NDOT Research Report

Report No. 700-18-803

TPF-5(358)
THE STRATEGIC INTEGRATION OF WILDLIFE MITIGATION INTO TRANSPORTATION PROCEDURES: A MANUAL FOR AGENCIES AND PARTNERS

June 2022

Nevada Department of Transportation
1263 South Stewart Street
Carson City, NV 89712

Contributing Partners

Alaska DOT
ARC Solutions, Inc.
Arizona DOT
California DOT
Iowa DOT
Ontario Ministry of Transportation
Oregon DOT
Michigan DOT
Minnesota DOT
New Mexico DOT
Parks Canada
Washington DOT

In Cooperation with

USDOT Federal Highway Administration

Disclaimer

This work was sponsored by the Nevada Department of Transportation. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of Nevada at the time of publication. This report does not constitute a standard, specification, or regulation.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. 700-18-803C	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle The Strategic Integration of Wildlife Mitigation into Transportation Procedures: A Manual for Agencies and Partners		5. Report Date June 30, 2022 6. Performing Organization Code
7. Author(s) Patricia Cramer, Julia Kintsch, Jeffery Gagnon, Norris Dodd, Terry Brennan, Lisa Loftus-Otway, Kimberly Andrews, Patrick Basting, Loran Frazier, Leonard Sielecki		8. Performing Organization Report No.
9. Performing Organization Name and Address Patricia Cramer P.O. Box 684, Gallatin Gateway, Montana 59730		10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Nevada Department of Transportation 1263 South Stewart Street Carson City, NV 89712		13. Type of Report and Period Covered Special Technical Report 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This manual is the result of research that explored approaches to the consideration of wildlife needs in transportation processes through a two-nation survey of transportation professionals, literature review, case studies of partnerships and other efforts to reduce wildlife-vehicle collisions (WVC) and accommodation of wildlife movement, and the input of dozens of transportation and ecology professionals on the research team and the supporting agency partners in this Pooled Fund Study. The 57 respondents to the on-line survey represented 31 U.S. states, six Canadian provinces, and 27 Metropolitan Planning Organizations (MPOs) in the U.S. The consistent response themes included: 1) The important information sources for integrating wildlife needs were WVC crash data and hotspots analyses of these data; 2) The most important parts of the planning process were collaboration with wildlife agencies and inclusion of wildlife mitigation plans into long range plans; and 3) The top four most common needs for improvement were – dedicated funding, legislative support to consider wildlife movement needs, collaboration with wildlife agencies, and instilling environmental stewardship and awareness within agencies. This manual instructs agency professionals and their partners on how the transportation planning process works across U.S. states and some Canadian provinces, and how wildlife concerns, specifically wildlife-vehicle conflicts, can be brought into the steps within the process. The goal of this manual is to inspire readers to help institutionalize wildlife concerns into transportation agency mission statements, long range plans, programming of projects, and all the steps to design, construct, and maintain transportation projects. A major step toward this goal is to win the hearts and minds of transportation professionals to think about wildlife in their everyday actions, and how they can help wildlife safely move across transportation infrastructure.

17. Key Words Wildlife, wildlife-vehicle collisions, WVC, wildlife-vehicle conflict, animal-vehicle collisions, AVC, transportation planning, connectivity, deer, turtles, snakes, endangered species, wildlife mitigation, wildlife crossing, underpass, overpass, long range planning, STIP, MPO, Metropolitan Planning Organization, RPO, Regional Planning Organization, partnerships	18. Distribution Statement No restrictions. This document is available through the: National Technical Information Service Springfield, VA 22161

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 330	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

The Strategic Integration of Wildlife Mitigation into Transportation Procedures: A Manual for Agencies and Partners

Report to the Nevada Department of Transportation and Federal Highway Administration Pooled Fund Study:

The Wildlife Vehicle Collision (WVC) Reduction and Habitat Connectivity Transportation Pooled Fund Project TPF 5(358)

Authored by:

Patricia Cramer

Julia Kintsch   Jeff Gagnon

Norris Dodd   Terry Brennan

Lisa Loftus-Otway   Kimberly Andrews

Pat Basting   Loran Frazier

Leonard Sielecki

June 2022

Cover Photo Credits: Mule deer – P. Cramer, Utah Department of Transportation; Black bear – Colorado Department of Transportation Colorado Parks and Wildlife, and ECO-resolutions; Toad – C. Slesar; Mountain lion- W. Vickers, University of California Davis Wildlife Health Center; White-tailed deer P. Cramer and Montana Department of Transportation.

ACKNOWLEDGMENT OF SPONSORSHIP

This work was sponsored by one or more of the following as noted:

X American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration, and was conducted in the **National Cooperative Highway Research Program,**

☐ Federal Transit Administration and was conducted in the **Transit Cooperative Research Program**,

☐ American Association of State Highway and Transportation Officials, in cooperation with the Federal Motor Carriers Safety Administration, and was conducted in the **Commercial Truck and Bus Safety Synthesis Program,**

☐ Federal Aviation Administration and was conducted in the **Airports Cooperative Research Program,** which is administered by the Transportation Research Board of the National Academies.

