El Dorado County
Integrated Natural Resources Management Plan - Phase I

Final Draft
Wildlife Movement and Corridors Report
November 3, 2010

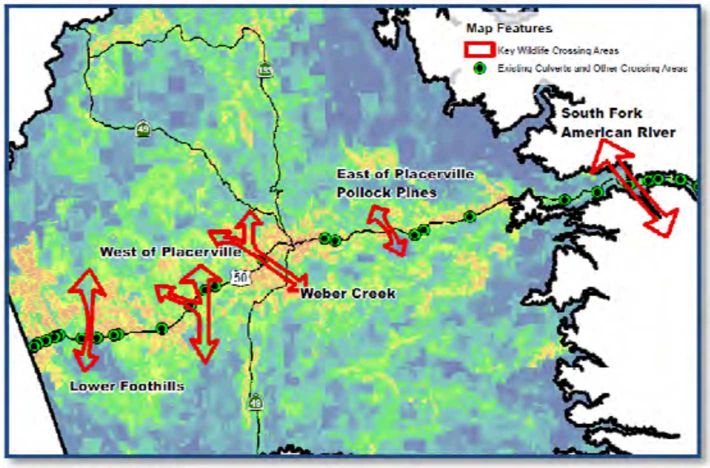

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Table of Contents

Page #

List of Tables

List of Figures

List of Appendices

Executive Summary

This report is the third of four being prepared by El Dorado County (County) as part of Phase I of the County's Integrated Natural Resources Management Plan (INRMP). The County's 2004 General Plan requires the INRMP as a mitigation measure to help compensate for impacts from development in the western County (General Plan Mitigation Measure 5.12-1).

One of the important roles of the INRMP is to plan for connectivity through the use of wildlife corridors and other improvements in land use and transportation to protect wildlife and their habitat. The goals of Objective 7.4.2 of the 2004 General Plan include the identification and protection, where feasible, of wildlife corridors, which are areas of habitat connecting wildlife populations separated because of human development or natural causes. Corridors are a subset of the idea of connectivity.

Connectivity is a habitat quality that is critical for many animal and plant species' well-being because it allows species to meet their daily, seasonal, and other ecological needs. Wildlife populations need connectivity of habitats just as they need sufficient space to provide for food, shelter, and social structures. Connectivity is essential for dispersal of young animals and plant seeds, migration routes, reproduction, and gene flow, and it allows plants and animals to re-colonize from one area to another when habitats are lost (e.g., from a catastrophic wildfire or development). Maintaining connectivity and sufficient habitat area for wildlife will help to ensure the continuation of the County's natural legacy for current and future generations and will meet General Plan goals for conserving biodiversity. In addition, as is the case with other counties that traverse the Sierra Nevada foothills, the County's land-use and transportation footprints and decisions affect wildlife and plant diversity in the region as a whole.

Connection with Habitat Mapping and Indicator Species Selection

Earlier INRMP Phase 1 tasks included preparing:

1. A Habitat Inventory and Mapping Report, which updated the County's habitat map database, including mapping landscape disturbance and large expanses of native vegetation, and
2. An Indicator Species Report, which identified indicator species that may be useful for monitoring effects of General Plan implementation.

These previous reports contribute to the Wildlife Movement and Corridors Report by showing where road and development fragmentation effects are greatest in the study area, and by identifying the extent and types of habitat for specific indicator species. This Wildlife Movement and Corridors Report covers the connectivity and movement needs of all vertebrate species in the study area, including the needs of the indicator species selected for possible future INRMP monitoring. Collectively, these reports will be applied in the future Phase II INRMP tasks to define areas where connectivity and corridors are needed, and to assess the sufficiency of existing [e.g., Weber Creek and Important Biological Corridors (IBC)] connectivity.

Connectivity

Conserving connectivity is an essential element of habitat conservation. In the western portion of the County, there is high quality habitat for 316 terrestrial vertebrate species (according to the California Wildlife Habitat Relations Model, Appendix E – Vertebrate Species Affected by

Transportation and Land Use Fragmentation). All of these species, including the 25 vertebrate indicator species, potentially will need to move in various compass directions, including north-south. Inhibition of this movement, or complete prevention of movement, will reduce available habitat area, reduce population size, segment populations, and create loss of genetic and population structure. Without planning and provisions for connectivity, these effects will be exacerbated as the level of road and land-use fragmentation increases, with local and regional isolation and possible extinction for many species.

Corridors & Linkages

Wildlife corridors or linkages are zones of varying widths that are either the last places left for wildlife or other ecological flows to move through an area, or are the planned areas for potential movement. As fragmentation and development increase, animal populations are more affected by adverse environmental conditions including human disturbance, disease, climate change, and other stressors. Therefore, connectivity among core habitat conservation areas (via corridors and linkages) becomes increasingly important with increasing human development.

Risk Management

Protecting important habitat properties like connectivity is a critical conservation action that will help protect biodiversity in general, as well as rare species and species of management concern. The reasons for this are described in more detail later in this report.

Protecting the ability of wildlife and plant species to move and disperse is a risk management strategy that can be incorporated into the County’s transportation and land use planning through the INRMP. Connectivity conservation actions will reduce the risk of negative impacts to biodiversity, individual species’ survival, habitat quality, and listed species. Additionally, these actions will help support the connectivity provisions of General Plan Policy 7.4.2.8, including Subsection D, which addresses connectivity for important habitat.

Focus of Report

This report analyzes prior research studies, describes the need for wildlife habitat connectivity and corridors, and evaluates existing connectivity in the study area, particularly the potential barrier effect of U.S. Route 50 (Highway 50) on wildlife movement and habitat connectivity. The report recommends ways that the barrier effects of Highway 50, major roads, and urban areas could be reduced through retrofit of existing transportation infrastructure (e.g., installation of new structures, parkways, etc.).

Retrofitting existing culverts with ledges, for example, is a relatively inexpensive way to improve connectivity. Ledges can be constructed for as little as $17 per linear foot, or $60,000 to retrofit all culverts surveyed along Highway 50. New structures are also an option, like the box culvert that Nevada County installed along Highway 49 and the under-crossing planned by Caltrans between the Greenstone and El Dorado interchanges along Highway 50 to facilitate deer crossings. When these new structures are built and include habitat improvements in the vicinity of the crossing itself, habitat connectivity can be improved and vehicle-wildlife collisions can be reduced. Design and implementation of these types of measures would be consistent with General Plan Policy 7.4.2.8 B, which identifies considerations for wildlife movement on future 4- and 6-lane roadways, as well as improving crossings of existing roadways.

Figure ES-1 shows the key Highway 50 wildlife crossing areas that have been identified in this report. Table ES-1 summarizes the information found in Appendix C, Potential Highway 50 Wildlife Crossings, and identifies the potential value of existing under-crossings (e.g., culverts and roads) to ground-dwelling mammals if improvements are made to the under-crossing features. In general, more structures are needed under Highway 50 to meet the crossing needs of ground-dwelling animals. Lastly, this report describes options to more accurately understand connectivity and corridors in the County when the County's INRMP is prepared.

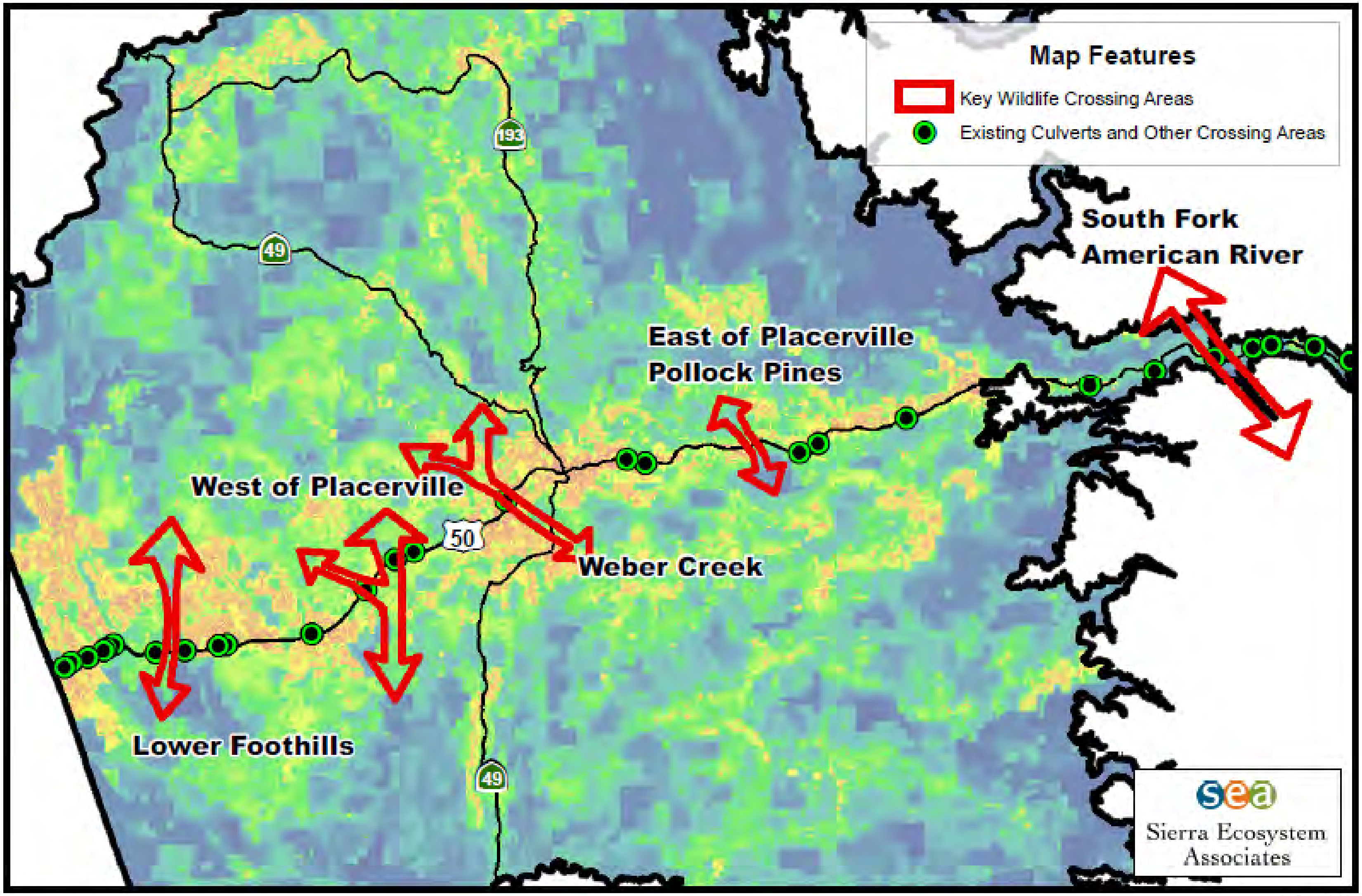

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Figure ES-1. Key Highway 50 Wildlife Crossing Areas

[1] Disturbance map created using County road density, parcel sizes, and parcel development status.

Table ES-1. Summary of Potential Value of Highway 50 Wildlife Under-Crossings

Appendix C Crossing #	Existing Highway 50 Crossings Name	Potential Value to Reptiles and Amphibians H= High Value M= Medium Value L = Low Value (e.g., lizard)	Potential Value to Small/Medium/Large Mammals H= High Value M= Medium Value L = Low Value (e.g., mouse, fox, deer)	Feasibility (General Plan consistency, cost) of Modifying Existing/Adding new connectivity H = High M = Moderate L= Low
1	Dunwood	M	M/L/L	H
2	Finders	M	M/L/L	M
3	Nugget	M	M/L/L	M
4	Joerger	M	M/L/L	H
5	Silva Valley Parkway	M	M/H/H	H
6	Tong Road	M	M/L/L	M
7	Bass Lake Road	M	M/H/H	H
8	Faith Lane	M	M/L/L	H
9	Cambridge Rd. #1	H	H/M/L	H
10	Cambridge Rd. #2	H	H/H/H	H
11	Chaparral	M	M/L/L	M
12	Shingle Springs Rd.	M	M/H/H	H
13	Dry Creek Tributary	H	H/H/M	M
14	Greenstone Rd.	M	M/H/H	H
15	Weber Creek Bridge	H	H/H/H	H
16	Smith Flat Rd.	H	H/H/H	H
17	Point View Dr. Bridge	M	M/H/H	H
18	Carson Rd. Bridge	M	H/H/H	H
19	Snows Rd. Bridge	M	M/H/H	H
20	Ridgeway Rd. Bridge	M	H/H/H	H
21	Pacific House	H	H/H/M	H
22	Ogilby Cyn	H	H/H/M	H
23	Riverton Bridge (SFAR) W	H	H/H/H	M
24	S. Fork Am. River E (#1)	H	H/H/H	M
25	S. Fork Am.River E (#2)	H	H/H/H	M
26	White Hall 1	H	M/L/L	M
27	White Hall 2	H	H/L/L	M
28	White Hall 3	H	H/L/L	M
29	Kyburz West	H	M/L/L	M
30	Kyburz East	H	M/L/L	M

1.0 Introduction

Wildlife corridors are a subset of the idea of connectivity. Connectivity is a habitat quality that is critical for many animal and plant species' well-being because it allows for species to meet their daily, seasonal, and other ecological needs. In the science and practice of conservation, landscape attributes are challenging to describe and protect compared to parcels of the landscape. Although connectivity has been an attribute of conservation area designs for the last 20 years, current approaches to species, habitat, and landscape conservation have not addressed the need for extensive connectivity. Current approaches also do not capture the changes in connectivity that are likely to occur in the near future. An important role of the INRMP is to plan for connectivity through the use of wildlife corridors and other improvements in land use to protect wildlife and their use of habitat. As climate change and other factors continue to modify landscapes and habitat, connectivity will remain important, allowing animals and their habitats to gradually adapt to new conditions.

Planning activities associated with preserving or restoring connectivity in a landscape must acknowledge the changes that are most likely to occur in the near future, including habitat disturbance caused by changes in the use of the land, edge effects on intact patches of suitable habitat, and barriers to wildlife movement created by structures or roadways. An important role of the INRMP is to plan how best to maintain connectivity through the management of land use patterns and the protection of existing wildlife movement, making informed choices for changes in land use designations or improvements to compromised habitats in order to protect wildlife and plants to the best ability of the County. Provisions for connectivity and freedom of movement can prevent genetic isolation and reduce the effects of fragmentation, which can otherwise lead to local or regional extinction.

Current conservation approaches sometimes overlook the needs of species by not maintaining wildlife movement. Certain wildlife species have nonetheless adapted to human activities and may even benefit from certain changes in land uses (e.g., agriculture) or transportation structures (e.g., road-sides). These are typically the less sensitive species such as medium-size omnivores (e.g., raccoons, opossums), medium-size carnivores, and certain rodents. Species sensitive to human activities and structures are unlikely to adapt or to have adapted, as is made evident by their absence in developed areas and by studies investigating relationships between disturbance and species responses.

This Introduction provides an overview of connectivity and its components. Section 2 discusses connectivity and wildlife movement in the western County, including the barrier effects of Highway 50 and other major roadways, and Section 3 provides strategies for improving wildlife movement and connectivity, such as protecting habitats and landscape corridors. Background scientific information, including information regarding habitat loss and fragmentation, wildlife corridors, the scientific basis supporting the need for connectivity, genetic and population effects of fragmentation, and threats to connectivity and permeability, is provided in Appendix A – Background Scientific Information. A glossary of terms is provided in Appendix B – Glossary of Terms, and Appendix C – Potential Highway 50 Wildlife Crossings identifies potential Highway 50 wildlife crossings. Appendix D – Crossing Structure Alternatives by Species provides a table of crossing structure attributes useful for medium and large mammals, and

Appendix E – Vertebrate Species Affected by Transportation and Land Use Fragmentation lists vertebrate species occurring within the INRMP study area. Lastly, Appendix F – Potential Approaches to Address Connectivity in the INRMP (Phase II) discusses possible future investigations for addressing wildlife movement, including tracking, wildlife cameras, Global Positioning System (GPS) and radio-collars and devices, and genetic testing.

1.1 General Plan Nexus

The importance of protecting wildlife corridors and movement to the County is shown in General Plan Objective 7.4.2. This Objective states in part: "*Identification and protection, where feasible, of critical fish and wildlife habitat including deer winter, summer, and fawning ranges; deer migration routes; stream and river riparian habitat; lake shore habitat; fish spawning areas; wetlands; wildlife corridors; and diverse wildlife habitat*." Protecting connectivity is an essential component of conserving habitat quality for wildlife and movement of specific species (i.e., deer), as well as the diverse wildlife of the County.

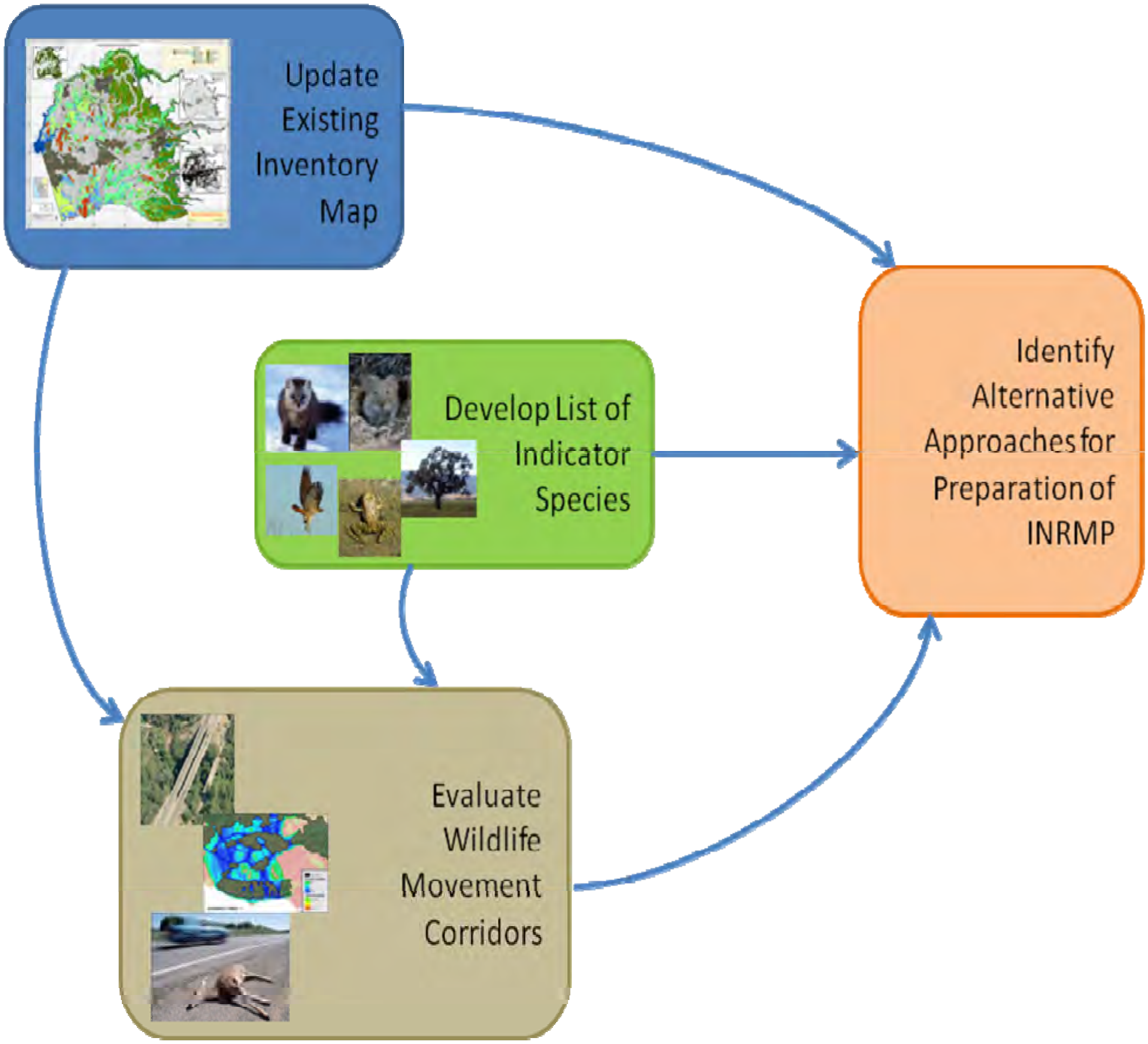
In addition to Objective 7.4.2, General Plan Policy 7.4.2.8, which establishes the INRMP, instructs the County to consider wildlife movement for four- and six-lane roadway projects, and to consider connectivity to adjacent protected lands and important habitats when planning or evaluating habitat acquisition. For these reasons a thorough understanding of the biology of connectivity and the application to the County is essential to the development of the INRMP.

For Phase I of the INRMP, the County has identified the need to evaluate habitat corridors and the barrier effects of roadways in the County. Appendix C of this report evaluates potential crossing locations along Highway 50, the characteristics of those crossings and methods to enhance their use. Evaluation of connectivity and wildlife movement in the western County in Phase II of INRMP activities will be used to update the location and function of the IBCs, which have regulatory functions in land use decision-making under General Plan Policy 7.4.2.9.

1.2 Connection with Habitat Mapping and Indicator Species Selection

Earlier INRMP Phase 1 tasks included updating the County's habitat map database, including mapping landscape disturbance and large expanses of native vegetation, as well as identification of indicator species that could be used in the future to evaluate effects of General Plan implementation. Products of these tasks contribute to the wildlife corridors report by providing useful information about road and development fragmentation effects in the study area and through identification of habitat needs of specific species. This report covers the connectivity and movement needs of all vertebrate species in the study area, including the needs of the indicator species. Figure 1. Connections among INRMP Phase I Tasks displays the relationships among these reports.

Figure 1. Connections among INRMP Phase I Tasks



1.3 Connectivity

Habitat and landscape quality for wildlife needs is often defined by a combination of forage availability and quality, how well reproductive needs are met, and relative connectivity for movement on daily to evolutionary time-scales. Connectivity is an attribute of habitat patches, where they exist, as well as of landscapes as a whole. Although connectivity is often used to describe habitat and landscape structure, it is most meaningful as a functional attribute that is particular to individual species. In areas with high diversity of motile species, a high proportion of the landscape may be required to meet movement needs for all species. Connectivity has also been described as one of the most critical elements in biodiversity conservation planning in the presence of climate change effects (Heller and Zavaleta, 2009). Saving and Greenwood (2002) analyzed habitat loss and fragmentation for various General Plan build-out and conservation policy options. Their conclusion was that the greatest concerns were the degradation of habitat quality that accompanies rural residential development (~1 unit/10 to 40-acre parcel) and the absence of a natural connection between the northern and southern sides of Highway 50 in the lower and mid-foothills. The first conclusion is important because of the proportion of the County fragmented by rural residential development – 40%. This fragmented area is greater than the area physically lost to development due to structures or roads – 4%.

Conserving connectivity is as fundamental a conservation concern as improving forage quality and about as easy to estimate and model for actual landscapes. Ultimately, connectivity is conserved for individual species or groups with similar needs. Connectivity is successfully conserved when movement across all spatial and temporal scales is possible, for a given species in a given landscape. It is also successful when movement within and among populations is protected to such a degree that genetic bottlenecks, population separations, population declines, local extinctions, failed re-colonizations, and species endangerment do not occur due to movement inhibition. It is also important to remember that other factors affecting species and population persistence may over-ride positive or negative aspects of the degree of connectivity. In the western County, there is high quality habitat for 316 terrestrial vertebrate species and habitat of any quality for 366 vertebrate species (according to the California Wildlife Habitat Relations Model, Appendix E – Vertebrate Species Affected by Transportation and Land Use Fragmentation). To maintain population well-being, all of these species, including the 25 vertebrate indicator species, will almost certainly need to move in various compass directions, including north-south. Inhibition of this movement, or complete prevention of movement, will almost certainly result in reduction in available habitat area, reduction in population size, segmentation of populations, and loss of genetic and population structure. This effect will be greatest for the species most sensitive to disturbance and least apparent for the least sensitive species that have adapted to human activities. Without planning and provisions for connectivity, these effects will be exacerbated as the level of road and land-use fragmentation increases, with local and regional isolation and possible extinction for many species. Barrier effects of developed corridors such as Highway 50 will be greater for ground-dwelling animals than for flying animals; there are 62 mammals and 33 herpetofauna (reptiles and amphibians) among the 316 terrestrial vertebrates with high quality habitat in the study area, and the remainder are birds.

1.4 Corridors and Linkages

In the context of the County, the effects of human development and activity have resulted in two general types of corridors: 1) existing linkages within zones of varying width (e.g., riparian corridors) that are either the last places left for wildlife or other ecological flows to move through an area (Figure 2A. Methods for Identifying Corridors – Western El Dorado County), and, 2) planned areas (i.e., IBCs) for potential movement (Figure 2B. Methods for Identifying Corridors – Potential Corridors for Mountain Lion in Southern California Using GIS Modeling, Figure 2C. Methods for Identifying Corridors – Prioritizing Deer Movement "Corridors" Based on Deer Herd Movement). For certain organisms and in certain places corridors may serve as critical connection solutions to maintain biodiversity and ecological flows. Because corridors primarily meet the needs of species least-sensitive to disturbance, including fragmentation effects, they may not effectively connect other species' habitat, depending on the species and the degree of fragmentation.

Figure 2A. Methods for Identifying Corridors – Western El Dorado County

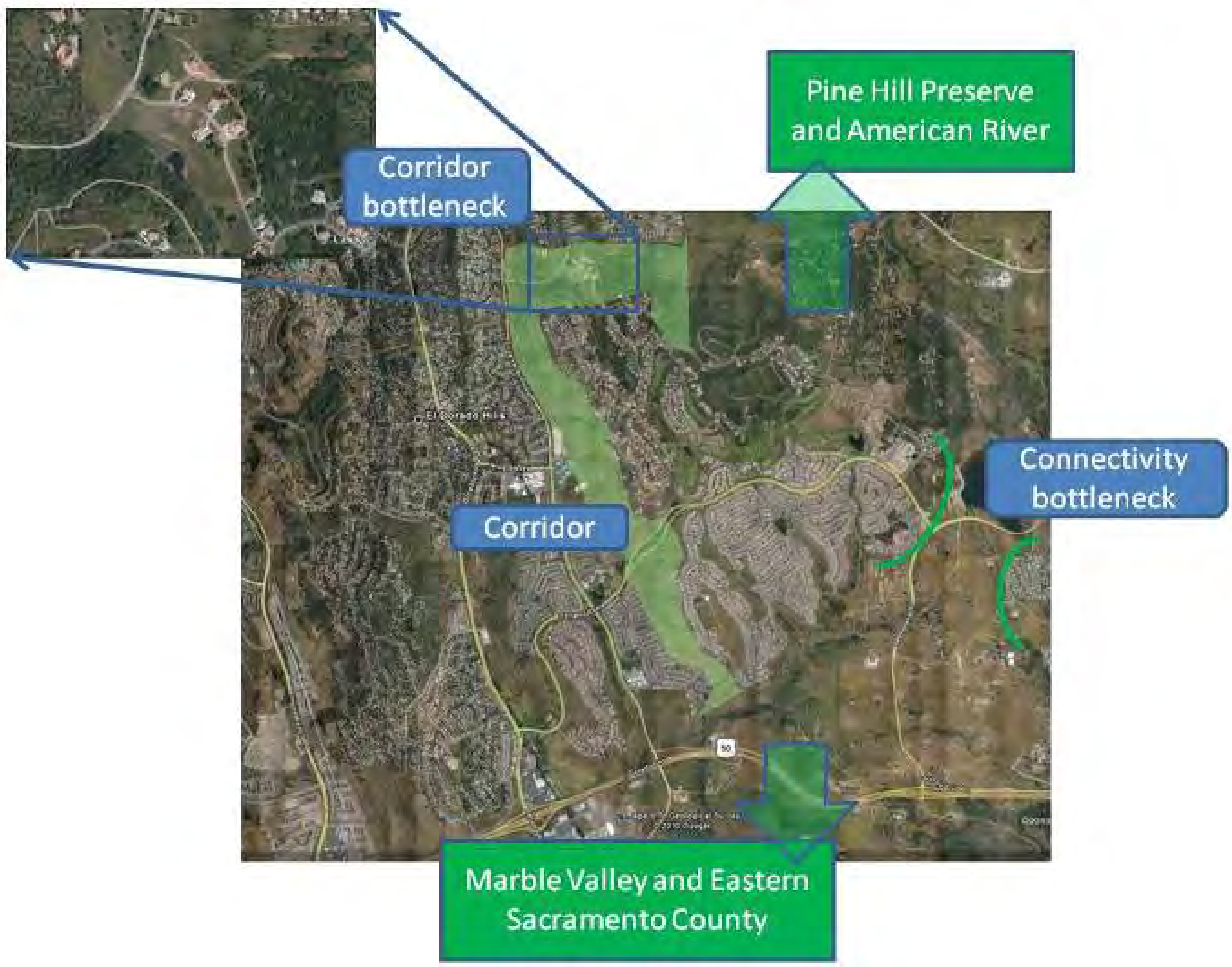


Figure 2B. Methods for Identifying Corridors – Potential Corridors for Mountain Lion in Southern California Using GIS Modeling

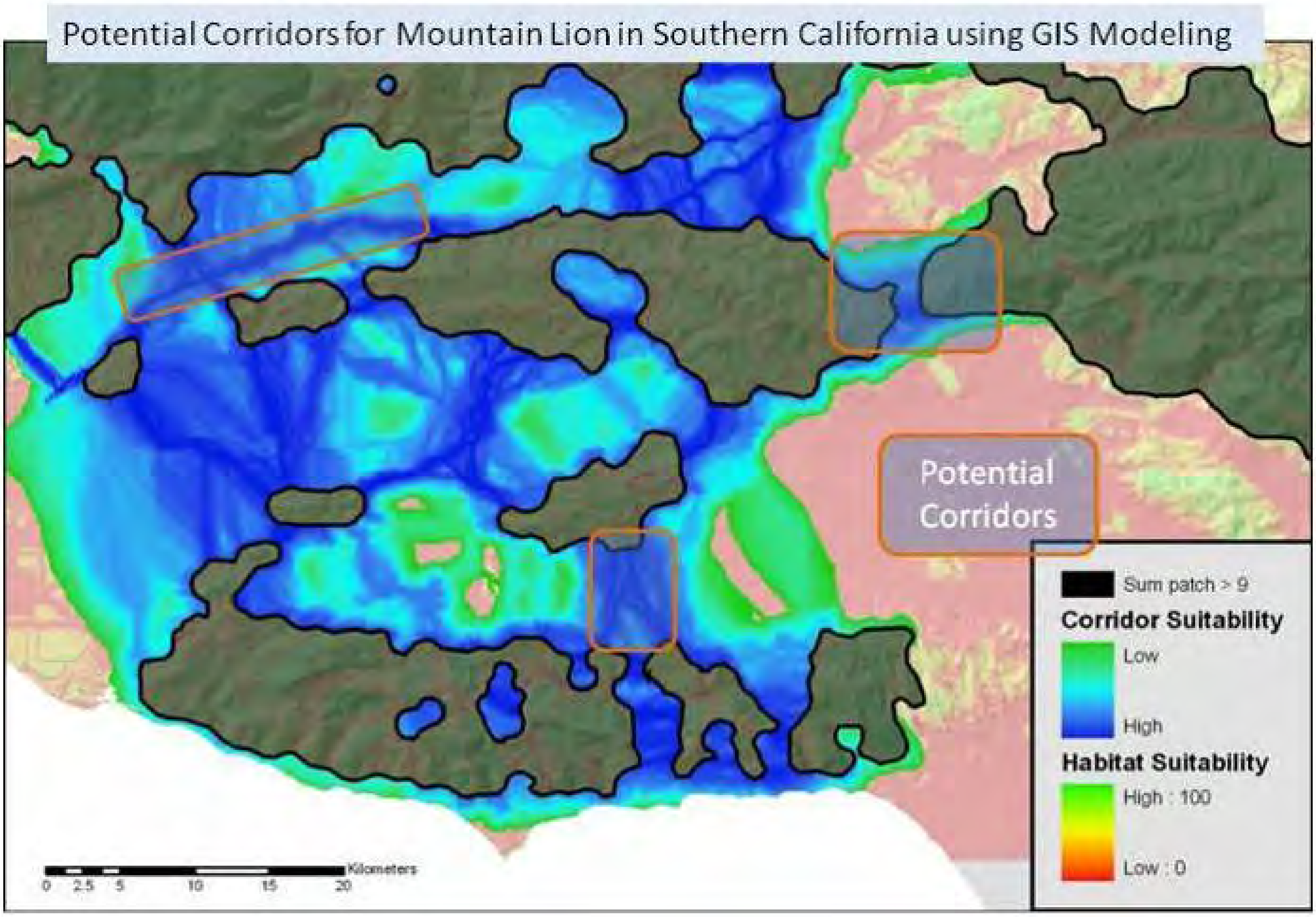
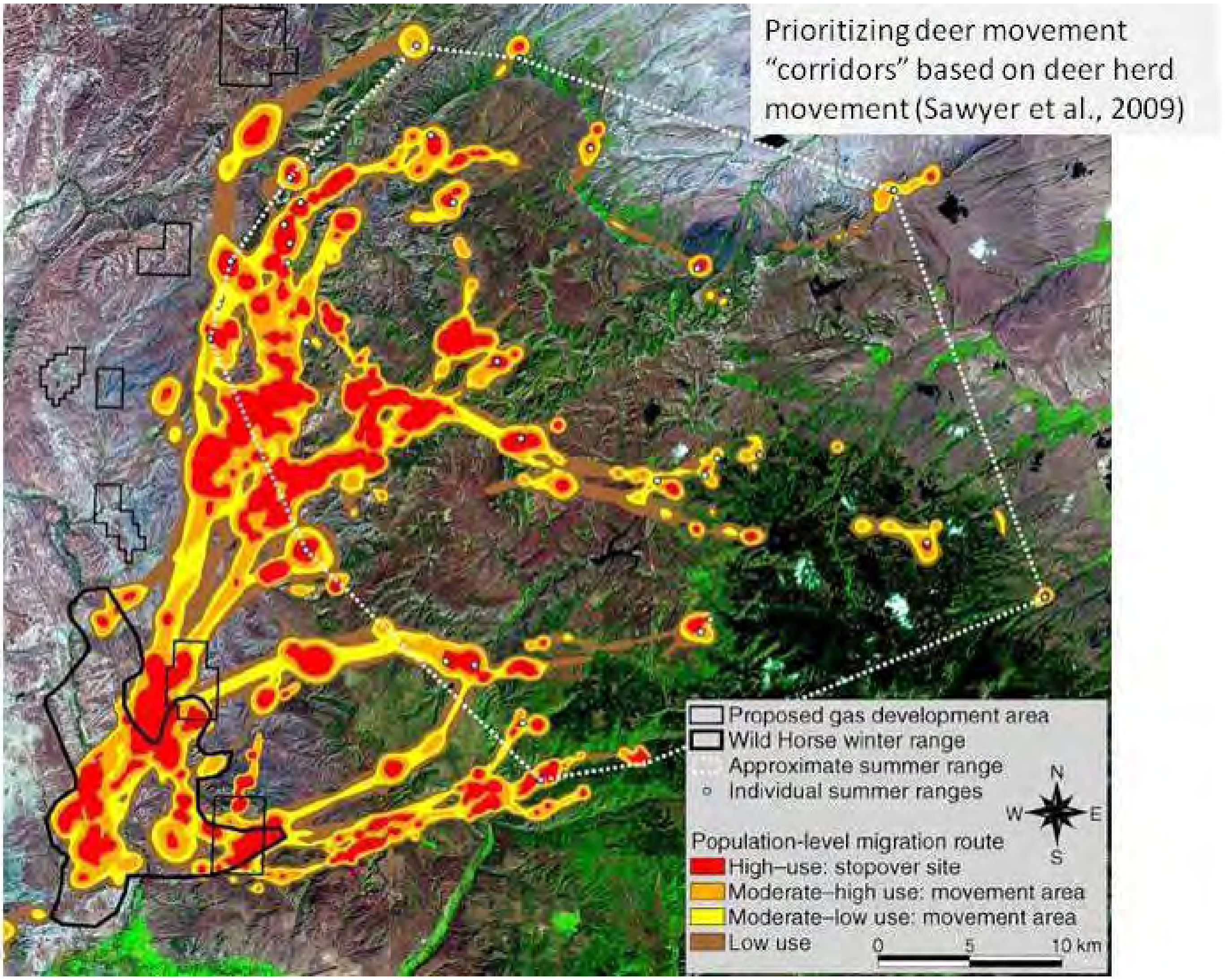


Figure 2C. Methods for Identifying Corridors – Prioritizing Deer Movement “Corridors” Based on Deer Herd Movement



In the western County, there are several parts of the landscape that could be called corridors because of their narrowness and likely role in limited wildlife movement (e.g., Figure 2A). In other parts of the County, there may be no movement of animals sensitive to humans (e.g., through housing sub-divisions; dark green areas in Figure 3A. Disturbance Gradient of Road Density and Small Parcel Sizes) or free movement of sensitive animals because they occupy unfragmented areas of native vegetation with little disturbance (Figure 3B. Large Expanses/Patches of Least Disturbed Lands). In the latter case, there are not necessarily corridors, though connectivity within and among areas of suitable habitat is still important.

IBCs have been mapped for the western County and have ramifications for permitted development within these areas (General Plan Policy 7.4.2.9). The placement and function of IBCs and areas not covered by IBCs will be reviewed with the new information contained within this report and the mapping conducted as part of INRMP Phase I. A preliminary scope for updating of IBCs will be described in the Task 2 "Optional Approaches". Revision of IBCs will take place in the INRMP Phase II planning activities. Existing and revised IBCs may overlap with riparian zones, but they may just as easily not do so, as their function is to provide connectivity among less-disturbed landscapes in the County. Areas not included in current or revised IBCs may have important connectivity function. In other words, not all connectivity functions for wildlife and plant community needs will be provided by IBCs; by themselves corridors provide only a part of connectivity needs for wildlife and plant communities. Remaining needs are met by appropriate planning in non-corridor areas.

This report describes the need for landscape connectivity, including maintaining wildlife corridors and linkages through developed areas, and evaluates wildlife corridors and connectivity in the INRMP study area (particularly the potential barrier effect of Highway 50 and nearby development on wildlife movement and habitat connectivity). This report also describes ways and estimates costs to reduce the barrier effects of Highway 50, major roads, and urban areas through retrofit of existing transportation structures and construction of new structures, including features like very wide vegetated buffers for animal cover. Conserving connectivity function will be important in general to maintaining biodiversity, especially for species most sensitive to human disturbance.

1.5 Risk Management

Protecting critical habitat properties like connectivity is an important conservation action that will help protect biodiversity in general, as well as rare species and species of management concern. It is a method for reducing the chance of eliminating subpopulations or populations of species sensitive to fragmentation. The reasons for this are described in the sections below, but include the following: 1) Many species are sensitive to human activity, including roads and traffic, and almost certainly will stay away from these areas even if that means failing to disperse or move to other habitat areas. This aversion effect of roads and other development results in fragmented populations and subpopulations of species. 2) Species that are fragmented into small, less effective populations are more likely to go extinct locally, or throughout their range. 3) Road impacts on individuals can be so great that populations may be reduced in size or eliminated, resulting in an increased chance of local or total extinction. 4) Fragmented populations may fail to re-colonize abandoned habitat, are more likely to suffer from genetic in-breeding effects, and almost certainly will genetically diverge from other subpopulations.

For these and other reasons, protecting the ability of wildlife and plant species to move and disperse is a risk management strategy that can be incorporated into transportation and land use planning. Connectivity conservation actions will reduce the risk of negative impacts to biodiversity, habitat quality, and listed species. Additionally, these actions will help support the connectivity provisions of General Plan Policy 7.4.2.8, including Subsection D, which addresses connectivity for important habitat.

Figure 3A. Disturbance Gradient of Road Density and Small Parcel Sizes

The darker green shown below is more disturbed.

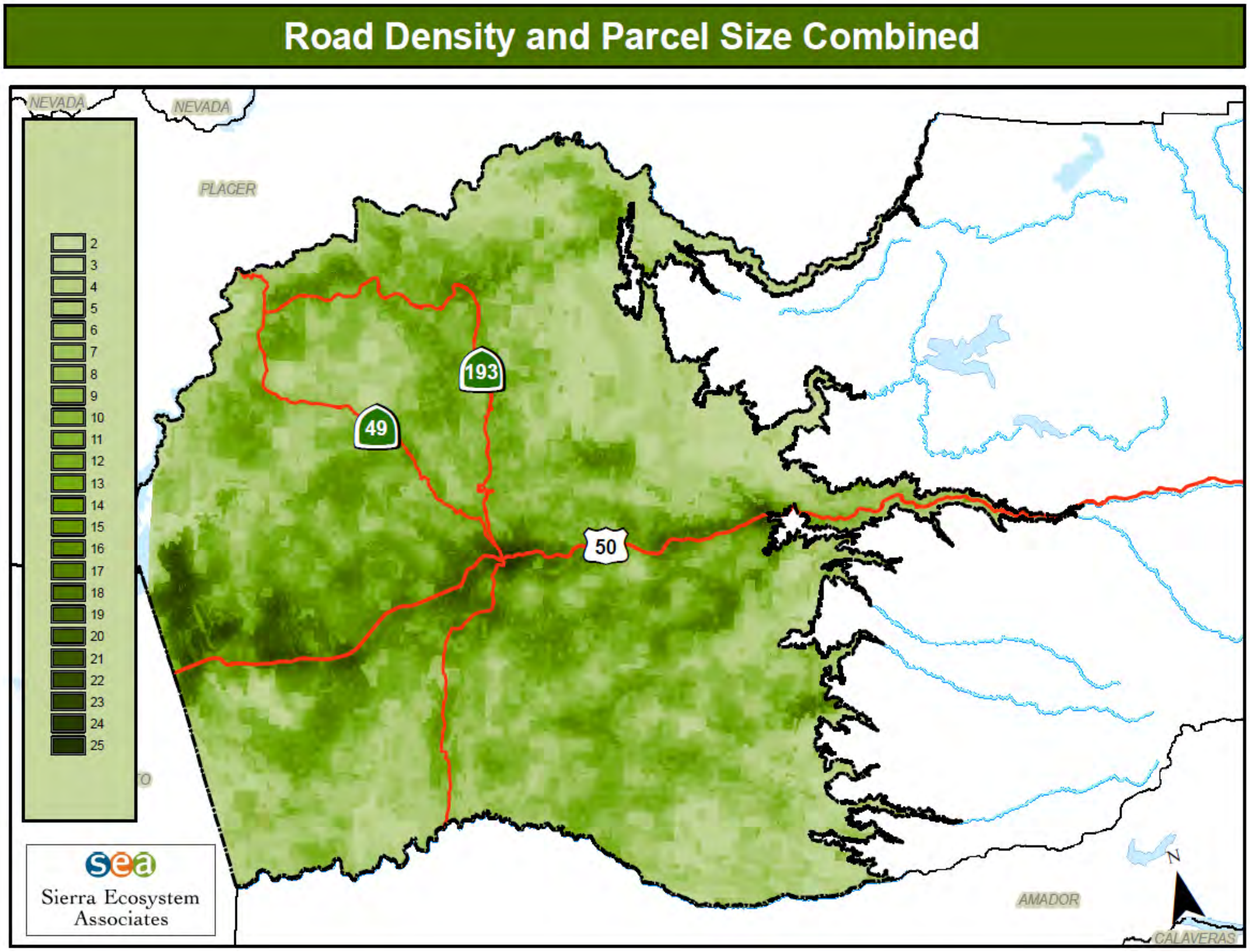
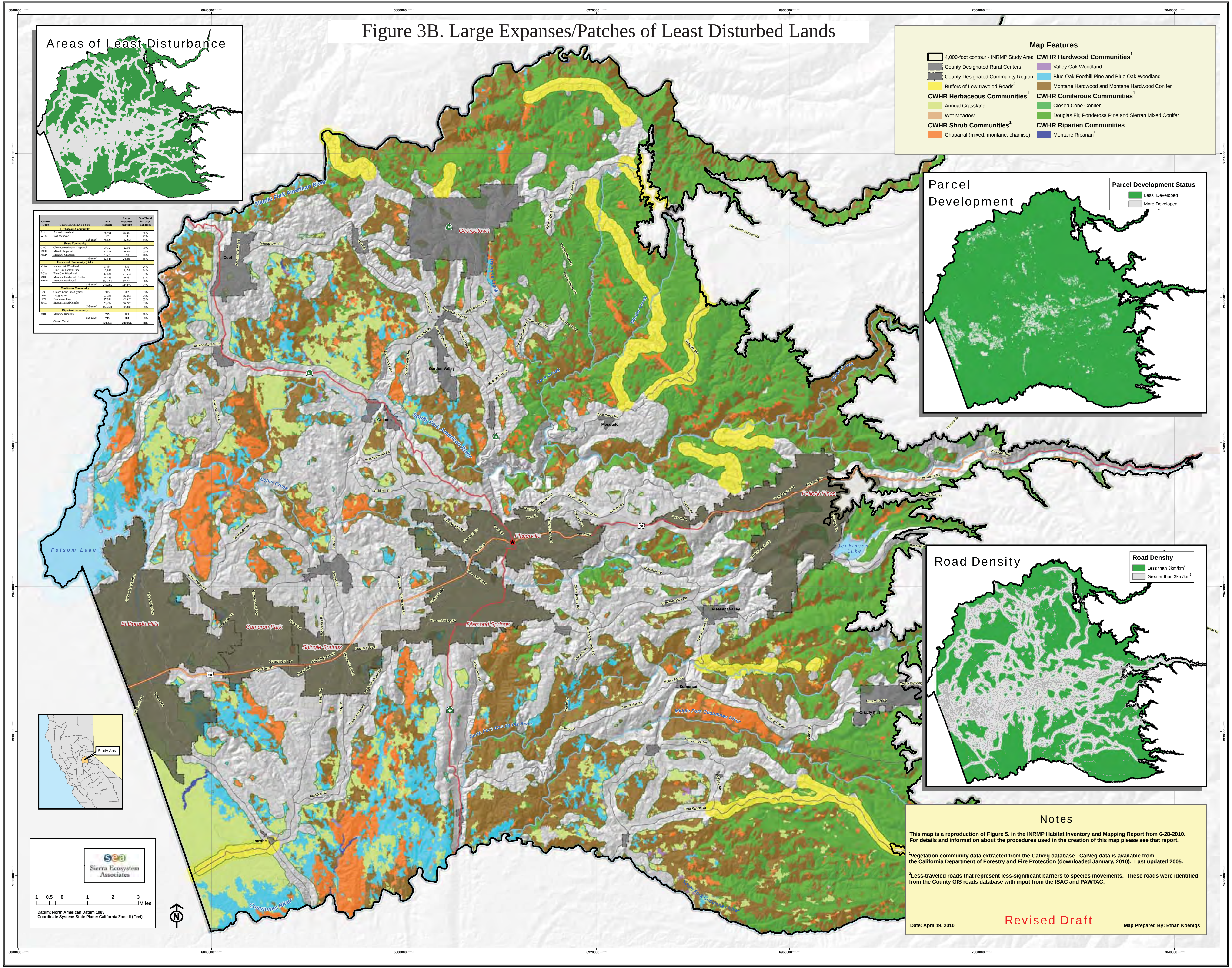


Figure 3B. Large Expanses/Patches of Least Disturbed Lands



Map Features

- ▭ 4,000-foot contour - INRMP Study Area
- ▨ County Designated Rural Centers
- ▨ County Designated Community Region
- 🟨 Buffers of Low-traveled Roads[2]

CWHR Herbaceous Communities[1]

- 🟩 Annual Grassland
- 🟫 Wet Meadow

CWHR Shrub Communities[1]

- 🟧 Chaparral (mixed, montane, chamise)

CWHR Hardwood Communities[1]

- 🟪 Valley Oak Woodland
- 🟦 Blue Oak Foothill Pine and Blue Oak Woodland
- 🟫 Montane Hardwood and Montane Hardwood Conifer

CWHR Coniferous Communities[1]

- 🟩 Closed Cone Conifer
- 🟩 Douglas Fir, Ponderosa Pine and Sierran Mixed Conifer

CWHR Riparian Communities

- 🟦 Montane Riparian[1]

CWHR Code	CWHR HABITAT TYPE	Total Acreage	Large Expanses Acreage	% of Total in Large Expanses
	Herbaceous Community			
AGS	Annual Grassland	78,401	35,251	45%
WTM	Wet Meadow	27	11	41%
	Sub-total	**78,428**	**35,262**	45%
	Shrub Community			
CRC	Chamise/Redshank Chaparral	3,672	2,891	79%
MCH	Mixed Chaparral	32,171	20,874	65%
MCP	Montane Chaparral	1,501	690	46%
	Sub-total	**37,344**	**24,455**	65%
	Hardwood Community (Oak)			
VOW	Valley Oak Woodland	3,434	819	24%
BOP	Blue Oak Foothill Pine	12,943	4,453	34%
BOW	Blue Oak Woodland	42,434	21,563	51%
MHC	Montane Hardwood Conifer	34,183	19,481	57%
MHW	Montane Hardwood	155,891	87,761	56%
	Sub-total	**248,885**	**134,077**	54%
	Coniferous Community			
CPC	Closed Cone Pine/Cypress	315	262	83%
DFR	Douglas Fir	62,284	46,443	75%
PPN	Ponderosa Pine	67,644	42,947	63%
SMC	Sierran Mixed Conifer	25,797	16,247	63%
	Sub-total	**156,040**	**105,899**	68%
	Riparian Community			
MRI	Montane Riparian	745	283	38%
	Sub-total	**745**	**283**	38%
	Grand Total	**521,442**	**299,976**	**58%**

Sierra Ecosystem Associates

1 0.5 0 1 2 3 Miles

Datum: North American Datum 1983
Coordinate System: State Plane: California Zone II (Feet)

Notes

This map is a reproduction of Figure 5. in the INRMP Habitat Inventory and Mapping Report from 6-28-2010. For details and information about the procedures used in the creation of this map please see that report.

