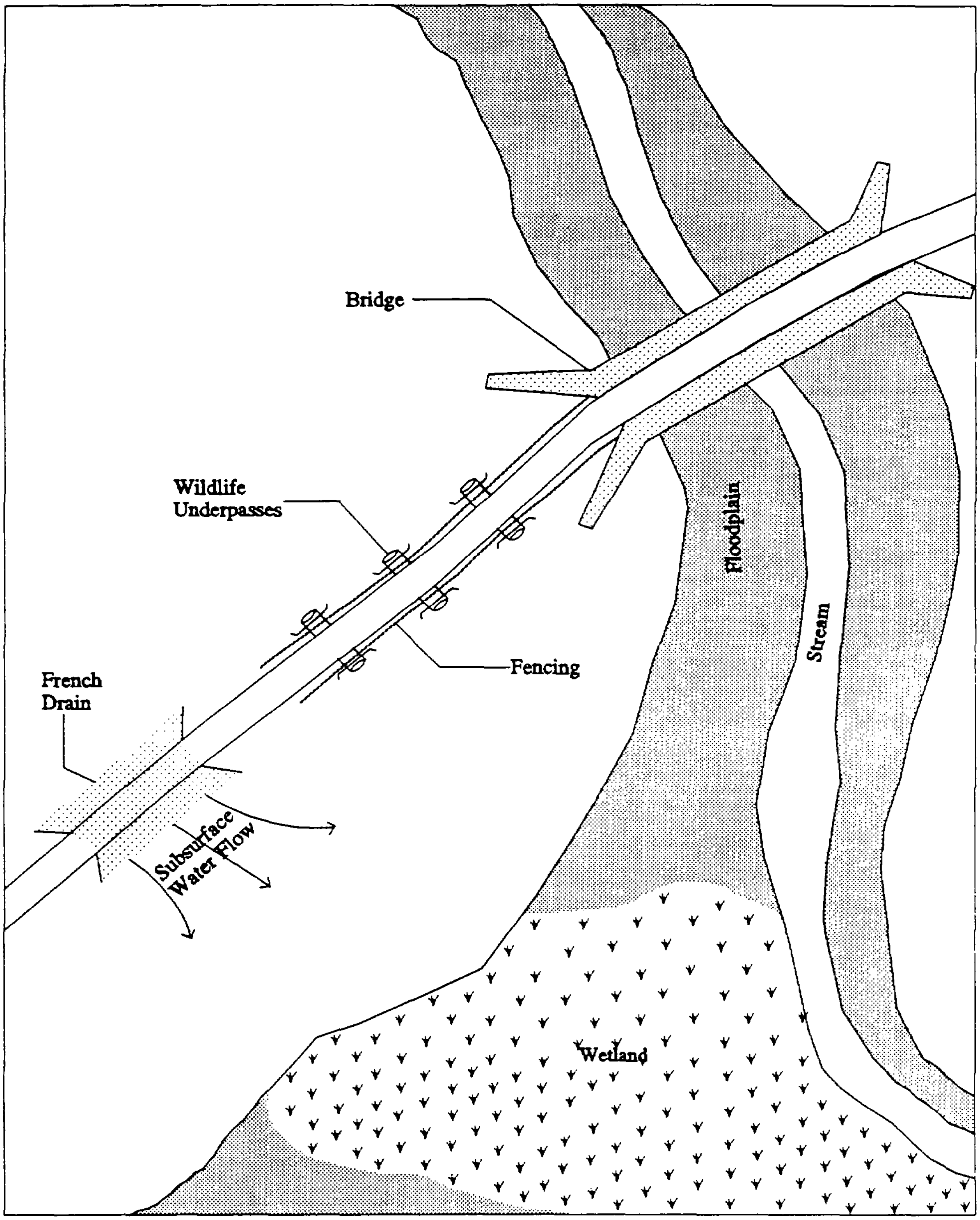


Figure 2. Mitigations in the Design Phase

6.2.3 Construction Phase

The construction phase consists of the vegetation removal, earth leveling, and paving steps provided for in the planning and design phases. While each of these steps is required by the preceding decisions, the specifics of the construction process can be modified to eliminate many of the short-term adverse impacts of completing these steps. The opportunities for mitigation in this phase are primarily best management practices (BMPs) that reduce soil erosion, toxic runoff, noise, and other construction-related pollution. Careful planning and supervision of construction operations can also reduce unnecessary vegetation removal and land scarring.

Mitigations of construction impacts are similar in urban, suburban, rural, and wildland settings, but their importance may vary dramatically. In wildland and rural settings, where there are more sensitive receptors, minimization of pollution and disturbance impacts is especially important. Even in urban and suburban settings, however, the cumulative effects of runoff from many highway projects may severely impact downstream waterbodies such as the Chesapeake Bay.

The principal mitigation measure in the construction phase is strict application of standard specifications for erosion and sediment control, including routine inspections (Krame et al. 1985). This involves the installation of erosion curtains, runoff settlement ponds, and stream diversions where necessary. In general, 200-ft grass filter strips should be provided around staging areas and special precautions should be taken to contain hazardous waste spills. Where possible, consideration should be given to soundproofing individual sensitive receptors and or completely eliminating construction during critical nesting or breeding periods.

An erosion control system plan should be carefully designed to minimally affect local water quality and to clean sediment-laden water resulting from the disturbed area. If a stream passes through the construction area, it should be diverted or piped so that it does not acquire sediment. All sediment-laden water is then channelized and directed to sediment ponds for treatment. Water should only be returned to the stream when it has a sediment load comparable to the undisturbed stream. To accomplish this, a ditch is built above the project and lined with plastic; a flexible pipe diverts the water; erosion bales are used to contain runoff; chemical agents may be used to settle clay silt.

Construction can also install permanent pollution control measures that stabilize the disturbed area and minimize soil movement through natural means. This includes the planting of grasses and the placement of rock at culvert outlets and small streams intercepted by cut slopes. Revegetation should include early topsoil placement, seeding, fertilization, and mulching for all disturbed areas (including marsh disposal areas). Many new innovative mulches and nettings are available to eliminate erosion and minimize plant growth delay. Retaining walls and sidehill structures can be built of modular components to fit into the natural topography and reduce construction time and limit impacts. Bridges can use precast structures and on deck construction techniques to minimize terrain disruption, tree removal, and stream encroachment. Haul bridges should be used to eliminate crossing streams with heavy equipment and specially designed machinery or mats should be used to reduce soil compaction.