DISCLAIMER

The Final Manual for the Nevada Department of Transportation and Federal Highway Administration Pooled Fund Study:
The Wildlife Vehicle Collision (WVC) Reduction and Habitat Connectivity Transportation Pooled Fund Project TPF 5(358)

The Strategic Integration of Wildlife Mitigation into Transportation Procedures: A Manual for Agencies and Partners

Authored by

Patricia Cramer, PhD
Wildlife Connectivity Institute, Gallatin Gateway, Montana

In conjunction with:

Julia Kintsch, MS
ECO-resolutions, Golden, Colorado

Jeff Gagnon, MS
Arizona Game and Fish Department, Phoenix, Arizona

Norris Dodd, MS,
Independent Wildlife Ecologist, Pinetop, Arizona

Terry Brennan, PE
USDA Forest Service (Retired), Grass Valley, California

Lisa Loftus-Otway, JD
University of Texas, Austin, Center for Transportation Research, Austin, Texas

Kimberly Andrews, PhD
University of Georgia, Savannah, Georgia

Pat Basting, BS
Independent Wildlife Ecologist, Montrose, Colorado

Leonard Sielecki, PhD, R.P. Bio, P. Ag
British Columbia Ministry of Transportation and Infrastructure

Loran Frazier, PE, MBA
TD & H Engineering, Great Falls, Montana

Dedication

This research project and manual were developed during the difficult time of the Covid 19 Pandemic. Several of the authors lost their parents during the project. This manual is dedicated to their memory:

Thomas Cramer

And

Barbara Jean Basting

Table of Contents

Table of Tables

Table of Figures

Acknowledgements

The research reported herein was performed under the Nevada Department of Transportation Project:" Research and Report on the Strategic Integration of Wildlife Mitigation into Transportation Procedures" as part of the Transportation Pooled Fund Project TPF 5(358) on Wildlife Vehicle Collision (WVC) Reduction and Habitat Connectivity.

Dr. Patricia Cramer, Independent Wildlife Researcher was the Principal Investigator on this project. Research team authors of the report include: Julia Kintsch of ECO-resolutions based in Golden Colorado; Jeff Gagnon, Arizona Department of Game and Fish, Phoenix, Arizona; Norris Dodd of Pinetop, Arizona; Terry Brennan, U.S.D.A. Forest Service, Retired, Grass Valley, California; Pat Basting, of Montrose, Colorado; Loran Frazier of TD & H Engineering, Great Falls, Montana; Dr. Leonard Sielecki of the British Columbia Ministry of Transportation and Infrastructure, Victoria, British Columbia; Lisa Loftus-Otway, University of Texas, Austin, Center for Transportation Research, Austin, Texas; and Dr. Kimberly Andrews, University of Georgia, Brunswick, Georgia.

The Research Team acknowledges the contributions of the Technical Advisory Committee for this project. These advisors include: Kenneth Chambers and Nova Simpson, Nevada Department of Transportation; Daniel Buford of the U.S. Federal Highway Administration; Jon Knowles, Alaska Department of Transportation; Justin White, and others in the Arizona Department of Transportation; Lindsay Vivian, Luz Quinell, Melinda Molnar and others of the California Department of Transportation; Steven Gent, Iowa Department of Transportation; Amanda Novak, Michigan Department of Transportation; Christopher Smith, Minnesota Department of Transportation; James Hirsch and Matthew Haverland of the New Mexico Department of Transportation; Cathy Giesbrecht, Amanda Seaman, Natalie Boyd, Lora Yurdakul, and Jennifer Newman of the Ontario Ministry of Transportation; Cidney Bowman, Oregon Department of Transportation; Glen Kalisz and Kelly McAllister, Washington Department of Transportation; Trevor Kinley, Vanessa Rodrigues, and Alexandra Taylor of Parks Canada; and Jeremy Guth and Sandra Jacobson, ARC Solutions, Inc.

Kelly Hardy of the American Association of State Highway Transportation Officials (AASHTO) was extremely helpful in helping contact AASHTO committee members for the survey and getting the results out. The state departments of transportation traffic safety engineers and their colleagues in every state DOT were extremely helpful in sharing crash data for our study. We appreciate the editing skills of Amy Hochberg, our editor. The participants in our survey are also owed a debt of gratitude for the time they took to fill out the survey and give their input. Chris Slesar of Vermont Transportation Agency (VTrans) dedicated time and photos for our case study on their Highways and Habitat program and we are thankful. Peter Leete of Minnesota Department of Natural Resources and liaison to the Minnesota Department of Transportation also dedicated time to helping develop our case study on his and his colleagues' work prior to his retirement and we appreciate his investment. Kristina Ernest also dedicated time, photos, and links to the many studies the Central Washington University students and scientists produced. Dale Becker, retired from the Confederated Salish and Kootenai Tribe's Wildlife Program, and Sheri Ruther of Pima County, Arizona's Environmental Planning were co-authors in the first report from this study, "The Strategic Integration of Wildlife Mitigation into Transportation Procedures: Practices, Partnerships, and Next Steps."

Correspondence regarding this study can be directed to the Principal Investigator:

Dr. Patricia Cramer, Wildlife Connectivity Institute, cramerwildlife@gmail.com.