[1] Vegetation community data extracted from the CalVeg database. CalVeg data is available from the California Department of Forestry and Fire Protection (downloaded January, 2010). Last updated 2005.

[2] Less-traveled roads that represent less-significant barriers to species movements. These roads were identified from the County GIS roads database with input from the ISAC and PAWTAC.

Date: April 19, 2010

Revised Draft

Map Prepared By: Ethan Koenigs

2.0 Connectivity and Wildlife Movement in the INRMP Study Area

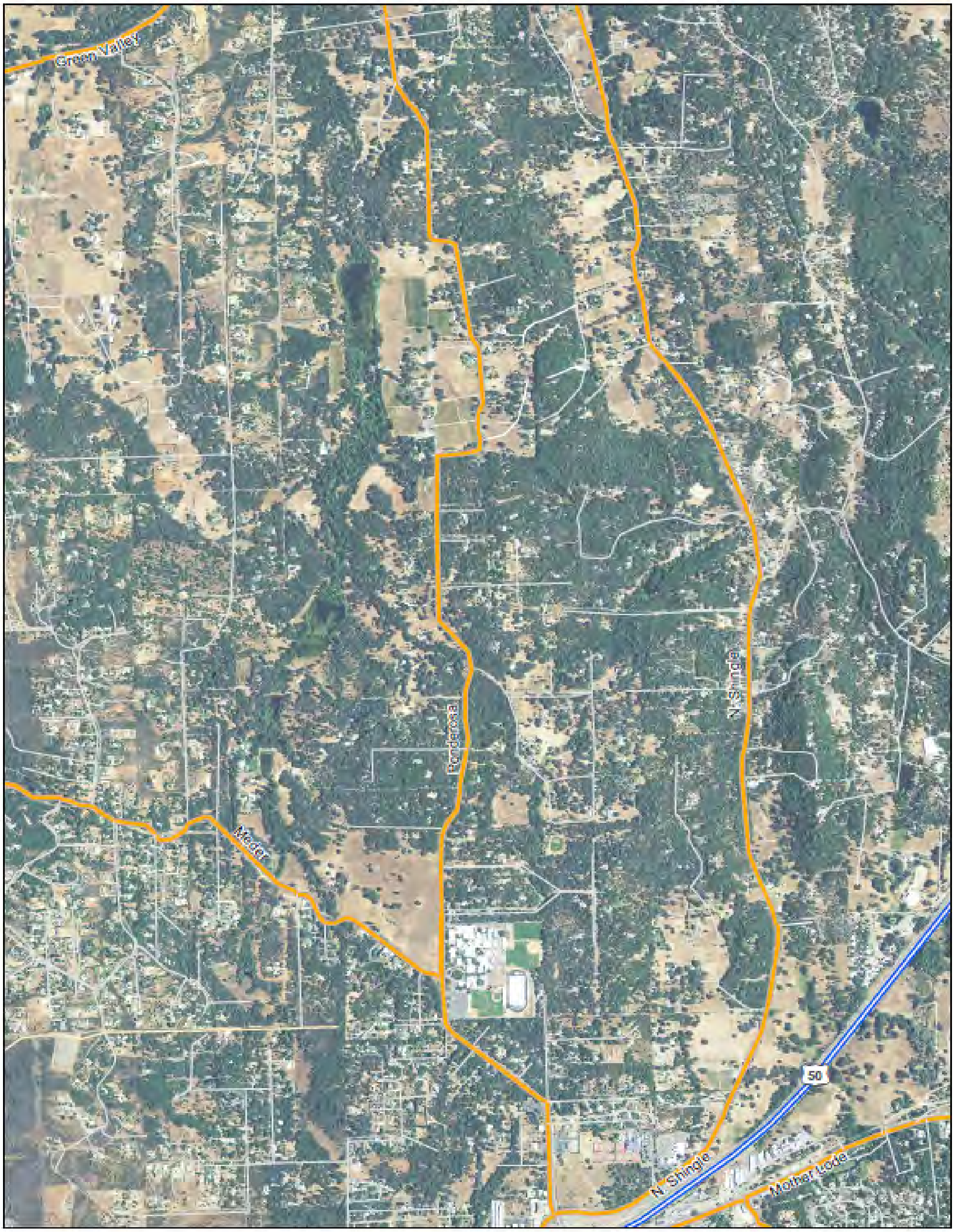
The western portion of the County has a variety of landscapes and levels of disturbance, from urban areas to wild areas, low-density rural development, agriculture, and actively-logged areas. These different levels of disturbance correspond to varying levels of fragmentation, which will affect wildlife and plant occupancy and dispersal. Moderately and highly fragmented areas will tend to have reduced likelihood of wildlife movement in any direction. Two possible directions of wildlife and other taxonomic groups' movement are north-south and east-west. Obviously, movement in other compass directions is possible and likely, but these directions are oriented roughly up and down the Sierra Nevada foothills and up and down the elevational gradient from the valley to the Pacific Crest. Barriers to wildlife movement and impacts to connectivity come from land uses and transportation networks. Previous plans in the County have attempted to deal with certain aspects of habitat conditions, for example, the Oak Woodland Management Plan (OWMP) (El Dorado County 2007). Previous analyses of general planning have expressed concern about the possible ramifications of different build-out scenarios (e.g., Saving and Greenwood, 2002). In particular, Saving and Greenwood point out that maintaining connectivity in the face of General Plan build-out is best accomplished through strategic purchases in critical areas where connectivity would be lost due to development, primarily along Highway 50. They further pointed out that the fragmentation and disturbance patterns and impacts would eventually be a result of the way development already-permissible under the General Plan was laid-out and controlled through County ordinances. For a given increase in population, types of development that are likely to have the greatest effect across the landscape are low-density residential (1 unit/5 to 10-acres) and rural residential (1 unit/10 to 40-acres). This may seem counter-intuitive, but because many animals are sensitive to roads, houses, fences, people's activities, and pets, the larger landscape area often affected by low-density and rural residential developments means that the effects cover a larger area. This section evaluates the need for connectivity in the context of existing and proposed development and conservation activities in the study area.

2.1 Wildlife Movement

According to the California Wildlife Habitat Relations system, there are 366 vertebrate species that could occur in western County habitats (Appendix E – Vertebrate Species Affected by Transportation and Land Use Fragmentation). 316 of these species have high habitat quality in the lower elevation plant communities in the western part of the study area. In comparison, 262 of the 366 could occur in the western 1/3 of the study area and 150 of these have high habitat quality (Appendix E – Vertebrate Species Affected by Transportation and Land Use Fragmentation). Of the 316 species, 95 are ground-dwelling (62 are mammals and 33 are herpetofauna) and the remainder are flying (birds and bats). Previous research, some of which is cited in this study, shows that wildlife move during daily, seasonal, and multi-annual time-frames. To do so, individuals, populations, and species need connected landscapes. Fragmentation almost certainly will inhibit the movement of all vertebrate species in the study area to varying degrees. Those species that move the most, which are usually the largest, almost certainly will require the highest level of connectivity. However, even the smallest organisms with the most limited individual home ranges need to disperse and mate with others of the same species in order to retain population and genetic structure. The movement of all species almost certainly will be affected by the presence of roads and similar development (Figure 4. Roads and

Rural Development Fragment Habitats in Western El Dorado County), meaning that as roads and associated development proliferates, species and population level effects almost certainly will occur, even if they are not measured.

Figure 4. Roads and Rural Development Fragment Habitats in Western El Dorado County



East-West Connectivity

East-west connectivity is likely to be affected by Highway 49 and major roads in the study area: Latrobe Road, South Shingle Road, Salmon Falls Road, Lotus Road, and others. This effect will depend on the wildlife species, position of the road in the landscape/habitat, traffic volumes, traffic speeds, road sinuousity (how curved it is), adjacent fencing, and opportunities to cross the road safely. Because the whole study area is hilly, most roads have a lot of curves. Fast-moving cars may not have time to avoid collision as they go around curves. Because of the degree of roadedness (combination of road density and road effects) in the study area, wildlife movement in any compass direction is likely to be affected at some point by roads and their use. North-south connectivity and wildlife movement is discussed in more detail below, especially as related to the Highway 50 urban and transportation corridor.

2.2 Barrier Effect of Highway 50 and Other Major Roadways

Highway 50 and other major roadways in the study area are very likely to function as partial or complete barriers to movement of ground-dwelling, terrestrial vertebrates. Complete barrier effects will result from some combination of physical characteristics of the right-of-way (ROW), traffic volumes, and sensitivity of the animals to roads and traffic. Less-sensitive animals and lower-use roads will result in lower barrier effects. The sections below discuss the barrier effects associated with Highway 50. Major roadways are likely to have many of the same types of effects, but these are likely to be less intense.

Highway 50 as Barrier

Highway 50 is a busy highway bisecting the Sierra Nevada and its foothill habitats between Folsom and Lake Tahoe. For much of its length, west of Placerville, it has associated urbanization in rural areas that add to the fragmenting effect of the highway (e.g., Saving and Greenwood, 2002). The combination of the 220-foot wide highway ROW, the >10,000 cars/day along the highway within the study area, and the associated rural-developed and urban areas provide a relatively effective barrier for ground-dwelling wildlife movement in the north-south compass direction in the foothills. Animals and ecological processes will be affected by the Highway 50 transportation corridor to varying degrees, with flying animals and seed dispersal affected less than ground-dwelling animals.

In three recent publications (Shilling et al., 2002, 2007; Spencer et al., 2010), Highway 50 stands out as a barrier to several identified corridor or linkage zones at the scale of the Sierra Nevada foothills. Shilling et al. (2002, 2007) used a landscape integrity index as the basis for a fine-resolution connectivity analysis of the Sierra Nevada using a least-cost corridor modeling approach within habitat zones. Spencer et al. (2010) used a similar approach, but with a more generalized analysis of the whole state. These two teams identified two slightly different linear connection strategies for the western County. Spencer et al. (2010) proposed one connectivity area in the western County, traversing east El Dorado Hills and Marble Valley to connect the grasslands to the south with the undeveloped lands around eastern Folsom Lake to the north (Figures 5A. Essential Habitat Connectivity Project – Sierra Nevada Foothills and Figure 5B. Essential Habitat Connectivity Project – Western El Dorado County). This area includes many roads and subdivisions, but is also the last open habitat in the western County in close proximity on either side of Highway 50. Shilling et al. (2002) identified two main areas for conservation of wildlife movement, one east of Placerville and the other west (Figure 6. Distribution of Intact Habitat Patches and Potential Corridors). These independent analyses, combined with the disturbance and habitat mapping from INRMP Task 1b, provide a relatively complete picture of the landscape connectivity and potential wildlife corridors in the western County. In all cases, remnant wildlife habitat connections (e.g., Marble Valley and Weber Creek) and rural residential development areas (e.g., east of Placerville) provide a few remaining landscape connections for north-south movement of wildlife in this portion of the Sierra Nevada foothills. Connections like the lower foothill corridor that traverses the Bass Lake Road interchange are important both regionally and within the County because they are unique and irreplaceable. In other words, there are no comparable wildlife corridors in the habitat zones each occupies; once developed, wildlife movement north and south across the Highway 50 corridor in the lower foothills almost certainly will cease.

The importance of Highway 50 in this picture is that its ROW surface is effectively an almost complete barrier to ground-moving wildlife, while a few under-crossing opportunities still exist. It is both a developed transportation corridor disturbing the surrounding ecology and the location of critical junctions between built and natural systems. Conserving and expanding remaining connections across the highway west of Placerville will be a critical action in the protection of foothill species requiring the ability to move and disperse within their habitat zones.

One way to assess Highway 50 is in terms of the number of wildlife that die from collisions with vehicles. The California Department of Transportation (Caltrans) has created a geo-referenced database of larger animals that its maintenance crews have cleaned up. Although the database goes back 40 years, it is not complete. In other words, there have been roadkilled animals that are not in the database. The distribution of deer roadkill and traffic volumes is shown in Figure 7. Comparison of Traffic Volumes and Deer Kill on Highway 50. Volumes of traffic are very high west of Placerville, becoming lower as the highway goes eastward. There are two primary peaks in deer roadkill along the highway. One is near Placerville itself and the other is roughly where Highway 50 runs along the American River.

Figures 5A. Essential Habitat Connectivity Project – Sierra Nevada Foothills Area

Shown below is the position of “essential connectivity areas” (a) in the Sierra Nevada foothills and (b) within El Dorado County (Source: Spencer et al. 2010).

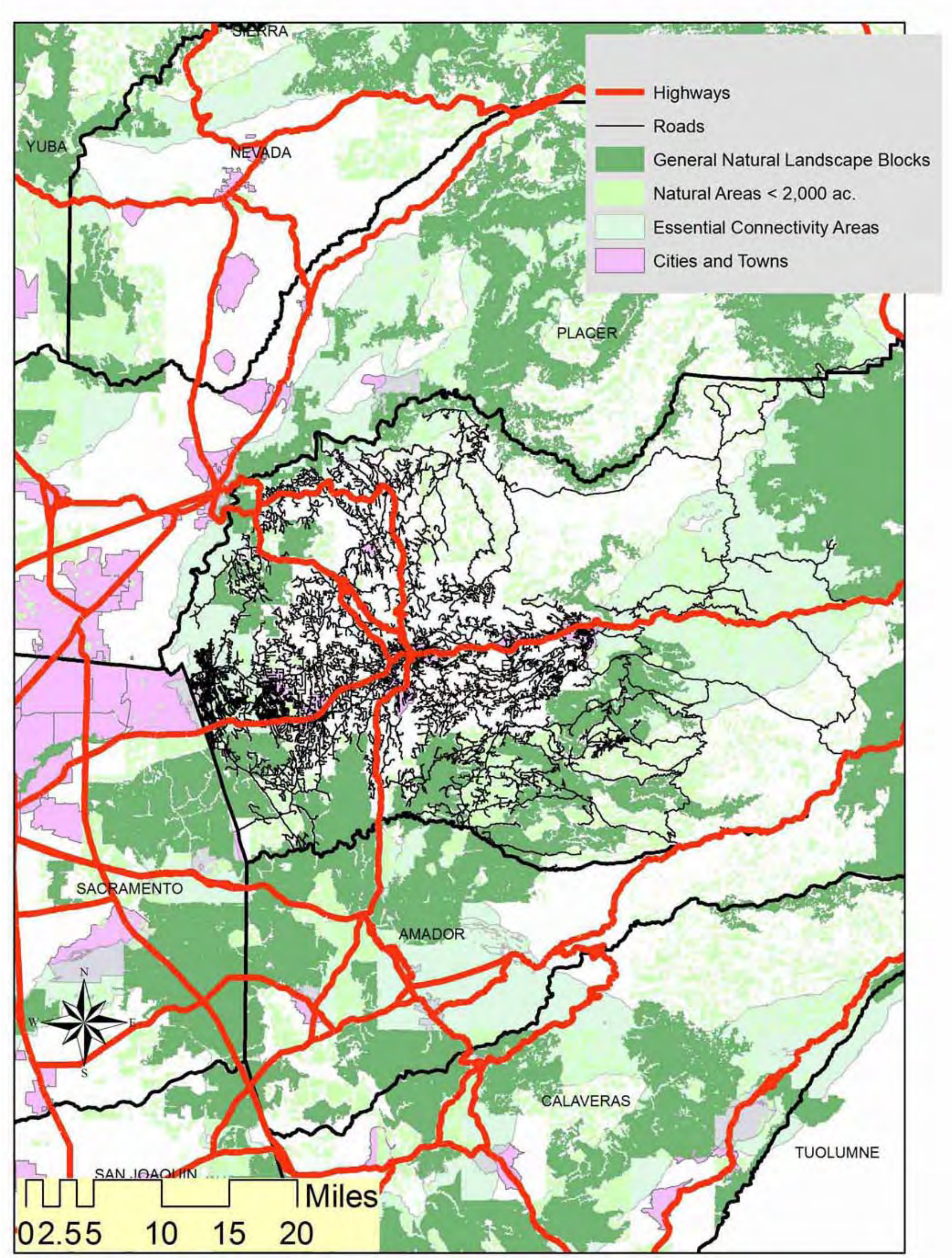


Figure 5B. Essential Habitat Connectivity Project – Western El Dorado County

The position of “essential connectivity areas” (a) in the Sierra Nevada foothills and (b) within El Dorado County (Source: Spencer et al. 2010) are shown below.

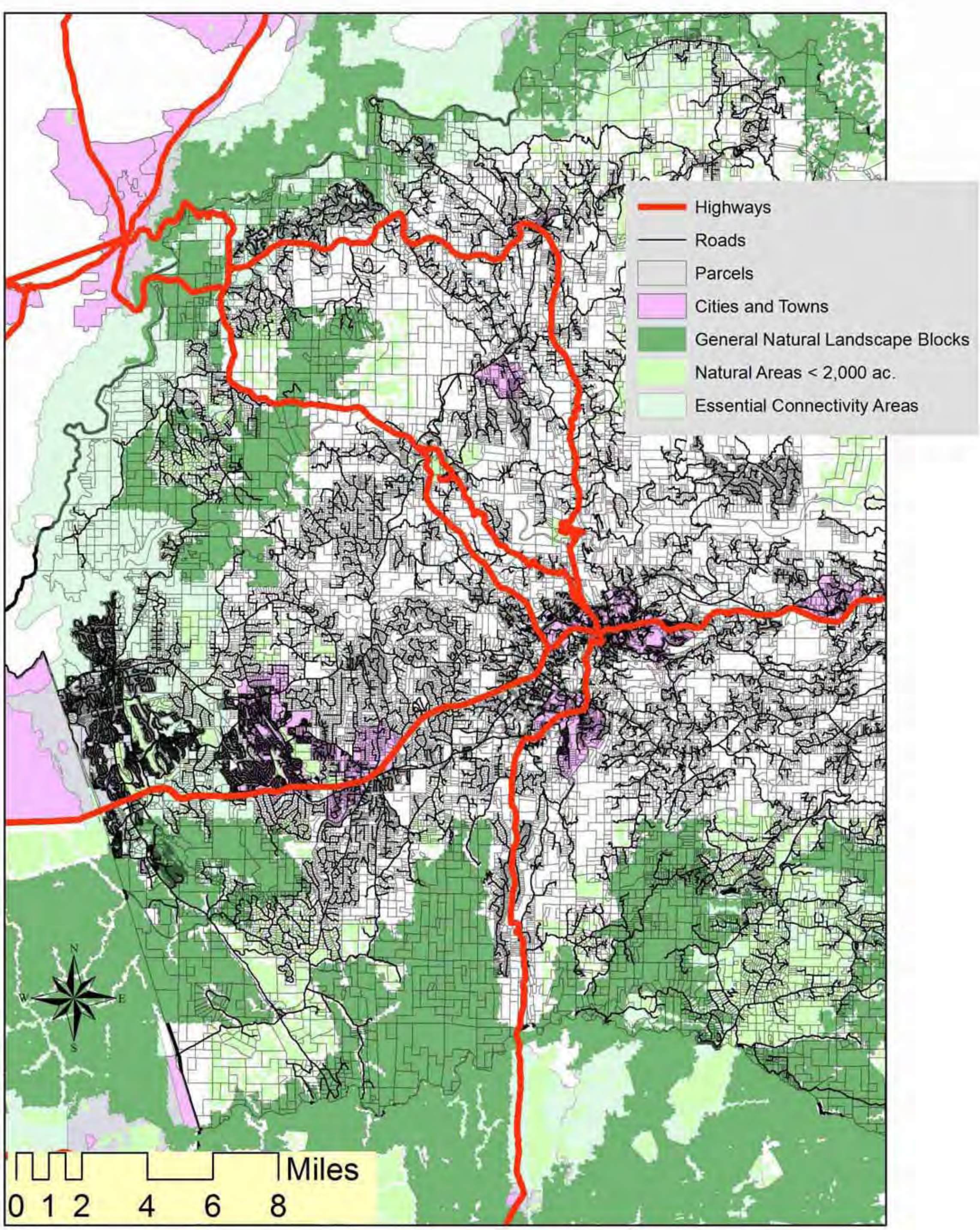


Figure 6. Distribution of Intact Habitat Patches and Potential Corridors

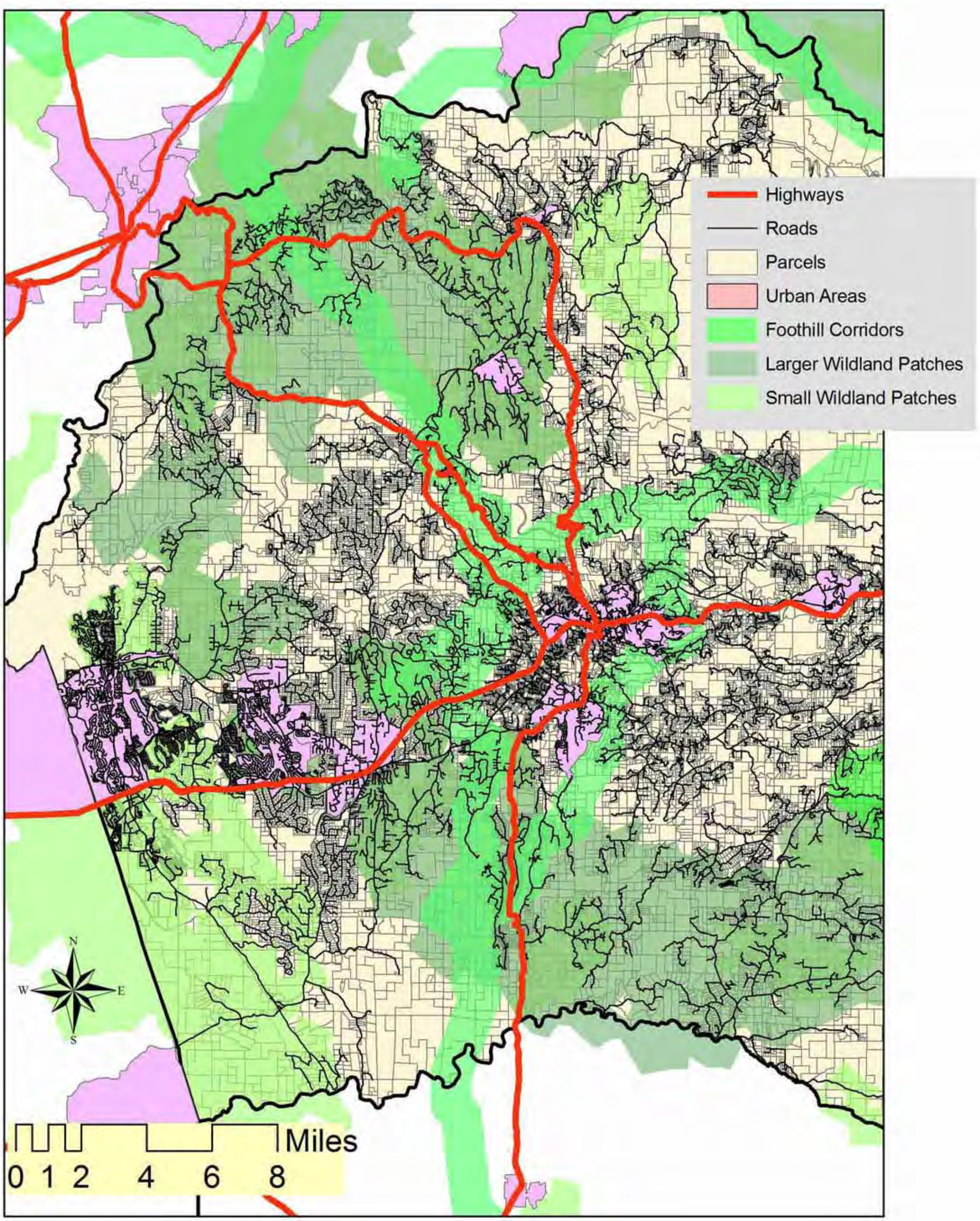
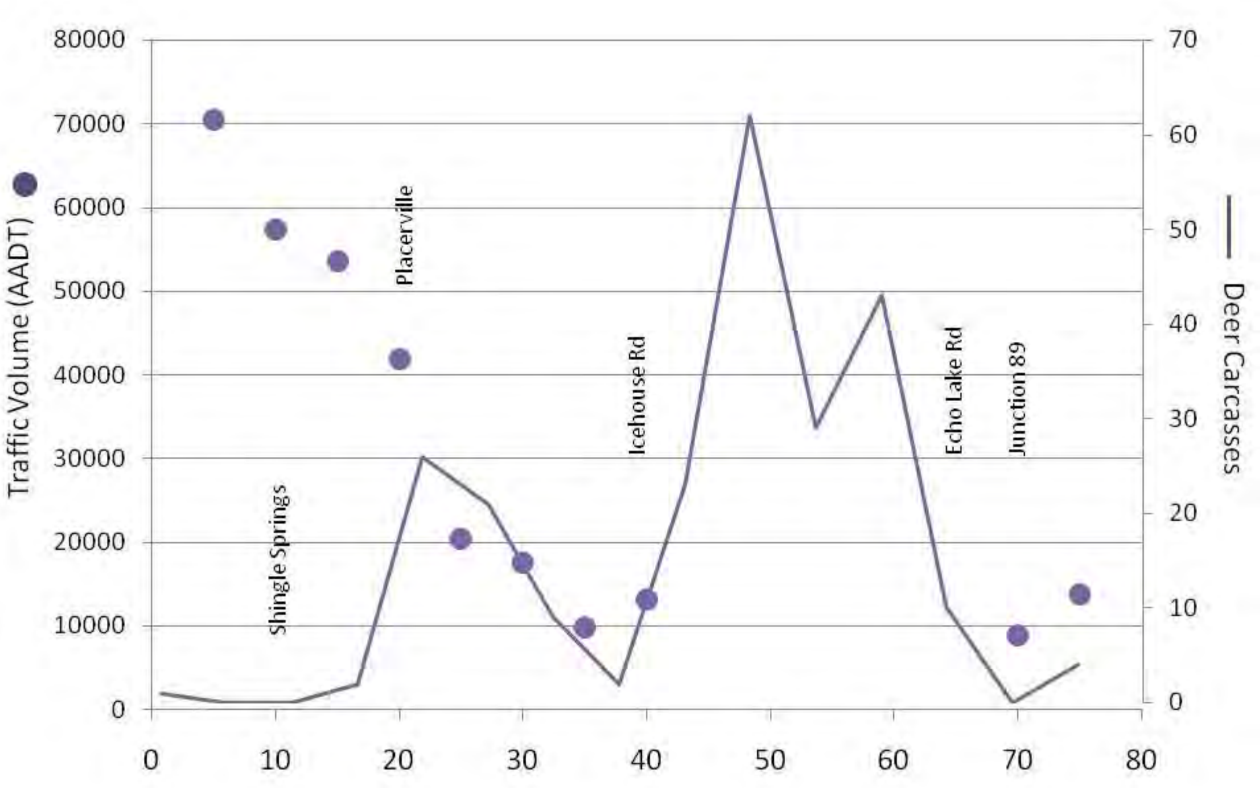


Figure 7. Comparison of Traffic Volumes and Deer Kill on Highway 50 (data from Caltrans)



2.3 Potential Crossing Locations along Highway 50

The surface of any busy highway is a dangerous place for animals. Most animals will avoid crossing the road surface itself, unless they have become habituated to the sound and sight of fast-moving vehicles. When highways have both concrete median barriers and high traffic volumes, it is less likely that animals will attempt to cross the surface and if they do, that they will survive. In some places, there are crossing opportunities that allow animals to cross the ROW, without using the road surface. For example, culverts, road and stream under-crossings, and road over-crossings all provide potential passage from one side of a highway to the other. These potential crossings vary in size from metal pipe culverts only a foot in diameter to bridged streams and roads up to 100 feet wide.

Between the border with Sacramento County and 4000’ elevation, Highway 50 is traversed by two dozen potential crossing locations, ranging from small drainage pipes to Weber Creek. Each of these was surveyed as a potential opportunistic crossing device for wildlife moving from one side of the highway to the other. Each was evaluated for its potential to provide wildlife with the connections needed to move within its habitat and to maintain important population structure and processes. Characteristics of these potential crossings are described in Appendix C – Potential Highway 50 Wildlife Crossings.

<u>Locations</u>

Potential locations to cross under Highway 50 were identified using a combination of field information and aerial imagery. Thirty potential locations were mapped for detailed evaluation, 24 of which were accessible (Figure 8A. Locations of Existing Potential Highway 50 Crossings in the Western Study Area, Figure 8B. Locations of Existing Potential Highway 50 Crossings in the Placerville to Pollock Pines Area, and Figure 8C. Locations of Existing Potential Highway 50 Crossings in the Eastern Study Area)). Each accessible location was characterized in detail in the field (Appendix C – Potential Highway 50 Wildlife Crossings).

The locations are: 1) Dunwood Corrugated Culvert Pipe; 2) Finders Concrete Box Culvert; 3) Nugget Concrete Box Culvert; 4) Joerger Concrete Box Culvert; 5) Silva Valley Parkway Bridge Under-Crossing; 6) Tong Road Concrete Box Culvert; 7) Bass Lake Road Under-Crossing; 8) Faith Lane Corrugated Culvert Pipe; 9) Cambridge Road Concrete Box Culvert (1); 10) Cambridge Road Concrete Box Culvert (2); 11) Chaparral Corrugated Culvert Pipe and Concrete Box Culvert; 12) Shingle Springs Road Bridge Under-Crossing; 13) Dry Creek Tributary at Red Hawk Pipe Culvert; 14) Greenstone Road Bridge Under-Crossing; 15) Weber Creek Bridge Under-Crossing; 16) Smith Flat Road Under-Crossing (this under-crossing is within the city limits of Placerville); 17) Point View Drive Bridge Under-Crossing (this under-crossing is within the city limits of Placerville); 18) Carson Road Bridge Under-Crossing; 19) Snows Road Bridge Under-Crossing; 20) Ridgeway Road Bridge Under-Crossing; 21) Pacific House Concrete Box Culvert; 22) Ogilby Canyon Concrete Box Culvert; 23) Riverton Bridge (South Fork American River); 24) South Fork American River Bridge Under-Crossing East #1; 25) South Fork American River Bridge Under-Crossing East #2; 26) White Hall 1 Corrugated Culvert Pipe; 27) White Hall 2 Corrugated Culvert Pipe; 28) White Hall 3 Corrugated Culvert Pipe; 29) Kyburz West Corrugated Culvert Pipe; 30) Kyburz East Corrugated Culvert Pipe.

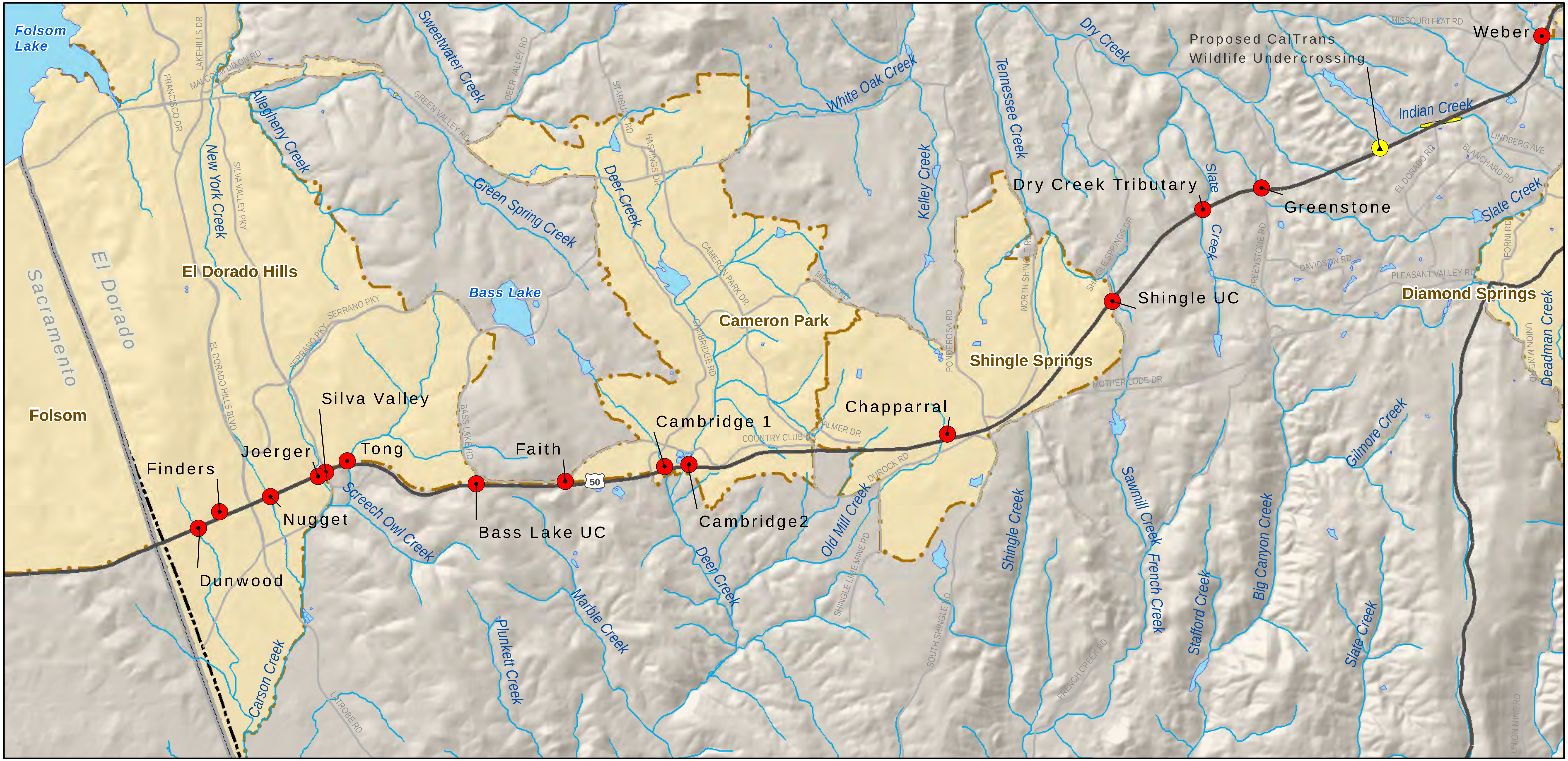


Figure 8a. Locations of Existing Potential Highway 50 Wildlife Crossings in the Western Study Area

El Dorado County Integrated Natural Resources Management Plan - Phase I

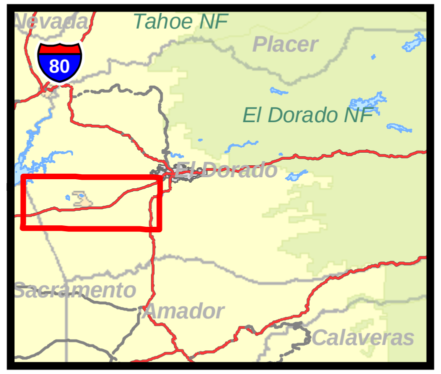
Wildlife Movement and Corridors Report

Legend

Administrative Boundaries
- Communities
- USFS Land
- INRMP Study Area
- Highway
- Major Roads

Hydrology
- Canal/Ditch
- Connector
- Pipeline
- Stream/River
- ● Existing Crossings

0 0.5 1 2 Miles



Date: 9/30/2010 Created By: Ethan Koenigs

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1 inch = 5,000 feet

NAD 1983 State Plane California II Feet

Prepared By:

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Sierra Ecosystem Associates

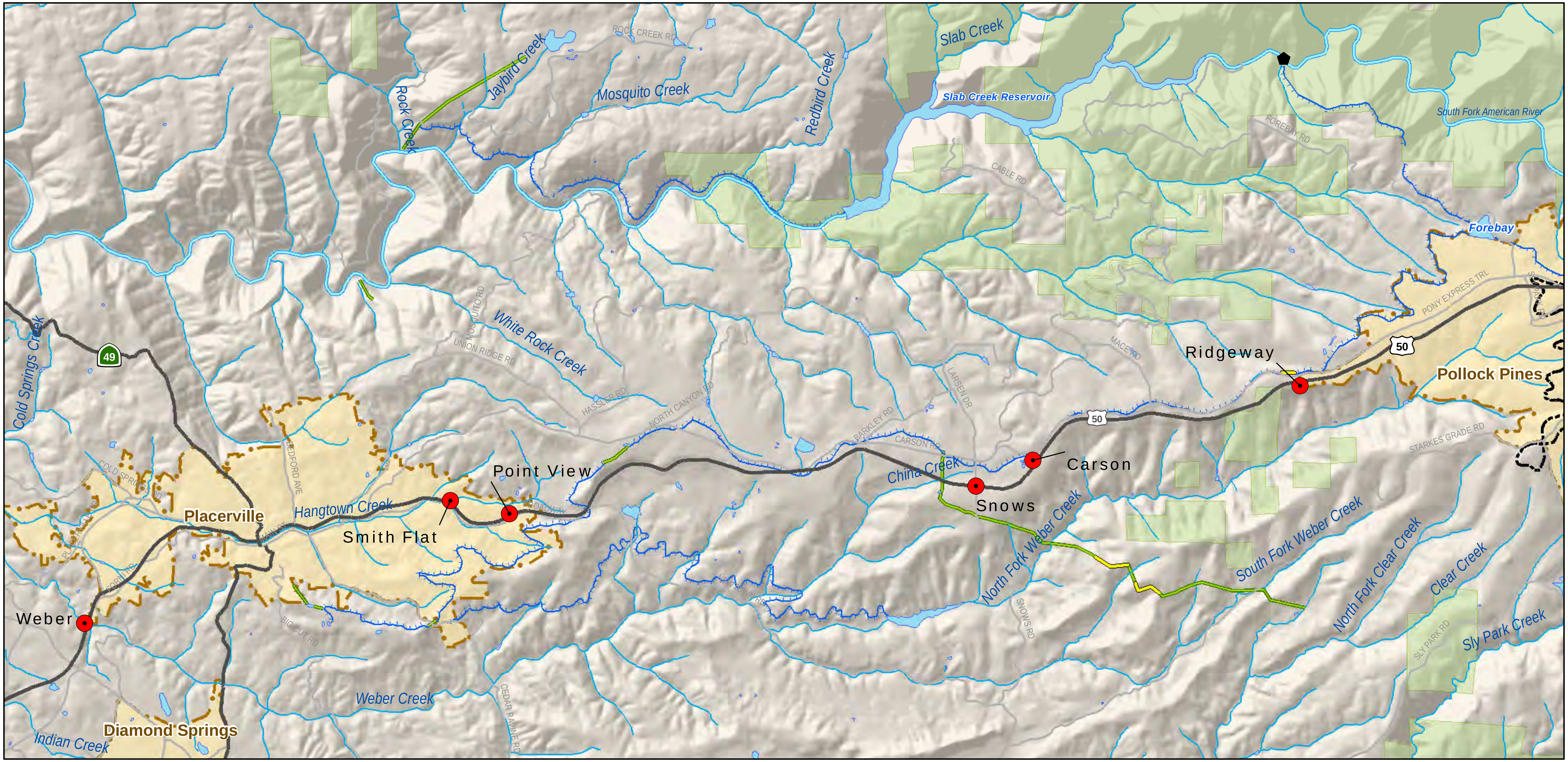


Figure 8b. Locations of Existing Potential Highway 50 Wildlife Crossings in the Placerville to Pollock Pines Area

El Dorado County Integrated Natural Resources Management Plan - Phase I

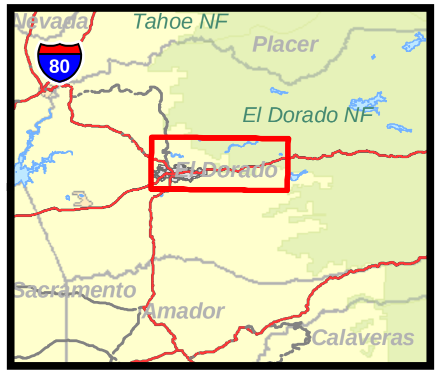
Wildlife Movement and Corridors Report

Legend

Administrative Boundaries
- Communities
- USFS Land
- INRMP Study Area
- Highway
- Major Roads

Hydrology
- Canal/Ditch
- Connector
- Pipeline
- Stream/River
- ● Existing Crossings

0 0.5 1 2 Miles



Date: 9/30/2010 Created By: Ethan Koenigs

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NAD 1983 State Plane California II Feet

Prepared By:

Sierra Ecosystem Associates

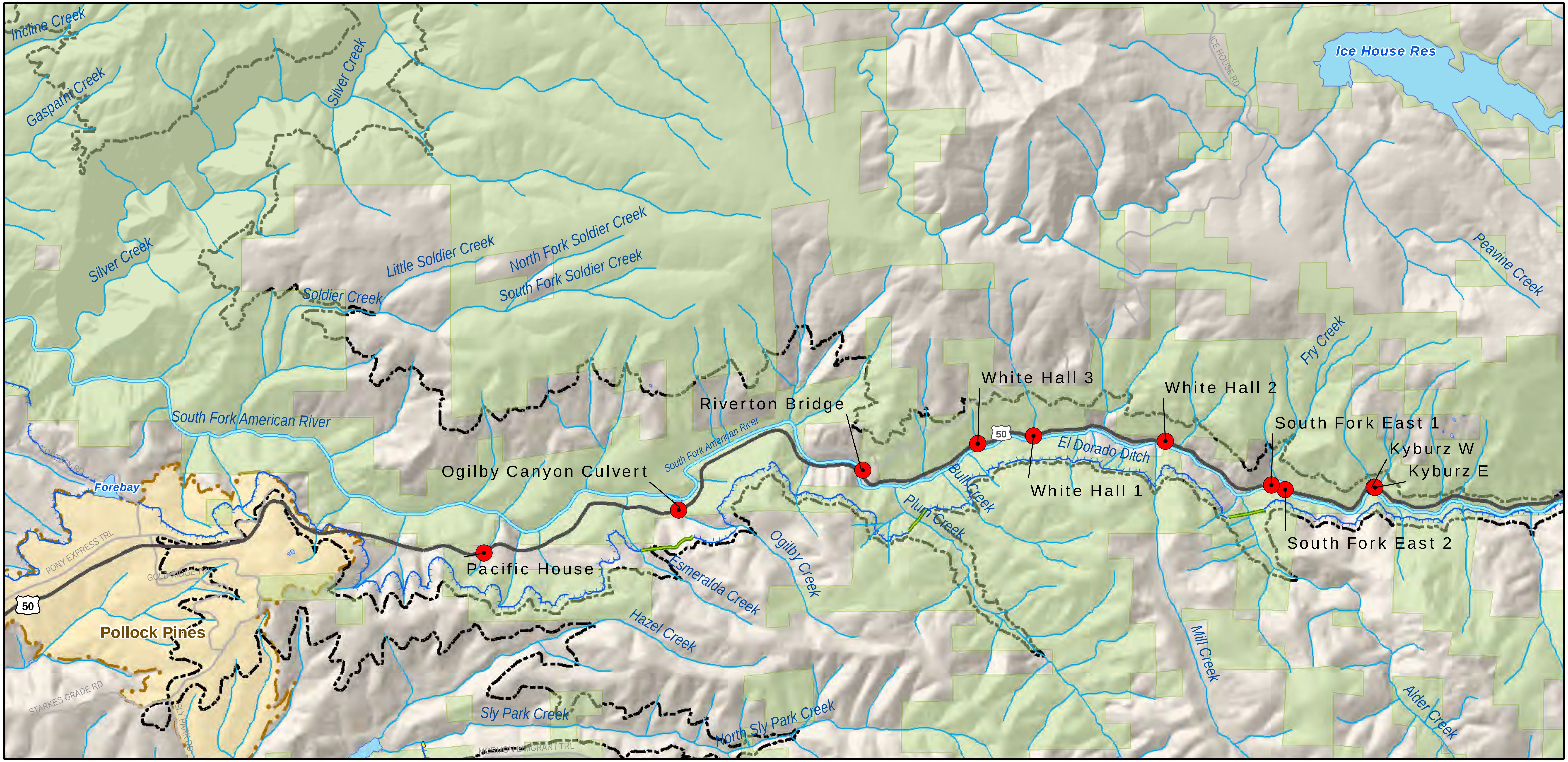


Figure 8c. Locations of Existing Potential Highway 50 Wildlife Crossings in the Eastern Study Area

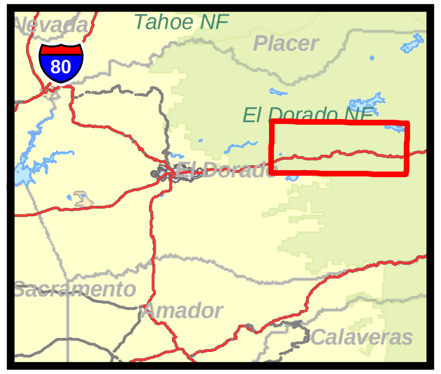
El Dorado County Integrated Natural Resources Management Plan - Phase I

Wildlife Movement and Corridors Report

Legend

Administrative Boundaries	Hydrology
▭ Communities	┄ Canal/Ditch
🟩 USFS Land	━ Connector
▭ INRMP Study Area	━ Pipeline
━ Highway	─ Stream/River
─ Major Roads	● Existing Crossings

0 0.5 1 2
Miles



Date: 10/13/2010 Created By: Ethan Koenigs

N

1 inch = 5,000 feet

NAD 1983 State Plane California II Feet

Prepared By:

Sierra Ecosystem Associates

Figure 9. Weber Creek Under-Crossing

Crossing Characteristics

Each potential highway crossing location was characterized using formal field surveying methods, aerial imagery analysis, and photography.