Stream relocation should consider the needs of the resident aquatic community. Construction should be limited to dates when spawning, nesting, and breeding are not at risk. If the relocation is permanent, construction must be a true recreation and provide fish habitat in the form of deep pools, riffle areas, and constant flow in new channel. The new stream should achieve a stable morphology and natural meander pattern (Rosgen 1985), and use natural materials and plantings. The original gravel size should be maintained in the streambed, and stream shading vegetation should remain on the banks. Where habitat structure have been lost, log dams, channel deflectors, overhang bank cover, lunker structures, and boulders can be added. Equally important is the maintenance of natural riparian zones by minimizing vegetation clearing and protecting areas that are not cleared.

Many innovative methods are available for maintenance of aesthetic characteristics following construction. A return to the natural landform is desirable for ecological as well as aesthetic reasons (e.g., microclimate conditions). Careful landscape work concentrated near the base of fills and at the top of cut slopes can blend the physical features of the site. Where slopes must be modified along the roadbed, adjacent areas can be flattened and rolled to reflect existing landscape characteristics. Rock cut sculpturing can retain natural fracture lines and cleared areas can be blended into "natural" forest openings. Careful revegetation efforts are critical and should use transplants of young trees from the neighboring area, as well as native grasses and wildflowers. Monitoring should be conducted to determine if vegetative invasion from natural areas is adequate.

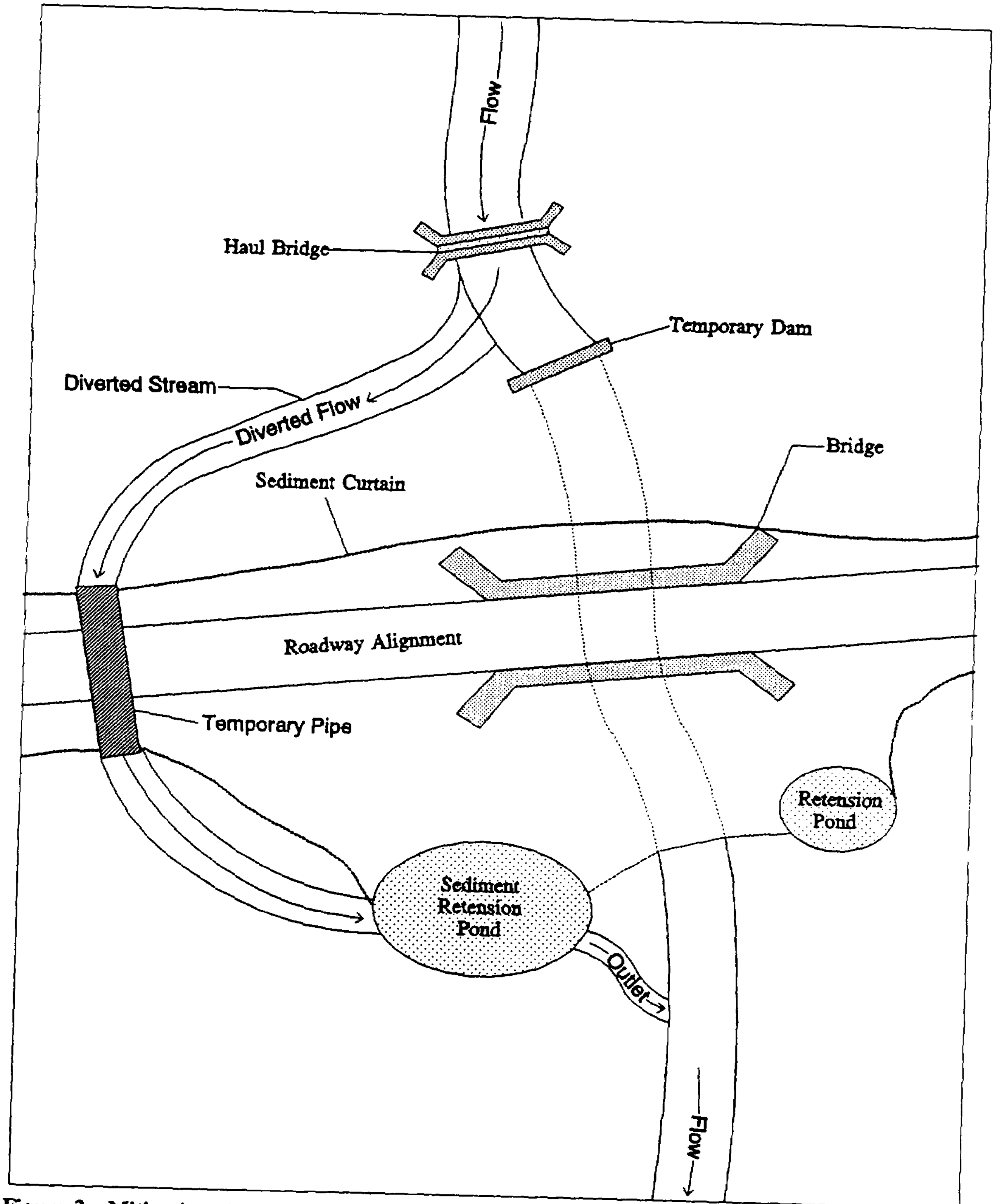


Figure 3. Mitigations in the Construction Phase

6.2.4 Operation and Maintenance Phase

The operation and maintenance phase is the long-term result of the three preceding phases. A highway will necessarily carry traffic and require regular maintenance activities. A certain amount of pollution (both surface runoff and atmospheric deposition of toxic materials) is associated with road traffic. Street painting, cleaning, and periodic construction also contribute to these impacts. Mitigation opportunities in this phase are basically long-term applications of BMPs similar to those used in the construction phase. Stormwater retention ponds are one of the most important. Another, equally important, mitigation opportunity is the requisite monitoring and enforcement activities required to ensure that mitigations included in the design phase remain functional for the life of the project.