Co-authors' Contact information

Terry Brennan, retired U.S. Forest Service, terrybrennan678@gmail.com

Julia Kintsch, ECO-resolutions, julia@eco-resolutions.com

Jeff Gagnon, Arizona Game and Fish Department, JGagnon@azgfd.gov

Norris Dodd, Independent Wildlife Researcher, doddnbenda@cableone.net

Leonard Sielecki, British Columbia Ministry of Transportation and Infrastructure, Leonard.Sielecki@gov.bc.ca

Pat Basting, Independent Wildlife Researcher, pbasting@msn.com

Loran Frazier, TD & H Engineering, Loran.Frazier@tdhengineering.com

Lisa Loftus-Otway, University of Texas, Austin, Center for Transportation Research, lisaloftusotway@outlook.com

Kimberly Andrews, University of Georgia, kma77@uga.edu

Key Terms and Abbreviations

Acronym	Definition
AADS	Animal-activated detection system
AADT	Average annual daily traffic (traffic volume)
AASHTO	American Association of State Highway Transportation Officials
AHDriFT	Adapted-Hunt Drift Fence Technique
AI	Artificial Intelligence
AZDOT	Arizona Department of Transportation
AVC	Animal-vehicle collisions. Crashes with wild and domestic animals or because of animals. They may or may not be reported crashes. The term is more of a phenomenon than a specific type of crash or carcass. Evolving to the term animal-vehicle conflict, which explains the effects of transportation on wildlife and animals, and not just collisions.
BACI	Before After Control Impact – a scientific approach
BCA	Benefit-cost analysis
BCMOTI	British Columbia Ministry of Transportation
BIL	The U.S. 2021 Transportation Act – the Bipartisan Infrastructure Law
BLM	Bureau of Land Management
CEQ	Council on Environmental Quality – a U.S. Whitehouse Administration's advisory council
CDOT	Colorado Department of Transportation
C.F.R.	Code of Federal Regulations
CHANJ	Connecting Habitat Across New Jersey
CMP	Corrugated metal pipe
CPW	Colorado Parks and Wildlife
CORA	Colorado Open Records Act
DEM	Digital Elevation Maps
DNR	Department of Transportation
DOT	Department of Transportation, for individual states in the U.S.
EA	Environmental Assessment
EIS	Environmental Impact Statement

Acronym	Definition
EPA	The U.S. Environmental Protection Agency
EO	Executive Order
FHWA	The U.S. Federal Highway Administration
GIS	Geographic information system
GPS	Global positioning system
HALT	Hobbs Active Light Trigger
HD	High definition
HSIP	Highway Safety Improvement Program – a source of funding from the U.S. federal government for highway safety projects
I-	Interstate highway abbreviation
ICOET	International Conference on Ecology and Transportation
INFRA	Nationally Significant Freight and Highway Projects
ITRD	International Transport Research Documentation (https://www.itf-oecd.org/international-transport-research-documentation-public)
ITD	Idaho Transportation Department
LED	Light emitting diode
LRTP	Long Range Transportation Plan
MDT	Montana Department of Transportation
MFWP	Montana Fish Wildlife and Parks
MnDOT	Minnesota Department of Transportation
MOA	Memorandum of Agreement
MoT	Ministry of Transportation for each province in Canada
MoTI	Ministry of Transportation and Infrastructure in Canada
MOU	Memorandum of Understanding
MPO	Metropolitan Planning Organization – a U.S. federally designated organization representing localities in all urbanized areas with human populations of 50,000 or more. The board is to carry out the metropolitan transportation planning process. See: URL: https://www.transit.dot.gov/regulations-and-guidance/transportation-planning/metropolitan-planning-organization-mpo
MSWP	Montanans for Safe Wildlife Passage
MTP	Metropolitan Transportation Plans – developed by MPOs
NDOT	Nevada Department of Transportation

Acronym	Definition
NGO	Non-government organization
NHIC	Natural Heritage Information Centre
NHP	Natural Heritage Program
NMDOT	New Mexico Department of Transportation
NEPA	National Environmental Protection Act
OHSA	Optimized hotspots analysis – performed in a GIS
OHV	Off-highway vehicle
PAS	Passage Assessment System, created by Kintsch and Cramer (2011) for Washington DOT to assess existing infrastructure for wildlife permeability of various types of species
PDO	Property Damage Only accidents
PE	Professional Engineer
PEL	Planning and Environmental Linkages- a collaborative decision making approach, FHWA approved
PFS	Pooled Fund Study
PIR	Passive Infrared
PIT	Passive integrated transponders – a type of tag on wildlife to use in telemetry tracking
PIT Crew	Montana Planning and Information Team
PROTECT	Program to Protect Resilient Operations for Transformative, Efficient, and Cost-saving Transportation
ROW	Road right of way, area owned by the transportation agency, stretching from the ROW fence to the ROW fence on each side of a road
RPM	Raised Pavement Markers
RPO	Regional Planning Organization
RTA	Regional Transportation Authority of Pima County, Arizona
SAFETEA-LU	The 2005 U.S Transportation Act: Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SAR	Species at Risk
SH	State Highway
SO 3362	U.S. Interior Secretarial Order 3362, concerning protecting habitat and corridors in 11 western states to protect mule deer, elk, and pronghorn
SR	State Road