The following field methods were used:

1. Potential locations were identified using Google Maps and expert opinion;
2. A field visit was made to confirm the actual presence of a crossing and exact geographic coordinates;

3. The crossing and opening dimensions were measured, when possible, using a tape measure or laser range finder, depending on size of the opening;
4. The crossing type, substrate, and construction materials were recorded;
5. The environmental and infrastructural context of each opening of the crossing was characterized from the opening itself to a 0.62-mile distance;
6. If the crossing opening was not accessible from some form of public ROW, then it was characterized from a distance; and,
7. All potential crossings and their landscape context were photographed.

The characteristics of all potential crossings were captured in a spreadsheet and series of photographs. The primary information for each site is presented in Appendix C – Potential Highway 50 Wildlife Crossings.

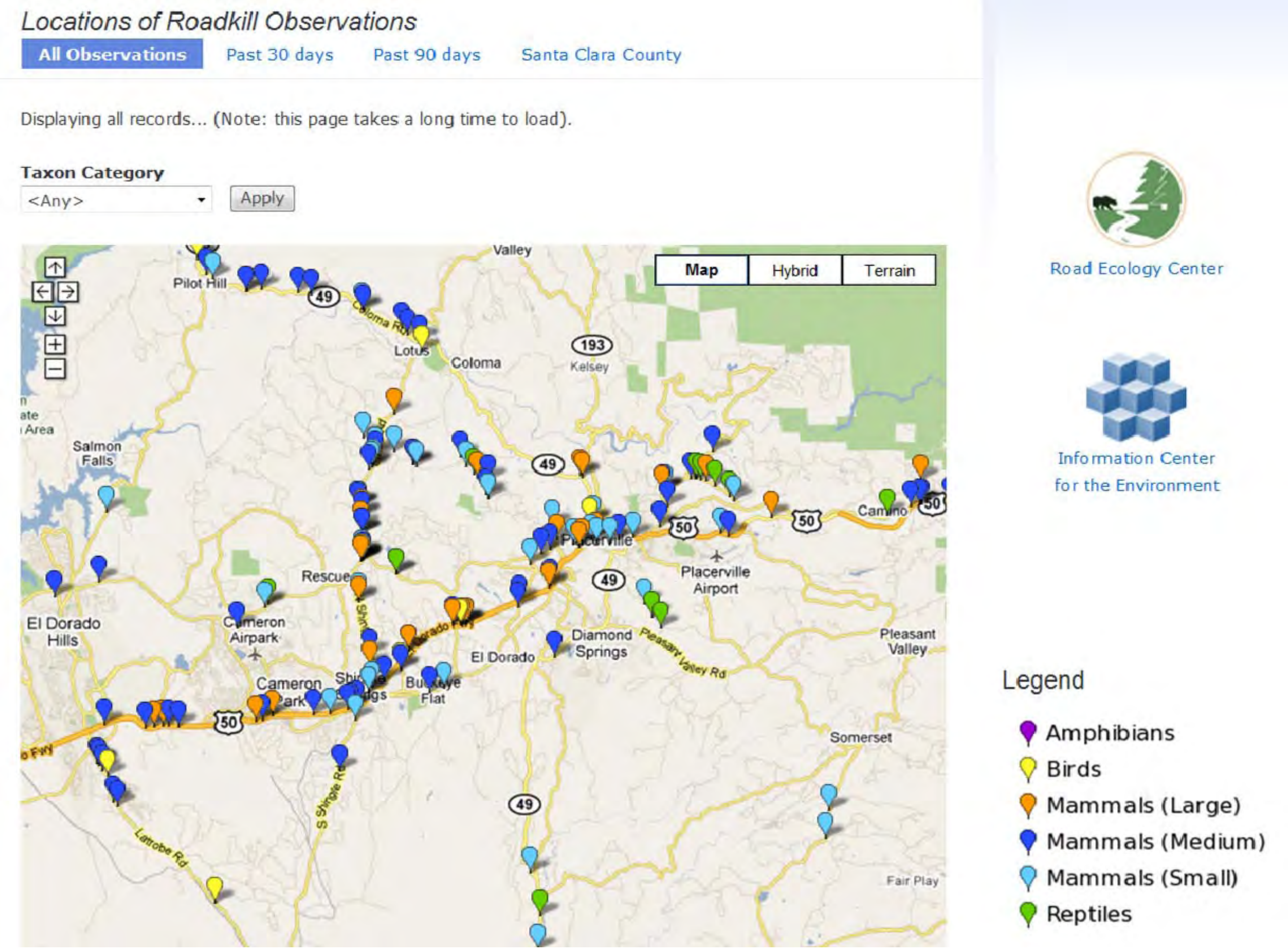
<u>Likelihood of Crossing Structure Use</u>
Each crossing was evaluated in the field and based on its context and characteristics for the likelihood that it could serve as a passage for wildlife to cross from one side of Highway 50 to the other. Likelihood of use was based on the potential crossing structure's attributes (e.g., appropriate substrate within the crossing, accessibility of the opening, dimensions of structure) and its adjacent landscape and habitat context. The results of this evaluation are presented in Appendix C – Potential Highway 50 Wildlife Crossings.

2.4 Other Roadway Barriers to Movement

Highway 50 is one barrier to wildlife movement in the County. There are other major roads that may have sufficient traffic to inhibit movement by wildlife, reduce genetic connections among populations, and result in wildlife-vehicle collisions. These include: Latrobe Road, South Shingle Road, Serrano Parkway, Green Valley Road, Salmon Falls Road, Lotus Road, North Shingle Road, Mother Lode Drive, Greenstone Road, Gold Hill Road, Highway 49, Georgetown Road, Missouri Flat Road, Sand Ridge Road, Pleasant Valley Road, Sly Park Road, Wentworth Springs Road, many of which have had roadkills reported on them (Figure 10. Locations of Roadkill in Western El Dorado County). All are not equal in the types or intensity of impacts because they vary in their location relative to natural systems (oak woodlands vs. conifer forests), have different traffic patterns, and are located in a range of development conditions, from sub-division to very rural.

Figure 10. Locations of Roadkill in Western El Dorado County

*Information reported on the California Roadkill Observation System (http://www.wildlifecrossing.net/California/)



Locations of Roadkill Observations

Displaying all records... (Note: this page takes a long time to load).

Taxon Category
<Any>

Smaller roads may have fewer and smaller opportunistic under-crossings for wildlife than highways because they will tend to intersect with perpendicular roads rather than bridging them and may have been constructed when stream passage requirements were different than they were for highway construction. Busy rural roads and roads between urban areas can have quite different and disproportionately high impacts to wildlife compared to highways. A highway may function as an effective barrier between populations, but cause few roadkill compared to traffic volume. In contrast, rural county roads in hilly areas may allow sufficient individual animals through to maintain genetic connections, but because of blind-spots in the road and larger gaps between cars, more animals may try to cross road surfaces and get killed doing so.

For certain taxonomic groups, roads are complete barriers to movement due to traffic. It is not uncommon for busy rural roads to account for 50-100% mortality of turtles, salamanders, toads, and frogs (reviewed by: Andrews et al., 2008), especially when rain or other environmental stimuli trigger movement associated with breeding. In one intensive study of a road between two ponds involving daily observations for over 2 years, the investigator never observed a successful crossing by a turtle from one side of the road to the other (Aresco, 2005). Mortality rates on roads are so high for amphibians and reptiles that in some areas they are likely to be the primary cause of death and may risk population sustainability (Andrews et al., 2008).

3.0 Strategies for Improving Wildlife Movement and Connectivity

Protection and enhancement of wildlife connectivity has been acknowledged as an important component of California statewide conservation strategies (Bunn et al. 2007). A recent planning and analysis effort (Spencer et al. 2010) was undertaken to identify linkages of statewide importance in California at low planning resolution. Momentum has been increasing globally over the past decade to include connectivity as a vital aspect of conservation planning at more local levels. This section describes some approaches to connectivity planning and implementation that could be applied to the ecological setting of the County.

3.1 Habitat Protection

The most effective management actions for landscape connectivity center on conservation of existing natural land cover and other ecological elements that enable wildlife movement. Intact landscapes facilitate these movement events more so than narrow corridors, stepping stones, or other types of linkage designs. However, due to human presence and activities across most of the planet, it is challenging to provide connectivity for all species in all places. Habitat intactness depends both on the distribution of our human infrastructure AND its use. For example, a road by itself may inhibit a few species from moving within a habitat type. Once cars travel on that road, the number of species inhibited from movement increases. Similarly, a 20-acre parcel with a house on it in one corner will inhibit nearby movement of certain sensitive species. If fences are present, dogs and cats allowed to roam, and the house and/or driveway placed near the center of the parcel, then fewer animals may move across the parcel, depending on adjacent land-uses. The location of development on the parcel is likely to affect the habitat and connectivity value of the parcel.

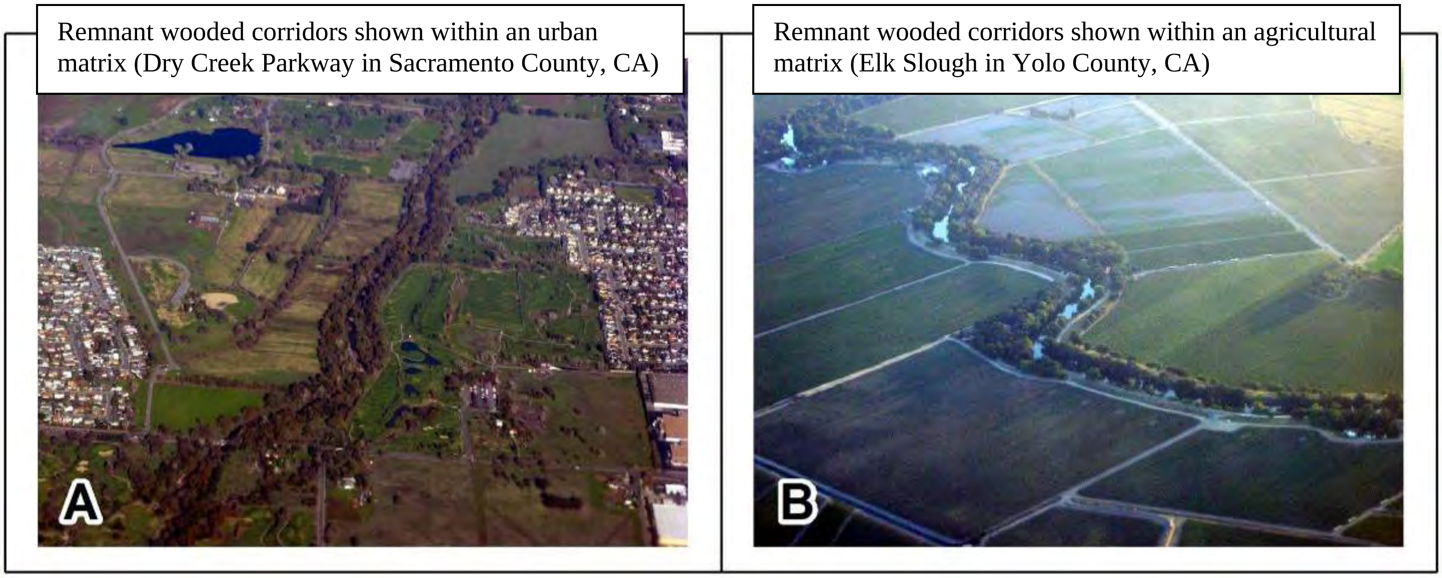
Habitat protection can consist of acquiring parcels for conservation by fee title purchase or easement from willing sellers, restrictions on development (Shilling and Girvetz 2007), or education of landowners about habitat stewardship. A comprehensive habitat and wildlife protection program would employ these tools and more (Saving and Greenwood, 2002). No one strategy is likely to work in all cases. The most extensive, but least protective mechanism for habitat and connectivity protection is education. The least extensive and most protective mechanisms are parcel acquisition and development restrictions.

While there are some areas of the County that might be categorized as intact landscapes, they are mostly confined to the higher elevation portions of the County. Within the INRMP planning area, there are opportunities to adopt various approaches for connectivity protection, depending on the location and the species and habitat targeted. The most difficult places are near urban areas and the most challenging species to protect are large, wide-ranging mammals. While acquisition of existing undisturbed patches may be necessary to retain landscape connectivity, especially at connectivity bottlenecks, the existing levels of human disturbance within the planning area likely necessitate additional management actions for future connectivity needs (Saving and Greenwood, 2002). In order to avoid species going locally, regionally, or completely extinct, land use and transportation planning based on the habitat and movement needs of animals and plants is inevitable.

3.2 Landscape Corridors

Where human impacts to the landscape have severely constrained wildlife movement (e.g., in urban and agricultural settings), one approach to connectivity conservation has been through management of linear movement corridors. These corridors often consist of remnant natural land cover that has remained undeveloped, in contrast to adjacent areas (Figure 11. Remnant Wooded Corridors). A typical corridor of this sort would be a riparian forest strip buffering a stream or river. Corridors can take the form of either continuous vegetation or “stepping stones”, between which individuals move across less hospitable habitat (Bennett 2003). Corridors can also result from active restoration for the purposes of linking two larger population source areas. Obviously, one of the most critical aspects of these corridors is that they lead from one place or habitat that animals want to be to another place they want to be. This management approach operates under the assumption that animals will in fact use these linear features to move across the landscape. For narrow corridors, only less sensitive wildlife (e.g., raccoons) will use these corridors; wider corridors will permit most animals to move through. While successful use of these corridors is far from universal, there are a number of studies that have been conducted over the past two decades that indicate that, in some circumstances at least, they are used for movement by some individuals (Tewksbury et al. 2002, Damschen et al. 2006). However, it is unlikely that all species of concern will be able to use the same corridor for movement; corridors need to be designed to meet the needs of particular species (Sieving et al. 2000). For species that use them, corridors can be one management approach for enabling movement through human-impacted landscapes. Restoration of wide vegetated buffers through developed landscapes is one way to return animal movement to these landscapes, where width primarily will determine actual use of the vegetation strip. Modifications to land use can be another management approach to facilitate wildlife movement through developing landscapes. However, caution should be taken in assuming that corridors can fully mitigate for additional habitat loss (Rosenberg et al. 1997).

Figure 11. Remnant Wooded Corridors



Remnant wooded corridors shown within an urban matrix (Dry Creek Parkway in Sacramento County, CA)

Remnant wooded corridors shown within an agricultural matrix (Elk Slough in Yolo County, CA)

* Photos P. Huber.

In the INRMP planning area, corridors might be one effective means by which to allow movement between identified large patches of native vegetation, especially in narrow strips separating urbanized areas in the vicinity of Highway 50. Saving and Greenwood (2002) identified one area between Shingle Springs and Placerville where landscape fragmentation was less severe near the Highway 50 corridor and a landscape corridor remnant was evident (their figure 5). Other areas near Pollock Pines are also evident from their modeling and analysis of General Plan buildout that could provide crossing of Highway 50. In parts of the landscape away from Highway 50, there is less evidence of landscape corridors. The OWMP identified several possible north-south corridor concepts for addressing the intense fragmentation effect of Highway 50-associated development. Besides Weber Creek, the Plan suggests the Dry Creek tributary and area just east of Greenstone Road as another important movement corridor. Other OWMP potential corridors have been identified to interconnect the OWMP Priority Conservation Areas (PCAs). There is considerable overlap between the PCAs and the large expanses of native vegetation mapped in the earlier task of INRMP Phase I. There is also overlap between the OWMP-identified potential corridors and the large expanses. Finally, there is moderate overlap among the IBCs, OWMP potential corridors, and landscape corridors from Shilling et al. (2002) and Shilling and Girvetz (2007). Many of these analyses relied on similar computational (e.g., GIS) or visual overlap of less-developed areas with areas of high habitat value, or connection between these areas. Therefore, the overlap of potential corridors among these studies may reinforce the findings of each other, but in areas of little overlap, the identified corridors may still be important. For example, a recent state agency report (Spencer et al., 2010) proposed an “essential habitat connection” between the southwest County grasslands and oak savannah and less-disturbed areas north of Highway 50. This finding affirms previous more-detailed studies (Shilling et al., 2002; Saving and Greenwood, 2002; Shilling et al., 2007) and suggests that from a regional perspective, this connection is vital to maintenance of regional wildlife movement, within and beyond the County.

Besides corridors and less-fragmented areas identified in earlier studies, other corridors that might be considered for conservation management are remnant riparian strips and adjacent uplands in the grasslands of the western portion of the County. If a corridor was identified through an intact habitat patch, then developing the remainder actually reduces overall connectivity. In other words, allowing development of a sub-division with a narrow strip of habitat left behind as a corridor is not effective to protect the movement needs of any but the least-sensitive species (e.g., raccoons). Restoring habitat in vegetated buffers or strips through developed landscapes is one option that could benefit wildlife movement, with the location, habitat composition, and width of the buffer-strip determining its effectiveness at providing movement.

3.3 Landscape Permeability

Wildlife movement and the gradual movement or dispersal of plant species depend on the intactness or permeability of the landscape. Depending on the ecological context, some species are able to use the land cover types more dominated by human use for movement or as part of their home ranges. For example, the giant garter snake (*Thamnophis gigas*) uses rice fields in the Central Valley of California as habitat and for dispersal between source populations. Management actions can be undertaken to make the human-dominated landscapes more permeable to animal movement and plant dispersal. This can include, for example, planting native vegetation in urban areas, reducing or eliminating harmful land use practices (e.g., heavy pesticide application in agricultural or residential areas or allowing free-roaming household pets in urban areas), or planting hedgerows (Baudry et al. 2003) or woodland “islands” in farming regions (Benayas et al. 2008). As with corridors, actual landscape permeability depends on the species (Hilty et al. 2006); management plans should therefore be tailored according to the needs of all biota in order to protect biodiversity. While increasing the permeability of the human-dominated landscape will not necessarily create the best habitat for resident individuals, it could provide enough ecological structure and function to the landscape to allow individuals and populations to disperse to more appropriate areas (Figure 12. Managing Agricultural Lands for Wildlife Usage).

There are several types of human-dominated landscape types within the INRMP planning area. In the western portion of the County, there are large pasture areas. East of this zone, there is a large amount of forested exurban, rural development, and agricultural lands. Finally, there are urban areas scattered throughout the planning area. In Saving and Greenwood (2002), landscape fragmentation is more apparent toward the western edge of the County and less apparent in the mid-County, near the eastern edge of the INRMP study area. These differences in fragmentation patterns will have different effects on wildlife movement and plant community processes, potentially necessitating different management and policy responses, or intensity of focus on the different parts of the study area. The fragmentation impacts and corresponding management responses will be different for the different study area zones because the animal and plant communities vary elevationally. The OWMP describes oak woodland loss as primarily being a fragmentation impact, as opposed to an impact on total habitat area. This is similar to the Saving and Greenwood (2002) finding. The Plan also cites the General Plan goal of maintaining landscape permeability as a way to preserve and restore wildlife movement. Different management strategies should be investigated since a planning goal of General Plan Policy 7.4.2.8 B is to conserve and restore landscape connectivity within these areas. For example, managing development to maintain rural characteristics is likely to also benefit wildlife and plant movement, assuming land management is consistent with these goals. Rural characteristics include roads with low traffic volumes and slow traffic speeds and large open spaces with either small clumps of houses, or very dispersed houses (>1/2 mile apart). Rural residential development (1 unit/10 to 40-acre parcel) will fragment habitat and impede movement of wildlife across the landscape. This is primarily due to avoidance of infrastructure, human activity, and pets that accompany even this low-density development. The effects will be less than the effects of higher-density development, but if the same number of people are accommodated, then the total habitat area affected will be greater. Potential solutions to this problem are available at many stages of land development activities, from subdivision, to zoning, to county ordinances, to permitting development plans, consistent with the GP land use pattern.

Figure 12. Managing Agricultural Lands for Wildlife Usage

Managing agricultural lands for wildlife usage (such as the wading birds in this flooded field in Solano County, California) is one example of increasing matrix permeability

*Photo P. Huber

3.1 Traffic

Traffic volume and speed are critical determinants of wildlife-vehicle collisions. However, there may be a complicated relationship between traffic volumes and the likelihood of collisions. For example, low traffic volumes may lead to a reduced aversion effect of roads (i.e., animals avoid roads because of noise and headlights), an increased rate of animal attempts to cross roads, and thus increased likelihood of collisions (Ng et al., 2004). Other investigators have found that traffic volume is a reasonable predictor of wildlife-vehicle collisions (Clevenger et al., 2003; Lode, 2000) or that speed was more significantly correlated with collisions than volume (Case, 1978). These findings have led to two main proposals for managing traffic to reduce collisions: reduced speed limits and warning signs in areas thought to be important for animal crossing. Reducing traffic speed can be accomplished by reducing speed limits and by placing speed bumps or rumble strips in roadways to discourage speeding. This may be an important management activity for roadways that consistently have wildlife-vehicle collisions. Signs have mixed effectiveness in terms of reducing traffic speeds. Studies of standard deer crossing signs have found them to be ineffective at reducing driver speed or number of crashes (FHWA, 2008). Placing warning signs seasonally or temporarily (Sullivan et al., 2004) or adding warning lights (Carr et al., 2003) may be more effective in reducing vehicle speed, but has only mixed effects on reducing collisions.

3.4 Crossing Structures

When areas that are being managed for wildlife connectivity intersect roads or other features that could reduce or eliminate animal movement, several options are available for mitigating the impacts. Speed reduction or enhanced and temporary warning signage might be enough to enable occasional road crossings, for example. In many cases, however, these measures would prove inadequate to achieve the goal of allowing movement of most individual animals and animal species across the barrier.

One solution that has been studied and in some cases implemented over the past decade is the construction of crossing structures. These can either be under-crossings (more common) or overpasses (less common). Under-crossings often take advantage of existing passages under barriers, such as road bridges over waterways (Figure 13. Level Walkway Added Under Existing Highway Bridge in Northern Minnesota to Facilitate Lynx Crossing). These existing passages can be enlarged or otherwise altered to make them more amenable to wildlife movement (Clevenger et al. 2001). Because the passages are already either in place or are required during construction, they are relatively inexpensive to implement. Overpasses are generally exclusively constructed for use by wildlife, making them a more expensive option than ad hoc under-crossings. A major advantage, though, is that the location of the overpasses can be optimized to what is known about animal movement in the planning area.

Figure 13. Level Walkway Added Under Existing Highway Bridge in Northern Minnesota to Facilitate Lynx Crossing

*Photo P. Huber

Some general caveats in using crossing structures to enhance landscape connectivity include the need to take species-specific traits into consideration in the planning phase (Clevenger and Waltho 2005). Species respond to crossing structure variables in different ways. Therefore, a variety of crossing structure types will generally be required to account for multi-species connectivity in a given planning area. Another caveat is that structures alone will probably not address management concerns with movement barriers. Additional infrastructure such as fencing to funnel animals towards crossing structures is often required for successful use. An example of this can be seen locally. As part of its license agreement to operate the El Dorado Hydroelectric Project, the El Dorado Irrigation District reduced animal drowning in its canals by building fences to direct or funnel animals to safe canal crossing areas.

As noted above, one consequence of designing contemporary crossing structures is that funneling of animals to the crossing structure is often required. Two issues associated with this funneling effect are: A) that the fencing used to funnel animals will have variable effectiveness depending on: i) abutment of fence ends against impassable barriers, ii) effectiveness of the fence in stopping all animal passage, iii) escape ramps for animals trapped on the road side of the fence to escape, and iv) appropriate behavioral response of animals to fencing; and B) that animals funneled together by fencing to individual crossings will be forced to interact in ways that may be to the detriment of animals that are prey for other animals.

The major barriers within the INRMP planning area that could most likely be mitigated through construction or enhancement of crossing structures are the major roads bisecting the County. Highway 50, with its large traffic volume and few current crossing opportunities is a promising candidate for investigation of crossing structure opportunities. However, before implementation of structures, analyses should be conducted to determine if there are adequate landscape connectivity opportunities in the land bordering possible structure locations. California Highway 49 in the County could be modified to provide under-crossings, fencing, and escape ramps similar to Nevada County Highway 49, as could other local roads with a higher traffic volume.

3.5 Existing Crossing Structures

Any ground-dwelling wildlife crossing of Highway 50 is currently accomplished across the highway surface or through opportunistic use of structures not originally designed for wildlife use. These existing structures include drainage culverts, bridged streams, and road under-crossings. Depending on the characteristics of the structure and the immediate environment of the opening, it may be useful for wildlife crossing of the Highway 50 ROW. To assess existing locations where wildlife may be attempting to cross Highway 50, all accessible ROW crossing structures were field-surveyed for: their structural attributes (e.g., width and height), the environment of the openings at each end, and the landscape context (data in Appendix C – Potential Highway 50 Wildlife Crossings). Photographs were also taken of each structure and its immediate environment. This information gives a first look at the potential of these structures as wildlife crossings.

Culverts

There are 10 corrugated metal pipes and pipe pairs and 7 concrete box culverts and culvert pairs across the Highway 50 ROW. They range in width from 2 to 15 feet and in height from 2 to 14 feet. All 17 culverts could be made suitable for crossing the ROW for small mammals, reptiles, and amphibians and in some cases for medium-sized mammals, too.

Bridged Streams

There are 2 bridged stream crossings by the Highway 50 ROW in the study area. These provide some of the best opportunities for wildlife movement because they are usually natural bottomed and provide riparian access at either end of the crossing. Weber Creek might be the most well-known of these, though it was not surveyed in detail here because of access issues. The bridge over Weber Creek is high and wide enough that any wildlife that tolerated the proximity to roads and houses to get to a spot under the bridge would probably readily cross. The Highway 50 bridge over the South Fork American River (near the turnoff to Ice House Road) is much lower than over Weber Creek, but still provides adequate passage space and line-of-sight for most wildlife to use it as a crossing.

Road Under-Crossings

There were 10 road under-crossings under the Highway 50 ROW. At lower elevations these tended to be busier interchanges than at higher elevations. They ranged in width from 38 to 100 feet and in height from 15 to 82 feet. An advantage of this type of under-crossing is that they tend to be very large and therefore will allow even the largest animals to pass through, some of which are sensitive to the height of the crossing roof. A disadvantage to this type of crossing is that cars use them to traverse the ROW, so any animal using the crossing opportunistically would have to avoid cars.

3.6 Adequacy of Existing Structures

The vegetation types, levels of development, and biodiversity present are different in the far western part of the County compared to the eastern edge of the study area (e.g., in the South Fork American River canyon). Because of these differences, the study area and corresponding potential highway crossings were separated into broadly defined zones. The lower foothill zone (Zone 1) extends from the County line to Shingle Springs and includes suburban development, degraded riparian zones, lower elevation grasslands, chaparral, and oak-dominated woodlands. The mid-foothills zone (Zone 2) extends from Shingle Springs to Camino and includes rural development and urban areas, oak woodlands, chaparral, and riparian zones. The upper foothills zone (Zone 3) extends from Camino to Kyburz and includes rural development and towns, mixed hardwoods/conifer, and closed-cone conifer.

The structures were evaluated for their suitability for large mammal, medium-sized mammal, small mammal, and herpetofauna use for opportunistic crossing (see Appendix C – Potential Highway 50 Wildlife Crossings for details on individual crossings). In the lower foothills, Zone 1, only the street under-crossings are likely to be currently adequate for medium and large mammals, assuming that they cross when traffic levels are low. Because the pipe and box culvert crossings are very long with no natural light, they may not be used by certain amphibians and small mammals. The street under-crossings may be occasionally used, but for small organisms, they are likely to pose a risk. In Zone 2 the situation is similar, except that there are more street under-crossings beneath the ROW and the Weber Creek under-crossing is available, providing more opportunities for medium and large mammals to cross. Again, the pipe and box culverts are long and lit only from the ends, meaning that small mammals and herpetofauna may not use them. The street under-crossings may provide for very rare crossings by less sensitive small mammals and herpetofauna. In Zone 3, there are street under-crossings for medium and large mammals and several pipe and box culverts for small mammals and herpetofauna that are short enough to permit natural lighting from each end. There is also the South Fork of the American River, which traverses under the ROW bridges.

Table 1 – Adequacy of Existing Road Crossings for Various Animal Groups

Zone	Description	Animal Group Adequacy
1	Lower Foothills, below Shingle Springs	Medium and large mammals – Silva Valley and Bass Lake Under-Crossing; Small mammals and herpetofauna -- none
2	Mid-Foothills, Shingle Springs to Camino	Medium and large mammals – Shingle Road, Greenstone Road, Weber Creek, Smith Flat Road, Point View Road; Small mammals and herpetofauna -- none
3	Upper Foothills, Camino to Kyburz	Medium and large mammals – Carson Road, Snows Road, Ridgeway Road, and South Fork American River; Small mammals and herpetofauna – White Hall and Kyburz crossings

Currently, there is no plan to maintain culverts and their openings for wildlife use and the conditions in the field reflect that. Some culvert bottoms were inundated and had no usable ledges for animals to walk on. Others had no easy access to the crossing itself, due to fencing, vegetation, and water pooling. Most culverts are concrete, which most animals (except certain amphibians when the concrete is wet) will not cross, especially for 200 feet through a tunnel. Although less sensitive animals (e.g., raccoons) may use these culvert crossings, previous research suggests that most won't because of the lack of appropriate substrate (Ehinger, et al., 2006, Carr et al., 2003)

Although individual crossings provide some potential for animal movement, the frequency of crossing types is very low in each zone, meaning that there are few crossings per mile. Medium and larger mammals can travel further in search of crossing a barrier like a highway, but small mammals and herpetofauna will not. Without frequent crossings, smaller animals will cross the surface of the ROW. In the western County part of Highway 50, this will bring them into contact with heavy traffic and/or a concrete median barrier, either of which make the surface a complete barrier to movement. Because of limited home range sizes and dispersal distances, the Arizona Game and Fish Department (2007) and Washington Department of Fish and Wildlife (Bates 2003) recommend a spacing of 150-300 feet between culvert under-crossings for small mammals and 500-1000 feet for medium-sized mammals. If crossings also have openings that are naturally-vegetated and accessible, then herpetofauna may also use them. This is true for most of the culverts, but not for the street under-crossings, which often have pavement centers and are challenging to access.

The immediate and landscape environmental context for crossings are critical determinants of the likelihood that crossings will be used by different animal groups. For example, most animals prefer a natural surface at the opening of the crossing structure, some absolutely require it. Even slight separations (i.e., a few inches) between a culvert opening and the adjacent landscape will determine whether or not a moving animal can access the opening. Ideally, an opening for a wildlife crossing will have an opening with natural vegetation and be attached at both ends to a natural habitat area that provides access and egress. Most of the culverts and street under-crossings were accessible at both ends from naturally-vegetated areas connected to less-disturbed habitat, allowing for functioning as wildlife corridors. Finders, Nugget, Faith, Cambridge, and

Chaparral culvert locations all had development near one or both ends of the crossings, which may limit use of these crossings by mammals and herpetofauna.

An important consideration for the accessibility and use of under-road crossings is the level of landscape disturbance in the vicinity of each opening. In the Habitat Inventory and Mapping Report, landscape disturbance was calculated based on road and developed parcels density (Figure 3A). These are two good proxy indicators for human-disturbance of the landscape. An estimate was made of the range of disturbance values within 500 meters of the opening of each potential crossing and the potential crossings grouped into 5 categories of landscape intactness between low (substantial landscape disturbance) and high (little landscape disturbance). These groupings are shown in the table below.

Table 2 – Current Level of Disturbance for Existing Roadway Crossings

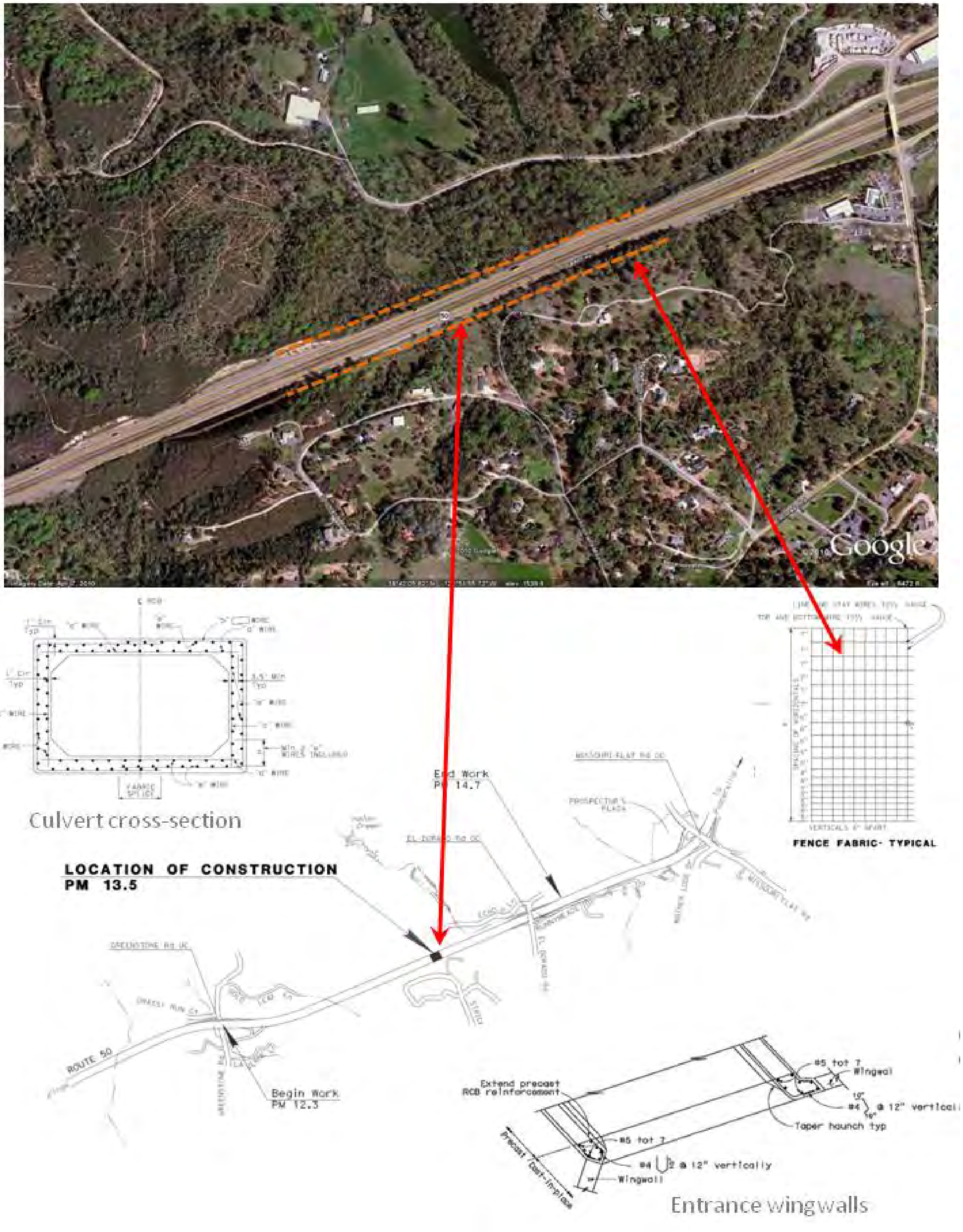
Landscape Intactness Condition (Low, Medium, High)	**Crossing Name**
Low	Finders, Nugget, Cambridge 1, Cambridge 2,
Low-Medium	Dunwood, Ridgeway
Medium	Joerger, Tong, Chaparral, Shingle, Greenstone, Point View, Snows, Carson
Medium-High	Silva Valley, Bass Lake, Faith, Weber Creek, South Fork American, White Hall 2
High	White Hall 1, White Hall 3, Kyburz West, Kyburz East

3.7 Potential for Additional Crossings of Highway 50

Currently, there is a potential Highway 50 crossing density of about 1 crossing of some type every 2-3 miles. They are likely to vary considerably in their utility for different wildlife groups because of their landscape context, size, and structure texture (e.g., natural vs. metal bottom). For example, the culvert crossings west of Shingle Springs may provide opportunities for amphibians and smaller mammals, but not for deer. Conversely, the larger openings of the road under-crossings in all zones may provide crossing opportunities for larger mammals such as deer and coyote, but not amphibians. Thus, there are few potential functional crossings of highway for each taxonomic group. It is possible that by working collaboratively with Caltrans, enhancements of existing structures and creation of new structures could be carried out with little cost to the County. Because Highway 50 is a state facility, its impacts are primarily the responsibility of the state. These impacts are considered with varying degrees of completeness in environmental documents for regional plans and proposed projects. Caltrans' continuing modification of Highway 50 results in many opportunities to fund mitigation actions for impacts to County wildlife. Caltrans usually welcomes local partners to help prioritize environmental mitigation actions.

Caltrans is currently constructing a deer under-crossing across the Highway 50 ROW west of El Dorado Road (see Figure 14. Caltrans Proposed Deer Under-Crossing – Highway 50 West of El Dorado Road). This crossing will be a 12-foot by 12-foot diameter, 203-foot long box culvert, with an openness ratio of 0.7, wingwalls at each end, and ~1/4 mile of fencing directing animals to the crossing entrance. The purpose of the crossing is to reduce deer mortality in the area. Coincidentally, the crossing is positioned just a short distance to the east of the IBC that crosses Highway 50 near Shingle Springs and the landscape corridor proposed by Shilling et al. (2002).

Figure 14. Caltrans Proposed Deer Under-Crossing – Highway 50 West of El Dorado Road



The smaller the animal and corresponding home range and dispersal distance, the greater the number of potential crossings needed. Conversely, for large mammals with larger home ranges and dispersal distances, fewer crossings are needed to maintain population structure.

A variety of types of crossing enhancements have been used to aid amphibian and reptile traversal of roads and highways (Andrews et al., 2008). For example, along Highway 58 in the Mojave Desert, a barrier fence, 3 bridges, and 24 culverts were constructed to aid the desert tortoise (*Gopherus agassizzii*) in crossing the highway ROW.

Size of New Structures

Individual wildlife species will vary in their use of crossing structures. There are several general rules for the design or retrofit of structures to increase their utility. Smaller mammals and herpetofauna prefer more enclosed spaces with some diffuse natural lighting. Large mammals prefer open spaces with a clear line of sight to the other side of the crossing. One measure of the combination of the size of a crossing opening and the length of the "tunnel" is the openness ratio: *Openness Ratio = (Culvert Height x Culvert Width)/Culvert Length* (e.g., Arizona Game and Fish Department, Bridge Guidelines, 2008: http://www.azgfd.gov/hgis/pdfs/BridgeGuidelines.pdf).

The openness ratio for the Smith Flat Road Bridge under-crossing is 85, which is ample size for any mammal. In contrast, the pipe-culvert under-crossing near Dunwood Drive near the western edge of the County is 0.04, which is too small for medium-sized mammals and possibly also for small mammals and herpetofauna. Design of new crossings should use openness and other crossing attributes – aperture opening, line of sight – to make the structures as useful as possible to the widest range of target species.

Appendix D – Crossing Structure Alternatives by Species provides a table of crossing structure attributes useful for medium and large mammals, generated by the Safe Passages program in 2007 (http://www.carnivoresafe passage.org/). These attributes are useful when proposing designs for crossings because they can be linked to engineering and cost requirements. The Arizona Game and Fish Department (2006) developed guidance for bridge and culvert design to facilitate animal crossings over or under the ROW. The values they give are smaller than those provided in Appendix D – Crossing Structure Alternatives by Species, but they also provide more detail about the relationships between opening dimensions and ROW width, crossing structure bottom material (e.g., natural substrate vs. metal or concrete), and other design features. A few of the size-related rules are listed in the table below:

Table 3 – Crossing Size Requirements for Various Animal Groups

Animal Group	Crossing Width	Crossing Length
Herpetofauna	1-2 feet okay	Short as possible, need natural lighting for longer crossings
Small Mammals	>1 foot high, cross-sectional area 2-4 square feet	Need natural lighting for longer crossings
Medium Mammals	>3 feet high, openness ratio >0.4, cross-sectional area >60 square feet for >75-foot crossing length	As short as possible
Large Mammals	>6 feet high, openness ratio >0.9, cross-sectional area >30 square feet for >75-foot crossing length	Open line of sight to other end

Frequency of New Structures

There are currently fewer crossing structures under the Highway 50 ROW than are needed to meet the crossing needs of the animals in the study area. As stated above, because of limited home range sizes and dispersal distances, a spacing of 150-300 feet between culvert under-crossings for the small mammals taxonomic group and 500-1000 feet for the medium-sized mammal taxonomic group is needed (Arizona Game and Fish Department, 2007; Bates 2003). Greater spacing may be adequate for larger mammals (~1 mile) depending on other environmental factors (e.g., nearby development). As future development occurs in the County, and to improve wildlife movement in the study area, crossings could be modified and new crossings added to meet the taxonomic group-based function and frequency requirements.

Costs for Crossing Enhancements

Typically, small city and county local government don’t fund the type of improvements discussed in this section. Usually, state and federal funding sources are available to assist with these types of projects.

There are a variety of costs that accompany developing wildlife connections across transportation rights-of-way. Retrofitting existing structures will almost always be less expensive than building new structures. Serving the crossing needs of multiple animal groups with a single structure will be more cost-effective than with several single-group structures. Monitoring the use of crossings must be done to encourage future crossing enhancements and to demonstrate biological effectiveness. The following sections provide cost estimates for crossing enhancements.

Retrofitting and Maintaining Culverts

In a study for the Colorado Department of Transportation, Meaney et al. (2007) found that retrofitting culverts with ledges for small mammals was both effective at providing passage for several species and relatively inexpensive. The cost at the time was $17-$20/linear foot, including shipping and installation. If all culvert crossings surveyed in the present study (~3,000 linear feet) were retrofitted with a single ledge, the total cost would be ~$60,000. There were several culverts that were not surveyed due to access issues, which may increase costs by 10-20%.

Maintaining culverts so that the openings are usable by herpetofauna, small mammals, and medium-sized mammals is an additional expense. Arched culverts with natural bottoms are more expensive to install than pipe culverts, but have natural bottoms and are very inexpensive to maintain. There are a variety of maintenance needs that drainage structures have to provide for (e.g., water flows) while maintaining both the structure's integrity and that of the immediate environment (Kocher et al., 2007). A study in Maine estimated an annual maintenance cost for a 2.5-foot pipe round culvert of $600 (ftp://ftp-fc.sc.egov.usda.gov/Economics/Technotes/EconomicsOfCulvertReplacement.pdf). Given the ~15, 2- to 4-foot pipe and box culverts under Highway 50, twice/year maintenance of culvert openings to facilitate wildlife use should not exceed about $1,000/culvert-year, or $15,000/year.

One additional cost that is difficult to estimate from available data is the planning cost for biologists, planners, and engineers to design new crossings or enhance existing crossings, including coordination among partner agencies and communicating with nearby landowners. It is likely that these costs could add roughly 50% or more to the cost of enhancing existing culverts.

Many countries and states have developed amphibian tunnels to reduce impacts to common and endangered amphibians alike (Federal Highways Administration web site: http://www.fhwa.dot.gov/environment/wildlifecrossings/main.htm). One common feature of these is to provide down-welling light into the tunnel through periodic openings in the tunnel ceiling. Culverts are essentially tunnels, but they lack the apertures that could enable natural lighting and use of the culverts by amphibians and small mammals. Retrofitting culverts to function as tunnels would require cutting apertures from the road-surface through the roof of the culvert. Factors such as engineering, design, and construction costs may prohibit this retrofit.

Building New Structures

Building new wildlife crossings is sometimes the only solution to connection problems across road and highway rights-of-way. The most expensive of these solutions are wildlife over and under-passes that have similar dimensions to street over- and under-passes. These typically cost approximately $1-2 million for a 30- to 50-yard long bridge under-pass, although installation of large pre-cast box or arched culverts has reduced the cost to <$1 million for under-passes that still provide wildlife passage (Huijser et al. 2007). Caltrans recently opened a bid for a box culvert along Highway 49 in Nevada County to facilitate deer crossing (bid # EA 03-2A6904) with a cost of $117,600 to construct (http://sv08data.dot.ca.gov/contractcost/details.php?Num=1362886) and associated costs for 3 deer ramps (which allow escape from roadway, $30,000, http://sv08data.dot.ca.gov/contractcost/details.php?Num=1362905) and fencing ($50,100, http://sv08data.dot.ca.gov/contractcost/details.php?Num=1362924). This combined cost of $200,000 for a single new deer crossing is a reasonable estimate for permitting passage of all-sized animals in the County under 2-lane major roads and highways. Costs would presumably be higher for the wider segments of Highway 50.

Monitoring Crossing Effectiveness

There are several ways to cost-effectively monitor the use of crossing and thus determine how well they meet biological and management goals. These methods vary in cost and in the types of information provided. Parks Canada commissioned a recent study of the most economical ways that local organizations and agencies could scientifically monitor wildlife movement and use of crossings (Ford et al., 2009). For short-term studies (several months to a year), the most economical method that provided sufficient data was the use of track-pads, which is a way to record the type and sometimes individual animal crossing a particular area. In their example, a 4-month study with 200 animal passages cost $7,552 for track-pads and $22,375 for cameras. For longer-term studies (>1 year), the most economical method was the use of cameras alone. Cameras have high up-front costs, but for many hundreds of crossings and over long use-periods, they are less costly per animal passage than track-pads, require less maintenance and can withstand a wider range of weather conditions. These values are in line with a 2010-2011 study by U.C. Davis investigators along I-80, which costs ~$60,000 for 10 monitoring locations between Auburn and Blue Canyon for ~6 months of field study.

4.0 References

Andrews, K.M, J.W. Gibbons, and D.M. Jochimsen 2008. Ecological effects of roads on amphibians and reptiles: a literature review. In: Urban Herpetology, J.C. Michael, R.E. Jung Brown, and B. Bartholomew (eds.), Herpetological Conservation 3: 121-143.

Aresco, M.J. 2005. Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a north Florida lake. Journal of Wildlife Management 69: 540-551.

Bates, K. 2003. Design of Road Culverts for Fish Passage. *Washington State Department of Fish and Wildlife*, Olympia, WA. 110 pp.

Baudry, J., F. Burel, S. Aviron, M. Martin, A. Ouin, G. Pain, and C. Thenail. 2003. Temporal variability of connectivity in agricultural landscapes: do farming activities help? *Landscape Ecology*, 18(3):303-314.

Beier, P. 1993. Determining minimum habitat areas and habitat corridors for cougars. *Conservation Biology*, 7(1):94-108.

Beier, P., D.R. Majka, and W.D. Spencer. 2008. Forks in the road: choices in procedures for designing wildland linkages. Conservation Biology, 22(4): 836-851.

Benayas, J.M.R., J.M. Bullock, and A.C. Newton. 2008. Creating woodland islets to reconcile ecological restoration, conservation, and agricultural land use. *Frontiers in Ecology and the Environment*, 6(6):329-336.

Bennett, A.F. 2003. *Linkages in the Landscape: the Role of Corridors and Connectivity in Wildlife Conservation*. IUCN, Cambridge, UK. 254 pp.

Berger, J. 2006. The last mile: how to sustain long-distance migration in mammals. *Conservation Biology*, 18(2):320-331.