As with the construction phase, the pollution impacts of the operation and maintenance phase generally have greater impact on the more sensitive wildland and rural habitats. However, because of the greater traffic volumes in urban and suburban settings, the cumulative effect of highway operation may be greater in these areas, especially in receiving waters. Fortunately, it is likely that greater mitigative efforts through maintenance programs will be available in higher traffic areas.

General highway management policies and programs can have a major beneficial effect on mitigating the impacts of highway operation and maintenance. Even programs to reduce driving miles, automobile emissions, and roadside litter are important. Direct mitigation measures in the operation and maintenance phase fall into the following categories:

- Control litter and limit potential pollution sources.
- Properly manage the storage, handling, and application (at optimal rates with well-maintained spreading equipment) of deicing chemicals.
- Manage pesticide and herbicide use so that sensitive receptors are not negatively impacted.
- Avoid direct discharge of highway runoff to receiving waters.
- Reduce runoff velocities through flatter grades, drop structures or baffles, or grassed waterways.
- Reduce pollutant concentrations in runoff by maintaining dense grass cover, increasing grass height, and leaving cuttings on the ground.
- Properly manage roadside and median vegetation, using only native species and enhancing wildlife food and cover where appropriate (e.g., for bird species not subject to road mortality).

Stormwater management is an important component of operation phase mitigation strategies and requires application of many of the measures discussed under the construction phase, including vegetative controls, detention basins, and infiltration systems. Vegetation management is associated with stormwater management, but also plays an important role in the mitigation of wildlife impacts. For example, vegetation can serve as noise buffers and shrub plantings can increase production of nesting birds (Leedy 1975). Mowing should be avoided prior to July so young birds and mammals can fledge and disperse; while, selective mowing and cutting can be used to maintain ecotone diversity. Invasion by exotic species poses a special problem that should not be enhanced by plantings of non-native species along roadways. Driver education programs can be targeted at reducing the transportation of exotics and intentional road kills, especially of box turtles.

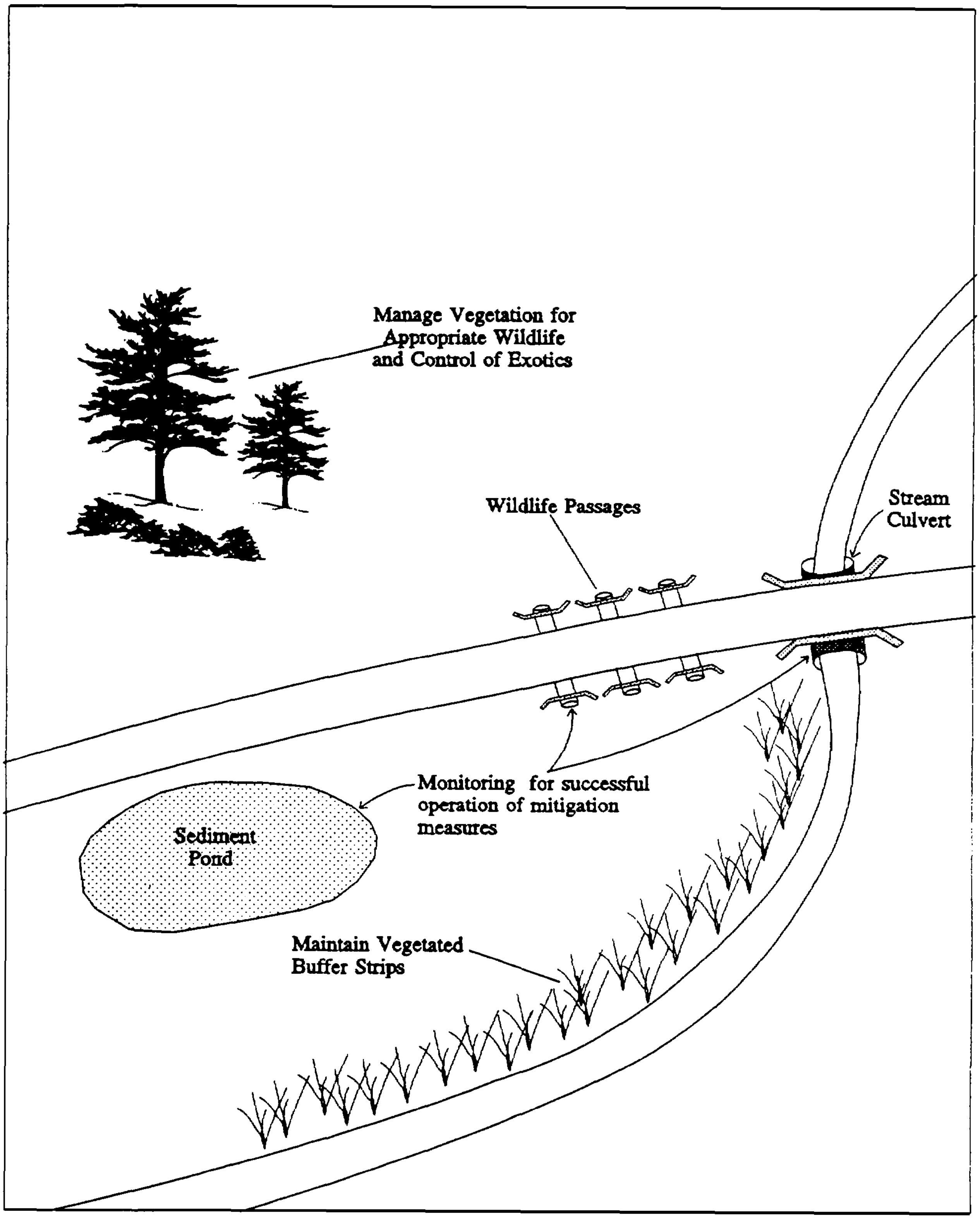


Figure 4. Mitigations in the Operations and Maintenance Phase

6.3 Ecological Restoration as Mitigation

When impacts to ecosystems cannot be avoided or substantially minimized during the planning, design, construction, and operation phases of highway development, mitigation falls to ecological restoration. Recent experience with wetlands mitigation involving the restoration or creation of wetlands has improved both the science of restoration (Kusler and Kentula 1989, Marble 1990, Hammer 1992) and the management of mitigation options for unavoidable losses (Kentula et al. 1993). Mitigation banking for highway impacts to wetlands has been initiated in several states under programs of varying design (Short 1988, Howorth 1991). An alternative to banks are "joint projects" where a group of developers agrees to carry out a specific mitigation project to compensate for specific losses. Although the restoration of large wetland areas that is possible under banking is desirable, the difficulty of compensating for the loss of on-site and like-wetland-type values suggests caution in relying solely on mitigation banks (Kusler 1992). Nonetheless, substantial opportunities exist for integrating these innovative approaches into FHWA procedures dealing with NEPA and Section 404 requirements (FHWA et al. 1988).