Acronym	Definition
STIP	U.S. State Transportation Improvement Plan. A 5-year planning document created by every U.S. DOT that include upcoming projects across the state.
TAC	Technical Advisory Committee – the members of the supporting organizations that advise the project. See Acknowledgement section for key members.
TIP	Transportation improvement programs – short range plans for upcoming transportation projects.
TRB	Transportation Research Board of the U.S National Academies (https://www.nationalacademies.org/trb/transportation-research-board)
TRID	Transportation Research Integrated Database - an integrated database that combines the records from TRB's Transportation Research Information Services, (TRIS) and the Joint Transport Research Centre's International Research Documentation (ITRD) Database. URL: https://trid.trb.org/.
TRIS	Transportation Information Services (http://www.trb.org/InformationServices/InformationServices.aspx)
TxDOT	Texas Department of Transportation
UDOT	Utah Department of Transportation
UDWR	Utah Division of Wildlife Ressources
U.S.	United State of America
USC	United States Code
USDA	U.S. Department of Agriculture
USDOT	U.S. Department of Transportation, the federal level DOT
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geologic Service
VHF	Very high frequency
VMS	Variable Message Sign
VTrans	Vermont Agency of Transportation
WARS	British Columbia Ministry of Transportation and Infrastructure Wildlife Accident Reporting System
WRI	Water Restoration Initiative
WSWPS	Colorado's Western Slope Wildlife Prioritization Study
WVC	Wildlife-vehicle collisions. The phenomenon of wildlife involved in crashes on the highway, whether reported or un-reported. It is evolving

Acronym	Definition
WVC	to represent wildlife-vehicle conflict, which includes crashes and the effects of transportation on wildlife such as reduced connectivity
WYDOT	Wyoming Department of Transportation

Chapter 1. Introduction to Wildlife-Vehicle Conflict and This Manual

Introduction to the Wildlife Vehicle Collision Reduction and Habitat Connectivity Study

Figure 1-1. Moose on a Minnesota highway. Photo Credit: P. Leete.

This manual is the product (one of several) of the Wildlife Vehicle Collision Reduction and Habitat Connectivity Pooled Fund Study, a collaborative research effort through the United States (U.S.) Federal Highway Administration Pooled Fund Program that ended in 2022. Partner agencies and a non-profit organization (the Partners) from the U.S. and Canada came together and funded this study with the goals of reducing wildlife-vehicle collisions for the safety of humans and wildlife, and to help restore wildlife connectivity in landscapes fragmented by roads (**Figure 1-1**). The Partners were led by the Nevada Department of Transportation, and included the U.S. Federal Highway Administration, and the Departments of Transportation (DOTs) of Alaska, Arizona, California, Iowa, Michigan, Minnesota, New Mexico, Oregon, and Washington. Canadian partners included the Ontario Ministry of Transportation (MoT), and Parks Canada. The non-profit, ARC Solutions, Incorporated was also a partner.

This manual focuses on integrating wildlife concerns into transportation processes and procedures. State, provincial, and smaller transportation agencies can use the presented standardized methods to integrate wildlife concerns into transportation processes. The science and practice of transportation ecology have grown exponentially in the past 20 years. This manual was delivered at a time when the body of research on wildlife and roads and proven standards on incorporating wildlife into transportation planning were robust enough that national level standards and guidance could be created for use across North America. The manual is not the first of its kind. Bissonette and Cramer (2008) produced a very similar manual with much of the same information. In a Report to Congress, Clevenger et al. (2011) provided many details on wildlife mitigation. This manual is an update of these and other efforts. It contains many clear examples and case studies of how people within and outside transportation agencies were able to partner to create projects, inform transportation procedures, create best management practices manuals, and other approaches to make these efforts more commonplace.

People are key; Bissonette and Cramer (2008) found agencies with the greatest number of wildlife crossing structures had just three to five people within the transportation agency who promoted wildlife. Today there are administrators, engineers, and planners that are also involved but whom may struggle to understand what types of structures and fences work, and how they can incorporate concerns for wildlife in regular transportation practice. The experiences of states, provinces, and other entities who have created standards and wildlife mitigation were used as examples and templates for this two-nation manual to help guide professionals and their partners in the consideration of wildlife during the course of transportation processes.

Overview of the Challenges of Transportation and Wildlife

This manual focuses on how transportation agencies and their partners can reduce the challenges and effects of wildlife-vehicle conflict, which is defined to include crashes with wildlife, road avoidance by animals that need to get across, habitat fragmentation, the extinction or extirpation of local wildlife populations, genetic isolation of wildlife populations due to roads, and other consequences of animals' inability to safely move across roads to necessary habitat across the landscapes, both terrestrial and aquatic.

Transportation agencies' missions have traditionally focused on what occurs within the road right-of-way. However, as the Context Sensitive Solutions and Designs process (American Association of State Highway and Transportation Officials Center for Environmental Excellence 2022) and other methods of considering beyond the road have become more common, it is time wildlife considerations become more standardized in transportation processes.

The safety of the motoring public is a concern that is part of a transportation agency mission, and wildlife-vehicle collisions pose a safety risk in every U.S. state and Canadian province. The reduction of the risk of wildlife-vehicle collisions is a safety goal all transportation personnel can get behind and work toward within the mission of an agency. This is how most proactive agencies, when it comes to wildlife crossing structures, begin their journey to include wildlife concerns in project delivery. As the process to build wildlife crossing structures and other wildlife infrastructure becomes more standardized, agencies find ways to protect wildlife and facilitate wildlife connectivity across roads for all types of terrestrial and aquatic species and processes, regardless of their risk to the traveling public.