Brückmann, S.V., J. Krauss, and I. Steffan-Dewenter. 2010. Butterfly and plant specialists suffer from reduced connectivity in fragmented landscapes. *Journal of Applied Ecology*, 47(4):799-809.

Bunn, D., A. Mummert, M. Hoshovsky, K. Gilardi, and S. Shanks. 2007. *California Wildlife: Conservation Challenges*. California Department of Fish and Game, Sacramento, CA. 597 pp.

Burbrink, F.T., C.A. Phillips, and E.J. Heske. 1998. A riparian zone in southern Illinois as a potential dispersal corridor for reptiles and amphibians. *Biological Conservation*, 86(2):107-115.

Carr, T., R. Dacanay, K. Drake, C. Everson, A. Sperry and K. Sullivan. 2003. Wildlife Crossings: Rethinking Road Design to Improve Safety and Reconnect Habitat. *Portland State University Planning Workshop*, Prepared for Metro. 111 pp.

Carroll, C., J.R. Dunk, and A. Moilanen. 2010. Optimizing resiliency of reserve networks to climate change: multispecies conservation planning in the Pacific Northwest, USA. *Global Change Biology*, 16(3):891-904.

Carroll, C., M.K. Phillips, N.H. Schumaker, and D.W. Smith. 2003. Impacts of landscape change on wolf restoration success: planning a reintroduction program based on static and dynamic spatial models. *Conservation Biology*, 17(2):536-548.

Carroll, C. 2007. Interacting effects of climate change, landscape conversion, and harvest on carnivore populations at the range margin: marten and lynx in the northern Appalachians. Conservation Biology, 21: 1092-1104.

Case, R.M. 1978. Interstate highway road-killed animals: A data source for biologists. Wildlife Society Bulletin 6: 8-13.

Clark, R.W., W.S. Brown, R. Stechert, and K.R. Zamudio. 2010. Roads, interrupted dispersal, and genetic diversity in timber rattlesnakes. *Conservation Biology*, 24(4):1059-1069.

Clevenger, A.P., B. Chruszcz, and K. Gunson. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. *Journal of Applied Ecology*, 38(6):1340-1349.

Clevenger, A.P., B. Chruszcz, and K. Gunson. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biol. Cons. 109: 15-26.

Clevenger, A.P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation*, 121(3):453-464.

Corlatti, L., Hackländer, K., and Frey-Roos, F. 2009. Ability of wildlife overpasses to provide connectivity and prevent genetic isolation. Conservation Biology 23: 548-556.

Crooks, K.R. 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. C*onservation Biology*, 16(2):488 502.

Damschen, E.I., N.M. Haddad, J.L. Orrock, J.J. Tewksbury, and D.J. Levey. 2006. Corridors increase plant species richness at large scales. *Science*, 313:1284–1286.

Dobson, A., K. Ralls, M. Foster, M.E. Soulé, D. Simberloff, D. Doak, J.A. Estes, L.S. Mills, D. Mattson, R. Dirzo, H. Arita, S. Ryan, E.A. Norse, R.F. Noss, and D. Johns. 1999.Corridors: reconnecting fragmented landscapes. Pages 129-170 in: Soulé, M.E., and J. Terborgh (eds). *Continental Conservation: Scientific foundations of Regional Reserve Networks*. Island Press, Washington, DC. 227 pp.

Dyer, S.J., J.P. O'Neill, S.M. Wasel, and S. Boutin. 2002. Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. *Canadian Journal of Zoology*, 80(5):839-845.

Ehinger, W., P. Garvey-Darda, R. Gersib, K. Halupka, P. McQueary, W. Meyer, R. Schanz and P. Wagner. 2006. Interstate 90 Snoqualmie Pass East MitigationDevelopment Team: Recommendation package. Submitted to: *U.S. Department of Transportation, Federal Highway Administration and Washington State Department of Transportation*.

El Dorado County 2007. El Dorado County Development Services Department – Planning Services. Oak Woodland Management Plan.

Epps, C. W., Palsboll, P. J., Wehausen, J. D., Roderick, G. K., Ramey II, R. R., and McCullough, D. R. 2005. Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep. Ecology Letters 8: 1029-1038.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annual Reviews of Ecology and Systematics 34: 487-515.

Falush, D., Stephens, M., and Pritchard, J.K. 2003 Inference of population structure using multilocus genotype data: loci and correlated allele frequencies. Genetics 164: 1567-1587.

Falush, D., Stephens, M., and Pritchard, J.K. 2007 Inference of population structure using multilocus genotype data: dominant markers and null alleles. Molecular Ecology Notes 7: 574 - 578.

FHWA. 2008. Wildlife-vehicle collision reduction study. Report to Congress by Federal Highway Administration, FHWA-HRT-08-034. Pp. 254.

Fischer, J., Lindenmayer, D.B. and Fazey, I. 2004. Appreciating ecological complexity: habitat contours as a conceptual landscape model. Conserv. Biol., 18, 1245–1253

Fischer, J., Brosi, B., Daily, G.C., Ehrlich, P.R., Goldman, R., Goldstein, J., Lindenmayer, Manning, A.D., Mooney, H.A., Pejchar, L., Ranganathan, J., Tallis, H. (2008) Should agricultural policies encourage land sparing or wildlife-friendly farming. Frontiers in Ecology and the Environment, 6(7): 380-385

Ford, A.T., A.P. Clevenger, and A. Bennett 2009. Comparison of methods of monitoring wildlife crossing-structures on highways. Journal of Wildlife Management, 73(7): 1213-1222 (http://www.transwildalliance.org/resources/2009929105144.pdf)

Forman, R.T.T. 2000. Estimate of the area affected ecologically by the road system in the United States. *Conservation Biology*, 14(1):31-35.

Forman, R. T. T. and Alexander, L. E. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29: 207-231.

Frankham, R., Ballou, J.D. and Briscoe, D.A. 2002 Introduction to Conservation Genetics. Cambridge: Cambridge University Press.

Gerlach, G., and Musolf, K. 2000. Fragmentation of landscape as a cause for genetic subdivision in bank voles. Conservation Biology 14:1066–1074.

Gillies, C.S., and C.C. St. Clair. 2008. Riparian corridors enhance movement of a forest specialist bird in fragmented tropical forest. *Proceedings of the National Academy of Sciences USA*, 105(50):19774-19779.

Hamilton, M.B. 2009. Population Genetics. Chichester: Wiley-Blackwell.

Heller, N.E. and Zavaleta, E.S. (2009). Biodiversity management in the face of climate change: A review of 22 years of recommendations. Biological Conservation, 142: 14-32.

Hilty, J.A., W.Z. Lidicker Jr., and A.M. Merenlender. 2006. *Corridor Ecology: the Science and Practice of Linking Landscapes for Biodiversity Conservation*. Island Press, Washington, DC. 323 pp.

Hilty, J.A., and A.M. Merelender. 2004. Use of riparian corridors and vineyards by mammalian predators in northern California. *Conservation Biology*, 18(1):126-135.

Hitchings, S.P. and Beebee, T.J. 1997. Genetic substructuring as a result of barriers to gene flow in urban *Rana temporaria* (common frog) populations: implications for biodiversity conservation. Heredity 79: 117-127.

Hodgson, J.A., C.D. Thomas, B.A. Wintle, and A. Moilanen. 2009. Climate change, connectivity and conservation decision making: back to basics. Journal of Applied Ecology 46: 964-969.

Hoekstra, J.M., T.M. Boucher, T.H. Ricketts, and C. Roberts. 2005. Confronting a biome crisis: global disparities of habitat loss and protection. *Ecology Letters*, 8(1):23-29.

Holderegger, R., and Wagner, H.H. 2006. A brief guide to Landscape Genetics. Landscape Ecology 21: 793-796.

Huber, P.R., S.E. Greco, and J.H. Thorne. 2010a. Spatial scale effects on conservation network design: trade-offs and omissions in regional versus local scale planning. *Landscape Ecology*, 25(5):683-695.

Huber, P.R., F.M. Shilling, J.H. Thorne, S.E. Greco, and N.E. Roth. 2010b. *Safe Passages and the City of Riverbank: wildlife connectivity in the San Joaquin Valley, California*. Final report. Wildlife Conservation Society, New York. 37 pp.

Huijser, M.P., A. Kociolek, P. McGowen, A. Hardy, A.P. Clevenger, R. Ament. 2007. Wildlife-vehicle collision and crossing mitigation measures: A toolbox for the Montana Department of Transportation. FHWA/MT-07-002/8117-34. Report prepared for the State of Montana Department of Transportation. 126 pages.

Jaeger, J.A.G., and L. Fahrig. 2004. Effects of road fencing on population persistence. *Conservation Biology*, 18(6):1651-1657.

Karban, R., and Huntzinger, M. 2006. How to do ecology. A concise handbook. Princeton, NJ: Princeton University Press.

Kautz, R., R. Kawula, T. Hoctor, J. Comiskey, D. Jansen, D. Jennings, J. Kasbohm, F. Mazzotti, R. McBride, L. Richardson, and K. Root. 2006. How much is enough? Landscape-scale conservation for the Florida panther. *Biological Conservation*, 130(1):118-133.

Keller, I., and Largiader, C.R. 2003. Recent habitat fragmentation caused by major roads leads to reduction of gene flow and loss of genetic variability in ground beetles. Proceedings of the Royal Society London, Series B 270:417–423.

Kindlmann, P. and Burel, F. 2008. Connectivity measures: a review. Landscape Ecology, 23: 879-890.

Kocher, S.D., J.M. Gerstein, and R.R. Harris. 2007. Rural roads: A construction and maintenance guide for California landowners. DANR Publication 8262, University of California Division of Agriculture and Natural Resources. 23 pp.

Kuehn, R., Hindenlang, K. E., Holzgang, O., Senn, J., Stoeckle, B., and Sperisen, C. 2007. Genetic effect of transportation infrastructure on Roe deer populations (*Capreolus capreolus*). Journal of Heredity. 98:13–22.

Latta, R. 2006. Integrating patterns across multiple genetic markers to infer spatial processes. Landscape Ecology 21: 809–820.

Lees, A.C., and C.A. Peres. 2008. Conservation value of remnant riparian forest corridors of varying quality for Amazonian birds and mammals. *Conservation Biology,* 22(2):439-449.

Lesbarrères, D., Primmer, C.R., Lodé, T., and Merilä, J. 2006. The effects of 20 years of highway presence on the genetic structure of *Rana dalmatina* populations. Ecoscience 13: 531-538.

Li, T., F. Shilling, J. Thorne, F. Li, H. Schott, R. Boynton, and A.M. Berry. 2010. Fragmentation of China's landscape by roads and urban areas. *Landscape Ecology*, 25(6):839-853.

Lindsay, D.L., Barr, K.R., Lance, R.F., Tweddale, S. A., Hayden, T. J., and Leberg, P. L. 2008. Habitat fragmentation and genetic diversity of an endangered, migratory songbird, the golden-cheeked warbler (*Dendroica chrysoparia*). Molecular Ecology 17: 2122-2133.

Lodé, T. 2000. Effect of a motorway on mortality and isolation of wildlife populations. Ambio 29: 163-166.

Loiselle, B.A., C.H. Graham, J.M. Goerck, and M.C. Ribeiro. 2010. Assessing the impact of deforestation and climate change on the range size and environmental niche of bird species in the Atlantic forests, Brazil. *Journal of Biogeography*, 37(7):1288-1301.

Machtans, C.S., M.-A. Villard, and S.J. Hannon. 1996. Use of riparian buffer strips as movement corridors by forest birds. *Conservation Biology*, 10(5):1366-1379.

Manel, S., Schwartz, M.K., Luikart, G., and Taberlet, P. 2003. Landscape genetics: Combining landscape ecology and population genetics. Trends in Ecology and Evolution 18: 1807-1816.

Marsh, D.M., Page, R.B., Hanlon, T.J., Corritone, R., Little, E.C., Seifert, D.E., and Cabe, P.R. 2008. Effects of roads on patterns of genetic differentiation in red-backed salamanders, *Plethodon cinereus*. Conservation Genetics 9:603-613.

McRae, B.H., and P. Beier. 2007. Circuit theory predicts gene flow in plant and animal populations. *Proceedings of the National Academy of Sciences USA*, 104(50):19885-19890.

McRae, B.H., B.G. Dickson, T.H. Keitt, and V.B. Shah. 2008. Using circuit theory to model connectivity in ecology, evolution, and conservation. *Ecology*, 89(10):2712-2724.

Meaney, C., M. Bakeman, M. Reed-Eckert, and E. Wostl. 2007. Effectiveness of ledges in culverts for small mammal passage. Report for the Colorado Department of Transportation, Report # CDOT-2007-9. 36 pp.

Meegan, R.P., and D.S. Maehr. 2002. Landscape conservation and regional planning for the Florida panther. *Southeastern Naturalist*, 1(3):217-232.

Naiman, R.J., H. Decamps, and M. Pollack. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications*, 3(2):209-212.

National Research Council. 1997. *Toward a sustainable future: addressing the long-term effects of motor vehicle transportation on climate and ecology*. National Academy Press, Washington, DC. 261 pp.

Ng, S.J., J.W. Dole, R.M. Sauvajot, S.P.D. Riley, and T.J. Valone. 2004. Use of highway undercrossings by wildlife in southern California. Biol. Cons. 115: 499 – 507.

Nicholls, C.I., M. Parrella, and M.A. Altieri. 2001. The effects of a vegetational corridor on the abundance and dispersal of insect biodiversity within a northern California organic vineyard. *Landscape Ecology*, 16(2):133-146.

Noël, S., Ouellet, M., Galois, P., and Lapointe, F. 2007. Impact of urban fragmentation on the genetic structure of the eastern red-backed salamander. Conservation Genetics 8: 599-606.

Noss, R.F., C. Carroll, K. Vance-Borland, and G. Wuerthner. 2002. A multicriteria assessment of the irreplaceability and vulnerability of sites in the Greater Yellowstone Ecosystem. *Conservation Biology*, 16(4):895-908.

Noss, R.F., and K.M. Daly. 2006. Incorporating connectivity into broad-scale conservation planning. Pages 587-619 in: Crooks, K.R., and M. Sanjayan, eds. *Connectivity Conservation*. Cambridge University Press, Cambridge, UK.

Pearson, R.G., and T.P. Dawson. 2005. Long-distance plant dispersal and habitat fragmentation: identifying conservation targets for spatial landscape planning under climate change. *Biological Conservation*, 123(3):389-401.

Pritchard, J.K., Stephens, M., and Donnelly, P. 2000. Inference of population structure using multilocus genotype data. Genetics 155: 945-959.

Prugnolle, F., and de Meeus, T. 2002. Inferring sex-biased dispersal from population genetic tools: a review. Heredity 88:161-165.

Reh, W., and Seitz, A. 1990. The influence of land-use on the genetic-structure of populations of the common frog *Rana temporaria*. Biological Conservation 54:239–249.

Riley, S.P.D., R.M. Sauvajot, T.K. Fuller, E.C. York, D.A. Kamradt, C. Bromley, and R.K. Wayne. 2003. Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California. *Conservation Biology*, 17(2):566–576.

Riley, S.P., Pollinger, J.P., Sauvajot, R.M., York, E.C., Bromley, C., Fuller, T.K., and Wayne, R.K. 2006. A southern California freeway is a physical and social barrier to gene flow in carnivores. Molecular Ecology 15: 1733–1741.

Rosenberg, D.K., B.R. Noon, and E.C. Meslow. 1997. Biological corridors: form, function, and efficacy. *BioScience*, 47(10):677–687.

Saving, Shawn C. and Gregory B. Greenwood. 2002. The Potential Impacts of Development on Wildlands in El Dorado County, CA. USDA Forest Service Gen. Tech. Rep. PSW-GTR-184.

Schooley, R.L. and J.A. Wiens. 2003. Finding habitat patches and directional connectivity. Oikos, 102(3): 559-570.

Schumaker, N.H. 1998. *A user's guide to the PATCH model*. EPA/600/R-98/135. U.S. Environmental Protection Agency, Corvallis, OR, USA.

Schumaker, N.H. 2010. *HexSim Version 2.0*. U.S. Environmental Protection Agency, Corvallis, OR, USA. Available from http://www.epa.gov/hexsim.

Schwartz, M.K., J.P. Copeland, N.J. Anderson, J.R. Squires, R.M. Inman, K.S. McKelvey, K.L. Pilgrim, L.P. Waits, and S.A. Cushman. 2009. Wolverine gene flow across a narrow climatic niche. *Ecology*, 90(11):3222-3232.

Semlitsch, R.D. 2000. Principles for management of aquatic-breeding amphibians. *Journal of Wildlife Management*, 64(3):615-631.

Shilling, F.M., E.H. Girvetz, C. Erichsen, B. Johnson, and P.C. Nichols 2002. “A Guide to Wildlands Conservation Planning in the Greater Sierra Nevada Bioregion”. California Wilderness Coalition, 187 pp.

Shilling, F.M and E.H. Girvetz 2007. Barriers to implementing a wildland network. *Landscape and Urban Planning*. Volume 80(1-2): 165-172.

Sieving, K.E., M.F. Willson, and T.L. De Santo. 2000. Defining corridor functions for endemic birds in fragmented south-temperate rainforest. *Conservation Biology*, 14(4):1120-1132.

Singleton, P.H., W.L. Gaines, and J.F. Lehmkuhl. 2002. *Landscape permeability for large carnivores in Washington: a geographic information system weighted-distance and least-cost corridor assessment*. Res. Pap. PNW-RP-549. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest. 89 pp.

Skagen, S.K., C.P. Melcher, W.H. Howe, and F.L. Knopf. 1998. Comparative use of riparian corridors and oases by migrating birds in southeast Arizona. *Conservation Biology*, 12(4):896-909.

Soulé, M.E. 1991. Land use planning and wildlife maintenance: guidelines for conserving wildlife in an urban landscape. Journal of the American Planning Association 57: 313-323.

Spackman, S.C., and J.W. Hughes. 1995. Assessment of minimum stream corridor width for biological conservation: species richness and distribution along mid-order streams in Vermont, USA. *Biological Conservation*, 71(3):325-332.

Spellerberg, I. F. 1998. Ecological effects of roads and traffic: A literature review. Global Ecology and Biogeography Letters 7:317-333.

Spencer, W.D., P. Beier, K. Penrod, K. Winters, C. Paulman, H. Rustigian-Romsos, J. Strittholt, M. Parisi, and A. Pettler. 2010. California Essential Habitat Connectivity Project: A Strategy for Conserving a Connected California. Prepared for California Department of Transportation, California Department of Fish and Game, and Federal Highways Administration.

Sullivan, T.L., A.E. Williams, T.A. Messmer, L.A. Hellinga, and S.Y. Kyrychenko. 2004. Effectiveness of temporary warning signs in reducing deer-vehicle collisions during mule deer migrations. Wildl. Soc. Bull. 32: 907-915.

Taylor, P.D., L. Fahrig, and K.A. With. 2006. Landscape connectivity: a return to basics. In: Connectivity Conservation eds. K.R. Crooks and M. Sanjayan, Cambridge University Press. Pp 29-43.

Taylor, P.D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos*, 68(3):571 573.

Tewksbury, J.J., D.J. Levey, N.M. Haddad, S. Sargent, J.L. Orrock, A. Weldon, B.J. Danielson, J. Brinkerhoff, E.I. Damschen, and P. Townsend. 2002. Corridors affect plants, animals, and their interactions in fragmented landscapes. *Proceedings of the National Academy of Sciences USA*, 99(20):12923–12926.

Theobald, D.M. 2006. Exploring the functional connectivity of landscapes using landscape networks. Pages 416-443 in: Crooks, K.R., and M. Sanjayan, eds. *Connectivity Conservation*. Cambridge University Press, Cambridge, UK.

Tischendorf, L. and L. Fahrig. 2000. On the usage and measurement of landscape connectivity. Oikos, 90(1): 7-19.

Trakhtenbrot, A., R. Nathan, G. Perry, and D.M. Richardson. 2005. The importance of long-distance dispersal in biodiversity conservation. *Diversity and Distributions*, 11(2):173-181.

Tremblay, M.A., and C.C. St. Clair. 2009. Factors affecting the permeability of transportation and riparian corridors to the movements of songbirds in an urban landscape. *Journal of Applied Ecology* , 46(6):1314-1322.

Underwood, E.C., K.B. Klausmeyer, R.L. Cox, S.M. Busby, S.A. Morrison, and M.R. Shaw. 2009. Expanding the global network of protected areas to save the imperiled Mediterranean biome. *Conservation Biology*, 23(1):43-52.

Urban, D., and T. Keitt. 2001. Landscape connectivity: a graph-theoretic perspective. *Ecology*, 82(5):1205-1218.

Urban, D.L., E.S. Minor, E.A. Treml, and R.S. Schick. 2009. Graph models of habitat mosaics. *Ecology Letters*, 12(3):260-273.

Vandergast, A. G., Bohonak, A. J., Weissman D. B., and Fisher, R. N. 2007. Understanding the genetic effects of recent habitat fragmentation in the context of evolutionary history: phylogeography and landscape genetics of a southern California endemic Jerusalem cricket (Orthoptera: Stenopelmatidae: Stenopelmatus). Molecular Ecology 16: 977-992.

Williams, P., L. Hannah, S. Andelman, G. Midgley, M. Araújo, G. Hughes, L. Manne, E. Martinez-Meyer, and R. Pearson. 2005. Planning for climate change: identifying minimum-dispersal corridors for the Cape Proteaceae. *Conservation Biology*, 19(4):1063-1074.

Web Resources
Southern Rockies Ecosystem Project “Carnivores Safe Passage” website
http://www.carnivoresafepassage.org/index.htm

Federal Highways Administration “Critter Crossing” web site
http://www.fhwa.dot.gov/environment/wildlifecrossings/main.htm

5.0 Annotated Bibliography

Andrews, K.M., J.W. Gibbons, and D.M. Jochimsen 2008. Ecological effects of roads on amphibians and reptiles: a literature review. In: Urban Herpetology, J.C. Michael, R.E. Jung Brown, and B. Bartholomew (eds.), Herpetological Conservation 3: 121-143.

> These authors review the primary direct and indirect effects of roads on amphibians and reptiles (herpetofauna), from road construction through utilization. The present research provides guidance for ways to study the ecological effects of roads on herpetofauna and offers suggestions for resolving conflict.

Aresco, M.J. 2005. Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a north Florida lake. Journal of Wildlife Management 69: 540-551.

> During this study, a stretch of road was checked daily for animals that had failed to cross or that were trying to cross between two ponds. Greater than 95% of certain species were killed on the roadway when attempting to cross. The installation of fencing directed to culvert under-crossings reduced mortality by 99% for amphibians.

Bates, K. 2003. Design of Road Culverts for Fish Passage. *Washington State Department of Fish and Wildlife*, Olympia, WA. 110 pp.

> This is a guide for landowners and engineers for designing culverts to improve fish passage. Detailed information is provided about meeting hydraulic and other needs, cost, and fish needs.

Baudry, J., F. Burel, S. Aviron, M. Martin, A. Ouin, G. Pain, and C. Thenail. 2003. Temporal variability of connectivity in agricultural landscapes: do farming activities help? *Landscape Ecology*, 18(3):303-314.

> This paper addresses the question of how agricultural incentives influence connectivity and whether these incentives can be used for biodiversity conservation management. Results from modeling simulations demonstrate differences in connectivity between farming systems over the course of multiple years. Policies should address the landscape level for greater effectiveness.

Beier, P. 1993. Determining minimum habitat areas and habitat corridors for cougars. *Conservation Biology*, 7(1):94-108.

> A population model is used to simulate mountain lion populations in order to predict minimum areas and levels of immigration needed to prevent extinction. Extinction risk is found to increase in areas less than 2200 km², and that immigration of as few as one to four individuals per decade was enough for population persistence. This implies that corridors can benefit small populations in areas with future potential loss of habitat.

Beier, P., D.R. Majka, and W.D. Spencer. 2008. Forks in the road: choices in procedures for designing wildland linkages. Conservation Biology, 22(4): 836-851.

> This paper outlines the major decisions that are necessary to effectively design wildland linkages. Recommendations include designing linkages for multiple species, explicitly acknowledging assumptions and uncertainty, and treating corridor dwellers differently than passage species. One issue the authors address is the subjective translation problem, i.e., how to translate from resource selection to resistance models.

Benayas, J.M.R., J.M. Bullock, and A.C. Newton. 2008. Creating woodland islets to reconcile ecological restoration, conservation, and agricultural land use. *Frontiers in Ecology and the Environment*, 6(6):329-336.

> The authors suggest that creation of “wooded islets” is a potentially effective alternative to either passive or active restoration in agricultural areas. These islets are small, dense blocks of native trees that can serve as seed sources in the event of farmland abandonment and provide ecosystem services.

Bennett, A.F. 2003. *Linkages in the Landscape: the Role of Corridors and Connectivity in Wildlife Conservation*. IUCN, Cambridge, UK. 254 pp.

> This book provides details on design and management of corridors for mitigating the negative effects of habitat fragmentation. The corridors considered in this in-depth review function as either habitat or avenues of movement. There are recommendations for both management and further scientific study.

Berger, J. 2006. The last mile: how to sustain long-distance migration in mammals. *Conservation Biology*, 18(2):320-331.

> The Greater Yellowstone region is home to a globally significant long-distance migration corridor used by multiple species. This corridor is historic, narrow, and threatened by potential development. The authors call for the creation of national migration corridors for protection of these ecological features.

Brückmann, S.V., J. Krauss, and I. Steffan-Dewenter. 2010. Butterfly and plant specialists suffer from reduced connectivity in fragmented landscapes. *Journal of Applied Ecology*, 47(4):799-809.

> This paper investigates the impact of habitat connectivity on butterfly and plant species in fragmented grasslands in Europe. Results show that total loss of connectivity would reduce species richness and that an effective connectivity index would combine patch size and distance in the surrounding landscape. The authors conclude that connectivity is very important for conservation of specialized butterfly and plant species and that grassland restoration should be used to increase connectivity in the region.

Bunn, D., A. Mummert, M. Hoshovsky, K. Gilardi, and S. Shanks. 2007. *California Wildlife: Conservation Challenges*. California Department of Fish and Game, Sacramento, CA. 597 pp.

> This is the California State Wildlife Action Plan. It includes both statewide and regional conservation planning themes and recommendations.

Burbrink, F.T., C.A. Phillips, and E.J. Heske. 1998. A riparian zone in southern Illinois as a potential dispersal corridor for reptiles and amphibians. *Biological Conservation*, 86(2):107-115.

> The study describes the usefulness of corridor design and designation using just riparian corridor width or other easily-measured parameters. Two-thirds of reptiles and amphibians surveyed had limited distribution along a riparian corridor and their distribution was best explained by habitat variables important for individual species. The study concludes with the observation that corridors are best designed based on habitat needs of each of the species of concern.

Carr, T., R. Dacanay, K. Drake, C. Everson, A. Sperry and K. Sullivan. 2003. Wildlife Crossings: Rethinking Road Design to Improve Safety and Reconnect Habitat. *Portland State University Planning Workshop,* Prepared for Metro. 111 pp.

> These workshop proceedings describe the best practices for reducing wildlife-vehicle collisions through wildlife crossings. The report includes descriptions of wildlife crossings and ways to implement them.

Carroll, C., J.R. Dunk, and A. Moilanen. 2010. Optimizing resiliency of reserve networks to climate change: multispecies conservation planning in the Pacific Northwest, USA. *Global Change Biology*, 16(3):891-904.

> The authors evaluate the effectiveness of using a focal species as an umbrella for protection of other species under climate change and how reserve networks can be made more resilient to climate change. The programs MAXENT and ZONATION are used to model distribution and identify an effective reserve network. The focal species reserves are found to overlap areas of high species richness but do poorly in representing core areas of other species. Results suggest that reserve systems designed for resilience can increase the likelihood of ecosystem preservation under climate change.

Carroll, C., M.K. Phillips, N.H. Schumaker, and D.W. Smith. 2003. Impacts of landscape change on wolf restoration success: planning a reintroduction program based on static and dynamic spatial models. *Conservation Biology,* 17(2):536-548.

> The authors use static and dynamic spatial models to investigate whether wolf reintroduction in the Southern Rockies would advance species recovery more than simple range expansion. The models predict that >1000 wolves could be supported but the dynamic models indicate that one of four subpopulations could be lost to future development. Active reintroduction to two sites could reduce the probability of extinction of the species in the region.

Carroll, C. 2007. Interacting effects of climate change, landscape conversion, and harvest on carnivore populations at the range margin: marten and lynx in the northern Appalachians. Conservation Biology, 21: 1092-1104.

> This fairly unique study looked at the interacting effects of climate change, land-use (logging), and trapping on marten and lynx in the U.S. Northeast. Spatially-explicit population models were used to measure degree of impact of these 3 population drivers. Climate change had the most impact and the author notes the advantage of population modeling over other models based only on biogeographic and climatic information.

Case, R.M. 1978. Interstate highway road-killed animals: A data source for biologists. Wildlife Society Bulletin 6: 8-13.

> This early study of roadkill identified the importance of animal carcasses as a source of data for biologists wanting to understand animal distribution.

Clark, R.W., W.S. Brown, R. Stechert, and K.R. Zamudio. 2010. Roads, interrupted dispersal, and genetic diversity in timber rattlesnakes. *Conservation Biology*, 24(4):1059-1069.

> This study uses molecular genetics and behavioral and ecological data to investigate the impact of roads on population structure and connectivity of timber rattlesnakes (*Crotalus horridus*). The authors find that snakes isolated by roads had significantly lower genetic diversity and higher genetic differentiation because of interruption of seasonal migration. Genetic effects are found despite the relatively recent construction of roads.

Clevenger, A.P., B. Chruszcz, and K. Gunson. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. *Journal of Applied Ecology*, 38(6):1340-1349.

> The authors investigate culvert use by small- and medium-sized mammals in Banff National Park, Canada. Weasels (*Mustela erminea* and *M. frenata*) and deer mice (*Peromyscus maniculatus*) used culverts for passage most frequently. Traffic volume, noise levels, and road width were found to be significant factors affecting culvert use. Structural variables affected use by weasels and martens (*Martes americana*). The authors conclude that culverts can potentially mitigate road effects and provide linkage. They recommend frequent spacing of culverts and abundant vegetation near culvert entrances.

Clevenger, A.P., B. Chruszcz, and K. Gunson. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biol. Cons. 109: 15-26.

> The authors studied roadkills of mammals and birds along a stretch of the Trans-Canada Highway. They found that landscape and highway variables such as nearby vegetation and availability of under-crossings determined roadkill distribution. They recommend mitigation measures for existing and new roads.

Clevenger, A.P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation*, 121(3):453-464.

> The authors study the issue of confounding variables in the assessment of wildlife crossing structure efficacy in Banff National Park, Canada. They find that in the absence of high human activity, crossing structure attributes best explained performance indices (however, these attributes differed between species). Distance to cover was found to be an important landscape variable for many species. The authors conclude that in order to maximize connectivity, a variety of species-specific crossing structures should be included in conservation planning.

Corlatti, L., Hackländer, K., and Frey-Roos, F. 2009. Ability of wildlife overpasses to provide connectivity and prevent genetic isolation. Conservation Biology 23: 548-556.

> This paper reviews the effectiveness of wildlife overpasses in facilitating habitat connectivity between road-isolated populations. Although many studies have observed overpass use by wildlife, they rarely evaluated the effectiveness of wildlife overpasses on genetic connectivity.

Crooks, K.R. 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. C*onservation Biology*, 16(2):488 502.

> The author investigates the effects of habitat fragmentation on the distribution and abundance of mammalian carnivores in southern California. Using track surveys, he found that fragment area and isolation were the two strongest descriptors. In urban habitat fragments, visitation rates increased at sites that had higher exotic cover and were closer to the urban edge because of increased abundance of fragmentation-enhanced carnivores at those sites. These results can be used to identify appropriate focal species depending on planning area fragmentation.

Damschen, E.I., N.M. Haddad, J.L. Orrock, J.J. Tewksbury, and D.J. Levey. 2006. Corridors increase plant species richness at large scales. *Science*, 313:1284–1286.

> The authors use large-scale, replicated field experiments to test the effectiveness of corridors in preserving biodiversity at large scales. Results showed that habitat patches connected by corridors retained more native plant species than did isolated patches. These differences increased over time and did not promote invasion by exotic species. The authors conclude that use of corridors in biodiversity conservation planning was appropriate.

Dobson, A., K. Ralls, M. Foster, M.E. Soulé, D. Simberloff, D. Doak, J.A. Estes, L.S. Mills, D. Mattson, R. Dirzo, H. Arita, S. Ryan, E.A. Norse, R.F. Noss, and D. Johns. 1999.Corridors: reconnecting fragmented landscapes. Pages 129-170 in: Soulé, M.E., and J. Terborgh (eds). *Continental Conservation: Scientific foundations of Regional Reserve Networks*. Island Press, Washington, DC. 227 pp.

> This book chapter details some of the scientific considerations in corridor planning within the context of regional conservation networks.

Dyer, S.J., J.P. O'Neill, S.M. Wasel, and S. Boutin. 2002. Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. *Canadian Journal of Zoology*, 80(5):839-845.

> The authors study the effects of roads seismic lines, and pipeline right-of-ways on woodland caribou movement in Canada using GPS collars to track 36 individuals. While seismic lines were not found to be barriers to movement, roads with moderate vehicle traffic were found to be semipermeable barriers. The greatest barrier effects of roads were found to be in late winter. The authors conclude that semipermeable barrier effects could lead to functional habitat loss.

Ehinger, W., P. Garvey-Darda, R. Gersib, K. Halupka, P. McQueary, W. Meyer, R. Schanz and P. Wagner. 2006. Interstate 90 Snoqualmie Pass East Mitigation Development Team: Recommendation package. Submitted to: *U.S. Department of Transportation, Federal Highway Administration and Washington State Department of Transportation*.

> This report from Washington Department of Transportation describes recommended mitigation actions for Interstate 90 in Washington.

El Dorado County 2007. El Dorado County Development Services Department – Planning Services. Oak Woodland Management Plan.

> The purpose of the OWMP is to outline the County's strategy for conservation of its valuable oak resources. Through the OWMP, the County identifies areas where conservation easements may be acquired from willing sellers as a means to offset and mitigate the loss or fragmentation of oak woodlands in other areas as a result of implementation of its 2004 General Plan. Additionally, the OWMP provides guidance for voluntary conservation and management efforts by landowners and land managers.

Epps, C. W., Palsboll, P. J., Wehausen, J. D., Roderick, G. K., Ramey II, R. R., and McCullough, D. R. 2005. Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep. Ecology Letters 8: 1029-1038.

> The authors analyze the effects of road barriers on genetic diversity in desert bighorn sheep (*Ovis canadensis nelsoni*). They used statistical analyses to infer changes in gene flow and diversity. They found rapid reduction in genetic diversity due to road barrier effects. They conclude that roads pose a severe threat to the persistence of naturally fragmented populations.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annual Reviews of Ecology and Systematics 34: 487-515.

> The author uses a quantified “road-effect zone” to estimate the area affected by roads in the United States. He found that approximately one-fifth of the total area of the U.S. is directly affected ecologically by roads. He suggests that over time this number is likely to rise rather than fall. He concludes by suggesting possible methods of reducing this affected area.

Falush, D., Stephens, M., and Pritchard, J.K. 2003 Inference of population structure using multilocus genotype data: loci and correlated allele frequencies. Genetics 164: 1567-1587.

> This paper presents a new method to analyze linkage loci, which infers population structure from multilocus genotype data. The authors note that this method has extended a previous method.

Falush, D., Stephens, M., and Pritchard, J.K. 2007 Inference of population structure using multilocus genotype data: dominant markers and null alleles. Molecular Ecology Notes 7: 574 - 578.

> This paper extended a previous method to infer population genetic structure. Using the new approach, more data types, such as AFLP, can be analyzed.

FHWA. 2008. Wildlife-vehicle collision reduction study. Report to Congress by Federal Highway Administration, FHWA-HRT-08-034. Pp. 254.

> This report by the federal Highways Administration describes the impact of wildlife-vehicle collisions on people and animals, including endangered species. It describes in detail mitigation measures that should be pursued to reduce wildlife-vehicle collisions.

Fischer, J., Lindenmayer, D.B. & Fazey, I. 2004. Appreciating ecological complexity: habitat contours as a conceptual landscape model. Conserv. Biol., 18, 1245–1253

> The authors describe a new way of thinking about landscape connectivity beyond the design concept of "corridors". They describe the ecological reality of gradations in connectivity from disconnected urban areas to well-connected natural areas. They recommend a combined approach of reflecting connectivity as a sort of topographic map, while recognizing species-specific and planning-specific constraints.

Fischer, J., Brosi, B., Daily, G.C., Ehrlich, P.R., Goldman, R., Goldstein, J., Lindenmayer, Manning, A.D., Mooney, H.A., Pejchar, L., Ranganathan, J., Tallis, H. 2008. Should agricultural policies encourage land sparing or wildlife-friendly farming. Frontiers in Ecology and the Environment, 6(7): 380-385

> The authors describe two ways that agriculture and conservation have interacted – setting aside land for conservation and intensive farming as dichotomous land-uses and wildlife-friendly farming where both uses are pursued in the same place. They recommend that both approaches be used depending on the setting and need.

Ford, A.T., A.P. Clevenger, and A. Bennett 2009. Comparison of methods of monitoring wildlife crossing-structures on highways. Journal of Wildlife Management, 73(7): 1213-1222 (http://www.transwildalliance.org/resources/2009929105144.pdf)

> The authors compare and describe different ways to monitor the use and effectiveness of wildlife crossings under and over highways. They focus on tracking and camera methods and concluded that cameras are cost-effective for long-term monitoring and tracking for short-term.

Forman, R.T.T. 2000. Estimate of the area affected ecologically by the road system in the United States. *Conservation Biology*, 14(1):31-35.

> The author uses a quantified "road-effect zone" to estimate the area affected by roads in the United States. He found that approximately one-fifth of the total area of the U.S. is directly affected ecologically by roads. He suggests that over time this number is likely to rise rather than fall. He concludes by suggesting possible methods of reducing this affected area.

Forman, R. T. T. and Alexander, L. E. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29: 207-231.

> The paper reviews main ecological effects of roads on their surrounding biotic and abiotic environment. It mainly focuses on roadkills occurrence, road avoidance and the genetic consequence of roads on the isolated wildlife populations. In addition, roads can cause local hydrologic, erosion effects and chemical effects, etc.

Frankham, R., Ballou, J.D. and Briscoe, D.A. 2002 Introduction to Conservation Genetics. Cambridge: Cambridge University Press.

> This textbook on conservation genetics is nicely presented and easy to understand. It suits a broader audience to anyone interested in conservation biology.

Gerlach, G., and Musolf, K. 2000. Fragmentation of landscape as a cause for genetic subdivision in bank voles. Conservation Biology 14:1066–1074.

> The authors found that only highways caused significant population subdivision of band vole, while other roadways, like country roads and railways, didn’t have such an effect.

Gillies, C.S., and C.C. St. Clair. 2008. Riparian corridors enhance movement of a forest specialist bird in fragmented tropical forest. *Proceedings of the National Academy of Sciences USA*, 105(50):19774-19779.

> The authors separated a forest-specialist bird (requires forest cover) and a forest-generalist bird (less specific about forest cover) from their home ranges and tracked their returns through mixed landscapes. Forest specialists used forested corridors, while generalists used other features, such as hedgerows and open fields.

Hamilton, M.B. 2009. Population Genetics. Chichester: Wiley-Blackwell.

> A book on population genetics. Population genetics concerns the genetic constitution of a population and how this constitution changes with time. This book is written for post-graduate students in biology or related fields.

Heller, N.E. and Zavaleta, E.S. (2009). Biodiversity management in the face of climate change: A review of 22 years of recommendations. Biological Conservation, 142: 14-32.

> This synthesis of recommendations identifies appropriate scales for planning and planning gaps in conservation. Greater integration is recommended with planning on human-dominated landscapes and improvement of adaptive management of landscapes.

Hilty, J.A., W.Z. Lidicker Jr., and A.M. Merenlender. 2006. *Corridor Ecology: the Science and Practice of Linking Landscapes for Biodiversity Conservation*. Island Press, Washington, DC. 323 pp.

> This book provides guidelines for corridor design and management based on both scientific research and practical experience. It is written with both researchers and managers in mind.

Hilty, J.A., and A.M. Merelender. 2004. Use of riparian corridors and vineyards by mammalian predators in northern California. *Conservation Biology,* 18(1):126-135.

> Riparian corridors were investigated as a method for encouraging or allowing wildlife movement through the landscape. Native carnivores were more likely to use wide riparian zones near large areas of undisturbed habitat than adjacent vineyards. Non-native predators were more common in vineyards far from less-disturbed habitat.

Hitchings, S.P. and Beebee, T.J. 1997. Genetic substructuring as a result of barriers to gene flow in urban *Rana temporaria* (common frog) populations: implications for biodiversity conservation. Heredity 79: 117-127.

> This paper studies the effect of urbanization on urban common frog populations. It shows that urbanization causes population differentiation and reduces genetic diversity of frog populations. Additionally, some inbreeding depression in the urban populations are also found.

Hodgson, J.A., C.D. Thomas, B.A. Wintle, and A. Moilanen. 2009. Climate change, connectivity and conservation decision making: back to basics. Journal of Applied Ecology 46: 964-969.

> Climate change is likely to affect many habitat qualities, including connectivity, which is increasingly a target of climate change adaptation. These authors argue that protecting habitat quality and total area will automatically protect connectivity.

Hoekstra, J.M., T.M. Boucher, T.H. Ricketts, and C. Roberts. 2005. Confronting a biome crisis: global disparities of habitat loss and protection. *Ecology Letters,* 8(1):23-29.

The authors examine a current “biome crisis”, the loss not just of species but whole ecosystems. They found that the ratio of habitat conversion to protected habitat in Mediterranean biomes to be 8:1, among other heavily impacted ecosystems. They conclude that a concerted and comprehensive response is needed to confront the loss of landscapes, ecological interactions, ecosystem services, and evolutionary potential.

Holderegger, R., and Wagner, H.H. 2006. A brief guide to Landscape Genetics. Landscape Ecology 21: 793-796.

> The paper gives a brief introduction to landscape genetics and provides a list of suggestions for landscape ecologists who want to conduct such landscape genetics research.

Huber, P.R., S.E. Greco, and J.H. Thorne. 2010a. Spatial scale effects on conservation network design: trade-offs and omissions in regional versus local scale planning. *Landscape Ecology*, 25(5):683-695.

> The authors investigate the effects of spatial scale on reserve selection and corridor identification. Using Marxan and Least Cost Corridor modeling tools, they compared results from regional and local analyses in the Central Valley of California. Large differences between conservation networks identified at the different scales were found. The results suggest that planning results from any one scale can omit potentially important ecological features identified at other spatial scales. The authors suggest that combining results from multiple scales of inquiry can be used to prioritize conservation actions.

Huber, P.R., F.M. Shilling, J.H. Thorne, S.E. Greco, and N.E. Roth. 2010b. *Safe Passages and the City of Riverbank: wildlife connectivity in the San Joaquin Valley, California*. Final report. Wildlife Conservation Society, New York. 37 pp.

> This report describes the results of a project that investigated landscape connectivity in the vicinity of the city of Riverbank, California. The authors used a new technique (“least cost surface modeling”) to measure connectivity for four focal species in the planning area. They integrate the results with urban density, road density, and future urban development to identify areas where conflicts between wildlife connectivity and human impacts could be expected.

Huijser, M.P., A. Kociolek, P. McGowen, A. Hardy, A.P. Clevenger, R. Ament. 2007. Wildlife-vehicle collision and crossing mitigation measures: A toolbox for the Montana Department of Transportation. FHWA/MT-07-002/8117-34. Report prepared for the State of Montana Department of Transportation. 126 pages.

> This manual describes the ways that transportation agencies can reduce wildlife-vehicle collisions on state highways. The report describes mitigation measures in terms of animal community served, implementation considerations, and information about potential effectiveness.

Jaeger, J.A.G., and L. Fahrig. 2004. Effects of road fencing on population persistence. *Conservation Biology*, 18(6):1651-1657.

> The authors investigate the trade-off between potential movement and animal mortality inherent in road fencing. Their models predicted a level of roadway mortality below which fencing is always harmful and above which always beneficial. In between these mortality values the degree of road avoidance by animals was most important. They recommend the use of fences when there is a very low road crossing success rate or when the population is low and road mortality threatens the overall population

Karban, R., and Huntzinger, M. 2006. How to do ecology. A concise handbook. Princeton, NJ: Princeton University Press.

> This excellent book gives an overview of important strategies in ecology research, including picking an important question, developing a testable work hypothesis, designing an experiment, analyzing data, and presenting a manuscript.

Kautz, R., R. Kawula, T. Hoctor, J. Comiskey, D. Jansen, D. Jennings, J. Kasbohm, F. Mazzotti, R. McBride, L. Richardson, and K. Root. 2006. How much is enough? Landscape-scale conservation for the Florida panther. *Biological Conservation*, 130(1):118-133.

> The authors identify regions in south Florida of high conservation value for Florida panther (*Puma concolor coryi*) protection. They investigated the importance of land cover and forest patch size in habitat selection. They identified Primary and Secondary zones and used least cost path analysis to identify linkages between these zones. They estimate that the network formed by these components could support 80-94 panthers for 100 years.

Keller, I., and Largiader, C.R. 2003. Recent habitat fragmentation caused by major roads leads to reduction of gene flow and loss of genetic variability in ground beetles. Proceedings of the Royal Society London, Series B 270:417–423.

> This paper shows that large roads are effective barriers to movement of a flightless ground beetle. The road barrier also leads to a loss of genetic variability in fragmented populations.

Kindlmann, P. and Burel, F. 2008. Connectivity measures: a review. Landscape Ecology, 23: 879-890.

> This article reviews the various metrics of connectivity that are relevant to conservation planning. The authors explain the meaning of landscape connectivity and make suggestions for pursuing connectivity research.

Kocher, S.D., J.M. Gerstein, and R.R. Harris. 2007. Rural roads: A construction and maintenance guide for California landowners. DANR Publication 8262, University of California Division of Agriculture and Natural Resources. 23 pp.

> The majority of roads are rural paved and un-paved roads. This guide describes how to design, build, and maintain these roads so as to reduce harm to the environment.

Kuehn, R., Hindenlang, K. E., Holzgang, O., Senn, J., Stoeckle, B., and Sperisen, C. 2007. Genetic effect of transportation infrastructure on Roe deer populations (*Capreolus capreolus*). Journal of Heredity. 98:13–22.

> The authors evaluate the effect of a fenced motorway in Central Switzerland on the genetic consequence of the roe deer, and revealed a barrier effect of the transportation infrastructure on movement of the roe deer population examined, but its effects on genetic diversity have not been detected.

Latta, R. 2006. Integrating patterns across multiple genetic markers to infer spatial processes. Landscape Ecology 21: 809–820.

> The author gives a guide about how to use different molecular markers to study landscape genetics because different molecular markers have their own merits and limitations.

Lees, A.C., and C.A. Peres. 2008. Conservation value of remnant riparian forest corridors of varying quality for Amazonian birds and mammals. *Conservation Biology*, 22(2):439-449.

> Riparian corridors are assumed to provide movement possibilities for animals through developed landscapes. This study investigated this idea and found that corridor benefits for birds and mammals were species-specific and dependent on width and intactness of the corridor.

Lesbarrères, D., Primmer, C.R., Lodé, T., and Merilä, J. 2006. The effects of 20 years of highway presence on the genetic structure of *Rana dalmatina* populations. Ecoscience 13: 531-538.