Adequate mitigation of ecological impacts from highway development may require restoration of habitat types other than wetlands. Fortunately, wetland restoration is increasingly being seen as a landscape or watershed level activity (NRC 1992) that includes restoration of other habitats (e.g., riparian areas and forests). At the same time, new mitigation efforts are being focused on restoration of endangered species habitats (David Wyatt, Caltrans, personal communication). Although the difficulties in achieving sustainable restored wetlands will doubtlessly be duplicated as restoration is undertaken for other habitat types, considerable success has been achieved for many habitats (notably forests and prairies). The following five-point framework is proposed for addressing ecosystem restoration (Southerland 1991):

1. Define the restoration goal.
2. Specify the restoration objectives of sustainability and ecological values.
3. Apply a holistic approach to achieve functional restoration.
4. Assess the restoration by comparison with reference systems and integrated measures.
5. Use practical criteria that reflect the desired ecosystem values for each ecosystem type.

Larger policy decisions, such as whether to restore for a particular use or for the natural condition, should be addressed in Step 1. It is also the time to determine how to incorporate the landscape setting into the project goals. When the goal is ecological restoration, the objective of a "natural sustainable community" should be explicitly stated. In addition, the specific suite of ecosystem values and services that are desired should be selected. This will determine the degree of restoration required and the expected deviation of the restored system from the predisturbance condition. Even when it is impossible to return affected areas (e.g., medians and roadsides) to their natural condition, innovative restoration techniques can be used to better integrate the areas into the surrounding landscape (Harker et al. 1993). Even simple tree planting along highways by organizations such as American Treeways and Maryland's Cloverleaf Foundation (in coordination with state highway departments) can benefit the landscape (Rodbell 1993).

The actual restoration steps required will depend on the condition of the degraded habitat to be restored. Two classes of restoration can be envisioned for highway-related impacts: (1) restoration of habitat which remains intact but is degraded by highway development activities and (2) restoration and creation of habitat (both in-kind and different habitats) as a replacement for habitat that has been converted to highway pavement or other incompatible use. The second class includes restoration or creation within the highway corridor of habitats that provide desired landscape functions but were not specifically degraded by highway activities. It is FHWA policy to encourage states to convert excess rights-of-way to public uses or to joint-use projects (Linker 1989). Increasingly, joint-use projects are being undertaken to construct engineered wetlands for basinwide control of nonpoint source pollution and water quality improvement. Other types of restoration within extensive right-of-way areas include habitat enhancement for certain birds species or restoration of remnant of prairie plant communities (Drake and Kirchner 1987). The most important factor in conducting right-of-way restorations (and maintenance) is the control of exotic species. Both accidental and purposeful introductions of non-native species (especially plants) must be avoided.

Depending on the severity of the degradation, ecological restoration will intervene at one of the following stages of restoration: detoxification, creation of physical structure, restoration of chemical balance and nutrient supply, return of vegetation and soil microfauna, integration of habitat features and spatial heterogeneity of patches, and colonization with fauna. Whatever the method employed, the assessment and modification of the restoration effort should be based on comparisons with appropriate reference systems to ensure that the desired ecosystem structures, functions, and values are attained. This reference-based approach may be most useful when combined with a regional ecological classification (such as Omernik's (1987) EPA ecoregions concept) and integrated measures of ecological integrity obtained from undisturbed ecosystems (such as Karr's (1991) Index of Biological Integrity).

6.4 Mitigation Monitoring

Monitoring is essential to understanding the effects of a project. It is likewise critical to evaluating the degree of implementation and success or failure of mitigation efforts. Effects observed through monitoring can help modify project management or improve future decisionmaking on projects with similar impacts, or in similar areas (Canter 1993). It is unlikely that adequate information on project effects and mitigation implementation and success will be obtained unless it is provided for in the monitoring program.

Many of the elements necessary for adequate monitoring will have been developed as part of project planning and environmental analysis. These include the following (Noss 1990):

- Gathering data.
- Establishing baseline conditions.
- Identifying ecological elements at risk.
- Selecting ecological goals and objectives.
- Predicting likely project impacts.
- Establishing the objectives of mitigation.

The following additional monitoring-specific steps can build upon these elements:

- Formulate specific questions to be answered by monitoring.
- Select indicators.
- Identify control areas/treatments.
- Design and implement monitoring.

- Confirm relationships between indicators and goals and objectives.
- Analyze trends and recommend changes to management.

The breadth and specificity of the monitoring program will be determined by the habitat mitigation goals. Mitigation of habitat impacts in the planning and design phases usually involve avoidance of sensitive habitats and monitoring is required ensure that the distribution of habitats was accurately understood and that the attenuation of impacts at the habitat boundary were as expected. Mitigation in the construction and operation phases primarily involve control of pollution. This is especially true for wetland and aquatic systems where, after physical alteration, off-site impacts to hydrology and water quality pose the greatest threat. Monitoring of pollution control measures is an essential part of the mitigation of highway construction and operation impacts.

The fact that many restoration projects designated as mitigation have not achieved their desired objectives is well documented. It is also believed that mitigation measures for many projects are not adequately implemented or enforced. Therefore, determination of the true effectiveness of mitigation should be the goal of monitoring programs.