The safety aspect of wildlife-vehicle crashes, which are those collisions that are reported to the departments and ministries of transportation, is an important entry for all interested in finding ways to raise awareness and fund measures that help wildlife safely move beneath or above the road in wildlife crossing structures and other measures, also referred to in this manual as mitigation.

Wildlife-Vehicle Reported Crashes and Societal Costs

Examining the extent of reported wildlife-vehicles crashes can help place a figure on the societal cost of those crashes, for either a stretch of road, a state or province, or a nation. Each reported crash is coded as to its severity as either: property damage only; injury crash with three different levels of injuries; or as a fatal crash. If the wildlife-related crashes and their severity type can be tallied for a jurisdiction and averaged over a year, the magnitude of wildlife crashes can be realized. Those crashes have estimated costs to society which are valued differently by each transportation department and the U.S. Federal Highway Administration (FHWA, Harmon et al. 2018).

The researchers in this study contacted the traffic safety engineers of all 50 U.S. states to gather their crash data on all crashes, crashes with animals, and in most states, crashes with wildlife. There are 13 states that did not delineate if a crash with an animal was with wildlife or a domestic animal. Therefore, animal crash data for all 50 states was used rather than leave out those 13 states' crashes that did not delineate wildlife. The analyses resulted in a national estimate of the magnitude of animal-vehicle crashes, not just wildlife crashes.

Each state's crash data for five years as of 2018 crash numbers were analyzed. Annually there were on average, at least 345,000 reported crashes with all animals across the U.S. There were on average 201.8 fatal crashes with animals each year. The societal cost of all these crashes, based on severity of injuries, fatalities, and property damage only for each crash, is over $10 billion annually, using the FHWA 2018 estimates for crash costs (values were not adjusted beyond the 2018 values given in Harmon et al. 2018), see **Figure 1-2**.

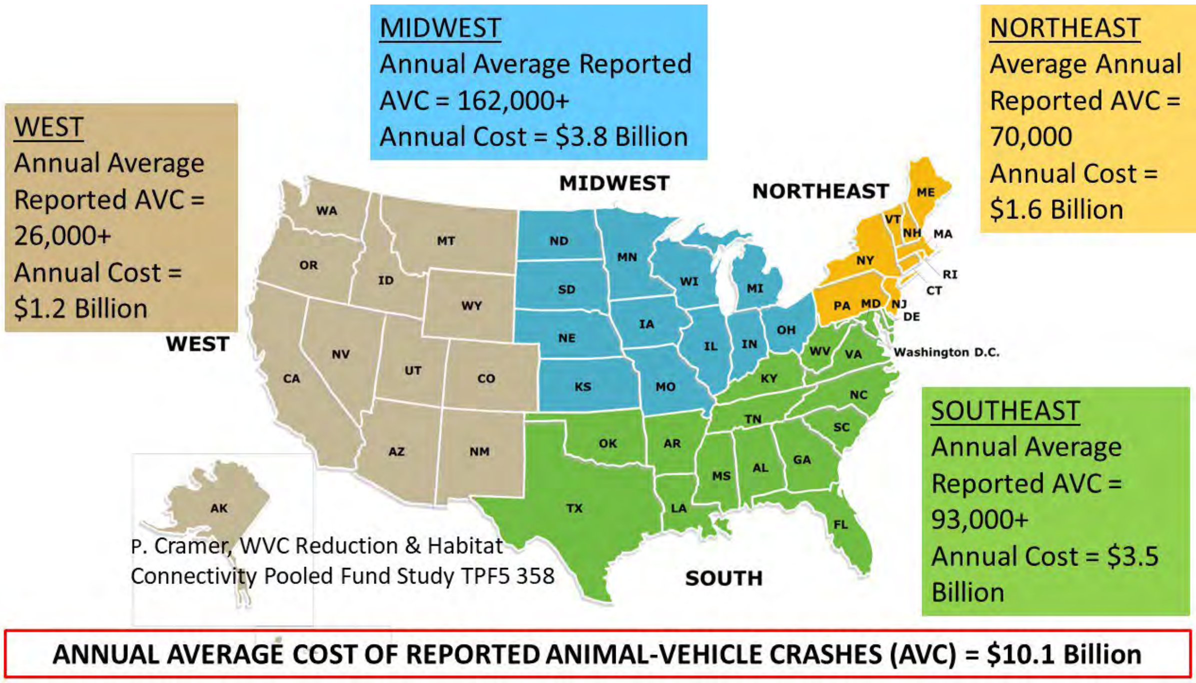

Figure 1-2. The annual average number of reported crashes with animals in U.S. regions, and the societal cost of those crashes, based on a census of all Departments of Transportation in 2020 and Federal Highway Administration crash values from Harmon et al. (2018).

The annual average cost to society of crashes with animals in each U.S. state were calculated based on each agency's own crash numbers over five years, and costs values for the various severities of crashes and the FHWA cost estimates. These are presented along with the annual average: number of crashes with all animals; the percentage of all the crashes that were animal-related; and number of fatal collisions with animals, **Table 1-1**.