> The authors investigate the genetic consequence of highways on a frog and find that the highway effectively reduces the individual movement, which further caused significant population subdivision and genetic diversity decrease.

Li, T., F. Shilling, J. Thorne, F. Li, H. Schott, R. Boynton, and A.M. Berry. 2010. Fragmentation of China's landscape by roads and urban areas. *Landscape Ecology*, 25(6):839-853.

> The authors use the effective mesh size method to evaluate the fragmentation caused by roads, railways, and urban areas in China. Fragmentation effects varied widely across China. Some areas of high biodiversity occurred in highly fragmented areas. The authors recommend the consideration of existing land division by planners when making development decisions.

Lindsay, D.L., Barr, K.R., Lance, R.F., Tweddale, S. A., Hayden, T. J., and Leberg, P. L. 2008 Habitat fragmentation and genetic diversity of an endangered, migratory songbird, the golden-cheeked warbler (*Dendroica chrysoparia*). Molecular Ecology 17: 2122-2133.

> This is one of few case studies on effects of anthropogenic barriers on bird population structure. The paper shows that habitat fragmentation like land use causes genetic differentiation among fragmented populations of the endangered golden-cheeked warbler.

Lodé, T. 2000. Effect of a motorway on mortality and isolation of wildlife populations. Ambio 29: 163-166.

> This study investigated the causes of road-way mortality of animals on one section of highway in France. The authors found 97 species, including endangered species, and measured mortality rates with and without animal passageways. They concluded that high traffic volumes affected population demography and exchanges across the highway from one side to the other.

Loiselle, B.A., C.H. Graham, J.M. Goerck, and M.C. Ribeiro. 2010. Assessing the impact of deforestation and climate change on the range size and environmental niche of bird species in the Atlantic forests, Brazil. *Journal of Biogeography*, 37(7):1288-1301.

> The authors examine the effects of deforestation and how future climate change could affect biodiversity. They used species distribution modeling to predict niches for bird species in Brazil. They found that large-scale deforestation has led to changes in spatial pattern and habitat use in bird species. Future climate change was also found to likely affect habitat use, although to a lesser degree than land use change. The authors conclude that future biodiversity planning should consider both past land use and future climate change.

Machtans, C.S., M.-A. Villard, and S.J. Hannon. 1996. Use of riparian buffer strips as movement corridors by forest birds. *Conservation Biology*, 10(5):1366-1379.

> Certain bird species prefer closed canopy forest-cover for home range and dispersal needs. These investigators looked at the occurrence and movement of birds in corridors (remnant habitat left after logging) and open areas. Their main findings were that dispersing juveniles used corridors and the number of adults decreased following logging due to loss of total habitat and therefore number of birds. Opening size determined frequency of movement of birds across gaps.

Manel, S., Schwartz, M.K., Luikart, G., and Taberlet, P. 2003. Landscape genetics: Combining landscape ecology and population genetics. Trends in Ecology and Evolution 18: 1807-1816.

> This landmark paper gives an overview of the new discipline, landscape genetics. The authors give an introduction to genetic tools and statistical approaches used to determine the effect of landscape feature on genetic consequence.

Marsh, D.M., Page, R.B., Hanlon, T.J., Corritone, R., Little, E.C., Seifert, D.E., and Cabe, P.R. 2008. Effects of roads on patterns of genetic differentiation in red-backed salamanders, *Plethodon cinereus*. Conservation Genetics 9:603-613.

> This research shows that interstate highways cause much more of a barrier effect to the red-backed salamanders than other secondary roads, which further makes a significantly greater genetic differentiation by highway than that of other small roads.

McRae, B.H., and P. Beier. 2007. Circuit theory predicts gene flow in plant and animal populations. *Proceedings of the National Academy of Sciences USA*, 104(50):19885-19890.

> The authors test an ecological connectivity model based on electrical circuit theory. It integrates all possible pathways connecting populations, therefore improving gene flow predictions. When the authors applied the model to mammal and tree species data, they found that the circuit-based model outperformed conventional gene flow models. They conclude that circuit theory provides the best method of bridging landscape and genetic data.

McRae, B.H., B.G. Dickson, T.H. Keitt, and V.B. Shah. 2008. Using circuit theory to model connectivity in ecology, evolution, and conservation. *Ecology*, 89(10):2712-2724.

> The authors introduce electrical circuit theory models for use in landscape connectivity modeling. This paper serves as a review of the theory, including ecological applications. The authors provide examples of how these models can be used in conservation planning.

Meaney, C., M. Bakeman, M. Reed-Eckert, and E. Wostl. 2007. Effectiveness of ledges in culverts for small mammal passage. Report for the Colorado Department of Transportation, Report # CDOT-2007-9. 36 pp.

> The authors investigated the effectiveness of culvert ledges in actually improving the movement of small mammals through culverts under roadways. They found the ledges to be effective in providing passage for small mammals and a cost-effective method for providing for movement.

Meegan, R.P., and D.S. Maehr. 2002. Landscape conservation and regional planning for the Florida panther. *Southeastern Naturalist*, 1(3):217-232.

> The authors use GIS methods to develop a conservation and restoration blueprint for Florida panthers (*Puma concolor coryi*). They used least cost path analysis to model colonization events. They argue that land protection is needed in the very near future and that the alternative of management of isolated populations is unfeasible.

Naiman, R.J., H. Decamps, and M. Pollack. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications*, 3(2):209-212.

> This paper focuses on the various benefits to landscapes, aquatic systems, and ecology in general of intact riparian zones. Riparian zones can regulate many natural functions and are a key driver of the health of natural landscapes.

National Research Council. 1997. *Toward a sustainable future: addressing the long-term effects of motor vehicle transportation on climate and ecology*. National Academy Press, Washington, DC. 261 pp.

> This book focuses on the long-term ecological effects of transportation networks and the challenges faced in addressing them. It details future research needs and issues that will need to be addressed.

Ng, S.J., J.W. Dole, R.M. Sauvajot, S.P.D. Riley, and T.J. Valone. 2004. Use of highway undercrossings by wildlife in southern California. Biol. Cons. 115: 499 – 507.

> This study focuses on the barrier effects of a highway in Southern California and the effectiveness of underpasses and culverts in alleviating some of these impacts. The authors found that the crossings could be effective, depending on species and dimensions of the crossings.

Nicholls, C.I., M. Parrella, and M.A. Altieri. 2001. The effects of a vegetational corridor on the abundance and dispersal of insect biodiversity within a northern California organic vineyard. *Landscape Ecology*, 16(2):133-146.

> Natural habitat areas can be home to native predators of various types and sizes. This study looked at the role of riparian corridors and natural habitat strips through vineyards in influencing pest insect presence and abundance in the vineyards. They found that near to natural habitat, insect predators were suppressing pest insect populations, pointing to a benefit of natural habitat near agriculture.

Noël, S., Ouellet, M., Galois, P., and Lapointe, F. 2007. Impact of urban fragmentation on the genetic structure of the eastern red-backed salamander. Conservation Genetics 8: 599-606.

> This study shows that the habitat fragmentation by urbanization causes genetic differentiation and reduces the genetic diversity of the urban populations.

Noss, R.F., C. Carroll, K. Vance-Borland, and G. Wuerthner. 2002. A multicriteria assessment of the irreplaceability and vulnerability of sites in the Greater Yellowstone Ecosystem. *Conservation Biology*, 16(4):895-908.

> The authors use a reserve selection algorithm with habitat suitability and population viability analyses to identify unprotected sites that are irreplaceable and vulnerable to degradation in the Greater Yellowstone Ecosystem. These sites would significantly contribute to conservation goals in the region if added to the conservation lands portfolio.

Noss, R.F., and K.M. Daly. 2006. Incorporating connectivity into broad-scale conservation planning. Pages 587-619 in: Crooks, K.R., and M. Sanjayan, eds. *Connectivity Conservation*. Cambridge University Press, Cambridge, UK.

> This book chapter focuses on detailing a variety of methods used in connectivity and corridor analysis. The authors also include a section on non-corridor types of connectivity. They conclude with a summary of guidelines that should be used to improve corridor planning.

Pearson, R.G., and T.P. Dawson. 2005. Long-distance plant dispersal and habitat fragmentation: identifying conservation targets for spatial landscape planning under climate change. *Biological Conservation*, 123(3):389-401.

> The authors develop a stochastic, spatially-explicit model to simulate plant dispersal under future climate change. They analyze the potential for long distance dispersal events between suitable habitat patches. They demonstrate the declining importance in spatial arrangement of patches with higher dispersal potential.

Pritchard, J.K., Stephens, M., and Donnelly, P. 2000. Inference of population structure using multilocus genotype data. Genetics 155: 945-959.

> This important paper presents an effective method to infer population structure. This method is implemented in an easily-used software “Structure”, and is used extensively by population geneticists.

Prugnolle, F., and de Meeus, T. 2002. Inferring sex-biased dispersal from population genetic tools: a review. Heredity 88:161-165.

> Sex-biased dispersal is a wide-spread pattern in vertebrate organisms. This paper describes different methods for inferring sex-specific dispersal using population genetic tools and discusses the problems they can raise.

Reh, W., and Seitz, A. 1990. The influence of land-use on the genetic-structure of populations of the common frog *Rana temporaria*. Biological Conservation 54:239–249.

> This paper gives a description of the barrier effect of a road on a common frog, and finds that the road causes a decrease in genetic diversity and increase in population differentiation.

Riley, S.P.D., R.M. Sauvajot, T.K. Fuller, E.C. York, D.A. Kamradt, C. Bromley, and R.K. Wayne. 2003. Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California. *Conservation Biology*, 17(2):566–576.

> The authors investigate the effect of development in a fragmented landscape in southern California on bobcats (*Lynx rufus*) and coyotes (*Canis latrans*). They compared radio-collar data with landscape variables to measure effects. Adult female bobcats had low levels of urban association and consequently require sufficient open space habitat for future population viability.

Riley, S.P., Pollinger, J.P., Sauvajot, R.M., York, E.C., Bromley, C., Fuller, T.K., and Wayne, R.K. 2006. A southern California freeway is a physical and social barrier to gene flow in carnivores. Molecular Ecology 15: 1733–1741.

> Highways can segment animal populations for species sensitive to roadways and traffic. This study focused on the role of a busy Southern California highway in segmenting carnivore populations – essentially dividing them in two so that they were genetically different.

Rosenberg, D.K., B.R. Noon, and E.C. Meslow. 1997. Biological corridors: form, function, and efficacy. *BioScience*, 47(10):677–687.

> The authors describe the form that biological corridors can take, and then they explore the evidence of functionality and effectiveness of corridors. They describe the habitat role that corridors can play, and caution that corridors may not fully mitigate for additional habitat loss.

Saving, Shawn C. and Gregory B. Greenwood. 2002. The Potential Impacts of Development on Wildlands in El Dorado County, CA. USDA Forest Service Gen. Tech. Rep. PSW-GTR-184.

> This paper describes the effects of the build-out of different 2004 General Plan alternatives on plant communities and landscapes in the County. The study relies on GIS modeling to assess these effects and draws conclusions about the extent and types of effects.

Schooley, R.L. and J.A. Wiens. 2003. Finding habitat patches and directional connectivity. Oikos, 102(3): 559-570.

> Functional connectivity means the connectivity of a landscape based on the needs of the process or organism flowing through the landscape. Many animals rely on senses to determine where to move, but this movement behavior is often not reflected in connectivity modeling. This paper describes perceptual ranges (how far and organism can sense its environment) and how they are important in connectivity analysis.

Schumaker, N.H. 1998. *A user's guide to the PATCH model*. EPA/600/R-98/135. U.S. Environmental Protection Agency, Corvallis, OR, USA.

> This report provides a guide for using the PATCH spatially explicit population model.

Schumaker, N.H. 2010. *HexSim Version 2.0*. U.S. Environmental Protection Agency, Corvallis, OR, USA. Available from http://www.epa.gov/hexsim.

> This report provides a guide for using the HexSim spatially explicit population model.

Schwartz, M.K., J.P. Copeland, N.J. Anderson, J.R. Squires, R.M. Inman, K.S. McKelvey, K.L. Pilgrim, L.P. Waits, and S.A. Cushman. 2009. Wolverine gene flow across a narrow climatic niche. *Ecology*, 90(11):3222-3232.

> The authors test a dispersal model for wolverines (*Gulo gulo*). They used least cost path analysis to represent genetic distance among individuals. Models focused on movement across spring snow better explained the data than did Euclidean distance. Least cost corridors for the U.S. Rocky Mountains were then generated using these findings.

Semlitsch, R.D. 2000. Principles for management of aquatic-breeding amphibians. *Journal of Wildlife Management*, 64(3):615-631.

> The author provides a review of threats, state of knowledge, and effective management of amphibian populations. He states that population dynamics and connectivity must be considered in effective management plans. Wetland loss is addressed, and finally landscape fragmentation is investigated.

Shilling, F.M., E.H. Girvetz, C. Erichsen, B. Johnson, and P.C. Nichols 2002. "A Guide to Wildlands Conservation Planning in the Greater Sierra Nevada Bioregion". California Wilderness Coalition, 187 pp.

> This was the first large-scale "wildlands" project in California and it focused on the Sierra Nevada bioregion. The intent of the study was to identify less-disturbed areas in the bioregion that were suitable for ecological reserves and determining the level of connectivity across the landscape.

Shilling, F.M and E.H. Girvetz 2007. Barriers to implementing a wildland network. *Landscape and Urban Planning*. Volume 80(1-2): 165-172.

> The authors investigate the potential acquisition cost of a reserve network in the Sierra Nevada, California, based on GIS findings from Shilling et al. (2002). The high cost was found to be prohibitive for an acquisition-only conservation strategy. The authors also identified barriers to wildlife movement and suggest mitigation efforts that could ameliorate some of the barrier effects.

Sieving, K.E., M.F. Willson, and T.L. De Santo. 2000. Defining corridor functions for endemic birds in fragmented south-temperate rainforest. *Conservation Biology*, 14(4):1120-1132.

> The authors analyze corridors for their function as either living space or suitable for movement by five bird species in Chile. They found a relationship between corridor length:width ratios and bird abundance. They also found that dense understory vegetation was important for short movement events. They conclude that corridors in agricultural areas can be designed for specific functions.

Singleton, P.H., W.L. Gaines, and J.F. Lehmkuhl. 2002. *Landscape permeability for large carnivores in Washington: a geographic information system weighted-distance and least-cost corridor assessment*. Res. Pap. PNW-RP-549. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest. 89 pp.

> This U.S. Forest Service report details potential habitat for four large carnivore species in Washington State. The authors conducted permeability analysis between large blocks of potential habitat. Finally, areas of overlap between linkages and highways were identified.

Skagen, S.K., C.P. Melcher, W.H. Howe, and F.L. Knopf. 1998. Comparative use of riparian corridors and oases by migrating birds in southeast Arizona. *Conservation Biology*, 12(4):896-909.

> This study focused primarily on the role of fragmented and continuous riparian zones in providing habitat for migrating birds in the Southwest. The primary finding was that size and isolation of riparian zones from each other was not important in use of the zones – all riparian areas were important. This was potentially because of the limitation on area of this habitat type.

Soulé, M.E. 1991. Land use planning and wildlife maintenance: guidelines for conserving wildlife in an urban landscape. Journal of the American Planning Association 57: 313-323.

> This study focused on the impacts of urban and suburban land development on landscape connectivity and wildlife movement. The author recommends consolidating natural open spaces and providing wildlife corridors in urban areas to mitigate some of this impact.

Spackman, S.C., and J.W. Hughes. 1995. Assessment of minimum stream corridor width for biological conservation: species richness and distribution along mid-order streams in Vermont, USA. *Biological Conservation*, 71(3):325-332.

> These investigators looked at plant, bird, and mammal distributions along riparian zones. They found that widths up to 175 meters were needed to retain 90% of bird species, whereas narrower widths were needed to provide for stream-side plant species. They conclude that no one-size-fits-all riparian width strategy could functionally replace stream-specific surveys and standards for riparian conservation.

Spellerberg, I. F. 1998. Ecological effects of roads and traffic: A literature review. Global Ecology and Biogeography Letters 7:317-333.

> This early review of ecological effects of roads found that quantifying ecological impacts of roads was uncommon, but planning for mitigating road effects was becoming more common. The author suggested two areas of additional research – localized pollutant effects at road-sides and wildlife passage across the right-of-way.

Spencer, W.D., P. Beier, K. Penrod, K. Winters, C. Paulman, H. Rustigian-Romsos, J. Strittholt, M. Parisi, and A. Pettler. 2010. California Essential Habitat Connectivity Project: A Strategy for Conserving a Connected California. Prepared for California Department of Transportation, California Department of Fish and Game, and Federal Highways Administration.

> This report is an analysis of California landscape intactness. Large habitat blocks are identified and least cost corridor analysis is performed between adjacent blocks. Chapters are devoted to including future climate change in analyses and how to scale down from statewide to regional spatial scales.

Sullivan, T.L., A.E. Williams, T.A. Messmer, L.A. Hellinga, and S.Y. Kyrychenko. 2004. Effectiveness of temporary warning signs in reducing deer-vehicle collisions during mule deer migrations. Wildl. Soc. Bull. 32: 907-915.

> This study looked at the relative effectiveness of warning signs for drivers, compared to permanent signs. They found that temporary signs and signs with enhancements were more effective than permanent and un-changing signs.

Taylor, P.D., L. Fahrig, and K.A. With. 2006. Landscape connectivity: a return to basics. In: Connectivity Conservation eds. K.R. Crooks and M. Sanjayan, Cambridge University Press. Pp 29-43.

> This book chapter gets into the basics of defining and conserving connectivity. In particular, the authors differentiate between "structural connectivity" – how intact a landscape is for animal movement, and "functional connectivity" – how much animals can actually move through a landscape.

Taylor, P.D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos*, 68(3):571 573.

> The authors propose landscape connectivity as a measure of landscape structure. They describe four fundamental processes in terms of connectivity. They conclude that the inclusion of connectivity increases the utility of a previous ecological framework.

Tewksbury, J.J., D.J. Levey, N.M. Haddad, S. Sargent, J.L. Orrock, A. Weldon, B.J. Danielson, J. Brinkerhoff, E.I. Damschen, and P. Townsend. 2002. Corridors affect plants, animals, and their interactions in fragmented landscapes. *Proceedings of the National Academy of Sciences USA*, 99(20):12923–12926.

> The authors report on a large-scale field experiment testing the effectiveness of corridors. Results show that corridors increase animal exchange between patches and facilitate pollination and seed dispersal. The authors conclude that corridors provide ecological function greater than their area would suggest and that they have positive impacts on plant and animal populations.

Theobald, D.M. 2006. Exploring the functional connectivity of landscapes using landscape networks. Pages 416-443 in: Crooks, K.R., and M. Sanjayan, eds. *Connectivity Conservation*. Cambridge University Press, Cambridge, UK.

> The author explores several methods of connectivity analysis in this book chapter. First he details the computation of effective distance (in contrast to Euclidean distance). This analysis technique is then incorporated in graph theory, which is the subject of the second portion of the chapter. Graph theory can be used to quantify landscape connectivity.

Tischendorf, L. and L. Fahrig. 2000. On the usage and measurement of landscape connectivity. Oikos, 90(1): 7-19.

> This is a seminal paper in contemporary studies of connectivity. It formalizes how connectivity should be defined and measured. It describes relationships between landscape structure and animal movement, including recommendations for how these relationships should be measured and interpreted.

Trakhtenbrot, A., R. Nathan, G. Perry, and D.M. Richardson. 2005. The importance of long-distance dispersal in biodiversity conservation. *Diversity and Distributions*, 11(2):173-181.

> The authors review conservation issues for which long distance dispersal (LDD) is most important. They discuss assessments of the importance of LDD, tools for quantifying LDD, and management of LDD. They conclude by demonstrating how incorporation of LDD can improve conservation management.

Tremblay, M.A., and C.C. St. Clair. 2009. Factors affecting the permeability of transportation and riparian corridors to the movements of songbirds in an urban landscape. *Journal of Applied Ecology* , 46(6):1314-1322.

> These authors investigated forest-dwelling songbird movement in association with closed and open spaces on the landscape. They found that, in general, the wider the spaces, the less willing birds were to cross them. This included open spaces across rivers where riparian canopy did not provide a close enough connection.

Underwood, E.C., K.B. Klausmeyer, R.L. Cox, S.M. Busby, S.A. Morrison, and M.R. Shaw. 2009. Expanding the global network of protected areas to save the imperiled Mediterranean biome. *Conservation Biology*, 23(1):43-52.

> The authors conduct a global gap analysis for the Mediterranean biome. California-Baja California was one of the regions with higher levels of protection (9% of total area). They found that protection is skewed towards montane elevations and that only shrubland exceeds 10% protection. They conclude by identifying biodiversity assemblages with high conservation priority.

Urban, D., and T. Keitt. 2001. Landscape connectivity: a graph-theoretic perspective. *Ecology*, 82(5):1205-1218.

> The authors introduce the use of graph theory in connectivity analysis. A combination of nodes and edges is used to model conservation networks. The minimum spanning tree, a graph construct, can be used to identify the importance of individual components for the network. They use this approach to model Mexican spotted owl (*Strix occidentalis lucida*) habitat.

Urban, D.L., E.S. Minor, E.A. Treml, and R.S. Schick. 2009. Graph models of habitat mosaics. *Ecology Letters*, 12(3):260-273.

> The authors review the use of graph theory in conservation applications. They consider the conceptual model, implementation, parameterization, testing, and potential implications. The authors conclude that the model is a robust framework for connectivity evaluation and suggest some next steps in research.

Vandergast, A. G., Bohonak, A. J., Weissman D. B., and Fisher, R. N. 2007. Understanding the genetic effects of recent habitat fragmentation in the context of evolutionary history: phylogeography and landscape genetics of a southern California endemic Jerusalem cricket (Orthoptera: Stenopelmatidae: Stenopelmatus). Molecular
Ecology 16: 977-992.

> This paper details a study undertaken to investigate the effect of habitat fragmentation on a California endemic insect. Genetic divergence was found to be correlated with contemporary urbanization. Genetic diversity within populations was found to be positively correlated with fragment size. The authors conclude by stressing the importance of connectivity for low vagility species.

Williams, P., L. Hannah, S. Andelman, G. Midgley, M. Araújo, G. Hughes, L. Manne, E. Martinez-Meyer, and R. Pearson. 2005. Planning for climate change: identifying minimum-dispersal corridors for the Cape Proteaceae. *Conservation Biology*, 19(4):1063-1074.

> This paper outlines a quantitative method developed to identify multiple corridors through shifting habitat suitabilities that minimize dispersal demands and area required. The authors were able to achieve the goal of species representation at a reasonable cost. They urge caution, however, in using current climate change models.

6.0 Acronyms and Other Terms

Caltrans	California Department of Transportation
County	El Dorado County
GIS	Geographic Information Systems
GPS	Global Positioning System
IBC	Important Biological Corridor
INRMP	Integrated Natural Resources Management Plan
LDD	Long-distance dispersal
OWMP	Oak Woodland Management Plan
PCAs	Priority Conservation Areas
ROW	Right-of-Way
SEPM	Spatially Explicit Population Models

7.0 List of Preparers

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Appendix A
Background Scientific Information

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List of Figures **Page #**

1.0 Habitat Loss and Fragmentation

Habitat loss and the accompanying fragmentation due to human land uses constitute the greatest threats to biodiversity currently (Dobson et al. 1999). As of 2005, 21.8% of the planet's land area had been converted to human use (Hoekstra et al. 2005). Within the Mediterranean biome of California (the whole state minus the deserts), conversion has been measured at 17% of the total area (Underwood et al. 2009). Landscapes can be fragmented by a variety of human uses including: urbanization, agriculture, transportation corridor development, logging, mining, and other industrial development (Figure A-1. Landscape Fragmentation Can Be Caused By A Variety of Human Land Uses).

While these numbers are relatively large and constitute a potential threat to resident species in their own right, perhaps a greater risk to the global biota is found in the spatial pattern of the disturbed areas and their effect on connectivity, a critical ecological function (Taylor et al. 1993). Many, if not most, animal species will not cross areas of urban development. Agricultural areas similarly generally see much reduced usage by animals for movement. Effects of development on animal movement are not restricted to the actual footprint of disturbance, however. Edge effects associated with human land use can negatively influence sensitive species well away from urban or agricultural areas. Potential impacts include noise, night lighting, domestic pets, air and water pollution, and generally increased human presence near urban and agricultural areas. Individual animals with home ranges in the vicinity of human-dominated areas can experience higher rates of mortality even if able to use these areas as habitat (Riley et al. 2003).

Habitat fragmentation and reduced capacity for animal movement can lead to isolated populations of species with an increased risk of local extinction. These human impacts can have effects not only on sensitive, wide ranging species such as mountain lion (Beier 1993, Kautz et al. 2006), but small species with limited dispersal capabilities as well (Vandergast et al. 2007, Brückmann et al. 2010). Increased fragmentation and associated decrease in average habitat patch size was found to generally eliminate six carnivore species in southern California (Crooks 2002). Loss of intermediate stepping stone habitat patches crucial to connectivity within some metapopulation networks can lead to increased risk of population extinction, even if the overall footprint of development is small (Semlitsch 2000).

Figure A-1. Landscape Fragmentation Can Be Caused By A Variety of Human Land Uses

A) Urban development (Sacramento County, CA)
B) B) Agriculture (Placer County, CA)
C) Logging and reservoir construction (El Dorado County, CA)
D) Mining (Robinson Mine in White Pine County, NV)

* Photos P. Huber.

2.0 Wildlife Corridors

Connectivity can be defined broadly as the permeability of a landscape to ecological flows, including wildlife movement. Connectivity defined as a property of landscapes, or even large relatively homogeneous patches, is probably the most reflective of ecological processes and patterns. Others have described connectivity as ‘‘*the degree to which landscape facilitates or impedes movement of organisms among patches*’’ (Taylor et al. 1993; Tischendorf and Fahrig 2000; Schooley and Wiens 2003) and “*the functional relationship among habitat patches due to their spatial distribution and the movement of organisms in response to landscape structure & the ease with which these individuals can move about within the landscape*’’ (Taylor et al. 1993; With et al. 1997; Kindlmann and Burel 2008). Wildlife corridors are a narrow expression of the concept of connectivity. They are geographically-constrained strips of land that are either the remnant habitat in a developed landscape, or are some geographer’s idea of what areas of land might provide for wildlife movement.

2.1 Connectivity and Wildlife Corridors

Connectivity is an attribute of all landscapes that refers to how much ecological flow, such as wildlife movement, the landscapes allow. Corridors are narrow zones of connectivity and are useful for certain animals, but not all. Individually they are a sub-set of connectivity and are most useful in developed settings (urban and agricultural). At the landscape scale, connectivity for individual taxa may be the most important of physiographic properties because it is a measure of intactness, which along with habitat type and forage availability describes what individual taxa and biodiversity need across daily to evolutionary timeframes. Connectivity is also an emergent property of landscapes in that it is not predictable from any one characteristic of the landscape, but is a predictable or measurable attribute of the landscape as an aggregate of characteristics. Defining connectivity can have profound effects on how this attribute is conserved in any landscape. In its most constrained application, primarily in conservation implementation, connectivity is defined as a land-corridor or linkage set-aside to allow wildlife movement (or other ecological flows). This type of designation is often consigned to urban or urbanizing environments, natural areas with heavy resource extraction (e.g., Carroll, 2007), or in places where other working definitions of connectivity have just not been introduced. This definition and corresponding spatial analyses are probably heavily-influenced by the needs of land planners to arrange exclusive, non-complementary sets of activities on distinct parcels or patches. At the least-constrained end of the spectrum, connectivity is defined as the permeability of a landscape to ecological flows, including wildlife movement (Fischer and Lindenmayer, 2004). Connectivity defined as a property of landscapes, or even large relatively homogeneous patches, is probably the most reflective of ecological processes and patterns, but often requires both creative scientific explanations to land-holders/managers and creative implementation instruments. This definition and corresponding spatial analyses are probably most influenced by ecology, with its study of gradations across space and time, and among inter-dependent ecosystem components. The profound difference between these two definitions of connectivity lies less in the ability to apply them at the landscape level – both have been carried out – and more in their relative value for conservation of biodiversity.

Connectivity is defined here as an emergent landscape property that can be expressed at the habitat patch or other scales and is scaled according to the particular movement needs of individual taxonomic groups or other ecological flow (Fischer and Lindenmayer, 2004). This definition is most like the habitat continuum concept (Fischer et al., 2004), which can be contrasted with the island-based patch and corridor model (“fragmentation model” in Fischer et al., 2004). The use of this definition provides the broadest application of connectivity analyses in ecological conservation. Connectivity “surfaces” can be constructed for landscapes using particular combinations of species and spatial-temporal scales. If necessary, the highest quality ridgelines on these surfaces can be used to show the most important lands for conservation for particular taxa in highly-contested land-management scenarios. This approach also allows for connectivity as an ecological attribute to be accurately and effectively conveyed to land-holders and managers, opening the door to more creative and wildlife-friendly land-management (Fischer et al., 2008).

A common differentiation made in the connectivity literature is between “structural connectivity” and “functional connectivity”, where the former is measured as landscape structure that may facilitate or inhibit wildlife movement and the latter is measured directly from wildlife movement, or estimated based on rules of organismal behavior and responses to landscape attributes (Kindlmann and Burel, 2008). The field of applied conservation is changing rapidly so that connectivity is more often estimated for several species on a landscape, rather than just calculating “structural connectivity” based on fragmentation patterns. Many landscapes will vary in their “functional connectivity” for different motile species. By measuring connectivity of landscapes for a wide-range of movement needs, conservation scientists can reveal the range of needs across landscapes and estimate how these needs might change or be impacted with future land-cover changes. Taylor et al. (2006) argue that structural connectivity is not a good stand-in for landscape connectivity, which was historically and is usually defined as being an attribute having relevance to moving animals (or similar flows). Landscape or habitat intactness is essentially what most investigators and land managers mean by “structural connectivity” and is an important landscape attribute when considering wildlife movement.

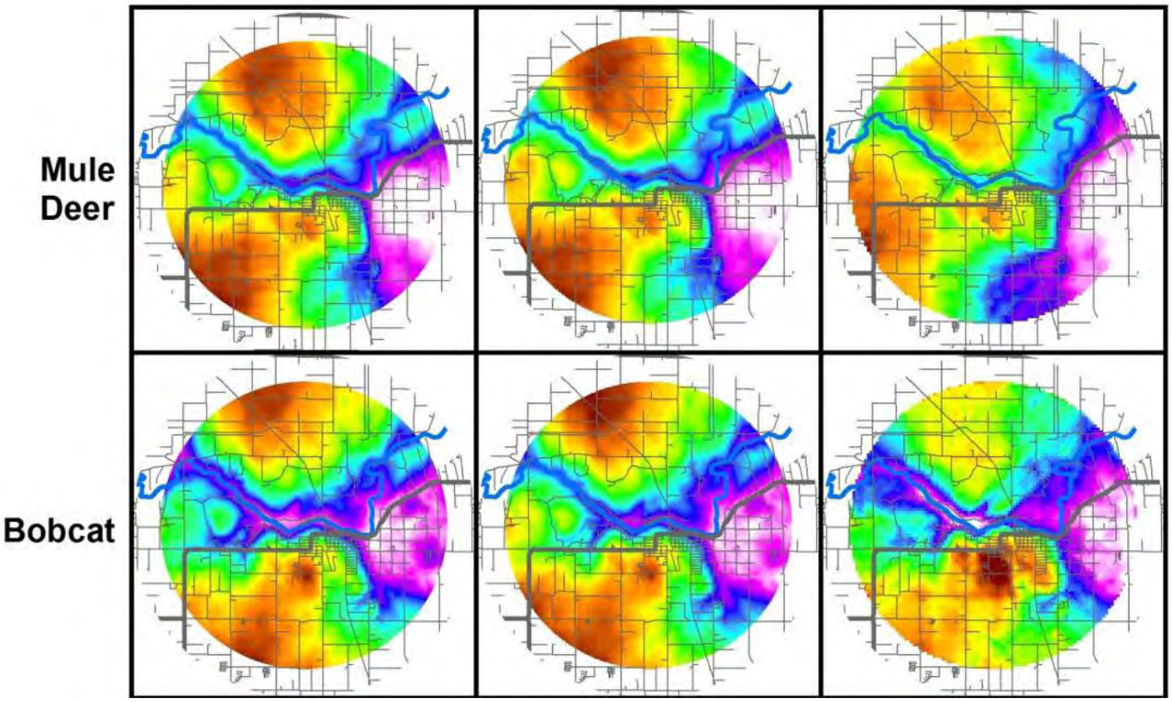
Extensive connectivity refers to wildlife movement throughout landscapes at rates and distributions that suit their needs. This can be contrasted with minimal connectivity that might be provided by “wildlife corridors” planned for developed environments, or even sometimes undeveloped environments. In reality, many landscapes provide some degree of movement through areas with intermediate levels of development. Expanding connectivity planning beyond “corridors” and “linkages” recognizes the ecological reality that animals move according to their needs more than according to our planning and that landscapes providing economic value are often managed for multiple purposes, including to maintain natural structure and function. A combination of traditional “linkage” planning and extensive connectivity planning may provide the opportunities that wildlife need to adapt to changing climatic, land-cover, and ecological conditions.

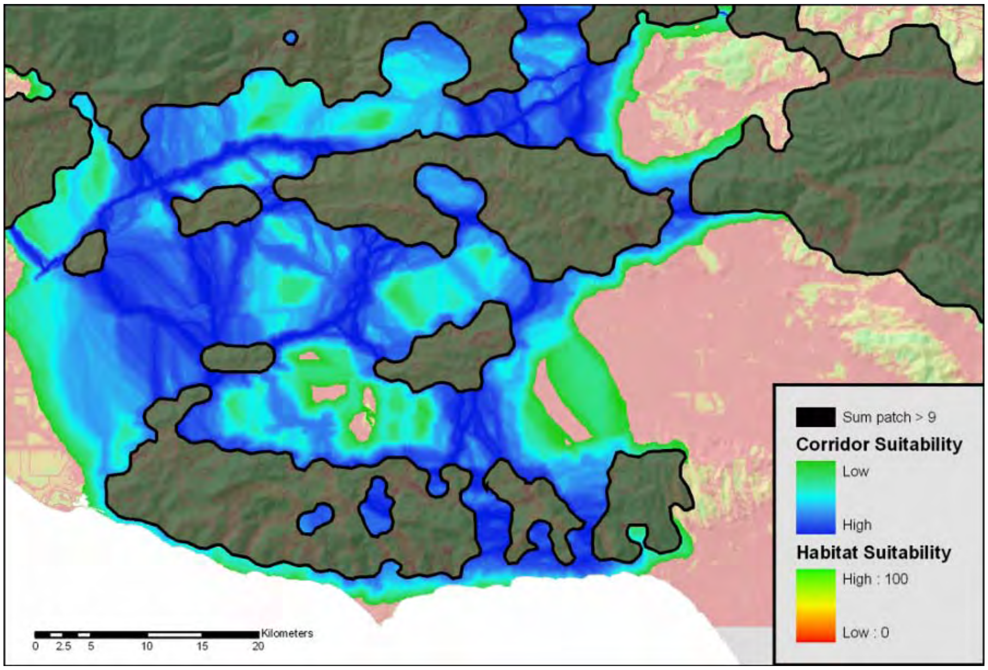
One ecological landscape component that can function as a linear wildlife corridor is riparian forest. Riparian forests naturally host a wide array of terrestrial and aquatic species. This ecological diversity is driven by the dynamic nature of geomorphic process, the altitudinal gradient inherent in streams and rivers, and the connection with upland areas beyond the edge of the riparian zone (Naiman et al. 1993). Wider intact riparian corridors generally provide habitat for more species than do narrow or degraded corridors. Lees and Peres (2008) found wide corridors in Brazil’s Atlantic forest to have nearly the full assemblage of native species while narrower corridors were generally lacking the full assemblage. Similarly, Spackman and Hughes (1995) in a study in Vermont found that while there was no one minimum width for all species, riparian corridors of up to about 550 feet in width as a minimum provided habitat for 90% of bird species. Not only do riparian corridors provide habitat for a wide variety of species, they also provide landscape connectivity for many of those species. Machtans et al. (1996) found riparian strips to enhance connectivity for juvenile forest birds and to maintain connectivity for adults in Alberta, Canada. Forest specialist bird species were found to use riparian corridors but not fencerows in Costa Rica (Gillies and St. Clair 2008). In Sonoma County, California, Hilty and Merelender (2004) found an 11-fold increase in mammalian predators in riparian corridors compared with adjacent vineyards, with more species found moving through wide corridors. They conclude that wide, well-vegetated riparian corridors may be necessary to maintain populations of predators in impacted landscapes. Insects were also found to use riparian corridors (Nicholls et al. 2001). Riparian corridors tend to be more ecologically effective if they are continuous rather than fragmented. Tremblay and St. Clair (2009) found a 50% decrease in forest bird movement in Alberta, Canada, when there were gaps of about 150 feet in the forest canopy. That being said, even discrete riparian patches can provide resting locations for migrating birds (Skagen et al. 1998). Intra-corridor patterns are important as well, and should be considered by conservation and land use planners and managers for maximizing use by animals. Individual species require different ecological components and natural history needs should be evaluated, especially for species with limited movement, such as reptiles and amphibians (Burbrink et al. 1998).

2.2 Modeling Connectivity and Corridors

Accurate analysis of connectivity should follow on from the theory or definition of connectivity, as well as the needs of the wildlife and natural processes in question. This raises the question of "connectivity for whom?" which applies both in terms of the natural systems being addressed and the planning process being served. The vast majority of connectivity analyses are directed, explicitly or not, to medium-large mammals, primarily because of a combination of data availability, species-specific knowledge, and bias toward certain taxonomic groups. Currently-available spatial data will tend to be more accurate at coarse grains and not suitable for the needs of smaller animals; we know the most about the behavior and movement of larger mammals; and there is generally more public support for the needs of large mammals. However, connectivity assessments that are based in understanding of landscape intactness and resilience that are conducted at multiple organismal scales, and that cover all taxa, are more likely to contribute to biodiversity conservation. Examples of connectivity model outputs are shown in Figure A-2. Connectivity Analyses for Mule Deer and Bobcat in the San Joaquin Valley.

Figure A-2. Connectivity Analyses for Mule Deer and Bobcat in the San Joaquin Valley





There are many connectivity analysis approaches, but they fall into two main camps: 1) The majority of approaches partition landscapes into the dichotomous categories – core/corridor and not core/corridor. These approaches treat connectivity as an exercise in getting from reserve A to reserve B along one or more pathways (also called corridors or linkages; Beier et al., 2008). 2) A minority of approaches treat the landscape as a gradient of permeability or habitat suitability (Fischer et al., 2004; Shilling et al., 2002; Shilling and Girvetz, 2007), where movement is a possibility based on habitat quality, disturbance, and the needs of the taxa.

A dichotomous illustration of connectivity may suit the needs of planners to have available explicit separation of the landscapes into the minimum area that the organisms need and what they may not need (or need less). For the vast majority of animals, a dichotomous representation is unlikely to be very accurate because of a combination of information availability, knowledge of the species' needs, and the tendency of most animals to be opportunistic across varying time scales when it comes to foraging and dispersing. Treating landscapes as having a continuum of permeability results in a cost (or benefit) surface, which may better suit the needs of wildlife because it includes representation of all possible habitat conditions, without excluding seemingly less-optimal areas. This approach also deals with the recent critique of Hodgson et al. (2009) by recognizing connectivity/intactness as a landscape property closely tied to other measures of habitat extent and quality. At first glance, the connectivity-continuum may seem less suitable for planning, solely because continua are less popular in conservation planning than dichotomous, polygonal representations of wildlife needs. However, a cost surface can be summarized to polygons fairly easily, allowing representation of both the continuum of connectivity and partitioning of dichotomous conditions. Another way to think about it is that corridors are all the places that wildlife use to move and collectively they define connectivity.

3.0 Need for Connectivity

Connectivity is needed for a variety of ecological needs of plants and animals. The first is for daily foraging movement, where animals move around landscapes to feed on short time-frames. Wildlife may need to move gradually across a landscape as they forage, or they may restrict their movements within a territory or home range. If roads or other development are present, certain species may defer movement near or across the developed areas. Others may move anyway and come into conflict with traffic, residential areas, and agricultural practices. A second need for connectivity is for seasonal movement or migration. The best local example of this is migration of deer herds from summer to winter habitat and back. In El Dorado County, this movement is primarily in an east-west direction, following elevational gradients. In some areas and for some deer herds, this movement follows roughly the same paths (e.g., drainages) every year, which could then be called migration corridors. If barriers form near or across seasonal migration routes and alternative routes, then migration may be hampered or even ended altogether, which could result in a loss of the migrating population. A third need for movement is for inter-generational dispersal, or juvenile and propagule dispersal. Many wildlife species have a reproductive strategy of dispersing juvenile animals to new areas to establish home ranges, take advantage of abandoned habitat, and to maintain population size. Juveniles are actively excluded or naturally choose to move out of adult home ranges. They will also have less experience with human disturbances than adults may have. Barriers to dispersal, or excessive loss of individual juveniles during dispersal (e.g., from wildlife-vehicle collisions), can result in reduction or elimination of populations and subpopulations. The fourth need for connectivity is for adaptation to changing climatic conditions. Vegetation and habitat conditions have changed over geological time (e.g., since recent ice ages) and over the last century (i.e., upward movement of trees species in response to warming). Changing climatic conditions (e.g., temperature and moisture) and vegetation conditions will result in the need for species to gradually or rapidly change their position on the landscape. State and federal government agencies have described connectivity as an important attribute of landscapes to facilitate adaptation by biodiversity to the climate change we are experiencing right now (e.g., California Climate Change Adaptation Strategy: http://www.climatechange.ca.gov/adaptation/; U.S. Environmental Protection Agency: http://www.epa.gov/climatechange/effects/adaptation.html).

4.0 Genetic and Population Effects of Fragmentation

Transportation infrastructure is a major cause of genetic discontinuity in wildlife, and its effect on animal dispersal and movement has been documented in many studies (Kuehn et al., 2007; Corlatti et al., 2009). Anthropogenic infrastructure may lead to habitat loss and fragmentation, decrease in gene flow, increase in genetic drift and loss of genetic diversity (Marsh et al., 2008). This section describes some of these effects, which are some of the most significant among impacts to wildlife from transportation infrastructure and land-use. Appendix B – Glossary of Terms will be useful for this section as it contains definitions of the technical terms used.

4.1 Introduction to Landscape Genetics

To study the general effects of artificial landscape features (e.g., highways) on population genetic structure, a new discipline, landscape genetics, has recently been developed. Landscape genetics integrates studies of landscape patterns and population genetics, and detects the correlation between genetic differentiation and landscape features. First described in the landmark paper by Manel et al. (2003), this field has flourished, evidenced by an increasing number of published papers on this topic (Holderegger & Wagner, 2006). The study of landscape genetics is best described as evaluating the effect of individual roads and/or road networks on the genetic structure of surrounding wildlife populations, and thereby provides guidance for minimizing detrimental ecological impacts on wildlife through designing mitigation actions and infrastructure.

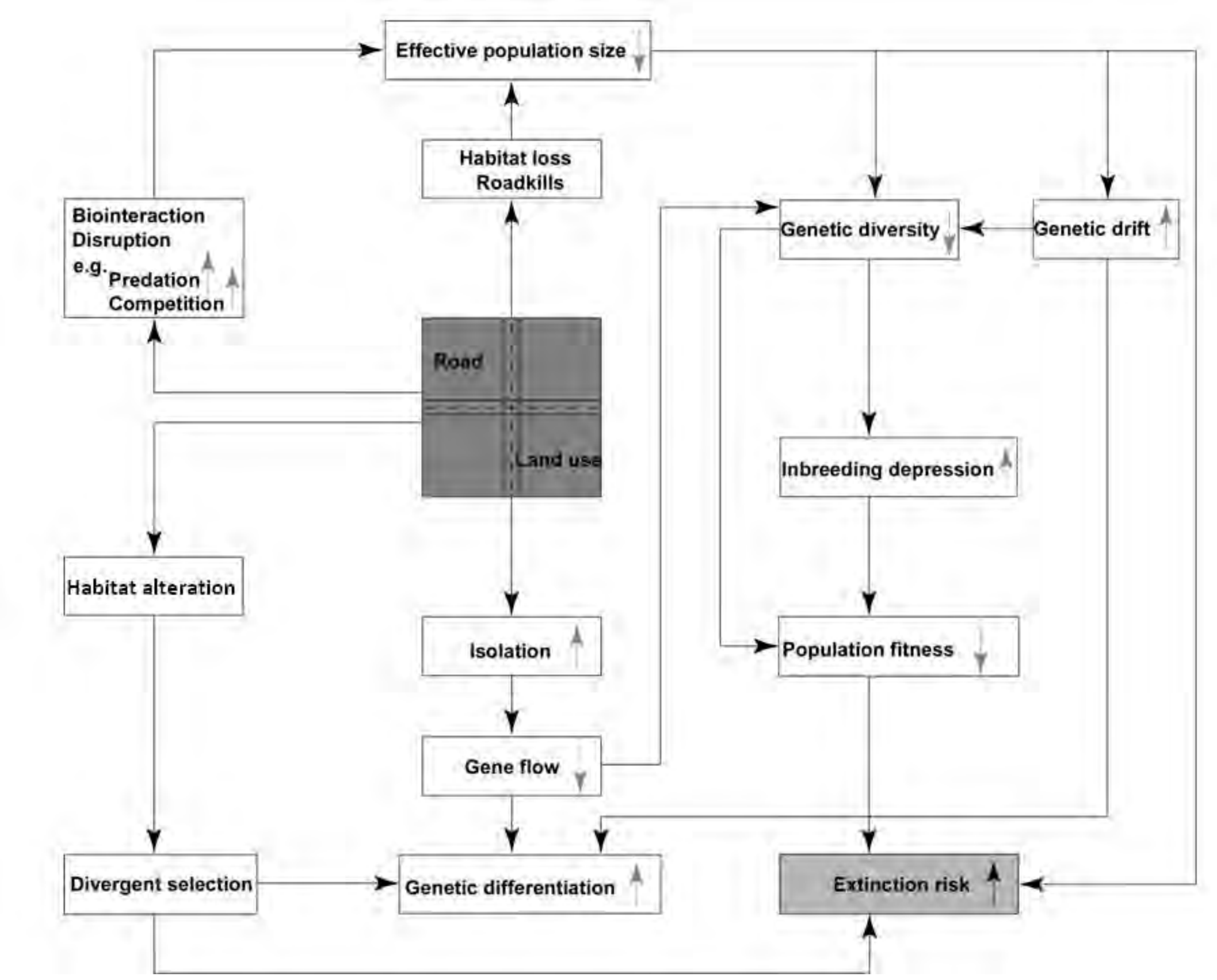
Population genetic structure is generally used to depict population subdivision based on genetics studies. Ideally, no genetic structure should be detected in a single mendelian population because every individual is hypothesized to move freely without any physical, genetic, or social preference and to mate randomly (Hamilton, 2009, p.105). However, this does not hold true for actual populations because of complex restrictions and preferences. (e.g., the mating chance of two individuals often depends on their location) (Hamilton, 2009, p.105). In fact, many factors may affect the mating opportunity of two individuals chosen randomly, such as geological and landscape barrier, and mating preference. Under this circumstance, selection and genetic drift may cause a population to be differentiated into subpopulations, which have the potential to move on different evolutionary trajectories.