In the case of mitigation based on ecological restoration, monitoring is essential to determine restoration effectiveness, and thus mitigation success. Practical criteria must be selected for use in evaluating the success of restoring the habitats of concern. Because the constraints of practical measurement are already being considered by various agencies in the development of environmental monitoring programs, a greater range of validated quantitative ecosystem parameters may soon be available for evaluation of restoration success (e.g., Hunsaker and Carpenter 1990). The following categories of criteria are proposed as the minimum from which habitat restoration indicators should be selected:

- Areal extent
- Absence of contamination
- Hydrology
- Water chemistry and quality
- Physical structure and soils
- Nutrients
- Productivity
- Microbial community
- Vegetation
- Habitat structure
- Biota
- Biological integrity
- Population response.

7. Summary of Mitigations for Ecological Impacts

The following table is a summary of the principal mitigation measures recommended for highway impacts arising in each phase of project development (planning, design, construction, and operation) within each of the four environmental settings (urban, suburban, rural, and wildland).

Table 4. Principal Mitigation Measures for Ecological Impacts By Phase and Setting of Highway Development

	Urban	Suburban	Rural	Wildland
Planning	Use alternative transportation options	Use alternative transportation options and select alignment to avoid sensitive environments	Select corridor and alignment to avoid sensitive habitats	Select corridor to avoid sensitive habitats and control secondary development
Design	Fence roadway to reduce road kills	Fence roadway to reduce road kills and provide connectivity of habitat with bridges and underpasses	Provide connectivity of habitat with bridges and underpasses	Reduce roadway footprint and provide connectivity of habitat with bridges and underpasses
Construction	Reduce erosion and pollution effects through best management practices	Reduce erosion and pollution effects through best management practices	Apply best management practices and protect sensitive receptors with walls and nonintrusive construction schedule	Apply best management practices and protect sensitive receptors with walls and nonintrusive construction schedule
Operation	Conduct trash removal and ensure operation of stormwater controls	Ensure operation of design mitigations and stormwater controls	Ensure operation of design mitigations and stormwater controls and manage roadside for rare communities	Ensure operation of design mitigations and stormwater controls and manage to control invasion of exotics

8. Bibliography

Adams, L.W. and A.D. Geis. 1981. Effects of Highways on Wildlife. Urban Wildlife Research Center and U.S. Fish and Wildlife Service. Prepared for U.S. Department of Transportation, Federal Highway Administration, Washington, DC. FHWA/RD-81/067.

Adamus, P.R., E.J. Clairain, Jr., R.D. Smith, and R.E. Young. 1987. Wetland Evaluation Technique (WET). Vol. II. Methodology. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS. 178 pp.

Anonymous. 1993. White Paper: Management of Weeds on Native American and Federal Natural Resource Lands for the Purpose of Maintaining and Restoring Healthy Ecosystems. Submitted to Federal Coordinating Committee on Science, Engineering, and Technology (FCCSET) by Federal Interdepartmental Committee for Management of Weeds (FICMW), Washington, DC.

Bailey, R.G. 1980. Description of the Ecoregions of the United States. U.S. Department of Agriculture, Forest Service. Miscellaneous Publication Number 1391. 77 pp.

Baker, C.O. and F.E. Votapka. 1990. Fish Passage Through Culverts. USDA-Forest Service, San Dimas, CA. Prepared for U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

Barrett, G.W. and P.J. Bohlen. 1991. Landscape Ecology. In: W.E. Hudson. *Landscape Linkages and Biodiversity*. Island Press, Washington, DC. pp. 149-161.

Bausch, C. 1991. NEPA Integration: Effective, Efficient Environmental Compliance in the 1990s. Proceedings of a Workshop at Hyatt Fairlakes, Fairfax, VA.

Bedford, B.L. and E.M. Preston. 1988. Developing the Scientific Basis for Assessing Cumulative Effects of Wetland Loss and Degradation on Landscape Functions: Status, Perspectives, and Prospects. *Environmental Management* 12(5):751-771.

Bell, M.C. 1991. Fisheries Handbook of Engineering Requirements and Biological Criteria. U.S. Army Corps of Engineers, North Pacific Division, Fish Passage Development and Evaluation Program, Portland, OR.

Bohm, P. and C. Henry. 1979. Cost-Benefit Analysis and Environmental Effects. *AMBIO* 8(1):18-24.

Buechner, M. 1987. Conservation in Insular Parks: Simulation Models of Factors Affecting the Movement of Animals Across Park Boundaries. *Biological Conservation* 41:57-76.

Burnett, S.E. 1992. Effects of a Rainforest Road on Movements of Small Mammals: Mechanisms and Implications. *Wildlife Research* 19:95-104.

Canter, L.W. 1993. The Role of Environmental Monitoring in Responsible Project Management. The *Environmental Professional* 15(1):76-87.

Case, R.M. 1978. Interstate Highway Road-Killed Animals: A Data Source for Biologists. *Wildlife Society Bulletin* 6(1):8-13.

Costanza, R., B.G. Norton, and B.D. Haskell. 1992. *Ecosystem Health: New Goals for Environmental Management*. Island Press, Washington, DC. 269 pp.

Council on Environmental Quality (CEQ). 1993. Incorporating Biodiversity Considerations Into Environmental Impact Analysis Under the National Environmental Policy Act. Council on Environmental Quality, Executive Office of the President, Washington, DC. 29 pp.

Council on Environmental Quality (CEQ). 1981. Forty Most Asked Questions Concerning CEQ's National Environmental Policy Act Regulations. *Federal Register* 46(55):18026-18038. March 23.

Csuti, B. 1991. Introduction to Conservation Corridors: Countering Habitat Fragmentation. In: W.E. Hudson. *Landscape Linkages and Biodiversity*. Island Press, Washington, DC. pp. 81-89.

Daly, C.B. 1993. For Salamanders, the 'Big Night' is Everything. *The Washington Post*, April 18.

De Waal Malefyt, S., J.J. De Waal Malefyt, and P.H. Astor. 1976. An Ecological Methodology Used in the Selection of a 500 KV Transmission Line Route in the Southwestern United States. In: Symposium on Environmental Concerns in Rights-of-Way Management, Mississippi State University. January 6-8.

Drake, L. and B. Kirchner. 1987. Protecting Remnant Natural Communities Along Rural Roadsides. *Natural Areas Journal* 7(2):79-80.