The state with the greatest number of reported animal-vehicle crashes was Michigan, with over 54,000 annually reported. New York was second, with over 40,000.

The state with the highest percentage of all crashes that were animal-related was South Dakota, with over 25 percent. Wyoming was second with over 20 percent.

The state with the greatest annual average of fatal accidents was Texas, with over 30 fatal animal-vehicle crashes per year. Michigan was second with over 18.

The state with the greatest cost to society based on FHWA crash values was Michigan, with over one billion dollars in costs to society for their animal-vehicle crashes. Texas was second with over 900 million dollars in costs to society for animal-vehicle crashes.

Table 1-1. For each U.S. state data are presented for: the annual average number of animal-vehicle crashes; the percentage of all crashes that were animal crashes; the annual average number of fatal animal-vehicle crashes; the annual cost to society for those crashes using state crash costs; and the Federal Highway Administration crash costs based on Harmon et al. 2018, for that state. Based on 2014-2018 crash data.

State	Annual Average Number of Animal-Vehicle Crashes	Percentage of Total Crashes	Annual Average Number of Fatal Crashes	Societal Cost Using State's Crash Costs	Societal Costs Using FHWA Crash Costs*
Alabama	2,424	1.59	1.40	$100,946,835	$89,537,280
Alaska	685	6.51	1.60	$46,472,960	$47,750,540
Arizona	2,117	1.74	1.80	$72,641,014	$77,466,560
Arkansas	2,495	3.20	3.67	$64,581,667	$104,943,533
California	2,131	0.45	4.80	$251,844,156	$149,765,700
Colorado	4,326	3.62	4.80	$87,695,460	$197,031,540
Connecticut	434	0.16	0.00	$4,108,000	$11,598,280
Delaware	1,531	5.87	0.40	$33,709,140	$33,709,140
Florida	✧	✧	✧	✧	✧
Georgia	14,489	3.77	4.80	$851,731,800	$428,343,420
Hawaii	36	0.37	0.20	$4,537,440	$4,537,440
Idaho	1,542	6.31	1.80	$47,538,374	$74,580,420
Illinois	16,245	5.18	5.80	$330,197,028	$403,181,180
Indiana	16,362	7.62	6.00	$359,596,580	$324,639,740
Iowa	6,915	12.91	2.60	$83,528,000	$175,772,240
Kansas	9,846	15.65	4.2	$166,192,800	$219,511,100
Kentucky	6,565	4.80	5.2	$158,227,125	$193,327,720
Louisiana	2,222	1.34	1.2	$73,233,190	$73,979,540
Maine	5,671	16.51	1.40	$103,153,400	$127,922,720
Maryland	1,936	1.73	1.00	$72,912,340	$72,912,340
Massachusetts	2,969	2.12	0.80	$90,119,680	$65,057,420
Michigan	54,328	17.30	18.75	$720,359,950	$1,122,628,350
Minnesota	1,944	2.33	6.00	$26,780,020	$153,436,320
Mississippi	4,222	5.30	2.80	$85,626,500	$110,992,380
Missouri	4,550	3.05	6.60	$186,598,040	$221,883,880
Montana	3,450	15.14	4.20	$100,302,700	$157,838,360
Nebraska	2,659	7.52	2.00	$95,103,644	$94,967,760
Nevada	625	1.30	1.80	$27,065,597	$44,770,940
New Hampshire	1,536	4.51	0.60	$39,879,780	$34,038,560
New Jersey	10,015	3.65	2.60	$156,111,786	$209,053,000
New Mexico	1,615	4.24	1.60	$27,209,440	$62,592,060

State	Annual Average Number of Animal-Vehicle Crashes	Percentage of Total Crashes	Annual Average Number of Fatal Crashes	Societal Cost Using State's Crash Costs	Societal Costs Using FHWA Crash Costs*
New York	40,465	8.19	6.20	$292,698,853	$757,995,900
North Carolina	21,658	7.15	3.60	$424,460,520	$509,066,100
North Dakota	2,749	18.84	1.20	$56,551,220	$56,551,220
Ohio	20,990	7.03	6.80	$296,927,145	$525,951,680
Oklahoma	1,451	2.08	5.40	$214,329,840	$154,712,880
Oregon	1,679	3.07	1.60	$115,306,260	$134,632,140
Pennsylvania	4,121	3.24	12.40	$327,329,692	$304,875,400
Rhode Island	989	2.02	0.00	$10,212,014	$22,345,080
South Carolina	3,151	2.30	6.20	$124,648,200	$182,486,240
South Dakota	4,845	25.97	2.00	$126,407,780	$99,953,980
Tennessee	8,967	4.37	5.00	$285,109,100	$285,109,100
Texas	11,614	0.02	30.80	$2,043,960,200	$917,888,680
Utah	3,374	5.68	3.00	$137,637,220	$121,227,460
Vermont	324	2.82	0.60	$9,653,686	$15,307,540
Virginia	6,405	4.99	2.20	$133,999,660	$195,799,100
Washington	1,665	3.17	0.80	$79,308,460	$62,114,420
West Virginia	1,795	5.15	3.20	$62,499,883	$107,399,960
Wisconsin	20,710	16.48	8.80	$416,241,806	$443,596,260
Wyoming	2,958	20.84	1.60	$157,765,296	$71,447,360
Total	345,795	5.14	201.82	$9,783,051,280	$10,056,229,963