4.2 Impacts of Roads and Highway Networks

Roads/highways can affect genetic structure by directly changing several key population genetic parameters, such as effective population size, gene flow, genetic drift and selection (as shown in Figure A-3. Diagram of Main Effects of Road and/or Land Use on Population Genetics). First, the road/highway construction may cause habitat loss while the traffic may cause animal-vehicle collisions, both of which can obviously result in decrease of effective population size. Second, road and highways may lead to habitat fragmentation, turning a previously continuous population into many smaller and isolated subpopulations, which may subsequently reduce genetic diversity and contribute to genetic differentiation. Third, roads and highways may also cause habitat alteration, like noise and chemical pollution (Spellerberg, 1998).

Figure A-3. Diagram of Main Effects of Road and/or Land Use on Population Genetics

The altered habitat may create a different selection pressure on the organisms, which may lead them to evolve adaptively.



The most common genetic consequence of roads and traffic is through habitat fragmentation, which is defined as splitting of contiguous areas into smaller and increasingly isolated patches (Fahrig, 2003). All roads may serve as barriers (animal-vehicle collision and road avoidance) to animal movements and hence break apart habitats of wildlife, causing formation of smaller and partially isolated subpopulations (Forman & Alexander, 1998). This may seriously restrict gene flow among those subpopulations. Furthermore, small isolated subpopulations tend to suffer from strong independent genetic drift and increasing inbreeding, which makes them prone to disease and loss of adaptive genetic diversity. As a consequence, the isolated populations are more vulnerable to stochastic extinction events due to decreased genetic diversity (Frankham et al., 2002) and lack of available rescue effect from immigration or recolonization (Soulé, 1991).

Several studies have reported decreases in genetic diversity in populations isolated by road barriers. For example, in southern California, the desert bighorn sheep (*Ovis canadensis nelsoni*) shows as much as 15% decrease of nuclear genetic diversity in populations that have been completely isolated by road networks for over 40 years (Epps et al., 2005). Similarly, compared to non-fragmented populations, populations of agile frog (*Rana dalmatina*) fragmented by highways exhibit significantly lower allelic richness (Lesbarrères et al., 2006). Moreover, a study on Jerusalem cricket (*Stenopelmatus* ‘*mahogani*’) shows a positive correlation between its genetic diversity and its current habitat patch size caused by urbanization (including road/highways) (Vandergast et al., 2007).

In addition to its effect on genetic diversity, another genetic consequence of road or highway barriers is to cause population differentiation, and the empirical evidence for this is ubiquitous (reviewed in Corlatti et al., 2009). This is not surprising due to the limited gene flow that will occur among isolated populations and possibly strong genetic drift in individual small, isolated populations. Increased genetic divergence among populations divided by road barrier has been reported in many varied taxa such as Jerusalem cricket (*Stenopelmatus* ‘*mahogani*’) (Vandergast et al., 2007), ground beetle (*Carabus violaceus*) (Keller & Largiader, 2003), red-backed salamanders (*Plethodon cinereus*) (Marsh et al., 2008), frog (*Rana temporaria*) (Reh & Seitz, 1990), agile frog (*Rana dalmatina*) (Lesbarrères et al., 2006), roe deer (*Capreolus capreolus*) (Kuehn et al., 2007), bank vole (*Clethrionomys glareolus*) (Gerlach & Musolf, 2000) and desert bighorn sheep (*Ovis canadensis nelsoni*) (Epps et al., 2005). Indeed, there are few ground-dwelling taxonomic groups that do not become genetically isolated by roads and highways.

4.3 Individual Road or Highway Effects

It is possible that individual roads and highways are sufficient to form effective barriers for animal dispersal and movement, causing population subdivision, decrease in gene flow, and consequently genetic differentiation. An individual roadway’s influence on the genetic differentiation of its surrounding wildlife may depend on intrinsic features of the road/highway itself, such as its age, width, and traffic volume. Roads and highways of varied features may have different effects. For instance, among six paved roads studied in Virginia and West Virginia, USA, the red-backed salamanders (*Plethodon cinereus*) populations divided by the interstate highway showed significantly greater genetic distance than those on the same side of the highway, while populations across other smaller roads were no more genetically distinct than those on the same side of the road. This result suggests that migration across the large roads is rare compared to that of the small roads (Marsh et al., 2008). Similarly, Gerlach and Musolf (2000) found that a recently constructed highway (~25 years old) contributed to a significant population subdivision of bank vole (*Clethrionomys glareolus*), while other road barriers including an old railway (~50 years old) and a rural road (~25 years old) did not. Even in the case of large, highly mobile species like bobcats and coyotes, there were obvious genetic differences between subpopulations on either side of the Ventura Freeway near Los Angeles (Riley et al., 2006). In this seven-year-long study, the researchers directly tracked the movement of individuals using radio-telemetry, and found higher isolation effects of the highway than that for secondary roads (about three times higher for bobcat and 11 times higher for coyote, respectively). Moreover, the genetic data further showed that the highway led to a clear genetic differentiation between populations of the two species on either side of the highway, and that the secondary road contributed to the bobcat's genetic differentiation between populations on either side of the road.

4.4 Genetic Effects of Non-Transportation Land-Uses

In addition to roads and highways, other forms of anthropogenic activities, like urbanization and agricultural land use, can also have negative effects on the genetic structure of surrounding wildlife populations, mostly by causing habitat fragmentation. For example, urban fragmented populations of common frogs (*Rana temporari*) present higher genetic differentiation and lower levels of genetic diversity when compared to rural common frog populations, which have relatively large continuous habitat (Hitchings & Beebee, 1997). Investigators in the same study also observed higher levels of mortality and developmental abnormality within the urban common frog populations than within the rural populations, suggesting that there was some inbreeding depression in the urban populations, partially due to decreased genetic diversity (Hitchings & Beebee, 1997). Similarly, the eastern red-backed salamander (*Plethodon cinereus*), a common species, was severely affected by habitat fragmentation due to land use (Noël et al., 2007): four populations sampled from mosaic forested habitats (caused by the urbanization) differentiated significantly and presented low levels of genetic diversity, whereas four populations located in the continuous habitat were genetically homogeneous and exhibited relatively high levels of genetic diversity. Even for a highly mobile bird, the golden-cheeked warbler (*Dendroica chrysoparia*), the isolation caused by agricultural lands clearly caused one population to diverge from other sampling populations (Lindsay et al., 2008).

5.0 Threats to Connectivity and Permeability

5.1 Land Use

In the INRMP planning region, approximately 4.3% of the total area has been converted to human-dominated land cover types (Figure A-4. Land Conversion in the INRMP Planning Area) (calculated by CalVeg dataset). These areas are largely concentrated along the Highway 50 transportation corridor running east-west through the central portion of the region. There are other scattered pockets of developed areas both north and south of this more-developed area. This overall footprint of development in the western County may constitute a threat to continued ecological functioning of the natural ecosystems, especially potential impacts to rare or highly localized biota.

Another threat is from the pattern of development, which could lead to potential loss of north-south and east-west connectivity across the planning region. Terrestrial animals attempting to move across this area are currently restricted to relatively narrow gaps between existing areas of human development. With future urban growth likely along the Highway 50 transportation corridor, landscape connectivity is likely to be further reduced through this area. If development occurs in other portions of the study area, additional patterns of connectivity (e.g., along the elevational gradient) could be threatened as well.

5.2 Transportation Networks

Another human impact on landscape connectivity, many times associated with conversion of natural habitat to human-dominated land cover, comes from transportation corridors (e.g., roads, and rail; Figure A-5. Transportation Corridor Impacts to Landscape Connectivity). As of 2000, there were approximately 3.8 million miles of roads in the United States, occupying roughly 1% of the land surface (National Research Council 1997).

Effects associated with these roads include habitat loss, direct mortality, air and water pollution, and noise (Forman 2000). The linear nature of transportation corridors can also act as a barrier to wildlife movement across the landscape. Highways and other major roads linking areas of human development can serve as nearly complete barriers to movement by many terrestrial species and other ecosystem flows (Epps et al. 2005, Li et al. 2010). In some cases, individuals will not attempt to cross roads because of the disturbance associated with them, leading to functional habitat loss such as was found with woodland caribou in Canada (Dyer et al. 2002). When attempts are made to cross roads, mortality can become a serious issue. Attempts to reduce mortality through actions such as fence construction can inversely lead to an increased barrier effect (Jaeger and Fahrig 2004). Even small roads can lead to reduced movement resulting in genetic impacts on some species (Clark et al. 2010). Linear features of human disturbance, such as roads or powerlines, can serve as barriers to species that require interior forest, even if no traffic is present.

Figure A-4. Land Conversion in the INRMP Planning Area

Black areas are human dominated land cover types (urban, agriculture, and barren), green is natural vegetation, and blue is water.

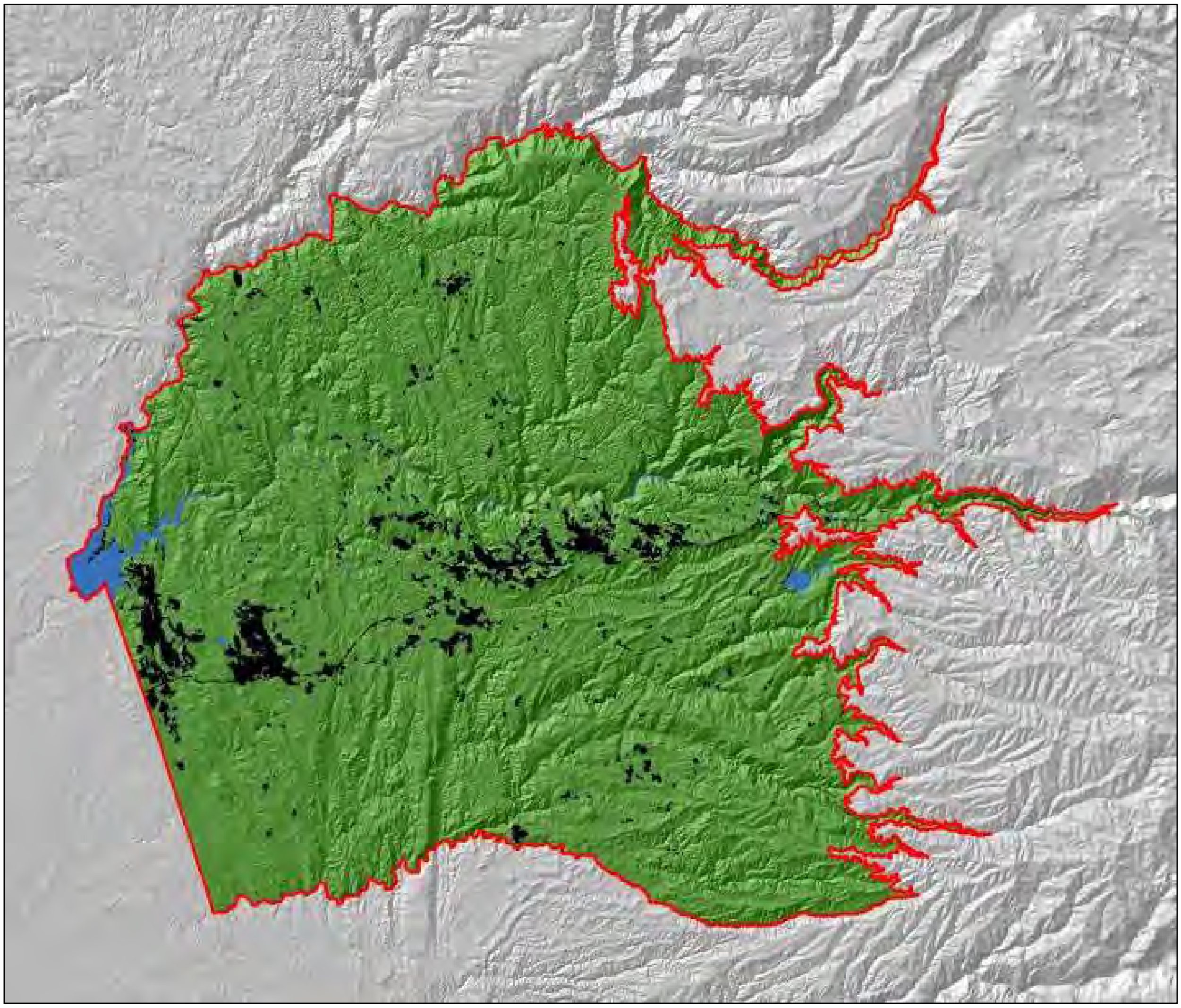
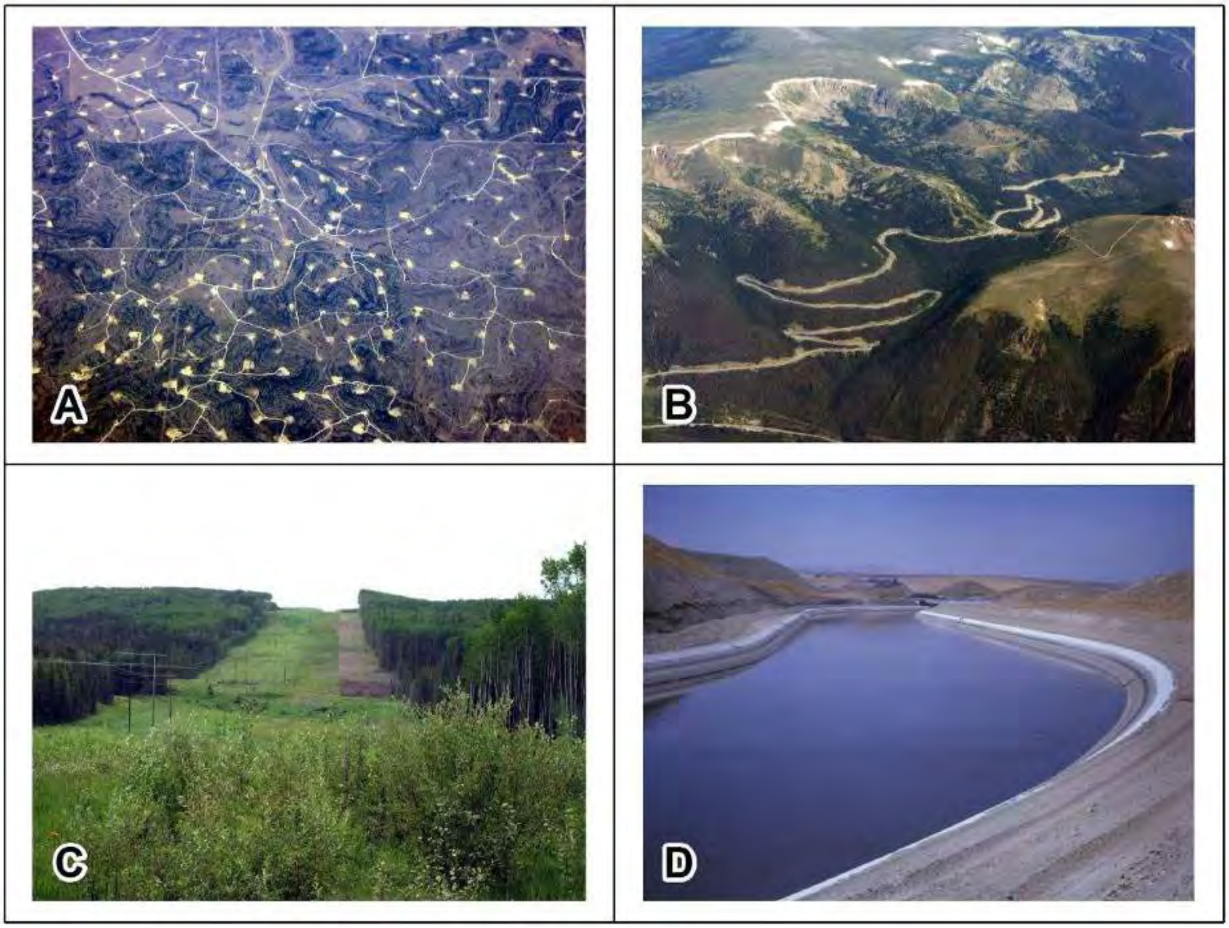


Figure A-5. Transportation Corridor Impacts to Landscape Connectivity

Caused by:

A) Dense road networks, rural Texas
B) Single major roads bisecting otherwise large habitat patches, U.S. Highway 40 over Berthoud Pass, CO
C) Transmission and pipeline corridors, boreal forest of Alberta, Canada
D) Water conveyance infrastructure, Delta – Mendota Canal in the Central Valley of California



* Photos P. Huber, except D (U.S. Bureau of Reclamation)

There are approximately 3,265 miles of roads within the INRMP planning area (Figure A-6. Roads in the INRMP Planning Area), or an average of 1.5mile/mile² across the region. While many of these are small rural or residential roads that could potentially allow many species to cross them relatively freely, there are some major roads in the study area that could very likely act as substantial barriers to many species. U.S. Highway 50 and State Highway 49, both major roads with a large volume of car and truck traffic, serve to effectively partition the planning area into four roughly equal-sized portions. These highways likely reduce potential animal movement both north-south (for species tracking a single ecosystem type) and east-west (for species conducting seasonal movement across elevations or that are in the process of adapting to climate change). In addition to these highways, there are other local roads that experience a large amount of daily traffic, further reducing areas of unimpeded movement within the four quadrants delineated by major highways.

5.3 Climate Change

Patches of currently intact habitat exhibiting high connectivity might still be at risk even if not threatened by human disturbance. Future climate change may lead to loss of connectivity between and among habitat patches (e.g., Figure A-7. Rising Winter Temperatures Have Enabled Pine Beetles to Increase Their Effects Across Much of Western North America). As the temperature in a given region changes, plant species associated with that temperature will need to move to track those changes.

In some cases they will be able to keep pace, but in others they will not be able to follow the requisite climate shifts. This will be especially true for those species that specialize in a narrow temperature range which will require long distance dispersal events to track the changes (Trakhtenbrot et al. 2005, Loiselle et al. 2010). These events will not occur if there is no potential connectivity along the temperature gradient, leading to possible local extinction of some species. Williams et al. (2005) identified corridors that could be used to facilitate dispersal of species of Proteaceae in the Cape Floristic Region of South Africa. The existence of protected corridors consisting of intact habitat will potentially enable these plant species (and associated animal species as well) track the shifting climate regime. When future climate change is combined with habitat fragmentation, the ability of species to track the changes might be reduced or eliminated as well, leading to increased extinction risk (Pearson and Dawson 2005). Climate change can also potentially have negative ecological effects in addition to shifting climate envelopes that could impact landscape connectivity (Figure A-7).

Figure A-6. Roads in the INRMP Planning Area

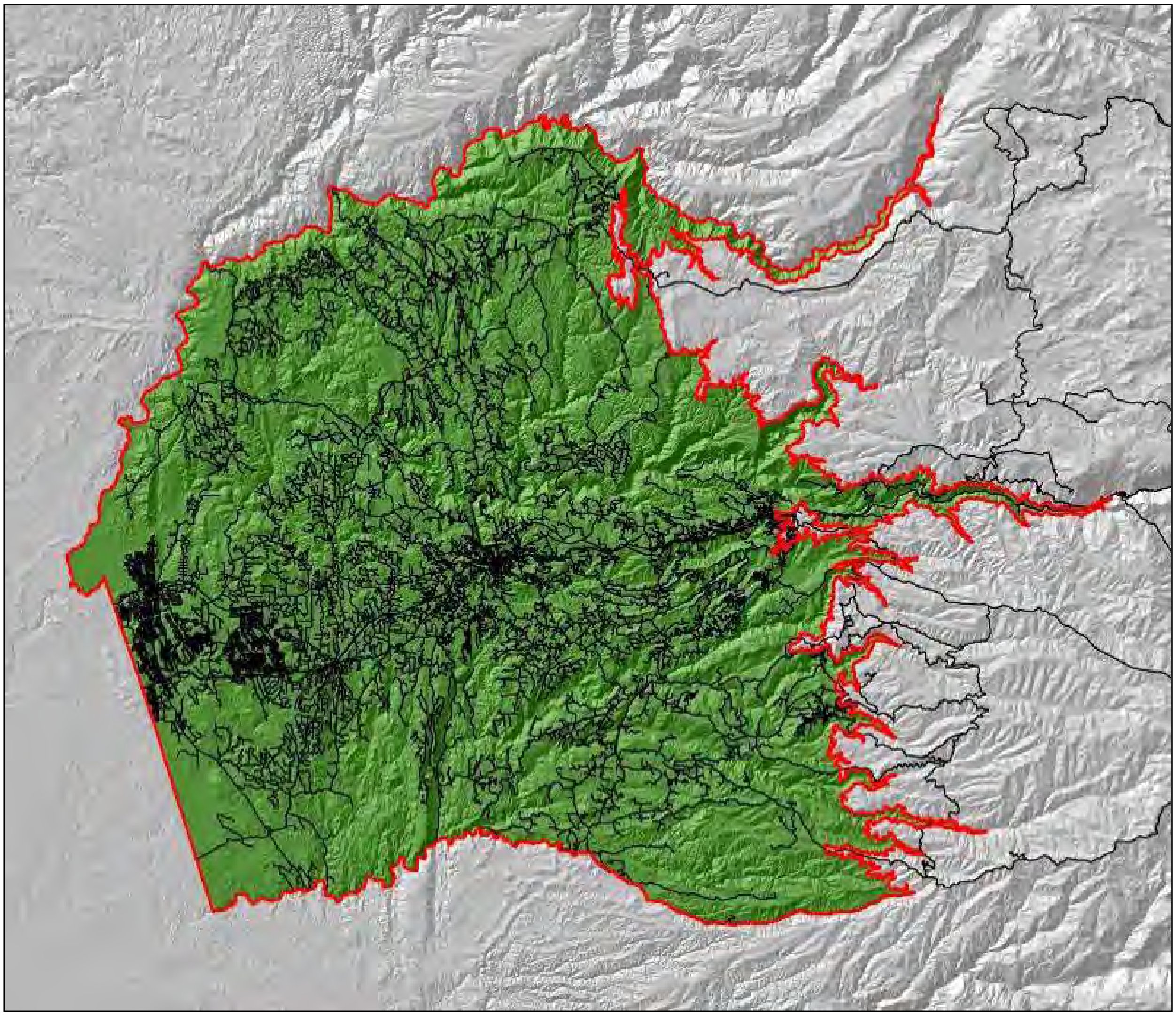


Figure A-7. Rising Winter Temperatures Have Enabled Pine Beetles to Increase Their Effects Across Much of Western North America

In Jackson County, Colorado, effects of climate change such as seen here can potentially impact forest and other connectivity in the coming decades.

Climate change models are used by international, federal, state, and private resource, transportation, land-use, and regulatory bodies for planning and analytical purposes. These models show that temperatures in the INRMP planning area are likely to rise over the coming decades (Figure A-8. Climate Change Projections Showing a Potential 3°-4° F Rise in Temperatures in the INRMP Planning Area by 2050). While the magnitude of the temperature rise is uncertain, average models show a perhaps 3°-4° F rise in temperatures by 2050 or so. For resident species to successfully adapt to this rise in temperatures, they will need to disperse uphill, i.e., from west to east. If a species is unable to shift its range quickly enough to follow the temperature gradient, either because of low dispersal ability, habitat fragmentation due to land conversion, or barriers to movement such as State Highway 49, then that species is likely to experience population reduction and potential extirpation from the County. Species with less ability to move and naturally occurring as discrete, isolated populations (e.g., serpentine plant species or wetland amphibians) will likely face the greatest pressures due to climate change.

Connectivity planning as a component of climate change adaptation has become an important conservation consideration over the past several years. It is the general scientific consensus that species will need to shift their ranges to track a changing climate, or even in the event of a prolonged drought, which are known to occur in Mediterranean climates like that in California. A number of approaches to this complex topic have been included in analysis efforts. A study undertaken in South Africa (Williams et al. 2005) used a sequence of climate models through time, species-specific habitat models, and known dispersal capabilities to identify grid cells that could serve as future habitat. Beier et al. (2008) use landscape "facets", or combinations of topographic elements, as potential dispersal corridors for species under a changing climate. Carroll et al. (2010) used a combination of models (MAXENT and ZONATION) to identify areas of climatic and topographic heterogeneity within potential future home ranges that could serve as refugia for northern spotted owls in the U.S. Pacific Northwest. These and other efforts seek to identify areas for conservation management that will most benefit species' adaptation to climate change.

The most likely need for planning for connectivity in the face of climate change is conservation or restoration of potential movement between lower and higher elevations, i.e., west-east direction, and movement north-south. Within this general theme, topographic and home range analyses should be undertaken to assess the ability of the County landscape to provide pathways of movement and potential climatic refugia. The American and Cosumnes River canyons could potentially provide local topographic heterogeneity within regional topographic features that could enable some species to move west-east. Higher elevation east-west trending ridgetops could also potentially serve as movement pathways. South-north movement would be facilitated by providing habitat connectivity in that orientation and mitigating barriers.

Figure A-8. Climate Change Projections Showing a Potential 3°-4° F Rise in Temperatures in the INRMP Planning Area by 2050

The black circle denotes the general location of the INRMP planning area. These projections are based on an ensemble average General Circulation Model under the Medium A1B emission scenario. The map was produced by Climate Wizard, an online tool developed by The Nature Conservancy (http://www.climatewizard.org/).

Appendix B
Glossary of Terms

Adaptive genetic diversity – Refers to genetic variations that have an effect on individual fitness.

Allelic richness – The number of alleles in a sampling population, one of the basic measures of genetic diversity. An allele is one of two or more forms of the DNA sequence of a particular gene.

Bayesian assignment – Bayesian clustering approach that uses multilocus genotypes to infer population structure and assign individuals to populations. Bayesian statistics use prior information, current data, and expert opinion to calculate probabilities of occurrence, in this case of individual assignment of animals to populations within a species.

Canonical correspondence analysis – An analysis method that correlates genetic diversity to related environmental factors, such as habitat fragmentation, and that can be used to identify environmental factors that contribute significantly to variations in genetic diversity.

Evolutionary trajectory – Refers to the evolutionary direction and process in which a given group of organisms experiences.

Effective population size – The number of individuals that can contribute genes equally to the next generation. The effective population size is usually smaller than the actual size of the population. The effective population size can be predicted by the formula $N_e = 4N_mN_f/(N_m + N_f)$, where N_m is the number of males and N_f is the number of females.

Fst values – The measure of genetic differentiation among populations developed by Sewall Wright. Fst is the proportion of the total genetic variance contained in a subpopulation relative to the total genetic variance. High Fst implies a considerable degree of differentiation among populations.

Gene Flow – The transfer of alleles of genes from one population to another through temporary or permanent migration of individuals or groups of individuals.

Genetic drift – The change in the relative frequency in which a gene allele occurs in a population due to random sampling and chance. The alleles in offspring are a random sample of those in the parents, and chance has a role in determining whether a given individual survives and reproduces. The effect of genetic drift is larger in small populations, and smaller in large populations.

Genetic divergence – The process in which two or more populations of an ancestral species accumulate independent genetic changes (mutations) through time. Ultimately, two separated populations could become two different species.

Genetic diversity – Any measure of the genetic variation at neutral or adaptive gene loci of a population or a species; in other words, how diverse are the populations.

Genetic structure – Refers to the extent to which such populations are genetically differentiated. It is quantified as the distribution of genetic variation within and among populations.

Genetic differentiation – The accumulation of differences in allelic frequencies between completely or partially isolated populations due to evolutionary forces such as selection or genetic drift.

Genetic marker/molecular marker – A gene or DNA sequence with a known location on a chromosome that can be used to identify individuals or species. It can be described as a variation (which may arise due to mutation or alteration in the genomic loci) that can be observed. Many genetic markers (e.g., mitochondrial DNA ormicrosatellites) with different features are used in population genetics and phylogeny according to their variability, selective/neutral characteristics, etc.

Genotype – The genetic constitution of an individual, e.g., the specific allele makeup of the individual.

Geographical information systems – Geographical information systems (GIS) can be used in landscape genetics to visualize spatial genetic patterns (e.g., boundaries) and also to generate hypotheses about the cause of genetic boundaries, because GIS enables landscape variables to be overlaid onto genetic data.

Geographical population – A group of individuals of the same species occupying a particular geographic area.

Heritage modes – Refers to genetic markers which have a specific inheritance system, such as paternal, maternal, and bi-parental inheritance. For example, in human beings, the mitochondrial DNA markers are only inherited by the mother, while the Y-chromosome markers are restricted to the father.

Hybrid – The offspring resulting from cross-breeding of different plants or animals taxa or populations.

Inbreeding – The reproduction from the mating of two genetically related parents, which can increase the chances of offspring being affected by recessive or deleterious traits. This generally leads to a decreased fitness of a population, which is called inbreeding depression.

Isolated subpopulations – A part or subdivision of a previously continuous population due to some barrier (usually geographical barriers).

Locus – The specific location of a gene on a chromosome

Mendelian population – A community of (diploid) sexually interbreeding organisms in which each individual has equal access to every other.

Mantel's test – An analysis method used to measure the association between genetic distance and an environmental variable, such as forest cover or temperature.

Microsatellite – The repeating sequences of 1-6 base pairs of DNA. The microsatellites are typically neutral and are extensively used as molecular markers in population genetics.

Multi-locus – Many different gene loci or gene locations.

Mutation rate – The chance of a mutation occurring in an organism or gene in each generation.

Nuclear genetic diversity – Refers to the genetic diversity of a gene located in the cell nucleus of a eukaryote. The term is used to distinguish nuclear genetic diversity from the mitochondrial genetic diversity, or in case of plants, also the chloroplast.

Population differentiation – Genetic differentiation among populations, the accumulation of differences in allelic frequencies between populations due to evolutionary forces such as selection or genetic drift.

Population genetic analysis – Usually refers to the analyses of genetic data using statistical tools and principles developed in the population genetic field.

Population subdivision – A large, continuous, original population is divided into many geographically isolated small populations due to barriers to gene flow**.**

Population structure – Usually refers to the genetic structure, that is the extent to which such populations are genetically differentiated. It is quantified as the distribution of genetic variation within and among populations.

Re-colonization – A second or renewed colonization from those surrounding populations after local extinction of a population from the habitat under research.

Selection – Usually refers to natural selection, which is the process by which certain heritable traits—those that make it more likely for an organism to survive and successfully reproduce—become more common in a population over successive generations. It is a key mechanism of evolution.

Selection pressure – Those factors that influence the direction of natural selection.

Sex-biased dispersal – The phenomenon that individuals of one sex stay or return to their natal site (or group) to breed, while individuals of the other sex are prone to disperse.

Spatial genetic pattern – The spatial features of genetic differentiation of the sampling populations over geographical scale.

Stochastic extinction events – Extinctions resulting from catastrophic natural and anthropogenic disasters such as fires, floods, or changes in water chemistry.

Testing correlation between two maps – An analysis method primarily used by Piazza *et al.* (Piazza *et al.*, Genetics and the origin of European languages. *Proc. Natl. Acad. Sci. U. S. A.* **92** (1995), pp. 5836–5840.), who found a significant correlation between gene frequency gradients in humans and archaeological dates of the first Neolithic European farmers, using a modified Pearson's correlation coefficient according to spatial data.

Appendix C
Potential Highway 50 Wildlife Crossings

Appendix C
Potential Highway 50 Wildlife Crossings

List of Figures **Page #**

The following potential crossings were identified from field and aerial photos (Google Earth) and characterized. Characterizations included crossing type, measured dimensions, exact location, and environmental context. The following pages provide this information in the form of a table and pictures for each potential crossing. Not all culverts and street under-crossings were assessed. Street under-crossings that were surrounded by concentrated residential and/or commercial development at either end were not assessed. Small steeply-angled culverts for drainage of slopes were generally not included. This is especially true of Highway 50 infrastructure east of Pollock Pines, where there are frequent small (12-24”) culverts draining slopes above the roads to slopes below.

Figure C-1. Lower Foothills Potential Crossings

Figure C-2. Lower-Mid Foothills Potential Crossings

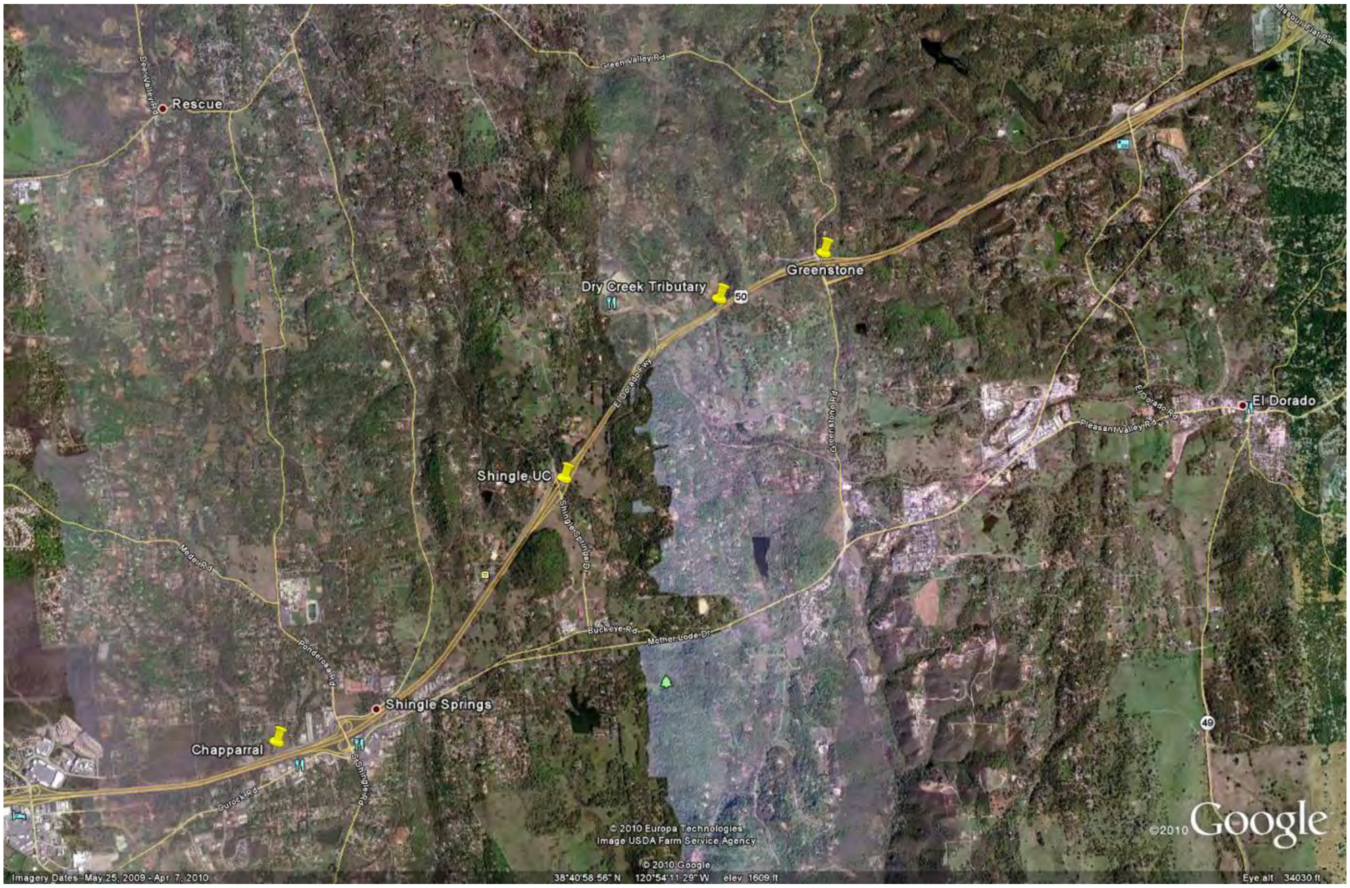


Figure C-3. Mid-Foothills Potential Crossings

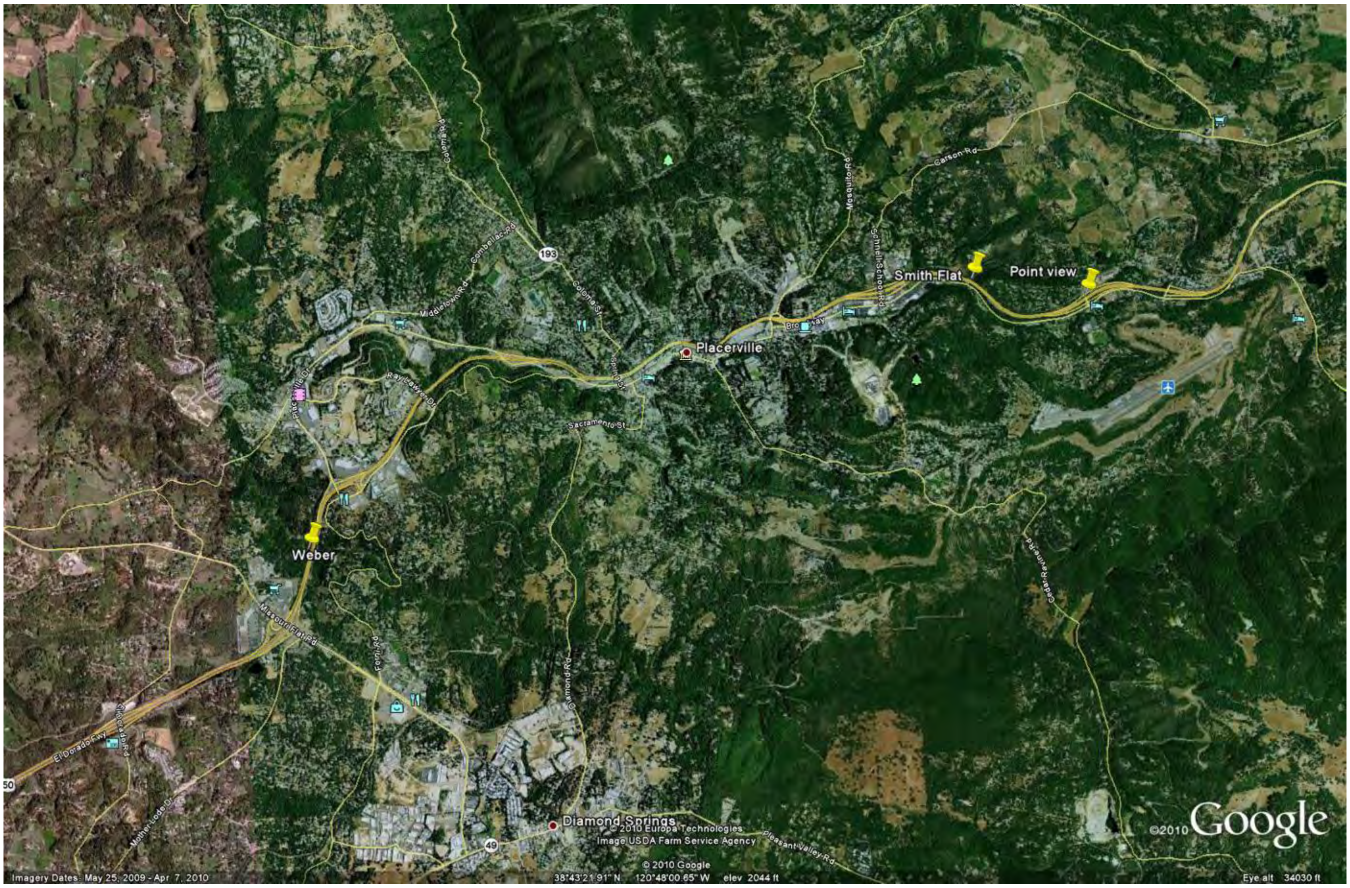


Figure C-4. Upper Foothills Potential Crossings

Figure C-5. Upper Foothills Potential Crossings (cont.)

1.0 Dunwood Corrugated Culvert Pipe

Crossing Type			
	Straight-sided metal pipe		
	Corrugated culvert pipe	X	X
	Concrete box culvert		
	Bridge UC		
	Other		
Crossing Dimensions			
	Height (ft)		
	Width (ft)		
	Diameter (ft)	3	3
	Length (ft)	215	215
	Openness Ratio	0.042	0.042
Crossing Bottom			
	Metal	X	X
	Concrete		
	Dirt		
	Asphalt		
	Vegetation		
	Stream-bed		
Opening Immediate Surroundings			
N side	Natural vegetation	X	X
	Dirt/gravel		
	Concrete		
	Asphalt street		
S side	Natural vegetation	X	X
	Dirt/gravel		
	Concrete		
	Asphalt street		
Location			
	Lat	38°38'58.06"N	38°38'58.06"N
	Long	121° 4'47.75"W	121° 4'47.75"W
Landscape Context			
	Within 50 m, North side	blue oak savanna	
	Within 50 m, South side	riparian zone	
	Within 200 m, North side	blue oak savanna	
	Within 200 m, South side	suburban dev	
	Within 1000 m, North side	suburban dev	
	Within 1000 m, South side	suburban dev	

Dunwood Corrugated Culvert Pipe

North Side: Large blue oak savanna grassland (highly degraded) with small stream drainage devoid of trees or other natural cover and surrounded by suburban development.

Westward landscape view toward culvert

Westward closer view toward culvert

Westward medium view toward culvert

Dunwood Corrugated Culvert Pipe

South Side: Narrow strip of natural vegetation (~85 meters wide) parallels hwy, and culvert empties into a riparian drainage with plenty of natural cover (Salix spp., blue oak, etc.), which then passes South through a second corrugated culvert (3-foot diameter) under suburban roadway. Both culverts are hanging culverts and have water running through bottoms presently. One under highway has barbed wire fence hanging 4 feet in front of it and across streambed. Both culverts are surrounded by rocky talus edges. Stream which culverts drain into exhibits varied amphibian life.

Westward medium view toward culvert

Close-up view of culvert opening

2.0 Finders Concrete Box Culvert

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	X
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	6
	Width (ft)	7
	Diameter (ft)	
	Length (ft)	380
	Openness Ratio	0.111
Crossing Bottom		
	Metal	
	Concrete	X
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°39'6.43"N
	Long	121° 4'33.88"W
Landscape Context		
	Within 50 m, North side	riparian zone/blue oak savanna
	Within 50 m, South side	riparian zone/commercial dev
	Within 200 m, North side	suburban dev
	Within 200 m, South side	riparian zone/commercial dev
	Within 1000 m, North side	suburban dev
	Within 1000 m, South side	riparian zone/commercial dev

Finders Concrete Box Culvert

South Side: Natural riparian zone with mature willows drains through large flood plain, travelling through several road culverts after draining from under the hwy. This large riparian zone (225 meters wide x 860 meters long) is surrounded to the West by suburban development and to the East with a large parking lot and commercial development. Property appears to be currently being prepped for development.

Landscape view of riparian near opening

Medium view of opening

Finders Concrete Box Culvert

North side: Relatively intact riparian zone with mature willow and oaks meanders into suburban development.

Close-up view of opening

3.0 Nugget Concrete Box Culvert

Crossing Type			
	Straight-sided metal pipe		
	Corrugated culvert pipe		x(ellipse)
	Concrete box culvert	2X*	
	Bridge UC		
	Other		
Crossing Dimensions			
	Height (ft)	6	4.5
	Width (ft)	4	6
	Diameter (ft)		
	Length (ft)	216	216
	Openness Ratio	0.111	0.125
Crossing Bottom			
	Metal		X
	Concrete	X	
	Dirt		
	Asphalt		
	Vegetation		
	Stream-bed		
Opening Immediate Surroundings			
N side	Natural vegetation	X	X
	Dirt/gravel		
	Concrete		
	Asphalt street		
S side	Natural vegetation	X	X
	Dirt/gravel		
	Concrete		
	Asphalt street		
Location			
	Lat	38°39'13.80"N	38°39'13.80"N
	Long	121° 4'0.95"W	121° 4'0.95"W
Landscape Context			
	Within 50 m, North side	Riparian zone	
	Within 50 m, South side	Riparian Zone/commercial dev	
	Within 200 m, North side	suburban dev/commercial dev	
	Within 200 m, South side	Riparian Zone/commercial dev	
	Within 1000 m, North side	suburban dev	
	Within 1000 m, South side	suburban dev	
*Two or more culverts side by side			

Nugget Concrete Box Culvert

North Side: Highway culvert (2 side-by-side concrete box culverts) connects to narrow (20 meters wide) riparian corridor, heavily invaded by Himalayan blackberry with lots of cover by Salix spp. This narrow corridor is bordered on East by golf course and West by suburban hard-scaping (shopping center parking lot).

Landscape view of opening

Close-up view of opening

Nugget Concrete Box Culvert

South Side: Culvert drains into strip of riparian vegetation (44 meters wide/129 meters long) which extends South into another culvert (parking lot road), which drains into another riparian strip (54 meters/184 meters). Both strips surrounded by parking lot (shopping center). Drainage of first culvert heavily invaded by Himalayan blackberry preventing access to culvert. Both drainages have ample cover from Salix spp. Both culverts submerged (6 inches) with stream.

Westward close-up view highway culvert

Westward close-up view second culvert

Eastward medium view highway culvert

Landscape view second culvert

4.0 Joerger Concrete Box Culvert

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	2x*
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	5
	Width (ft)	2
	Diameter (ft)	
	Length (ft)	208
	Openness Ratio	0.048
Crossing Bottom		
	Metal	
	Concrete	X
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°39'23.86"N
	Long	121° 3'29.82"W
Landscape Context		
	Within 50 m, North side	riparian zone
	Within 50 m, South side	riparian zone
	Within 200 m, North side	blue oak savanna
	Within 200 m, South side	blue oak savanna (power sta to SW)
	Within 1000 m, North side	riparian zone/suburban dev
	Within 1000 m, South side	blue oak woodland/suburban dev
*Two or more culverts side by side		

Joerger Concrete Box Culvert

North Side: Natural riparian corridor with myriad native plant species surrounded by blue oak woodland and savanna to North and West, though suburban development begins to North at 218 meters and high speed road parallels corridor from 12 to 150 meters to East.

Medium view of vicinity of culvert opening

Close-up view of culvert opening (behind tree)

Joerger Concrete Box Culvert

South Side: 2 side-by-side box culverts, completely submerged open into natural riparian corridor with plenty of native herb species, willow species, evidence of beavers (dams, pools). Myriad amphibian/bird diversity. Power station and barbed wire fence (77 meters to Southwest). High speed road 122 meters to East.

Medium view of riparian context of opening

Close-up view of opening

5.0 Silva Valley Parkway Bridge Under-Crossing

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	
	Bridge UC	X
	Other	
Crossing Dimensions		
	Height (ft)	15
	Width (ft)	45
	Diameter (ft)	
	Length (ft)	135
	Openness Ratio	5.000
Crossing Bottom		
	Metal	
	Concrete	
	Dirt	
	Asphalt	X
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
S side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	x
Location		
	Lat	38°39'26.03"N
	Long	121° 3'25.02"W
Landscape Context		
	Within 50 m, North side	blue oak woodland/suburban dev
	Within 50 m, South side	blue oak woodland/suburban dev
	Within 200 m, North side	blue oak woodland/suburban dev
	Within 200 m, South side	blue oak woodland/suburban dev
	Within 1000 m, North side	blue oak woodland/suburban dev
	Within 1000 m, South side	blue oak woodland/suburban dev

Silva Valley Parkway Bridge Under-Crossing

North/South Side: High velocity two-lane rural roads runs through this under-crossing with 45 degree naturally vegetated sides (grass/weeds).