Erman, D.C., J.D. Newbold, and K.B. Roby. 1977. Evaluation of Streamside Bufferstrips for Protecting Aquatic Organisms. Office of Water Resource and Technology No. 165. Department of Interior, Washington, DC.

Federal Highway Administration (FHWA). 1992. Position Paper: Secondary and Cumulative Impact Assessment in the Highway Project Development Process. Project Development Branch, HEP-31, FHWA, Washington, DC. April.

Federal Highway Administration (FHWA), National Marine Fisheries Service, U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, and U.S. Fish and Wildlife Service. 1988. Applying the Section 404 Permit Process to Federal-Aid Highway Projects. Washington, DC. FHWA-RE-88-028.

Ferris, C.R. 1979. Effects of Interstate 95 on Breeding Birds in Northern Maine. *Journal of Wildlife Management* 43:421-427.

Forman, R.T.T. and M. Godron. 1986. *Landscape Ecology*. John Wiley and Sons, New York. 619 pp.

Forman, R.T.T. and M. Godron. 1981. Patches and Structural Components for a Landscape Ecology. *BioScience* 31:733-740.

Frey, T.H. and R. Hexem. 1985. Major Uses of Land in the United States: 1982. Economic Research Service Agricultural Economics Report No. 535. U.S. Government Printing Office. Washington, DC.

Gates, J.E. 1991. Powerline Corridors, Edge Effects, and Wildlife in Forested Landscapes of the Central Appalachians. In: J.E. Rodiek and E.G. Bolen. *Wildlife and Habitats in Managed Landscapes*. Island Press, Washington, DC. pp. 12-32.

Golet, F.C. 1976. Wildlife Wetland Evaluation Model. In: J.S. Larson, ed. Models for Assessment of Freshwater Wetlands. University of Massachusetts Water Resources Research Publication No. 32, Amherst. 91 pp.

Goodman, D. 1987. The Demography of Chance Extinction. In: M.E. Soule, ed. *Viable Populations for Conservation*. Cambridge University Press. pp. 11-34.

Gosselink, J.G., G.P. Shafer, L.C. Lee, D.M. Burdick, D.L. Childers, N.C. Leibowitz, S.C. Hamilton, R. Boumans, D. Cushman, S. Fields, M. Koch, and J.M. Visser. 1990. Landscape Conservation in a Forested Wetland Watershed: Can We Manage Cumulative Impacts? *Bioscience* 40:588-600.

Hammer, D.A. 1992. *Creating Freshwater Wetlands*. Lewis Publishers, Boca Raton, FL. 312 pp.

Harker, D., S. Evans, M. Evans, and K. Harker. 1993. *Landscape Restoration Handbook*. Lewis Publishers, Boca Raton, FL.

Harris, L.D. 1984. *The Fragmented Forest: Island Biogeography Theory and the Preservation of Biotic Diversity*. University of Chicago Press, IL. 211 pp.

Harris, L.D. 1988. The Faunal Significance of Fragmentation of Southeastern Bottomland Hardwood Forest. In: D. Hook and R. Lea, eds. Proceedings of the Symposium: Forested Wetlands of the Southeastern United States. General Technical Report SE-50. U.S. Department of Agriculture, Forest Service, Asheville, NC.

Harris, L.D. and K. Atkins. 1990. Faunal Movement Corridors in Florida. In: W.E. Hudson. *Landscape Linkages and Biodiversity*. Island Press, Washington, DC. pp. 117-134.

Horak, G.C., E.C. Vlachos, and E.W. Cline. 1983. Methodological Guidance for Assessing Cumulative Impacts on Fish and Wildlife. Report to U.S. Fish and Wildlife Service. Dynamac Corporation, Fort Collins, CO.

Howorth, L.S. 1991. Highway Construction and Wetland Loss: Mitigation Banking Programs in the Southeastern United States. *The Environmental Professional* 13:139-144.

Hunsaker, C.T. and D.E. Carpenter. 1990. Environmental Monitoring and Assessment Program—Ecological Indicators. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC. EPA 600/3-90/060.

Hunt, A., H.J. Dickens, and R.J. Whelan. 1987. Movement of Mammals Through Tunnels Under Railway Lines. *Australian Zoologist* 24:89-93.

Idaho Cooperative Fish and Wildlife Unit. 1991. Gap Analysis Newsletter, Volume 1, Number 1. University of Idaho, Moscow.

Irwin, F. and B. Rodes. 1992. Making Decisions on Cumulative Environmental Impacts: A Conceptual Framework. World Wildlife Fund, Washington, DC. 54 pp.

Johnson, A.S. 1989. The Thin Green Line: Riparian Corridors and Endangered Species in Arizona and New Mexico. In: G. Mackintosh, ed. In Defense of Wildlife: Preserving Communities and Corridors. Defenders of Wildlife, Washington, DC. pp. 35-46.

Karr, J.R. 1991. Biological Integrity: A Long-Neglected Aspect of Water Resource Management. *Ecological Applications* 1:66-84.

Kentula, M.E., R.P. Brooks, S.E. Gwin, C.C. Holland, A.D. Sherman, and J.C. Sifneos. 1993. *An Approach to Improving Decision Making in Wetland Restoration and Creation*. Lewis Publishers, Boca Raton, FL. 192 pp.

Krame, A.D., R.G. Rolan, and L.A. Smith. 1985. Reference Manual for Assessing Water Quality Impacts from Highway Maintenance Practices - Volume III. U.S. Department of Transportation, Federal Highway Administration, Washington, DC. FHWA/RD-85/059.

Kuchler, A.W. 1964. Potential Natural Vegetation of the Conterminous United States. New York. American Geographical Society. Special Publication number 36.

Kusler, J.A. 1992. The Mitigation Banking Debate. *National Wetlands Newsletter* 14(1):4.

Kusler, J.A. and M.E. Kentula. eds. 1989. Wetland Creation and Restoration: The Status and Science (2 vols.). U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR. EPA/600/3-89/038a,b.

Lane, P.A. and R.R. Wallace. 1988. A User's Guide to Cumulative Effects Assessment in Canada. Canadian Environmental Assessment Research Council, Ottawa, Ontario.