* = Harmon et al. 2018 FHWA estimated societal costs. ✦= Numbers and Costs could not be calculated due to reporting complexities in different data worksheets

Ecological Consequences of Roads and Traffic

Wildlife-vehicle collisions and wildlife-vehicle conflict inflict far more damage within the natural world than what we record in crashes and their effects to humans. Olson (2013) found there were 5.6 times more large mammals collected along Utah roads than reported in crash data. Donaldson and Lafon (2008) documented over nine times more large animals collected by Virginia DOT maintenance personnel than recorded in crashes. If all the reported animal crashes were with wildlife (which they are not) and the more modest "Olson factor" is multiplied to the national annual average of 346,985 animal-crashes, there are on average at least 1.9 million large animals killed each year on U.S. roads administered by departments of transportation. The number is far higher, as the Virginia crews found for large animals, and the tally on medium to small animals is not included. These numbers also do not account for animal-vehicle crashes on the approximately 75 percent of roads present that are not administered by the state departments of transportation. These other roads are administered by cities, counties, the U.S. Forest Service, the U.S. Bureau of Land Management, sovereign nations, and other entities.

What do those numbers tell us about the effects of wildlife-vehicle conflict? Can wildlife populations sustain this level of mortality on roads? How do animals access the areas they need to survive with increasing traffic and vehicle miles traveled, additional road lanes, and new highways?

These challenges are met by the creative and persistent people within and outside of transportation agencies who partner together for wildlife. The ecological goal for measures (or mitigation as it is called here) that help wildlife navigate the roaded landscape is to provide and restore connectivity for all members of the suites of species present nearby. This means mitigation planning is not for just the safety of the public in motor vehicles, but also wildlife population survival of all types of species. A brief overview of road and vehicle effects on wildlife movement can help explain why this is necessary.

Huijser et al. (2008) estimated that 21 U.S federally listed threatened or endangered wildlife species were threatened by vehicle collisions.

In 2018, 11 western states listed their top wildlife migration corridors for mule deer, elk, and pronghorn in accordance with the U.S. Interior Secretarial Order 3362. This order mandated Interior Department agencies work with state wildlife agencies to help protect these three species, their winter range, and migration corridors. All 11 states listed vehicle collisions and roads as major threats to these species.

Vehicle collisions are not the only threat to wildlife. Some species need to cross roads to access habitat and mates, but avoid roads and/or traffic on roads. These include pronghorn (Dodd et al. 2010), and grizzly bear (Waller and Servheen 2010).

The impact of roads and vehicles are most severe on amphibians and reptiles. Rytwinski and Fahrig (2012) analyzed 75 studies on the effects of roads and vehicles on various wildlife species and found these species' populations are most vulnerable. The threats from roads and vehicles to amphibians and reptiles include direct mortality, and the loss, degradation, and fragmentation of habitat (Gunson et al. 2016).

Roads fragment wildlife habitat, which cause animals to be virtually trapped in areas bordered by roads. As climate change brings about exacerbates droughts, wildfires, and other weather-related phenomenon, animals of all kinds will need to move to access unaffected habitat such as moving up in elevation and north in latitude, to areas that do not become as hot and dry as others, or to move out of areas that are subjected to wildfire or flooded by spring runoff or rising oceans.

These road and vehicle effects and how to minimize their impacts are the focus of this manual. This manual discusses how transportation processes can take into consideration wildlife needs to move and survive.

How to Use this Manual

This manual is designed for all who may have input into the way transportation procedures and processes are carried out. It is intended to help professionals and the public provide input into transportation planning so that wildlife-vehicle collisions and wildlife connectivity are considered in every step of the process. There are four main chapters in this manual. Each chapter has a different color coded page border to assist with accessing information quickly. Appendices round out the information.

Chapter 2. Prioritization

The prioritization chapter demonstrates how transportation safety and ecological factors can be analyzed to provide guidance in addressing the most pressing areas of concern for wildlife-vehicle conflict.

Chapter 3. Planning, Project Development and Everyday Operations

This chapter defines how the six main steps to the transportation process typically operate in transportation agencies, **Figure 1-3**. Methods are documented on how to include wildlife concerns early in the transportation planning process, in programming, in the design stages of a project, as construction proceeds, and in everyday maintenance operations. Chapter 3 is the heart of the manual.

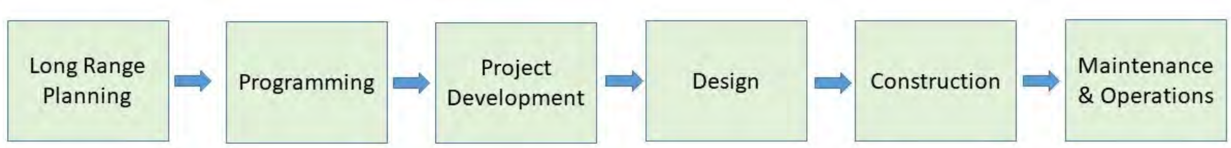

Figure 1-3. The flow diagram of the transportation process.