View through under-pass

6.0 Tong Road Concrete Box Culvert

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	3X*
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	8
	Width (ft)	7.5
	Diameter (ft)	
	Length (ft)	336
	Openness Ratio	0.179
Crossing Bottom		
	Metal	
	Concrete	X
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°39'31.49"N
	Long	121° 3'10.83"W
Landscape Context		
	Within 50 m, North side	riparian zone/blue oak woodland
	Within 50 m, South side	riparian zone/blue oak woodland
	Within 200 m, North side	blue oak woodland
	Within 200 m, South side	blue oak woodland
	Within 1000 m, North side	blue oak woodland/suburban dev
	Within 1000 m, South side	blue oak woodland/suburban dev
*Two or more culverts side by side		

Tong Road Concrete Box Culvert

South Side: Private road, so only brief access. More relatively intact riparian vegetation and blue oak woodland (no pictures).

Tong Road Concrete Box Culvert

North Side: Healthy blue oak woodland and riparian corridor with mature oak, willow trees and native perennial vegetation. 3 side-by-side box culverts each submerged (6 inches), with no ledge for dry passage. No light or view to other side of box culvert, however, due to curve in shape.

View of riparian near opening

Close-up view of opening

7.0 Bass Lake Road Under-Crossing

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	
	Bridge UC	X
	Other	
Crossing Dimensions		
	Height (ft)	15.33
	Width (ft)	38
	Diameter (ft)	
	Length (ft)	120
	Openness Ratio	4.855
Crossing Bottom		
	Metal	
	Concrete	
	Dirt	
	Asphalt	X
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
S side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	x
Location		
	Lat	38°39'19.20"N
	Long	121° 1'47.38"W
Landscape Context		
	Within 50 m, North side	hwy on/off-ramps
	Within 50 m, South side	hwy on/off-ramps
	Within 200 m, North side	Rd/blue oak savanna
	Within 200 m, South side	Rd/blue oak savanna
	Within 1000 m, North side	rural development/blue oak savanna
	Within 1000 m, South side	rural development/blue oak Woodland

Bass Lake Road Under-Crossing

Moderate velocity two-lane road, any wildlife would have to cross two lanes of traffic in order to use underpass, though there appears to be fairly contiguous grassland/blue oak savanna to North though fragmented, and blue oak woodland to South. Both sides of under-crossing show scattered rural and exurban development with barbed wire fencing and private roads.

8.0 Faith Lane Corrugated Culvert Pipe

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	X
	Concrete box culvert	
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	
	Width (ft)	
	Diameter (ft)	4.4
	Length (ft)	185
	Openness Ratio	0.105
Crossing Bottom		
	Metal	X
	Concrete	
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°39'19.95"N
	Long	121° 0'49.56"W
Landscape Context		
	Within 50 m, North side	riparian zone/blue oak savanna
	Within 50 m, South side	riparian zone/blue oak savanna
	Within 200 m, North side	blue oak savanna/suburban dev
	Within 200 m, South side	blu oak woodland/suburban dev
	Within 1000 m, North side	blue oak savanna/suburban dev
	Within 1000 m, South side	blue oak woodland

Faith Lane Corrugated Culvert Pipe

North Side: Narrow riparian corridor alongside highway. Access to culvert restricted by extraordinarily thick willow grove in front of culvert.

Medium view of riparian near opening

Close-up view from above of opening

Faith Lane Corrugated Culvert Pipe

South Side: culverts empty into woody riparian corridor with mature oaks alongside of suburban neighborhood. Access to South side of culverts restricted by sturdy barbed wire fence and Himalayan blackberry running parallel to drainage.

Close-up view of openings

9.0 Cambridge Road Concrete Box Culvert (1)

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	X
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	7
	Width (ft)	10
	Diameter (ft)	
	Length (ft)	265
	Openness Ratio	0.264
Crossing Bottom		
	Metal	
	Concrete	
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	X
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°39'26.92"N
	Long	120°59'45.08"W
Landscape Context		
	Within 50 m, North side	riparian zone/blue oak woodland
	Within 50 m, South side	narrow riparian zone/commercial dev
	Within 200 m, North side	riparian zone/blue oak woodland
	Within 200 m, South side	blue oak woodland/rural dev
	Within 1000 m, North side	suburban dev
	Within 1000 m, South side	blue oak woodland/rural dev

Cambridge Road Concrete Box Culvert (1)
South Side: narrow riparian zone surrounded by commercial development, and then further South blue oak woodland patches in rural development matrix.

Cambridge Road Concrete Box Culvert (1)
North Side: Healthy riparian zone with mature oaks and willow spp, huge beaver dam and pool surrounded by heavily invaded grassland (Centaurea sp., etc.). Property currently for sale and surrounded by suburban development.

Medium view near openings

Close-up view of opening

10.0 Cambridge Road Concrete Box Culvert (2)

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	X (ARCH)
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	14
	Width (ft)	14.66
	Diameter (ft)	
	Length (ft)	210
	Openness Ratio	0.977
Crossing Bottom		
	Metal	
	Concrete	X
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°39'27.92"N
	Long	120°59'29.38"W
Landscape Context		
	Within 50 m, North side	riparian zone/blue oak woodland
	Within 50 m, South side	riparian zone/blue oak woodland
	Within 200 m, North side	blue oak woodland
	Within 200 m, South side	rural dev/blue oak woodland
	Within 1000 m, North side	suburban matrix/riparian zone
	Within 1000 m, South side	rural dev/riparian zone

Cambridge Road Concrete Box Culvert (2)
South Side: empties into a narrow riparian zone rimmed by private rural properties (fencing, no pictures).

Cambridge Road Concrete Box Culvert (2)
North Side: Healthy riparian zone with mature valley oaks, blue oaks, willow, California grape. Stream shows ample amphibian life and small (5 inch) fish, edges of stream have in parts heavy invasion by Himalayan blackberry, but also exhibit native perennials. Culvert is large arch concrete culvert with good visibility and light from end to end. Though the stream runs down the length of the culvert there are ledges on either side of the culvert to allow dry passage. North side property currently for sale.

Riparian near culvert opening

Close-up view of culvert opening

11.0 Chaparral Corrugated Culvert Pipe and Concrete Box Culvert

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	X (diam)
	Concrete box culvert	X (h & w)
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	4
	Width (ft)	6
	Diameter (ft)	4.5
	Length (ft)	330
	Openness Ratio	0.073
Crossing Bottom		
	Metal	x(pipe)
	Concrete	x(box)
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	x
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	x
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	
	Long	
Landscape Context		
	Within 50 m, North side	
	Within 50 m, South side	
	Within 200 m, North side	
	Within 200 m, South side	
	Within 1000 m, North side	
	Within 1000 m, South side	

Chaparral Corrugated Culvert Pipe and Concrete Box Culvert

North Side: A concrete box culvert next to a pipe culvert drain a natural riparian corridor with mature oaks and willows. Riparian zone is invaded by Himalayan blackberry and surrounded by patches of degraded blue oak savanna and less degraded blue oak woodland which are fragmented by a suburban matrix.

Close-up view of opening

Chaparral Corrugated Culvert Pipe and Concrete Box Culvert

South Side: very narrow riparian corridor surrounded by commercial development (no pictures).

12.0 Shingle Springs Road Bridge Under-Crossing

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	
	Bridge UC	X
	Other	
Crossing Dimensions		
	Height (ft)	25
	Width (ft)	78
	Diameter (ft)	
	Length (ft)	184
	Openness Ratio	10.598
Crossing Bottom		
	Metal	
	Concrete	
	Dirt	
	Asphalt	X
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
S side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
Location		
	Lat	38°40'48.44"N
	Long	120°54'53.47"W
Landscape Context		
	Within 50 m, North side	Hwy off/on ramp
	Within 50 m, South side	Hwy off/on ramp
	Within 200 m, North side	Roads/blue oak woodland
	Within 200 m, South side	Roads/blue oak woodland
	Within 1000 m, North side	blue oak woodland/rural dev
	Within 1000 m, South side	blue oak woodland/rural dev

Shingle Springs Road Bridge Under-Crossing

Shingle Springs Drive is a high velocity thoroughfare that cuts through patches of blue oak woodland and savanna in a rural development matrix. Wildlife would have to cross on/off ramps and frontage roads before even gaining access to the under-crossing.

North Side

South Side

13.0 Dry Creek Tributary at Red Hawk Pipe Culvert

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	X
	Concrete box culvert	
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	11
	Width (ft)	11
	Diameter (ft)	11
	Length (ft)	302
	Openness Ratio	0.401
Crossing Bottom		
	Metal	X
	Concrete	
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°41'34.71"N
	Long	120°53'53.96"W
Landscape Context		
	Within 50 m, North side	riparian zone/blue oak savanna
	Within 50 m, South side	riparian zone/blue oak savanna
	Within 200 m, North side	blue oak woodland/rural dev
	Within 200 m, South side	blue oak woodland
	Within 1000 m, North side	blue oak woodland/rural dev
	Within 1000 m, South side	blue oak woodland/rural dev

Dry Creek Tributary at Red Hawk Pipe Culvert

North side: This very large corrugated metal pipe empties into an artificial pond surrounded by riparian vegetation and dense Himalayan blackberry bushes. Houses are within view of the opening.

Inside culvert looking North

Dry Creek Tributary at Red Hawk Pipe Culvert

South side: This end of the pipe is surrounded by an open grass/savannah landscape. The very small stream was running in September.

Looking North toward culvert

Inside culvert looking South

14.0 Greenstone Road Bridge Under-Crossing

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	
	Bridge UC	X
	Other	
Crossing Dimensions		
	Height (ft)	15.5
	Width (ft)	38
	Diameter (ft)	
	Length (ft)	140
	Openness Ratio	4.207
Crossing Bottom		
	Metal	
	Concrete	
	Dirt	
	Asphalt	X
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
S side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
Location		
	Lat	38°41'45.22"N
	Long	120°53'15.85"W
Landscape Context		
	Within 50 m, North side	Hwy off/on ramp
	Within 50 m, South side	Hwy off/on ramp
	Within 200 m, North side	blue oak woodland/rural dev
	Within 200 m, South side	blue oak woodland/rural dev
	Within 1000 m, North side	blue oak woodland/rural dev
	Within 1000 m, South side	blue oak woodland/rural dev

Greenstone Road Bridge Under-Crossing

Though Greenstone Road itself is a high velocity road there is a riparian corridor paralleling the road approximately 24 meters to the West of the road, which might serve as a potential corridor for wildlife.

North Side

South Side

15.0 Weber Creek Bridge Under-Crossing

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	
	Bridge UC	x
	Other	
Crossing Dimensions		
	Height (ft)	
	Width (ft)	
	Diameter (ft)	
	Length (ft)	
	Openness Ratio	
Crossing Bottom		
	Metal	
	Concrete	
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	X
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°43'0.66"N
	Long	120°50'12.86"W
Landscape Context		
	Within 50 m, North side	blue oak woodland
	Within 50 m, South side	blue oak woodland
	Within 200 m, North side	blue oak woodland/rural dev
	Within 200 m, South side	blue oak woodland/rural dev
	Within 1000 m, North side	blue oak woodland/rural dev/suburb dev
	Within 1000 m, South side	blue oak woodland/rural dev

Weber Creek Bridge Under-Crossing

Limited access, detailed analysis and photographs not possible.

Aerial view (Google Earth)

16.0 Smith Flat Road Bridge Under-Crossing

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	
	Bridge UC	X
	Other	
Crossing Dimensions		
	Height (ft)	82
	Width (ft)	100
	Diameter (ft)	
	Length (ft)	106
	Openness Ratio	77.358
Crossing Bottom		
	Metal	
	Concrete	
	Dirt	
	Asphalt	X
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
S side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
Location		
	Lat	38°44'0.45"N
	Long	120°46'14.36"W
Landscape Context		
	Within 50 m, North side	lower montane forest/chapparal/rural dev
	Within 50 m, South side	lower montane forest/chapparal/rural dev
	Within 200 m, North side	lower montane forest/chapparal/rural dev
	Within 200 m, South side	lower montane forest/chapparal/rural dev
	Within 1000 m, North side	lower montane forest/chapparal/rural dev
	Within 1000 m, South side	lower montane forest/chapparal/rural dev

Smith Flat Road Bridge Under-Crossing

A particularly tall and wide highway under-crossing, Smith Flat occurs at the intersection of blue oak and foothill pine dominated woodland, chaparral, and lower montane ponderosa pine forest. There appear to be large patches of habitat on either side of the crossing, but they are interspersed within a matrix of rural development limiting wildlife movement.

17.0 Point View Drive Bridge Under-Crossing

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	
	Bridge UC	X
	Other	
Crossing Dimensions		
	Height (ft)	20
	Width (ft)	68
	Diameter (ft)	
	Length (ft)	92
	Openness Ratio	14.783
Crossing Bottom		
	Metal	
	Concrete	
	Dirt	
	Asphalt	X
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
S side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
Location		
	Lat	38°43'53.52"N
	Long	120°45'36.10"W
Landscape Context		
	Within 50 m, North side	lower montane forest/rural dev
	Within 50 m, South side	lower montane forest/rural dev
	Within 200 m, North side	lower montane forest/rural dev
	Within 200 m, South side	lower montane forest/rural dev
	Within 1000 m, North side	lower montane forest/rural dev
	Within 1000 m, South side	lower montane forest/rural dev

Point View Drive Bridge Under-Crossing

This highway under-crossing has flat banks on either side of the roadway, but there are on and off ramps on either side of the underpass, as well as various roadways and parking lots which would seem to limit wildlife movement.

18.0 Carson Road Bridge Under-Crossing

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	
	Bridge UC	X
	Other	
Crossing Dimensions		
	Height (ft)	15.33
	Width (ft)	45
	Diameter (ft)	
	Length (ft)	85
	Openness Ratio	8.116
Crossing Bottom		
	Metal	
	Concrete	
	Dirt	
	Asphalt	X
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
S side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
Location		
	Lat	38°44'16.88"N
	Long	120°39'55.96"W
Landscape Context		
	Within 50 m, North side	Lower montane forest/agriculture-orchards/rural dev
	Within 50 m, South side	Lower montane forest/agriculture-orchards/rural dev
	Within 200 m, North side	Lower montane forest/agriculture-orchards/rural dev
	Within 200 m, South side	lower montane forest/ rural dev
	Within 1000 m, North side	Lower montane forest/agriculture-orchards/rural dev
	Within 1000 m, South side	lower montane forest/ rural dev

Carson Road Bridge Under-Crossing

A high velocity under-crossing with narrow banks on either side of the roadway under the underpass at 40 degree inclines. The surrounding area is a matrix of lower montane woodland, agriculture (primarily orchards), and rural development. There is more rural development to the North side of the highway than the South, which shows continuity with a larger forest patch.

North Side:

South Side:

19.0 Snows Road Bridge Under-Crossing

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	
	Bridge UC	X
	Other	
Crossing Dimensions		
	Height (ft)	15
	Width (ft)	45
	Diameter (ft)	
	Length (ft)	85
	Openness Ratio	7.941
Crossing Bottom		
	Metal	
	Concrete	
	Dirt	
	Asphalt	X
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
S side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
Location		
	Lat	38°44'4.07"N
	Long	120°40'33.16"W
Landscape Context		
	Within 50 m, North side	lower montane forest/agriculture-orchards
	Within 50 m, South side	lower montane forest/agriculture-orchards
	Within 200 m, North side	lower montane forest/agriculture-orchards
	Within 200 m, South side	lower montane forest/agriculture-orchards/rural dev
	Within 1000 m, North side	lower montane forest/agriculture-orchards/rural dev
	Within 1000 m, South side	lower montane forest/agriculture-orchards/rural dev

Snows Road Bridge Under-Crossing

Snows Under-Crossing has flat banks on either side of the roadway and on the North side there is a fence between the roadway and the natural vegetation bank. The under-crossing is located where rural development and agriculture (orchards) fragment lower montane forest.

20.0 Ridgeway Road Bridge Under-Crossing

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	
	Bridge UC	X
	Other	
Crossing Dimensions		
	Height (ft)	25
	Width (ft)	41
	Diameter (ft)	
	Length (ft)	90
	Openness Ratio	11.389
Crossing Bottom		
	Metal	
	Concrete	
	Dirt	
	Asphalt	X
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
S side	Natural vegetation	
	Dirt/gravel	
	Concrete	
	Asphalt street	X
Location		
	Lat	38°44'52.72"N
	Long	120°37'1.77"W
Landscape Context		
	Within 50 m, North side	rural dev/lower montane forest
	Within 50 m, South side	lower montane forest
	Within 200 m, North side	rural dev/lower montane forest
	Within 200 m, South side	lower montane forest
	Within 1000 m, North side	rural dev/lower montane forest
	Within 1000 m, South side	lower montane forest

Ridgeway Road Bridge Under-Crossing

Ridgeway Under-Crossing has steep banks (45 degrees) and hosts a high velocity roadway. There are on and off ramps and roads on either side of the under-crossing which could pose risks for crossing wildlife. To the South of the under-crossing is a large patch of lower montane forest, but to the North is a matrix of rural development within forest.

21.0 Pacific House Concrete Box Culvert

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	X
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	9
	Width (ft)	8
	Diameter (ft)	
	Length (ft)	115
	Openness Ratio	0.626
Crossing Bottom		
	Metal	
	Concrete	X
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°45'35.18"N
	Long	120°30'58.45"W
Landscape Context		
	Within 50 m, North side	lower montane forest
	Within 50 m, South side	lower montane forest
	Within 200 m, North side	rural dev/lower montane forest
	Within 200 m, South side	rural dev/lower montane forest
	Within 1000 m, North side	lower montane forest
	Within 1000 m, South side	lower montane forest

Pacific House Concrete Box Culvert

Box concrete culvert with sediment-filled bottom and no water. North side is open access and adjacent to open under-growth conifer forest. Residences within 200 m of opening. South side is open, with dense herbaceous, deciduous tree, and blackberry growth nearby. Single residence within 200 m.

North end view from tunnel

South end opening

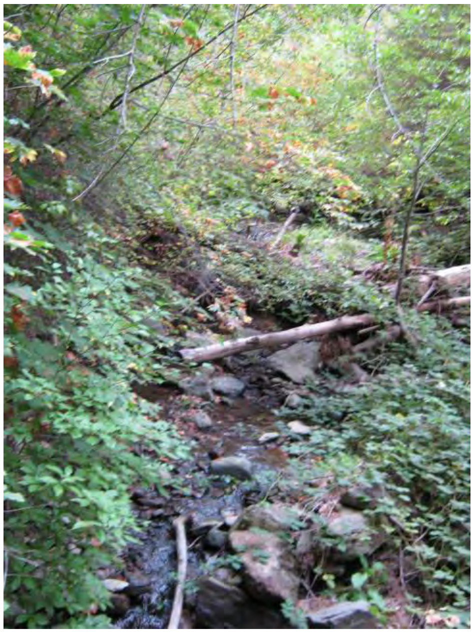
22.0 Ogilby Canyon Concrete Box Culvert

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	X
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	10
	Width (ft)	8
	Diameter (ft)	
	Length (ft)	170
	Openness Ratio	0.471
Crossing Bottom		
	Metal	
	Concrete	X
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°45'55.22"N
	Long	120°30'51.39"W
Landscape Context		
	Within 50 m, North side	lower montane forest
	Within 50 m, South side	lower montane forest
	Within 200 m, North side	lower montane forest
	Within 200 m, South side	lower montane forest
	Within 1000 m, North side	lower montane forest
	Within 1000 m, South side	lower montane forest

Ogilby Canyon Concrete Box Culvert

North side of the opening is surrounded by natural conifer forest, near American River riparian. South end of tunnel, vegetation is relatively dense riparian cover with perennial stream running in September. Tunnel bottom is concrete, slippery with algae and unlikely to be traversed by deer.

View to South from tunnel entrance



Looking into Southern entrance (Northern end visible as point of light)

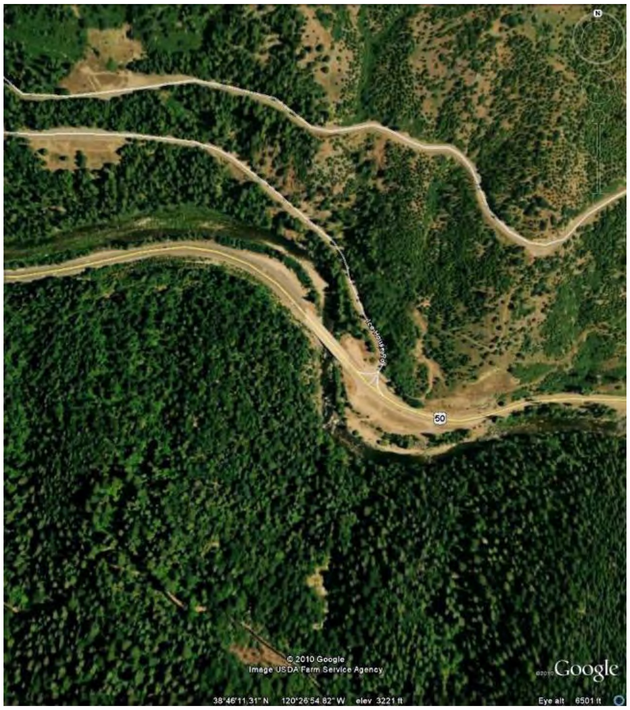
23.0 Riverton Bridge (South Fork American River)

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	
	Bridge UC	X
	Other	
Crossing Dimensions		
	Height (ft)	31
	Width (ft)	185
	Diameter (ft)	
	Length (ft)	73
	Openness Ratio	78.562
Crossing Bottom		
	Metal	
	Concrete	
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	X
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°46'12.31"N
	Long	120°23'53.98"W
Landscape Context		
	Within 50 m, North side	lower montane forest
	Within 50 m, South side	lower montane forest
	Within 200 m, North side	lower montane forest
	Within 200 m, South side	lower montane forest
	Within 1000 m, North side	lower montane forest
	Within 1000 m, South side	lower montane forest

Riverton Bridge (South Fork American River)

River and narrow riparian corridor pass under highway bridge. There are opportunities to move under the bridge, though this is probably limited in high flows and for wildlife species that are averse to relatively open riparian zones and rocky side-slopes.

Aerial View



Looking N under bridge

24.0 South Fork American River Bridge Under-Crossing East #1

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	
	Bridge UC	X
	Other	
Crossing Dimensions		
	Height (ft)	30
	Width (ft)	250
	Diameter (ft)	
	Length (ft)	58
	Openness Ratio	129.310
Crossing Bottom		
	Metal	
	Concrete	
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	X
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°46'00.83"N
	Long	120°22'16.78"W
Landscape Context		
	Within 50 m, North side	lower montane forest
	Within 50 m, South side	lower montane forest
	Within 200 m, North side	lower montane forest
	Within 200 m, South side	lower montane forest
	Within 1000 m, North side	lower montane forest
	Within 1000 m, South side	lower montane forest

South Fork American River Bridge Under-Crossing East #1

Large riparian under-crossing with access from both sides of bridge. Rip-rapping on both banks limits easy footing, though there are benches at summer and winter river levels where movement would be possible.

View under bridge from North

Rip-rap on West bank of under-crossing

25.0 South Fork American River Bridge Under Crossing East #2

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	
	Concrete box culvert	
	Bridge UC	X
	Other	
Crossing Dimensions		
	Height (ft)	30
	Width (ft)	430
	Diameter (ft)	
	Length (ft)	58
	Openness Ratio	222.414
Crossing Bottom		
	Metal	
	Concrete	
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	X
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°46'02.76"N
	Long	120°22'26.44"W
Landscape Context		
	Within 50 m, North side	lower montane forest
	Within 50 m, South side	lower montane forest
	Within 200 m, North side	lower montane forest
	Within 200 m, South side	lower montane forest
	Within 1000 m, North side	lower montane forest
	Within 1000 m, South side	lower montane forest

South Fork American River Bridge Under Crossing East #2

Large riparian under-crossing with access from both sides of bridge. Rip-rapping on both sides limits easy footing, though there are benches at summer and winter river levels where movement would be possible on the East side and possibly on the West side.

View under bridge looking West

View North under bridge and adjacent vegetation

26.0 White Hall 1 Corrugated Culvert Pipe

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	3X*
	Concrete box culvert	
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	
	Width (ft)	
	Diameter (ft)	4
	Length (ft)	65
	Openness Ratio	0.246
Crossing Bottom		
	Metal	X
	Concrete	
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°46'29.93"N
	Long	120°25'0.19"W
Landscape Context		
	Within 50 m, North side	lower montane forest
	Within 50 m, South side	lower montane forest
	Within 200 m, North side	lower montane forest
	Within 200 m, South side	lower montane forest
	Within 1000 m, North side	lower montane forest
	Within 1000 m, South side	lower montane forest
*Two or more culverts side by side		

White Hall 1 Corrugated Culvert Pipe

North Side: drainage appears to have good vegetative cover and provide a potential riparian corridor, though there is some invasion by Himalayan Blackberry.

Landscape view from North side

Close-up view North side

South side of the culvert pipes slope down steeply from roadway to river, which would limit wildlife access dramatically.

27.0 White Hall 2 Corrugated Culvert Pipe

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	2X*
	Concrete box culvert	
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	
	Width (ft)	
	Diameter (ft)	3
	Length (ft)	90
	Openness Ratio	0.100
Crossing Bottom		
	Metal	X
	Concrete	
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°46'25.97"N
	Long	120°23'34.62"W
Landscape Context		
	Within 50 m, North side	lower montane forest
	Within 50 m, South side	lower montane forest
	Within 200 m, North side	lower montane forest
	Within 200 m, South side	lower montane forest
	Within 1000 m, North side	lower montane forest
	Within 1000 m, South side	lower montane forest
*Two or more culverts side by side		

White Hall 2 Corrugated Culvert Pipe

The two side-by-side culverts appear to drain a rather steep drainage without much vegetative cover larger than the sporadic shrub. Additionally, both culverts are hanging culverts on the south side, perching in the air above the American River, into which they drain. This would definitely limit successful wildlife use of the culverts.

Landscape view of opening (behind green sign)

South side of culvert

North side of culvert

28.0 White Hall 3 Corrugated Culvert Pipe

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	2X*
	Concrete box culvert	
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	
	Width (ft)	
	Diameter (ft)	3
	Length (ft)	57
	Openness Ratio	0.158
Crossing Bottom		
	Metal	X
	Concrete	
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°46'26.45"N
	Long	120°25'36.64"W
Landscape Context		
	Within 50 m, North side	lower montane forest
	Within 50 m, South side	lower montane forest
	Within 200 m, North side	lower montane forest
	Within 200 m, South side	lower montane forest
	Within 1000 m, North side	lower montane forest
	Within 1000 m, South side	lower montane forest
*Two or more culverts side by side		

White Hall 3 Corrugated Culvert Pipe

North Side: a rather narrow, but still covered with mature riparian vegetation, stream drainage. As the culverts are rather small, they would maybe be only appropriate for small mammals and herps/amphibians. Some sort of short netting or fencing may be necessary to prevent wildlife from attempting to cross the road in that case.

Medium view of opening from North side

Close-up view of opening

29.0 Kyburz West Corrugated Culvert Pipe

Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	X
	Concrete box culvert	
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	
	Width (ft)	
	Diameter (ft)	2
	Length (ft)	53
	Openness Ratio	0.075
Crossing Bottom		
	Metal	X
	Concrete	
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°46'0.68"N
	Long	120°21'19.73"W
Landscape Context		
	Within 50 m, North side	lower montane forest
	Within 50 m, South side	lower montane forest
	Within 200 m, North side	lower montane forest
	Within 200 m, South side	lower montane forest
	Within 1000 m, North side	lower montane forest
	Within 1000 m, South side	lower montane forest

Kyburz West Corrugated Culvert Pipe

Drainage with ample mature riparian vegetation and cover, culvert is quite small and would probably only facilitate small wildlife movement.

Close-up view of opening on North side

Medium view of landscape on North side

30.0 Kyburz East Corrugated Culvert Pipe

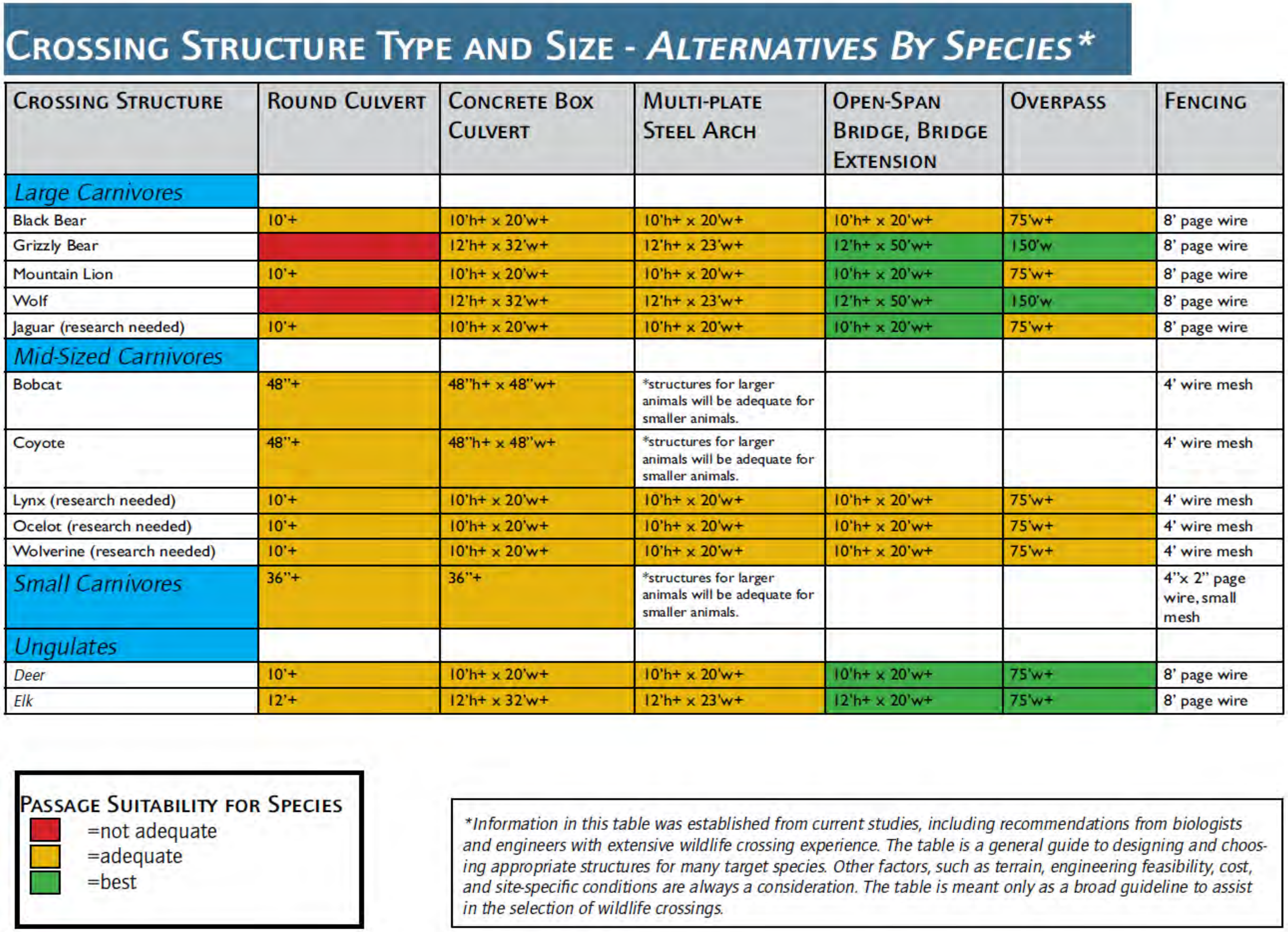
Crossing Type		
	Straight-sided metal pipe	
	Corrugated culvert pipe	X
	Concrete box culvert	
	Bridge UC	
	Other	
Crossing Dimensions		
	Height (ft)	
	Width (ft)	
	Diameter (ft)	2
	Length (ft)	53
	Openness Ratio	0.075
Crossing Bottom		
	Metal	X
	Concrete	
	Dirt	
	Asphalt	
	Vegetation	
	Stream-bed	
Opening Immediate Surroundings		
N side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
S side	Natural vegetation	X
	Dirt/gravel	
	Concrete	
	Asphalt street	
Location		
	Lat	38°46'0.47"N
	Long	120°21'19.11"W
Landscape Context		
	Within 50 m, North side	lower montane forest
	Within 50 m, South side	lower montane forest
	Within 200 m, North side	lower montane forest
	Within 200 m, South side	lower montane forest
	Within 1000 m, North side	lower montane forest
	Within 1000 m, South side	lower montane forest

Kyburz East Corrugated Culvert Pipe

Drainage with ample mature riparian vegetation and cover, culvert is quite small and would probably only facilitate small wildlife movement.

Close-up view of opening on North side

Appendix D
Crossing Structure Alternatives by Species



CROSSING STRUCTURE TYPE AND SIZE - *ALTERNATIVES BY SPECIES**

CROSSING STRUCTURE	ROUND CULVERT	CONCRETE BOX CULVERT	MULTI-PLATE STEEL ARCH	OPEN-SPAN BRIDGE, BRIDGE EXTENSION	OVERPASS	FENCING
Large Carnivores						
Black Bear	🟨 10'+	🟨 10'h+ x 20'w+	🟨 10'h+ x 20'w+	🟨 10'h+ x 20'w+	🟨 75'w+	8' page wire
Grizzly Bear	🟥	🟨 12'h+ x 32'w+	🟨 12'h+ x 23'w+	🟩 12'h+ x 50'w+	🟩 150'w	8' page wire
Mountain Lion	🟨 10'+	🟨 10'h+ x 20'w+	🟨 10'h+ x 20'w+	🟩 10'h+ x 20'w+	🟨 75'w+	8' page wire
Wolf	🟥	🟨 12'h+ x 32'w+	🟨 12'h+ x 23'w+	🟩 12'h+ x 50'w+	🟩 150'w	8' page wire
Jaguar (research needed)	🟨 10'+	🟨 10'h+ x 20'w+	🟨 10'h+ x 20'w+	🟩 10'h+ x 20'w+	🟨 75'w+	8' page wire
Mid-Sized Carnivores						
Bobcat	🟨 48"+	🟨 48"h+ x 48"w+	*structures for larger animals will be adequate for smaller animals.			4' wire mesh
Coyote	🟨 48"+	🟨 48"h+ x 48"w+	*structures for larger animals will be adequate for smaller animals.			4' wire mesh
Lynx (research needed)	🟨 10'+	🟨 10'h+ x 20'w+	🟨 10'h+ x 20'w+	🟨 10'h+ x 20'w+	🟨 75'w+	4' wire mesh
Ocelot (research needed)	🟨 10'+	🟨 10'h+ x 20'w+	🟨 10'h+ x 20'w+	🟨 10'h+ x 20'w+	🟨 75'w+	4' wire mesh
Wolverine (research needed)	🟨 10'+	🟨 10'h+ x 20'w+	🟨 10'h+ x 20'w+	🟨 10'h+ x 20'w+	🟨 75'w+	4' wire mesh
Small Carnivores	🟨 36"+	🟨 36"+	*structures for larger animals will be adequate for smaller animals.			4"x 2" page wire, small mesh
Ungulates						
Deer	🟨 10'+	🟨 10'h+ x 20'w+	🟨 10'h+ x 20'w+	🟩 10'h+ x 20'w+	🟩 75'w+	8' page wire
Elk	🟨 12'+	🟨 12'h+ x 32'w+	🟨 12'h+ x 23'w+	🟩 12'h+ x 20'w+	🟩 75'w+	8' page wire

PASSAGE SUITABILITY FOR SPECIES
🟥 =not adequate
🟨 =adequate
🟩 =best

**Information in this table was established from current studies, including recommendations from biologists and engineers with extensive wildlife crossing experience. The table is a general guide to designing and choosing appropriate structures for many target species. Other factors, such as terrain, engineering feasibility, cost, and site-specific conditions are always a consideration. The table is meant only as a broad guideline to assist in the selection of wildlife crossings.*

Safe Passages program in 2007 (http://www.carnivoresafepassage.org/)

Appendix E
Vertebrate Species Affected by Transportation and Land-Use Fragmentation

Data generated using the California Wildlife Habitat Relationships System (CWHR) Supported by the California Interagency Wildlife Task Group and Maintained by the California Department of Fish and Game Database Version 8.2 (2008)		
Date generated: 8/16/2010		
* Habitats are grouped roughly by elevation. Some species may appear in more than one group.		
CWHR Suitability Index was chosen as "High" for Reproduction, Cover and Feeding to exclude marginal species		
	CWHR Habitat Type Designation*:	
Group 1: Annual Grassland, Barren Land, Chamise/Redshank Chaparral, Mixed Chapparal,Lacustrine,Valley Oak Woodland, Wet Meadow	Group 2: Blue Oak/Foothill Pine, Blue Oak Woodland, Montane Chaparral, Montane Hardwood, Montane Riparian, Ponderosa Pine	Group 3: Closed Cone Pine/Cypress, Douglas Fir, Montane Hardwood Conifer, Sierran Mixed Conifer
CALIFORNIA TIGER SALAMANDER	CALIFORNIA TIGER SALAMANDER	LONG-TOED SALAMANDER
LONG-TOED SALAMANDER	CALIFORNIA NEWT	CALIFORNIA SLENDER SALAMANDER
CALIFORNIA NEWT	COMMON ENSATINA	HELL HOLLOW SLENDER SALAMANDER
CALIFORNIA SLENDER SALAMANDER	CALIFORNIA SLENDER SALAMANDER	CALIFORNIA RED-LEGGED FROG
ARBOREAL SALAMANDER	ARBOREAL SALAMANDER	BLACK-CROWNED NIGHT HERON
WESTERN SPADEFOOT	PACIFIC CHORUS FROG	TURKEY VULTURE
WESTERN TOAD	HELL HOLLOW SLENDER SALAMANDER	OSPREY
YOSEMITE TOAD	SIERRA NEVADA YELLOW-LEGGED FROG	BALD EAGLE
PACIFIC CHORUS FROG	GREAT BLUE HERON	SHARP-SHINNED HAWK
BULLFROG	GREAT EGRET	COOPER'S HAWK
HELL HOLLOW SLENDER SALAMANDER	BLACK-CROWNED NIGHT HERON	NORTHERN GOSHAWK
SIERRA NEVADA YELLOW-LEGGED FROG	WOOD DUCK	RED-TAILED HAWK
PIED-BILLED GREBE	COMMON MERGANSER	GOLDEN EAGLE
EARED GREBE	TURKEY VULTURE	AMERICAN KESTREL
WESTERN GREBE	OSPREY	PEREGRINE FALCON
AMERICAN WHITE PELICAN	WHITE-TAILED KITE	PRAIRIE FALCON
DOUBLE-CRESTED CORMORANT	BALD EAGLE	SOOTY GROUSE
GREAT BLUE HERON	SHARP-SHINNED HAWK	WILD TURKEY
GREAT EGRET	COOPER'S HAWK	MOUNTAIN QUAIL
SNOWY EGRET	NORTHERN GOSHAWK	BAND-TAILED PIGEON
CATTLE EGRET	RED-SHOULDERED HAWK	MOURNING DOVE
GREEN HERON	RED-TAILED HAWK	BARN OWL
BLACK-CROWNED NIGHT HERON	ROUGH-LEGGED HAWK	FLAMMULATED OWL
TUNDRA SWAN	GOLDEN EAGLE	WESTERN SCREECH OWL
GREATER WHITE-FRONTED GOOSE	AMERICAN KESTREL	GREAT HORNED OWL
SNOW GOOSE	MERLIN	NORTHERN PYGMY OWL
CANADA GOOSE	PEREGRINE FALCON	SPOTTED OWL
WOOD DUCK	PRAIRIE FALCON	NORTHERN SAW-WHET OWL
GREEN-WINGED TEAL	WILD TURKEY	COMMON NIGHTHAWK
MALLARD	CALIFORNIA QUAIL	BLACK SWIFT
NORTHERN PINTAIL	MOUNTAIN QUAIL	VAUX'S SWIFT
CINNAMON TEAL	BAND-TAILED PIGEON	WHITE-THROATED SWIFT
NORTHERN SHOVELER	MOURNING DOVE	CALLIOPE HUMMINGBIRD
GADWALL	GREATER ROADRUNNER	RUFOUS HUMMINGBIRD
EURASIAN WIGEON	BARN OWL	LEWIS' S WOODPECKER
AMERICAN WIGEON	FLAMMULATED OWL	ACORN WOODPECKER
CANVASBACK	WESTERN SCREECH OWL	RED-BREASTED SAPSUCKER
REDHEAD	GREAT HORNED OWL	WILLIAMSON'S SAPSUCKER
RING-NECKED DUCK	NORTHERN PYGMY OWL	NUTTALL'S WOODPECKER
LESSER SCAUP	BURROWING OWL	HAIRY WOODPECKER
COMMON GOLDENEYE	SPOTTED OWL	WHITE-HEADED WOODPECKER
BUFFLEHEAD	LONG-EARED OWL	NORTHERN FLICKER
HOODED MERGANSER	NORTHERN SAW-WHET OWL	PILEATED WOODPECKER
COMMON MERGANSER	LESSER NIGHTHAWK	OLIVE-SIDED FLYCATCHER
RUDDY DUCK	COMMON NIGHTHAWK	WESTERN WOOD-PEWEE
TURKEY VULTURE	COMMON POORWILL	HAMMOND'S FLYCATCHER
OSPREY	BLACK SWIFT	DUSKY FLYCATCHER
WHITE-TAILED KITE	WHITE-THROATED SWIFT	PACIFIC-SLOPE FLYCATCHER
BALD EAGLE	BLACK-CHINNED HUMMINGBIRD	ASH-THROATED FLYCATCHER
NORTHERN HARRIER	ANNA'S HUMMINGBIRD	WESTERN KINGBIRD
SHARP-SHINNED HAWK	CALLIOPE HUMMINGBIRD	PURPLE MARTIN

	CWHR Habitat Type Designation*:	
Group 1: Annual Grassland, Barren Land, Chamise/Redshank Chaparral, Mixed Chapparal,Lacustrine,Valley Oak Woodland, Wet Meadow	Group 2: Blue Oak/Foothill Pine, Blue Oak Woodland, Montane Chaparral, Montane Hardwood, Montane Riparian, Ponderosa Pine	Group 3: Closed Cone Pine/Cypress, Douglas Fir, Montane Hardwood Conifer, Sierran Mixed Conifer
COOPER'S HAWK	RUFOUS HUMMINGBIRD	VIOLET-GREEN SWALLOW
RED-SHOULDERED HAWK	BELTED KINGFISHER	NORTHERN ROUGH-WINGED SWALLOW
RED-TAILED HAWK	LEWIS' S WOODPECKER	BARN SWALLOW
ROUGH-LEGGED HAWK	ACORN WOODPECKER	STELLER'S JAY
GOLDEN EAGLE	RED-BREASTED SAPSUCKER	COMMON RAVEN
AMERICAN KESTREL	WILLIAMSON'S SAPSUCKER	MOUNTAIN CHICKADEE
MERLIN	NUTTALL'S WOODPECKER	CHESTNUT-BACKED CHICKADEE
PEREGRINE FALCON	DOWNY WOODPECKER	OAK TITMOUSE
PRAIRIE FALCON	HAIRY WOODPECKER	RED-BREASTED NUTHATCH
RING-NECKED PHEASANT	WHITE-HEADED WOODPECKER	WHITE-BREASTED NUTHATCH
WILD TURKEY	NORTHERN FLICKER	PYGMY NUTHATCH
CALIFORNIA QUAIL	PILEATED WOODPECKER	BROWN CREEPER
VIRGINIA RAIL	WESTERN WOOD-PEWEE	ROCK WREN
SORA	WILLOW FLYCATCHER	WINTER WREN
COMMON MOORHEN	HAMMOND'S FLYCATCHER	GOLDEN-CROWNED KINGLET
AMERICAN COOT	DUSKY FLYCATCHER	RUBY-CROWNED KINGLET
BLACK-BELLIED PLOVER	PACIFIC-SLOPE FLYCATCHER	WESTERN BLUEBIRD
SNOWY PLOVER	BLACK PHOEBE	TOWNSEND'S SOLITAIRE
SEMIPALMATED PLOVER	SAY'S PHOEBE	HERMIT THRUSH
KILLDEER	ASH-THROATED FLYCATCHER	AMERICAN ROBIN
BLACK-NECKED STILT	WESTERN KINGBIRD	VARIED THRUSH
AMERICAN AVOCET	HORNED LARK	WRENTIT
GREATER YELLOWLEGS	PURPLE MARTIN	CASSIN'S VIREO
LESSER YELLOWLEGS	TREE SWALLOW	HUTTON'S VIREO
WILLET	VIOLET-GREEN SWALLOW	WARBLING VIREO
SPOTTED SANDPIPER	NORTHERN ROUGH-WINGED SWALLOW	ORANGE-CROWNED WARBLER
WHIMBREL	BANK SWALLOW	NASHVILLE WARBLER
LONG-BILLED CURLEW	CLIFF SWALLOW	YELLOW WARBLER
MARBLED GODWIT	BARN SWALLOW	YELLOW-RUMPED WARBLER
RUDDY TURNSTONE	STELLER'S JAY	BLACK-THROATED GRAY WARBLER
WESTERN SANDPIPER	WESTERN SCRUB-JAY	TOWNSEND'S WARBLER
LEAST SANDPIPER	BLACK-BILLED MAGPIE	HERMIT WARBLER
DUNLIN	YELLOW-BILLED MAGPIE	WILSON'S WARBLER
SHORT-BILLED DOWITCHER	AMERICAN CROW	WESTERN TANAGER
LONG-BILLED DOWITCHER	COMMON RAVEN	BLACK-HEADED GROSBEAK
WILSON'S SNIPE	MOUNTAIN CHICKADEE	GREEN-TAILED TOWHEE
WILSON'S PHALAROPE	OAK TITMOUSE	CALIFORNIA TOWHEE
BONAPARTE'S GULL	BUSHTIT	CHIPPING SPARROW
RING-BILLED GULL	RED-BREASTED NUTHATCH	FOX SPARROW
CALIFORNIA GULL	WHITE-BREASTED NUTHATCH	GOLDEN-CROWNED SPARROW
HERRING GULL	PYGMY NUTHATCH	WHITE-CROWNED SPARROW
CASPIAN TERN	BROWN CREEPER	DARK-EYED JUNCO
COMMON TERN	ROCK WREN	WESTERN MEADOWLARK
FORSTER'S TERN	CANYON WREN	BULLOCK'S ORIOLE
ROCK PIGEON	BEWICK'S WREN	PURPLE FINCH
BAND-TAILED PIGEON	HOUSE WREN	CASSIN'S FINCH
MOURNING DOVE	WINTER WREN	RED CROSSBILL
GREATER ROADRUNNER	AMERICAN DIPPER	PINE SISKIN
BARN OWL	GOLDEN-CROWNED KINGLET	EVENING GROSBEAK
WESTERN SCREECH OWL	RUBY-CROWNED KINGLET	PLUMBEOUS VIREO
GREAT HORNED OWL	BLUE-GRAY GNATCATCHER	HARRIS'S SPARROW
NORTHERN PYGMY OWL	WESTERN BLUEBIRD	TROWBRIDGE'S SHREW
BURROWING OWL	MOUNTAIN BLUEBIRD	LONG-EARED MYOTIS
LONG-EARED OWL	TOWNSEND'S SOLITAIRE	LONG-LEGGED MYOTIS
SHORT-EARED OWL	SWAINSON'S THRUSH	SILVER-HAIRED BAT
NORTHERN SAW-WHET OWL	HERMIT THRUSH	BIG BROWN BAT
LESSER NIGHTHAWK	AMERICAN ROBIN	HOARY BAT
COMMON NIGHTHAWK	VARIED THRUSH	BRUSH RABBIT