Larson, R. 1993. Interior's 9th Bureau Set to Survey Life. *The Washington Times*. September 24.

Laudenslayer, W.F., Jr. 1986. Summary: Predicting Effects of Habitat Patchiness and Fragmentation. In: J. Verner, M.L. Morrison, and C.J. Ralph, eds. *Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates*. University of Wisconsin Press, Madison. pp. 331-333.

Leedy, D. 1975. Highway-Wildlife Relationships. Volume 1: A State-of-the-Art Report. FHWA-RD-76-4.

Leibowitz, S.G., B. Abburzzese, P. Adamus, L. Hughes, and J. Irish. 1992. A Synoptic Approach to Cumulative Impact Assessment—A Proposed Methodology. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR. EPA/600/R-92/167.

Linker, L.C. 1989. Creation of Wetlands for the Improvement of Water Quality: A Proposal for the Joint Use of Highway Right-of-Way. In: D.A. Hammer. *Constructed Wetlands for Wastewater Treatment.* Lewis Publishers, Chelsea, MI. pp. 695-701.

Mader, H.J. 1984. Animal Habitat Isolation by Roads and Agricultural Fields. *Biological Conservation* 29:81-96.

Marble, A.D. 1990. A Guide to Wetland Functional Design. Federal Highway Administration, Office of Implementation, McLean, VA. FHWA-IP-90-010.

McCrain, G.R. 1992. Habitat Evaluation Procedures (HEP) Applied to Mitigation Banking in North Carolina. *Journal of Environmental Management* 35:153-162.

McHarg. I. 1969. *Design with Nature.* Natural History Press, New York, NY. 197 pp.

McLeese, R.L. and E.P. Whiteside. 1977. Ecological Effect of Highway Construction Upon Michigan Woodlots and Wetlands: Soil Relationships. *Journal of Environmental Quality* 6(4):467-471.

Mertz, D.B. 1971. The Mathematical Demography of the California Condor. *American Naturalist* 105:437-453.

Muschack, W. 1990. Pollution of Street Run-Off by Traffic and Local Conditions. *The Science of the Total Environment* 93:419-431.

National Research Council. 1992. *Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy.* National Academy Press, Washington, DC. 552 pp.

National Research Council. 1986. *Ecological Knowledge and Environmental Problem-Solving.* National Academy Press, Washington, DC.

Norse, E.A. 1990. *Ancient Forests of the Pacific Northwest.* The Wilderness Society, Washington, DC. 327 pp.

Noss, R.F. 1990. Indicators for Monitoring Biodiversity: A Hierarchical Approach. *Conservation Biology* 4(4):355-364.

Omernik, J.M. 1987. Ecoregions of the Conterminous United States: Map Supplement. *Association of American Geographers* 77(1):105-107.

O'Neil, L.J., T.M. Pullen, Jr., and R.L. Schroeder. 1991. A Wildlife Community Habitat Evaluation Model for Bottomland Hardwood Forests in the Southeastern United States. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Oxley, D.J., M.B. Fenton, and G.R. Carmody. 1974. The Effects of Roads on Small Mammals. *Journal of Applied Ecology* 11:51-59.

Pace, F. 1990. The Klamath Corridors: Preserving Biodiversity in the Klamath National Forest. In: Hudson, W.E., ed. *Landscape Linkages and Biodiversity*. Island Press, Washington, DC, pp. 105-106.

Paine, R.T. 1969. The *Pisaster-Tegula* Interaction: Prey Patches, Predator Food Preference, and Intertidal Community Structure. *Ecology* 50:950-961.

Pfister, R.D. and S.F. Arno. 1980. Classifying Forest Habitat Types Based on Potential Climax Vegetation. Forest Science 26:52-70.

Povilitis, T. 1989. Living with Deer. *HSUS News*, Fall 1989:24-27.

Rodbell, P.D. 1993. Greening America's Highways. *Urban Forests* 13(2):16-18.

Rosgen, D.L. 1985. A Stream Classification System. In: Riparian Ecosystems and Their Management. First North American Riparian Conference. Rocky Mountain Forest and Experimental Station, RM-120. pp. 91-95.

Schroeder, R.L. 1986. Habitat Suitability Index Models: Wildlife Species Richness in Shelterbelts. Biological Report 82. U.S. Department of Interior, Fish and Wildlife Service, Washington, DC.

Scott, J.M., B. Csuti, J.D. Jacobi, and J.E. Estes. 1987. Species Richness: A Geographic Approach to Protecting Future Biological Diversity. *Bioscience* 37:782-788.

Sheate, W.R. and R.M. Taylor. 1990. The Effect of Motorway Development on Adjacent Woodland. *Journal of Environmental Management* 31:261-267.

Sheridan, D. 1988. Oasis Under Siege. *Defenders* Nov/Dec 88:16-24.

Short, C. 1988. Mitigation Banking. U.S. Fish and Wildlife Service, Biological Report 88(41). Washington, DC.

Short, H.L. and S.C. Williamson. 1986. Evaluating the Structure of Habitat for Wildlife. In: J. Verner, M.L. Morrison, and C.J. Ralph, eds. *Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates*. University of Wisconsin Press, Madison. pp. 97-104.

Southerland, M. 1993. Habitat Evaluation: Guidance for the Review of Environmental Impact Assessment Documents. Report to U.S. Environmental Protection Agency, Office of Federal Activities. Dynamac Corporation, Rockville, MD. 129 pp.

Southerland, M. 1991. Ecosystem Restoration Criteria: A Review and Conceptual Framework. Report to U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation. Dynamac Corporation, Rockville, MD. 53 pp.

Southerland, M., T. Holderman, A. King, K. Plumer, A. Steiner, N. Talbot, and M. Vuotto. 1991. Targeting Priority Natural Resource Areas: A Review of National Lists. Report to U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation. Dynamac Corporation, Rockville, MD. 37 pp. + appendices.

Southerland, M.T. and J.B. Stribling. in press. Status of Biological Criteria Development and Implementation. In Davis, W. and T. Simon. eds. *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making*. Lewis Publishers, Chelsea, MI.