	CWHR Habitat Type Designation*:	
Group 1: Annual Grassland, Barren Land, Chamise/Redshank Chaparral, Mixed Chapparal,Lacustrine,Valley Oak Woodland, Wet Meadow	Group 2: Blue Oak/Foothill Pine, Blue Oak Woodland, Montane Chaparral, Montane Hardwood, Montane Riparian, Ponderosa Pine	Group 3: Closed Cone Pine/Cypress, Douglas Fir, Montane Hardwood Conifer, Sierran Mixed Conifer
COMMON POORWILL	WRENTIT	SNOWSHOE HARE
BLACK SWIFT	NORTHERN MOCKINGBIRD	MOUNTAIN BEAVER
VAUX'S SWIFT	CEDAR WAXWING	YELLOW-PINE CHIPMUNK
WHITE-THROATED SWIFT	PHAINOPEPLA	ALLEN'S CHIPMUNK
BLACK-CHINNED HUMMINGBIRD	LOGGERHEAD SHRIKE	LONG-EARED CHIPMUNK
ANNA'S HUMMINGBIRD	EUROPEAN STARLING	CALIFORNIA GROUND SQUIRREL
CALLIOPE HUMMINGBIRD	CASSIN'S VIREO	GOLDEN-MANTLED GROUND SQUIRREL
RUFOUS HUMMINGBIRD	HUTTON'S VIREO	WESTERN GRAY SQUIRREL
BELTED KINGFISHER	WARBLING VIREO	DOUGLAS' SQUIRREL
LEWIS' S WOODPECKER	ORANGE-CROWNED WARBLER	NORTHERN FLYING SQUIRREL
ACORN WOODPECKER	NASHVILLE WARBLER	BOTTA'S POCKET GOPHER
RED-BREASTED SAPSUCKER	YELLOW WARBLER	DEER MOUSE
WILLIAMSON'S SAPSUCKER	YELLOW-RUMPED WARBLER	BRUSH MOUSE
NUTTALL'S WOODPECKER	BLACK-THROATED GRAY WARBLER	PINYON MOUSE
DOWNY WOODPECKER	TOWNSEND'S WARBLER	DUSKY-FOOTED WOODRAT
HAIRY WOODPECKER	HERMIT WARBLER	BUSHY-TAILED WOODRAT
NORTHERN FLICKER	MACGILLIVRAY'S WARBLER	HEATHER VOLE
WESTERN WOOD-PEWEE	COMMON YELLOWTHROAT	COMMON PORCUPINE
WILLOW FLYCATCHER	WILSON'S WARBLER	COYOTE
HAMMOND'S FLYCATCHER	WESTERN TANAGER	GRAY FOX
PACIFIC-SLOPE FLYCATCHER	BLACK-HEADED GROSBEAK	BLACK BEAR
BLACK PHOEBE	LAZULI BUNTING	RINGTAIL
SAY'S PHOEBE	GREEN-TAILED TOWHEE	RACCOON
ASH-THROATED FLYCATCHER	SPOTTED TOWHEE	AMERICAN MARTEN
WESTERN KINGBIRD	CALIFORNIA TOWHEE	FISHER
HORNED LARK	CHIPPING SPARROW	ERMINE
PURPLE MARTIN	BREWER'S SPARROW	LONG-TAILED WEASEL
TREE SWALLOW	BLACK-CHINNED SPARROW	AMERICAN BADGER
VIOLET-GREEN SWALLOW	LARK SPARROW	WESTERN SPOTTED SKUNK
NORTHERN ROUGH-WINGED SWALLOW	SAGE SPARROW	STRIPED SKUNK
BANK SWALLOW	SAVANNAH SPARROW	MOUNTAIN LION
CLIFF SWALLOW	FOX SPARROW	BOBCAT
BARN SWALLOW	SONG SPARROW	MULE DEER
STELLER'S JAY	LINCOLN'S SPARROW	LARGE-EARED WOODRAT
WESTERN SCRUB-JAY	GOLDEN-CROWNED SPARROW	WESTERN FENCE LIZARD
BLACK-BILLED MAGPIE	WHITE-CROWNED SPARROW	WESTERN SKINK
YELLOW-BILLED MAGPIE	DARK-EYED JUNCO	NORTHERN ALLIGATOR LIZARD
AMERICAN CROW	WESTERN MEADOWLARK	RUBBER BOA
COMMON RAVEN	BROWN-HEADED COWBIRD	GOPHER SNAKE
MOUNTAIN CHICKADEE	BULLOCK'S ORIOLE	WESTERN TERRESTRIAL GARTER SNAKE
CHESTNUT-BACKED CHICKADEE	PURPLE FINCH	WESTERN RATTLESNAKE
OAK TITMOUSE	HOUSE FINCH	Total Number of Species:150
BUSHTIT	RED CROSSBILL	
WHITE-BREASTED NUTHATCH	PINE SISKIN	
PYGMY NUTHATCH	LESSER GOLDFINCH	
BROWN CREEPER	LAWRENCE'S GOLDFINCH	
ROCK WREN	PLUMBEOUS VIREO	
CANYON WREN	VAGRANT SHREW	
BEWICK'S WREN	DUSKY SHREW	
HOUSE WREN	ORNATE SHREW	
WINTER WREN	WATER SHREW	
AMERICAN DIPPER	TROWBRIDGE'S SHREW	
RUBY-CROWNED KINGLET	BROAD-FOOTED MOLE	
BLUE-GRAY GNATCATCHER	YUMA MYOTIS	
WESTERN BLUEBIRD	LONG-EARED MYOTIS	
MOUNTAIN BLUEBIRD	FRINGED MYOTIS	
HERMIT THRUSH	LONG-LEGGED MYOTIS	
AMERICAN ROBIN	SILVER-HAIRED BAT	
VARIED THRUSH	BIG BROWN BAT	

	CWHR Habitat Type Designation*:	
Group 1: Annual Grassland, Barren Land, Chamise/Redshank Chaparral, Mixed Chapparal,Lacustrine,Valley Oak Woodland, Wet Meadow	Group 2: Blue Oak/Foothill Pine, Blue Oak Woodland, Montane Chaparral, Montane Hardwood, Montane Riparian, Ponderosa Pine	Group 3: Closed Cone Pine/Cypress, Douglas Fir, Montane Hardwood Conifer, Sierran Mixed Conifer
WRENTIT	HOARY BAT	
NORTHERN MOCKINGBIRD	PALLID BAT	
CALIFORNIA THRASHER	WESTERN MASTIFF BAT	
AMERICAN PIPIT	BRUSH RABBIT	
CEDAR WAXWING	DESERT COTTONTAIL	
PHAINOPEPLA	SNOWSHOE HARE	
NORTHERN SHRIKE	BLACK-TAILED JACKRABBIT	
LOGGERHEAD SHRIKE	MOUNTAIN BEAVER	
EUROPEAN STARLING	YELLOW-PINE CHIPMUNK	
CASSIN'S VIREO	ALLEN'S CHIPMUNK	
HUTTON'S VIREO	LONG-EARED CHIPMUNK	
WARBLING VIREO	CALIFORNIA GROUND SQUIRREL	
ORANGE-CROWNED WARBLER	GOLDEN-MANTLED GROUND SQUIRREL	
NASHVILLE WARBLER	WESTERN GRAY SQUIRREL	
YELLOW WARBLER	DOUGLAS' SQUIRREL	
YELLOW-RUMPED WARBLER	NORTHERN FLYING SQUIRREL	
BLACK-THROATED GRAY WARBLER	BOTTA'S POCKET GOPHER	
TOWNSEND'S WARBLER	MOUNTAIN POCKET GOPHER	
HERMIT WARBLER	CALIFORNIA POCKET MOUSE	
COMMON YELLOWTHROAT	AMERICAN BEAVER	
WILSON'S WARBLER	WESTERN HARVEST MOUSE	
WESTERN TANAGER	DEER MOUSE	
BLACK-HEADED GROSBEAK	BRUSH MOUSE	
BLUE GROSBEAK	PINYON MOUSE	
LAZULI BUNTING	DUSKY-FOOTED WOODRAT	
SPOTTED TOWHEE	BUSHY-TAILED WOODRAT	
CALIFORNIA TOWHEE	CALIFORNIA VOLE	
RUFOUS-CROWNED SPARROW	LONG-TAILED VOLE	
CHIPPING SPARROW	COMMON MUSKRAT	
BLACK-CHINNED SPARROW	BLACK RAT	
VESPER SPARROW	NORWAY RAT	
LARK SPARROW	HOUSE MOUSE	
SAGE SPARROW	WESTERN JUMPING MOUSE	
SAVANNAH SPARROW	COMMON PORCUPINE	
GRASSHOPPER SPARROW	COYOTE	
FOX SPARROW	GRAY FOX	
SONG SPARROW	BLACK BEAR	
LINCOLN'S SPARROW	RINGTAIL	
GOLDEN-CROWNED SPARROW	RACCOON	
WHITE-CROWNED SPARROW	AMERICAN MARTEN	
DARK-EYED JUNCO	FISHER	
RED-WINGED BLACKBIRD	ERMINE	
TRICOLORED BLACKBIRD	LONG-TAILED WEASEL	
WESTERN MEADOWLARK	AMERICAN MINK	
YELLOW-HEADED BLACKBIRD	AMERICAN BADGER	
BREWER'S BLACKBIRD	WESTERN SPOTTED SKUNK	
BROWN-HEADED COWBIRD	STRIPED SKUNK	
BULLOCK'S ORIOLE	MOUNTAIN LION	
GRAY-CROWNED ROSY-FINCH	BOBCAT	
PURPLE FINCH	MULE DEER	
HOUSE FINCH	LARGE-EARED WOODRAT	
PINE SISKIN	WESTERN POND TURTLE	
LESSER GOLDFINCH	WESTERN FENCE LIZARD	
LAWRENCE'S GOLDFINCH	SAGEBRUSH LIZARD	
AMERICAN GOLDFINCH	WESTERN SKINK	
HOUSE SPARROW	GILBERT'S SKINK	
CLARK'S GREBE	SOUTHERN ALLIGATOR LIZARD	
JUNIPER TITMOUSE	NORTHERN ALLIGATOR LIZARD	
PLUMBEOUS VIREO	RUBBER BOA	
BAIRD'S SANDPIPER	RINGNECK SNAKE	
PECTORAL SANDPIPER	SHARPTAIL SNAKE	

	CWHR Habitat Type Designation*:	
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RED-NECKED PHALAROPE	RACER	
HARRIS'S SPARROW	GOPHER SNAKE	
VIRGINIA OPOSSUM	CALIFORNIA MOUNTAIN KINGSNAKE	
VAGRANT SHREW	WESTERN TERRESTRIAL GARTER SNAKE	
BROAD-FOOTED MOLE	WESTERN AQUATIC GARTER SNAKE	
LITTLE BROWN BAT	WESTERN RATTLESNAKE	
YUMA MYOTIS	Total Number of Species:235	
FRINGED MYOTIS		
LONG-LEGGED MYOTIS		
CALIFORNIA MYOTIS		
WESTERN SMALL-FOOTED MYOTIS		
WESTERN PIPISTRELLE		
BIG BROWN BAT		
HOARY BAT		
PALLID BAT		
BRAZILIAN FREE-TAILED BAT		
WESTERN MASTIFF BAT		
AMERICAN PIKA		
BRUSH RABBIT		
DESERT COTTONTAIL		
BLACK-TAILED JACKRABBIT		
MOUNTAIN BEAVER		
YELLOW-PINE CHIPMUNK		
LONG-EARED CHIPMUNK		
YELLOW-BELLIED MARMOT		
BELDING'S GROUND SQUIRREL		
CALIFORNIA GROUND SQUIRREL		
GOLDEN-MANTLED GROUND SQUIRREL		
WESTERN GRAY SQUIRREL		
NORTHERN FLYING SQUIRREL		
BOTTA'S POCKET GOPHER		
NORTHERN POCKET GOPHER		
MOUNTAIN POCKET GOPHER		
CALIFORNIA POCKET MOUSE		
HEERMANN'S KANGAROO RAT		
CALIFORNIA KANGAROO RAT		
AMERICAN BEAVER		
WESTERN HARVEST MOUSE		
DEER MOUSE		
BRUSH MOUSE		
PINYON MOUSE		
DUSKY-FOOTED WOODRAT		
BUSHY-TAILED WOODRAT		
MONTANE VOLE		
CALIFORNIA VOLE		
LONG-TAILED VOLE		
COMMON MUSKRAT		
BLACK RAT		
NORWAY RAT		
HOUSE MOUSE		
WESTERN JUMPING MOUSE		
COMMON PORCUPINE		
COYOTE		
RED FOX		
GRAY FOX		
BLACK BEAR		
RINGTAIL		
RACCOON		
AMERICAN MARTEN		

	CWHR Habitat Type Designation*:	
Group 1: Annual Grassland, Barren Land, Chamise/Redshank Chaparral, Mixed Chapparal,Lacustrine,Valley Oak Woodland, Wet Meadow	Group 2: Blue Oak/Foothill Pine, Blue Oak Woodland, Montane Chaparral, Montane Hardwood, Montane Riparian, Ponderosa Pine	Group 3: Closed Cone Pine/Cypress, Douglas Fir, Montane Hardwood Conifer, Sierran Mixed Conifer
ERMINE		
LONG-TAILED WEASEL		
AMERICAN MINK		
AMERICAN BADGER		
WESTERN SPOTTED SKUNK		
STRIPED SKUNK		
NORTHERN RIVER OTTER		
MOUNTAIN LION		
BOBCAT		
MULE DEER		
LARGE-EARED WOODRAT		
WESTERN POND TURTLE		
WESTERN FENCE LIZARD		
COAST HORNED LIZARD		
WESTERN SKINK		
GILBERT'S SKINK		
SOUTHERN ALLIGATOR LIZARD		
RINGNECK SNAKE		
SHARPTAIL SNAKE		
RACER		
STRIPED RACER		
GOPHER SNAKE		
COMMON KINGSNAKE		
CALIFORNIA MOUNTAIN KINGSNAKE		
COMMON GARTER SNAKE		
WESTERN TERRESTRIAL GARTER SNAKE		
WESTERN AQUATIC GARTER SNAKE		
WESTERN RATTLESNAKE		
Total Number of Species:316		

Appendix F
Potential Approaches to Address Connectivity in the INRMP (Phase II)

Appendix F
Potential Approaches to Address Connectivity in the INRMP (Phase II)

Page #

List of Figures

Potential Approaches to Address Connectivity in the INRMP (Phase II)

The inventory and monitoring components of the final INRMP are planned to be regularly updated over time. The purpose of the updates will be to track development effects on wildlife habitat. In order to preserve habitat, it is important to consider connectivity. Connectivity can be measured by a variety of scientific approaches, which are described below.

1.0 Wildlife Movement

The best way to measure connectivity on a landscape is to look at the distribution and movement of the organisms of concern. Depending on the size and type of organisms, there are several common ways to measure their occurrence and distribution. Each method provides data for part of the overall story of individual or groups of species. By combining several methods, accurate assessments of wildlife movement, population well-being, and species occurrence are possible. The following sections describe potential approaches that the County can use to better understand and/or monitor changes in connectivity in the INRMP study area.

1.1 Tracking

Wildlife leave tracks in soft substrate when they move. Two common methods for capturing tracks are track counts and trackplates. Measuring track counts is accomplished by placing a substrate (e.g., sand) across an opening (e.g., in front of a culvert opening) or alongside a road and periodically photographing new tracks of animals crossing the area. Track plates are metal plates covered in a dark powder, such as printer ink powder, and placed in front of contact paper and bait. Animals trying to get the bait cross the ink and the contact paper, and leave their tracks behind for identification. These methods allow for species identification and possibly relative abundance.

1.2 Wildlife Cameras

Motion-triggered cameras placed at locations where wildlife movement is constrained (e.g., crossing under roadway) are a cost-effective way of recording multiple animal passages. The main constraint on this method is having a confined area or bait station so that animals are close enough to photograph. A digital camera with a built-in motion detector is fastened to a tree or infrastructure facing the constrained movement area. Batteries and data cards are replaced periodically. This method allows for species identification, and sometimes individual identification.

1.3 GPS and Radio-Collars and Devices

This relatively labor-intensive method provides the most accurate information about wildlife distribution, home range size, and movement patterns. Tracking devices, including collars, are attached to individual animals. Radio collars are less expensive, but require technical staff to locate animals using antennae. GPS collars are more expensive, but can be set to drop off automatically, allowing recovery of the device and the corresponding data. A variant on this is GPS collars with satellite communication that allow for real-time tracking of animals.

1.4 Genetic Testing

There are several ways to collect genetic data from animals. One is to place a device capable of catching hairs from a passing animal (e.g., the I-80 U.C. Davis project uses a gun-cleaning brush at the entrance of track plates). These devices can be placed across culvert opening, or at the entrance to baited enclosures. Another method is to trap live animals and take a blood or other tissue sample for testing. In either case, not much material is needed to identify and differentiate among wildlife species and among populations of the same species.

1.5 County Public Health – Animal Services Data

By keeping track of roadkill information, one can get a general idea of where animals are trying to cross. The County's Animal Services Department keeps records of reported roadkill and publishes a Dead Animals Activities List, which describes the kinds of animals that have been picked up and the names of the roads but does not give exact locations. The list is based on archived reports that can be researched to determine species-specific problem areas.

2.0 Genetic Fragmentation

As described above, road and highway construction and use can affect surrounding wildlife through population differentiation and genetic isolation. The first step in testing the genetic effects of roads and highways on wildlife populations is to evaluate the genetic structure (including genetic divergence and diversity) of a given taxon, and then correlate it to the road/highway (network) barriers.

To detect effects of roads and highways on the genetic structure, it is necessary to collect enough samples from individuals of different geographical populations from appropriate landscape and taxonomic groups, and then choose suitable genetic markers for population structure analysis (Manel et al., 2003; Holderegger & Wagner, 2006). Based on the collected genetic data, a variety of genetic analyses and statistical analyses are performed to determine the spatial genetic pattern and its correlation with roads, highways, and other land uses (see Manel et al., 2003 for more detailed information).

Three steps are necessary before assessment of population divergence and genetic diversity: 1) Choose an appropriate road, highway, or combination of infrastructure. As mentioned above, many features of roads and highways, like traffic volume and road-way size and age, may affect wildlife crossing and the timing for genetic divergence. For a given road or highway, its features should be carefully evaluated before studying its effect on spatial genetic patterns. 2) Choose an appropriate taxon. Different organisms have varied movement abilities, life history traits and effective population size. Those species characterized by weak movement ability, rapid life cycle and small effective population size are more likely to respond to artificial disturbance with population differentiation and decreases in genetic diversity, while other organisms may need longer time or be less affected. 3) Choose appropriate molecular markers. Different molecular markers also present different heritage modes, mutation rates and effective population sizes, which may be reflected in the resulting genetic structure (Latta, 2006). Generally, highly variable molecular markers (e.g., microsatellites) may be more suitable than conservative (less-variable) markers (Gerlach & Musolf, 2000).

To test the effect of roads on genetic differentiation, sampling methods should be specifically designed according to features of the studied organisms and road/highway. However, there are some general rules. Control and replication should always be conducted for experiments. Sampling sites should be scattered on both sides of the road, and for each side, several sampling sites should be included. As general guidance, 15-30 independent replicates of each treatment (e.g., near road and far from roads) are needed (Karban & Huntzinger, 2006, p. 43). Notably, it is necessary to collect both female and male individuals in each sampling site because of possible sex-biased dispersal, which is a wide-spread pattern in vertebrate organisms (Prugnolle & de Meeus, 2002).

Once genetic data are obtained, a variety of population genetic analysis and statistical analysis can be performed to determine spatial genetic pattern and its correlation with roads and highways. For analyzing spatial genetic pattern, as Manel et al., (2003) summarized, there are usually two sets of six approaches. The first set of approaches is to assess genetic differentiation (Fst values) among populations over large geographic area when geographical populations are known in advance. The other set of approaches is to assess spatial genetic patterns at an individual level without defining geographical populations in advance. Among the latter set, the Bayesian assignment, which is implemented in STRUCTURE software version 2.3.3 (http://pritch.bsd.uchicago.edu/structure.html; Pritchard et al., 2000; Falush et al., 2003; Falush et al., 2007), is widely used to test the effect of roads and highways on genetic structure. With the Bayesian assignment, all individuals are firstly clustered into different assumed genetic populations based on multilocus genotype data, and then all individuals of unknown origin are assigned to those assumed populations with varied probability. The number of assigned populations informs the population structure. The probability for an individual to be clustered in those assigned populations indicates its possible single origin or mixed origins (hybrid). After identifying population differentiation, some other statistical tests can be used to detect the correlation between population differentiation and road barriers. For this, Manel et al. have listed four different approaches, including Mantel's test, canonical correspondence analysis, geographical information systems and testing correlation between two maps (Manel et al., 2003).

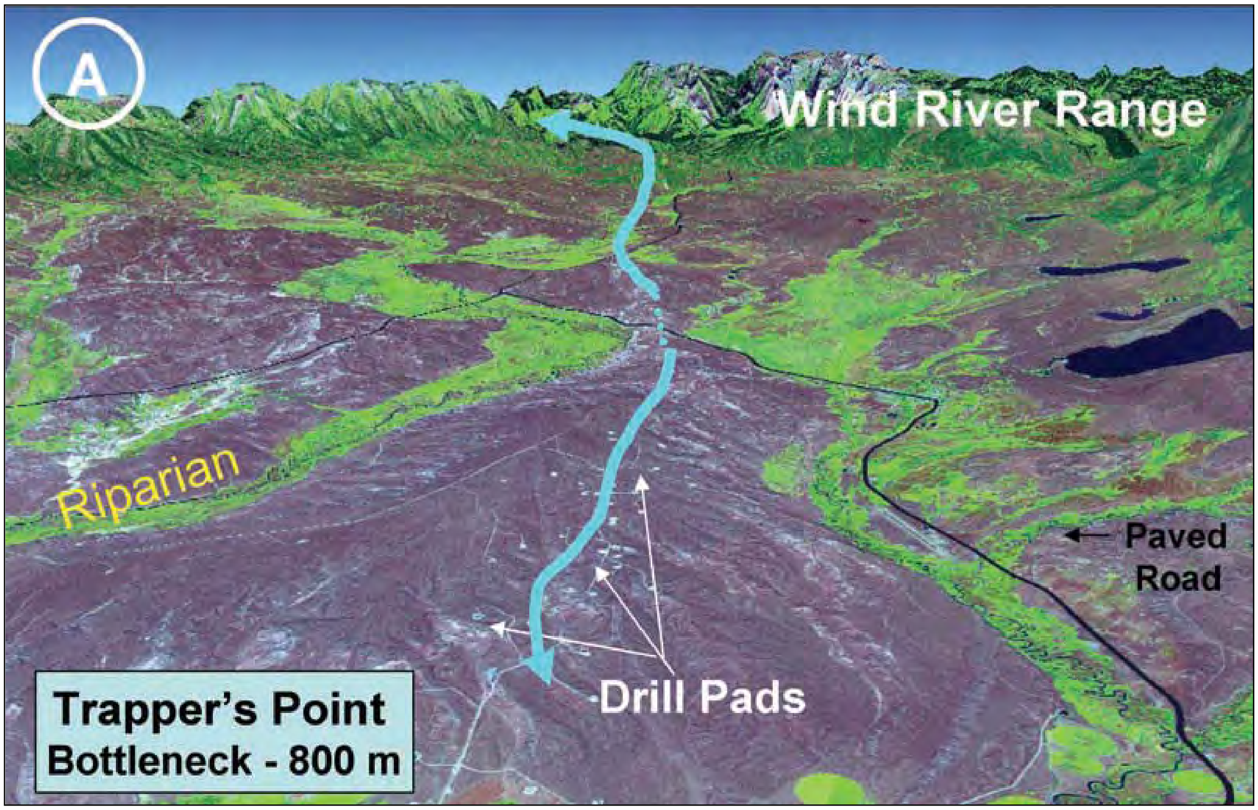
3.0 Connectivity Modeling

3.1 Expert Knowledge and Empirical Data

Perhaps the simplest method of corridor identification is through utilization of expert knowledge derived from time spent observing animals in the field (Noss and Daly 2006). Biologists that have first-hand experience witnessing animal use of particular areas for movement can delineate these or similar areas on a map. An example of this approach might be the identification of a seasonal migration route for a particular species (Figure F-1. Pronghorn Migration Corridor; Berger 2006). Another approach might be a study examining the use patterns of potential corridors by an animal species (Sieving et al. 2000). Still another means of gathering field data on animal movement could be through radio- or GPS-collar tracking of individual animals (Beier 1993). This approach allows for spatially explicit movement data to be incorporated into a connectivity analysis.

Figure F-1. Pronghorn Migration Corridor

The pronghorn migration corridor is shown below in blue was identified by biologists in western Wyoming. Also shown is a movement bottleneck and human development (from Berger 2006).



These expert/empirically-derived corridors can be incorporated into a conservation planning process in a variety of ways. Some planning benefits to this sort of approach include a low cost (assuming the field work is already complete), and easily explained methodology, and an ability to finish the work quickly. Drawbacks include restricting the planning products to known movement corridors, assuming they exist, and the usually ad hoc nature of ecological knowledge within a given planning region. Many times a more systematic approach is preferable.

3.2 Least Cost Modeling

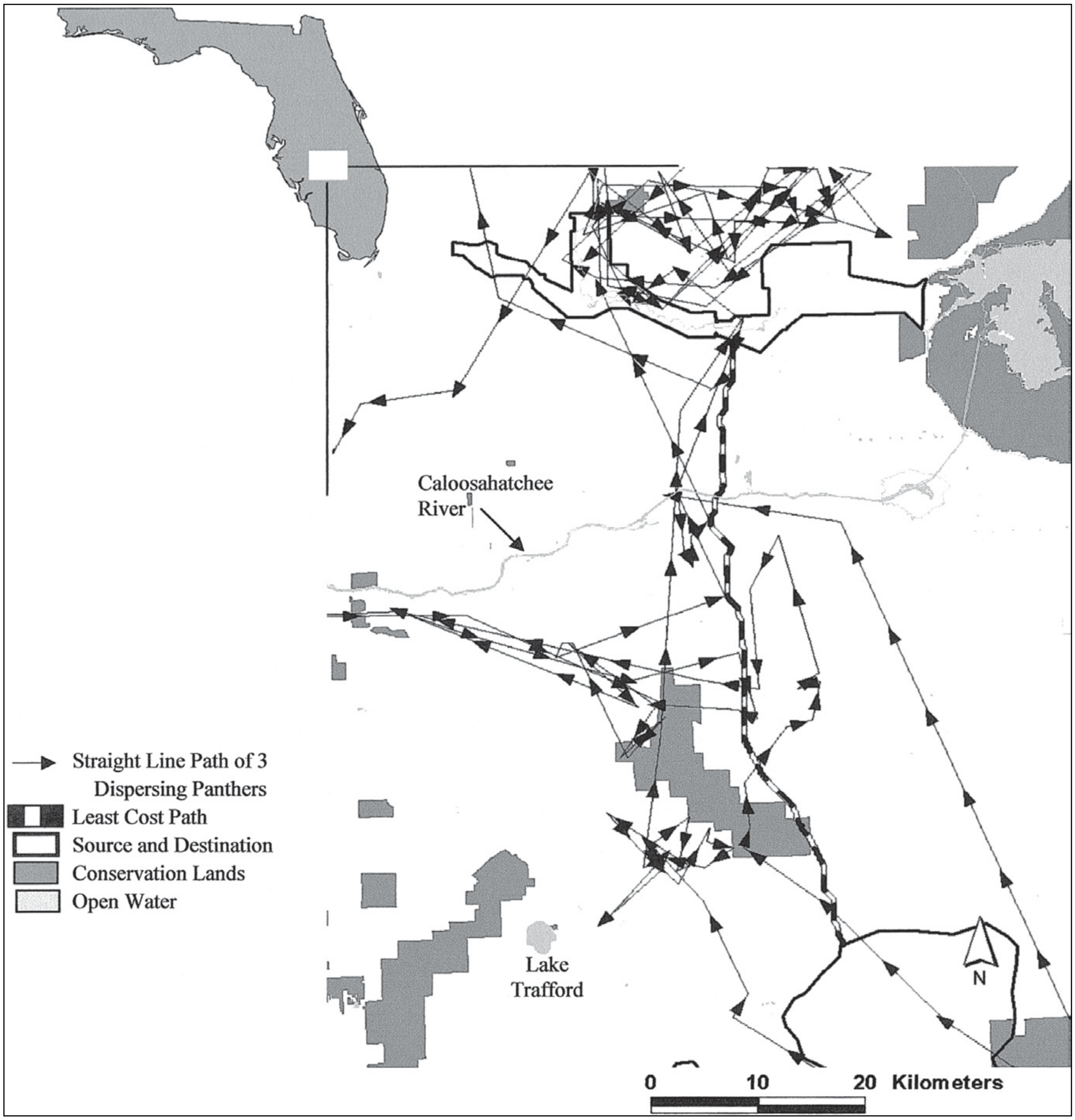
A commonly used method of connectivity analysis is "least cost modeling" (Theobald 2006). This technique uses a "cost surface" to calculate the path of least resistance between designated endpoints. The term "cost" in this context does not refer to economic cost but rather to the ecological cost (or "resistance") exacted on an individual animal trying to move across a landscape. The cost surface should ideally incorporate landscape variables that influence the movement patterns of an individual of a particular species, as identified through field studies. Typical variables include land cover, slope, barriers to movement, etc. In practice, however, relatively little is known about how individual species move across a landscape, so habitat suitability is commonly used as a proxy for this movement information. Endpoints used in least cost modeling are often known populations of the species being modeled, existing reserves between which animal movement is important, seasonal habitats on either end of a migration route, etc. Using the cost surface and the endpoints, “cost distance” is calculated for every raster cell in the analysis area (Theobald 2006). Cost distance is the cumulative cost from that particular cell to an endpoint as calculated by taking the least costly route. Finally, the route following the low cost raster cells is identified.

The simplest type of least cost modeling results in a least cost “path” between the endpoints (Meegan and Maehr 2002, Kautz et al. 2006, Schwartz et al. 2009). This path is a single line passing through the low cost raster cells. While the path is not necessarily a straight line (and usually is not, except in very homogenous landscapes), it does not have width and describes one single potential route between endpoints (Figure F-2. Least Cost Path for Florida Panther). A single path might enable conceptual clarity; however, for most animal movement, individuals will not follow one single route.

A least cost modeling technique that probably better captures the patterns of potential movement between endpoints involves identification of a “corridor” (Singleton et al. 2002, Theobald 2006, Beier et al. 2008, Huber et al. 2010a). Least cost corridor modeling does not identify one single “best” path but rather a gradation of connectivity values between endpoints. Typically, a connectivity value threshold is used to identify a discrete corridor. This corridor may have variable width and can potentially consist of several strands. The advantages of using corridor modeling as opposed to path modeling include a better representation of potential movement as well as the potential for greater flexibility in a management context (for example, if there are multiple strands, it might be preferable from a management standpoint to manage one particular strand for connectivity purposes).

Figure F-2. Least Cost Path for Florida Panther

Least cost path for the Florida panther and actual movement routes taken by radio-collared panthers are shown below (from Meegan and Maehr 2002).



There are several limitations inherent in both least cost path and modeling, however. The required endpoint designation implies a prior knowledge of source and destination locations of individuals being modeled. Least cost path and corridor analyses are not designed to capture uncertainty that often is inherent in human knowledge of source and destination in animal movement. Further, path and corridor analyses are generally meant to capture discrete locations of animal movement. When incorporated into a management context, these movement models can lead to a binary vision of the landscape: namely areas that are used by animals for movement and those that are not. This concept of landscape use can belie the gradient of use found in many places. The variably-developed landscape within which areas of higher connectivity are embedded can often play a role in animal movement and resource use that is neglected in many connectivity analyses.

There have recently been efforts made to address these modeling limitations. For example, Huber et al. (2010b) used a series of overlapping least cost corridor analyses to estimate landscape connectivity for several focal species in a portion of the San Joaquin Valley, California (Figure F-3. Least Cost Surface as Calculated for Bobcat). This method calculated connectivity between numerous combinations of study area perimeter segments in order to create a full two-dimensional least cost "surface" and to avoid assumptions concerning endpoint designation. However, because multiple analyses are being conducted, the computation time increases accordingly.

3.3 Circuit Theory

A relatively new method developed for assessing landscape connectivity is "circuit theory" (McRae and Beier 2007, McRae et al. 2008). This technique, adapted from electrical circuit theory, simultaneously accounts for multiple sources and destinations while identifying those areas that might serve as "pinch points", i.e., narrower critical habitat connections. This method results in a two-dimensional connectivity surface for the entire study area (Figure F-4. Sample Results from a Circuit Theory Analysis). An important feature of this method for connectivity planning is the identification of key linkage points, through which many individuals would be forced to travel when traversing a landscape. This can aid in the prioritization of connectivity planning activities.

Similar to least cost analysis, a circuit theory-based connectivity analysis requires the creation of a cost surface. Then "current" is summed between two or more source patches. Barriers, which do not allow any movement, can be included in the analysis in addition to the cost surface. Overall, the analytic process is generally equivalent in computation time to least cost analysis.

Figure F-3. Least Cost Surface as Calculated for Bobcat

Areas of high modeled connectivity are shown in pink and white, while areas of low connectivity are shown in orange and brown. Gray lines are roads, and the blue line is a river (from Huber et al. 2010).

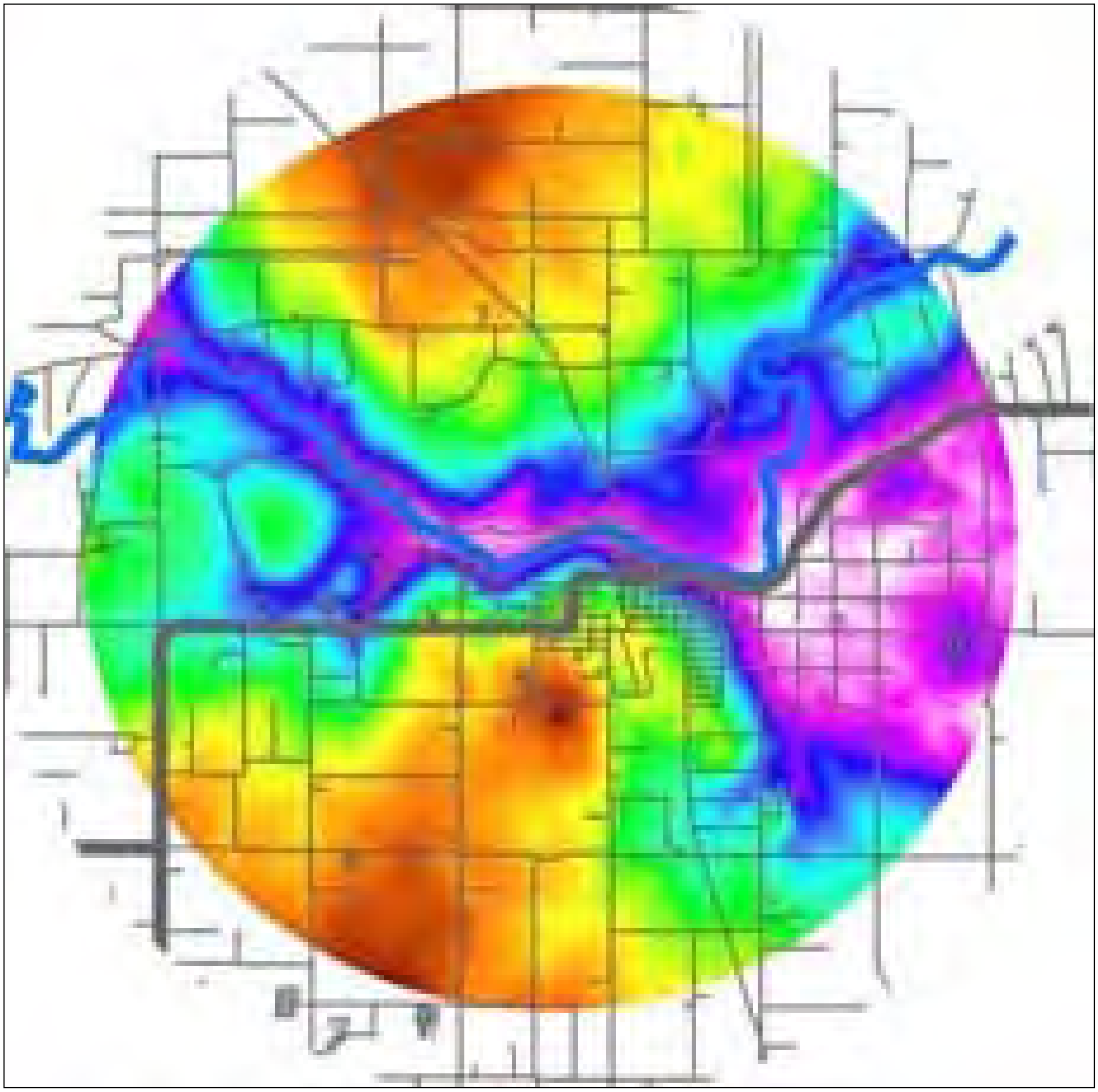
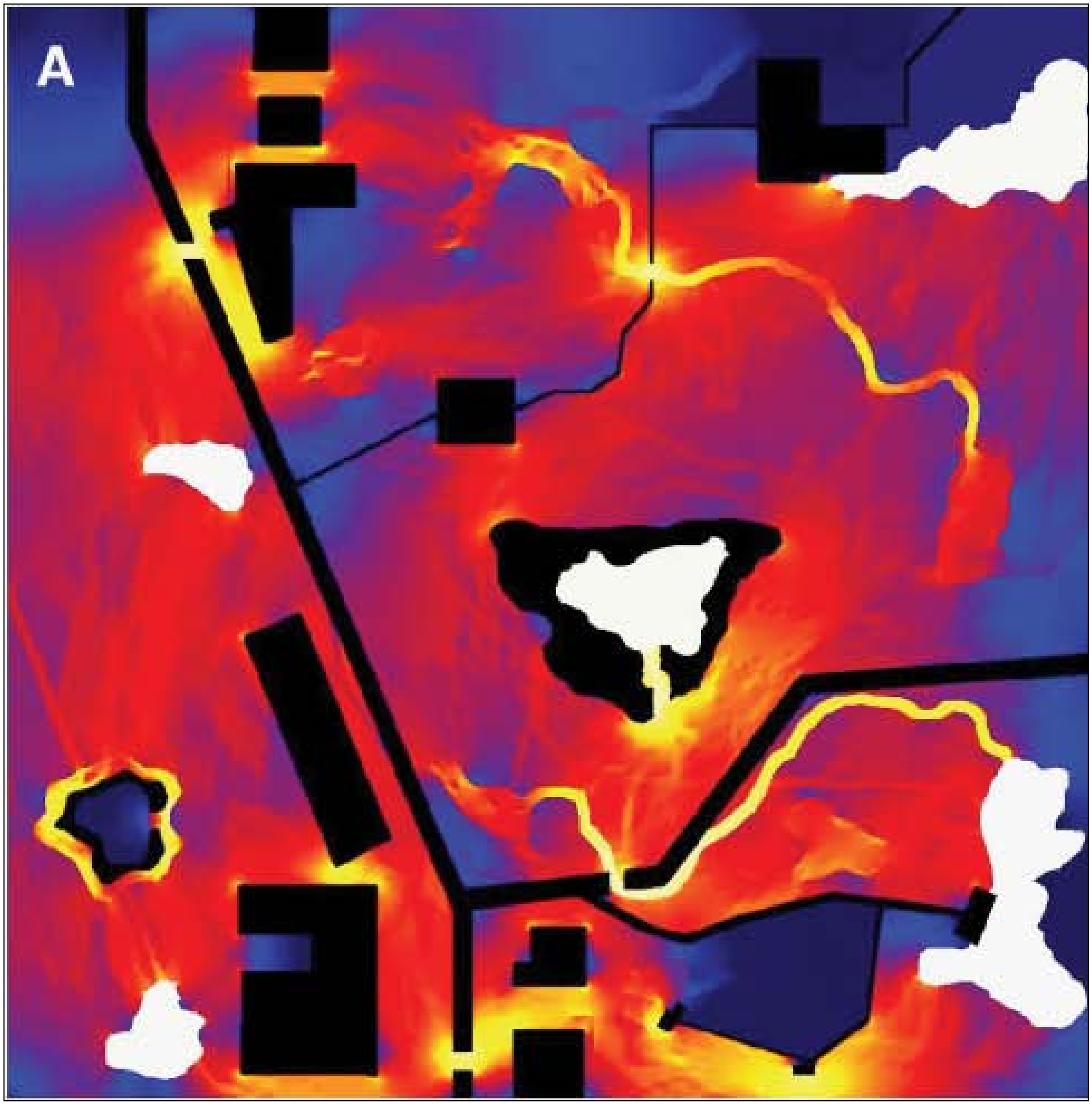


Figure F-4. Sample Results From a Circuit Theory Analysis

Shown below are source patches (white), barriers (black), and “summed current” (dark → bright, with bright showing cells with lowest cumulative cost). From McRae et al. 2008.



3.4 Spatially Explicit Population Models

While least cost and circuit-based connectivity analyses focus on the static landscape scale, spatially explicit population models (SEPM) attempt to approximate movement patterns by predicting what individual animals will actually do within a landscape context (Noss and Daly 2006). SEPM offer the advantage over other methods of incorporation of factors such as population dynamics and species-specific behavioral patterns into the model. There is also the potential to include dynamic landscape processes in the analysis. Models such as PATCH (Schumaker 1998) and HexSim (Figure F-5. Modeled Tule Elk Herd Expansion from Potential Reintroduction Site; Schumaker 2010) have been used to model potential wolf reintroduction (Carroll et al. 2003) and important conservation areas in the Greater Yellowstone Ecosystem (Noss et al. 2002).

SEPM allow planners to evaluate the demographic consequences of various land use scenarios on species within a study area. This can provide greater insight into functional connectivity than do static models, such as least cost models. The major drawback of this approach however is the greatly increased complexity and uncertainty inherent in the computational process (Noss and Daly 2006). Many input parameters are required, many of which are not known for most species (especially movement data). The complexity of SEPM also generally requires a much longer processing time than do static models.

3.5 Graph Models

Graph theory is concerned with potential flow through an entire network and how the individual components influence this flow. Graphs are landscape representations composed of nodes and links. These refer respectively to habitat patches and actual or potential connectivity (Urban et al. 2009). Link length can be determined by Euclidean distance between patches, but cost distance (see above) is often used in graph analysis instead. While graph modeling is not used to identify the actual reserve network, it can be used to identify key linkages within the network, which, if lost, could have widespread ramifications to future ecological function of the rest of the network. As such, it is a useful modeling tool for understanding the effects of network perturbation. One example of use of graph models in conservation planning is a study by Urban and Keitt (2001) where the authors identified a “minimum spanning tree” (Figure F-6. Graph Model Showing the Minimum Spanning Tree for Mexican Spotted Owl Habitat Patches in the Southwestern U.S.) that could serve a minimum viable population of Mexican spotted owls in the southwestern U.S. Graph models are probably best used in conjunction with other connectivity modeling techniques.

Figure F-5. Modeled Tule Elk Herd Expansion from Potential Reintroduction Site

Red indicates areas of higher likely elk occupancy. Results from studies such as these can be used to evaluate landscape connectivity. From an unpublished study, Huber et al.

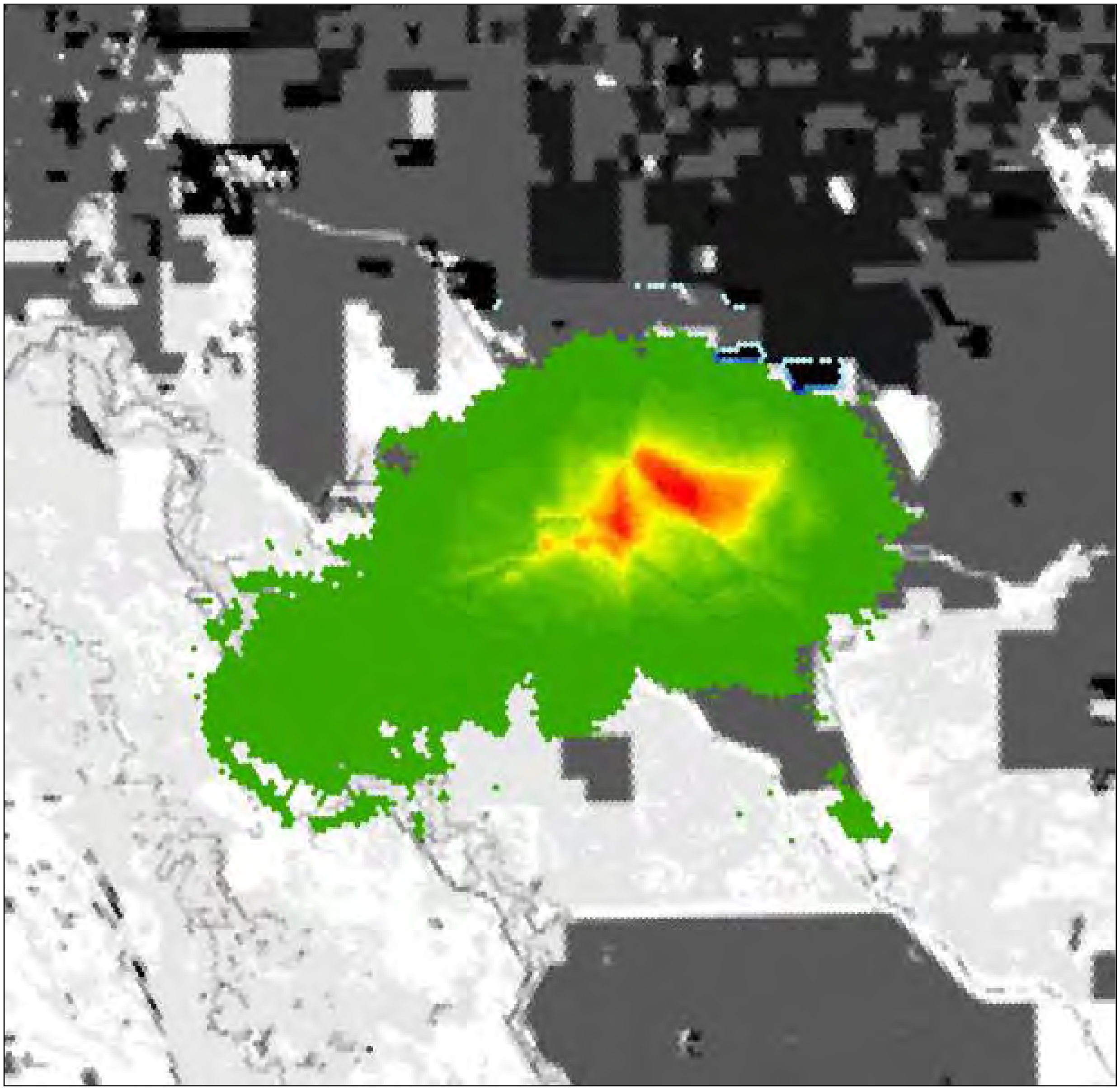


Figure F-6. Graph Model Showing the Minimum Spanning Tree for Mexican Spotted Owl Habitat Patches in the Southwestern U.S.

Potential habitat is shown in green, lines are links of the tree (Urban and Keitt 2001).