Stull, E.A., K.E. Lagory, and W.S. Vinikour. 1987. Methodologies for Assessing the Cumulative Environmental Effects of Hydroelectric Development on Fish and Wildlife in the Columbia River Basin (2 vols.). Bonneville Power Administration, U.S. Department of Energy, Portland, OR.

Suter II, G.W. 1990. Endpoints for Regional Ecological Risk Assessments. *Environmental Management* 14:9-23.

Temple, S.A. 1986. Predicting Impacts of Habitat Fragmentation on Forest Birds. In: J. Verner, M.L. Morrison, and C.J. Ralph, eds. *Wildlife 2000: Modeling Habitat Relationships of Terrestrial Vertebrates*. University of Wisconsin Press, Madison. pp.301-304.

Terborgh, J. 1992. Why American Songbirds are Vanishing. *Scientific American* 266(5):98-104.

Terrene Institute. 1993. Roads and Riparian Area Protection: A Guide to Environmental Considerations in Road Design and Maintenance. Draft. Terrene Institute, Washington, DC.

Thomas, J.W., W.C. Maser, and J.E. Rodiek. 1979. Edges. In: J.W. Thomas, ed. Wildlife Habitats in Managed Forest: The Blue Mountains of Oregon and Washington. USDA, Forest Service, Agriculture Handbook No. 553, Washington, DC.

Turner, M.G. 1990. Landscape Changes in Nine Rural Counties in Georgia. *Photogrammetric Engineering and Remote Sensing* 56(3):379-386.

U.S. Army Corps of Engineers (COE). 1980. A Habitat Evaluation System for Water Resources Planning. Environmental Analysis Branch, Planning Division, Lower Mississippi Valley Division, U.S. Army Corps of Engineers, Vicksburg, MS.

U.S. Army Corps of Engineers (COE) Environmental Laboratory. 1987. Corps of Engineers Wetlands Delineation Manual. Technical Report Y-87-1, Waterways Experiment Station, Vicksburg, MS.

U.S. Army Corps of Engineers (COE) and Minnesota Environmental Quality Board. 1988. The Minnesota Wetland Evaluation Methodology for North Central United States. St. Paul District U.S. Army COE. 113 pp.

U.S. Congress. 1991. Conference Report on H.R. 2950, Intermodal Surface Transportation Infrastructure Act of 1991. Congressional Record-House Vol. 137, No. 177-Part IV, Washington, DC, Tuesday, November 26. p. H 11517-11610.

U.S. Congress, Office of Technology Assessment (OTA). 1987. Technologies to Maintain Biological Diversity. Office of Technology Assessment, Washington, DC.

U.S. Department of Agriculture (USDA), Forest Service. 1978. Roadless Area Review and Evaluation (Rare II). Draft Environmental Statement 78-04.

U.S. Department of Interior (DOI), Fish and Wildlife Service. 1980. Habitat Evaluation Procedures (HEP) Manual. 102 ESM, U.S Fish and Wildlife Service, Washington, DC.

U.S. Department of Transportation (DOT) and Michigan Department of Transportation (DOT). 1991. Draft Environmental Impact Statement. Grand Rapids South Beltline from I-196 to I-96 in Ottawa and Kent Counties, Michigan. FHWA-MI-EIS-91-01-D.

U.S. Department of Transportation (DOT) and Wisconsin Department of Transportation (DOT). 1991. Final Environmental Impact Statement. U.S.H. 53, Trego to Kent Road, Washburn and Douglas Counties, Wisconsin. FHWA-WISC-EIS-89-05-F.

U.S. Environmental Protection Agency (EPA). 1993. Guidelines for Preparation of the 1994 State Water Quality Assessments (305(b) Reports). U.S. EPA, Office of Water, Washington, D.C. EPA841-B-93-004.

U.S. Environmental Protection Agency (EPA). 1990. Biological Criteria: National Program Guidance for Surface Waters. U.S. EPA, Office of Water Regulations and Standards, Washington, DC. EPA-440/5-90-004.

Van Der Zande, A.N., W.J. Der Keurs, and W.J. Van Der Weijden. 1980. The Impact of Roads on the Densities of Four Bird Species in an Open Field Habitat—Evidence of a Long-distance Effect. *Biological Conservation* 18:299-321.

Veen, J. 1973. De verstoring van weidevogelpopulaties. *Stedeb. en Volkshisv.* 53:16-26.

Ward, A.L., N.E. Fornwalt, S.E. Henry, and R.A. Hodorff. 1980. Effects of Highway Operation Practices and Facilities on Elk, Mule Deer, and Pronghorn Antelope. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. Prepared for U.S. Department of Transportation, Federal Highway Administration, Washington, DC. FHWA/RD/79/143.

West Virginia Department of Transportation (DOT). 1992. Corridor Selection Supplemental Draft Environmental Impact Statement (SDEIS): Appalachian Corridor H Elkins to Interstate 81. West Virginia DOT, Division of Highways, Charleston, WV.

Westman, W.E. 1985. *Ecology, Impact Assessment, and Environmental Planning*. Wiley-Interscience, New York, NY.

Whitcomb, R.F., C.S. Robbins, J.F. Lynch, B.L. Whitcomb, M.K. Klimkiewicz, and D. Bystrak. 1981. Effects of Forest Fragmentation on Avifauna of Eastern Deciduous Forest. In: R.L. Burgess and D.M. Sharpe, eds. *Forest Island Dynamics in Man-Dominated Landscapes*. Springer-Verlag, New York.

Wilcove, D.S. 1985. Nest Predation in Forest Tracts and the Decline of Migratory Songbirds. *Ecology* 66:1211-1214.

Wilcove, D.S. and R.M. May. 1986. National Park Boundaries and Ecological Realities. *Nature* 324:206-207.

Wilcox, B.A. and D.D. Murphy. 1985. Conservation Strategy: The Effects of Fragmentation on Extinction. *American Naturalist* 125:879-887.

Wilson, E.O. ed. 1988. *Biodiversity*. National Academy Press, Washington, DC. 521 pp.

Yahner, R.H. 1988. Changes in Wildlife Communities Near Edges. *Conservation Biology* 2(4):333-339.