Chapter 4. Monitoring Strategies

This chapter details how science can be conducted before a project begins, and for years afterward, to evaluate if the mitigation for wildlife met stated goals, otherwise known as performance measures. There is also a monitoring plan template.

Chapter 5. Summary and Recommendations

This final chapter gives a broad point-by-point list of the knowledge generated in this study, and 35 recommended actions transportation agencies and their partners can take to increase the consideration of wildlife in transportation processes, which would make the roads safer for motorists, and protect wildlife populations across the U.S. and Canada.

There are five appendices. These appendices present the information in much deeper and detailed methods than the main body of the manual.

Appendix A. Case Studies

Appendix A presents dozens of case studies demonstrating how others have implemented successful mitigation strategies that this manual hopes to inspire.

Appendix B. Data

Appendix B presents the data needed for prioritization and other steps along the transportation process.

Appendix C. Memoranda of Understanding.

Appendix C presents several state Memorandum of Understanding between transportation and wildlife agencies.

Appendix D. Wildlife Mitigation

Appendix D gives details of most types of wildlife mitigation.

Appendix E. A Wildlife Monitoring Plan Guide

This appendix offers a detailed set of plans to monitor wildlife mitigation based on objectives, limitations, and wildlife.

While this manual has suggested ways to incorporate wildlife considerations and projects into the transportation planning process (see **Figure 1-4**, the study's guiding diagram), it is not meant to be the final and only source of information. This practice and science is continually adapting to new and more effective solutions and information. Each situation is unique with regards to terrain, human activities, and wildlife interactions and habituations. Further, wildlife is unpredictable and cannot be expected to react the same way even though the stimuli and characteristics are the same. Therefore, collaboration among multiple disciplines throughout the entire planning, design and construction process will be necessary to have successful wildlife crossing solutions. While using plans and specifications from a previous project might be the easier way to proceed, it might not be the best solution for the wildlife being considered and that is the goal of these types of projects: to get the animal safely across the road and keep the motoring public safe. New plans and approaches made in partnership are the way forward.

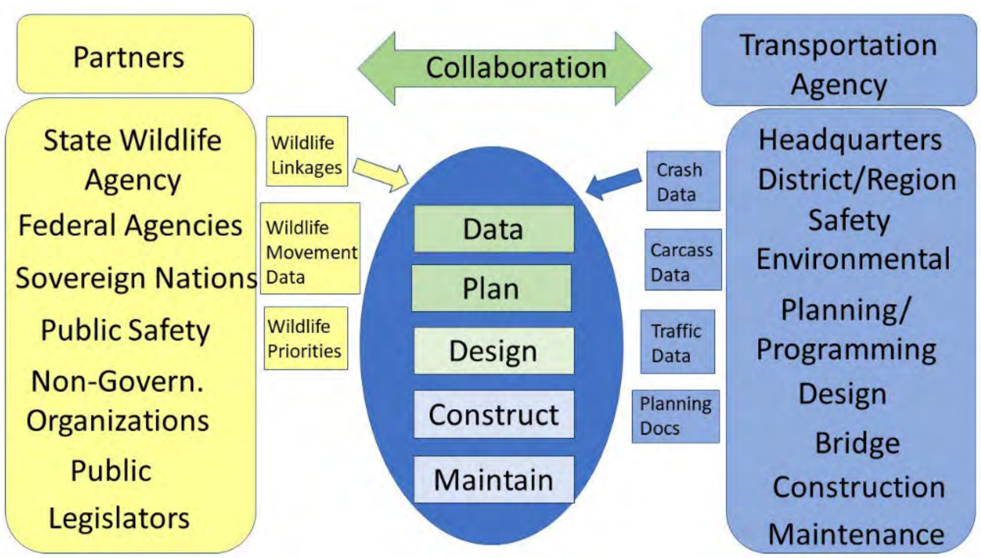

Figure 1-4. The transportation process: data needed, transportation agency divisions, and outside partners important to the creation of wildlife mitigation.

Chapter 2. Prioritization

Introduction

Figure 2-1. Mule deer migrated over a US 93 overpass in Nevada. Photo Credit: N. Simpson, Nevada DOT.

Data collection and analyses are needed to address wildlife needs to move across roads. These data include transportation safety, ecological, and feasibility factors that are analyzed to provide an objective approach of prioritizing the most pressing areas of wildlife and vehicle conflict. This chapter presents prioritization approaches based on various objectives. It is strongly recommended that priority areas for wildlife mitigation be based on multiple factors that include both wildlife needs and transportation safety conflicts, and not based solely on crash data. No one index or analysis of a single factor can adequately encompass the many essentials to keep motorists safe and wildlife populations alive and moving (**Figure 2-1**).

Data important to the prioritization of areas for wildlife crossing structures and wildlife-vehicle collision reduction are presented in **Figure 2-2**. They are based on the approach that a series of maps is brought together to create a prioritization map of road segments most important to reduce wildlife-vehicle conflict. Other data may be incorporated, including information from the public and citizen science. The majority of these data are available in Geographic Information System (GIS) files. This allows a GIS analyst to use ArcGIS or other software to evaluate every segment of every road for its intersection with these variables to prioritize wildlife-vehicle conflict areas in the manner the participating parties have agreed to map.

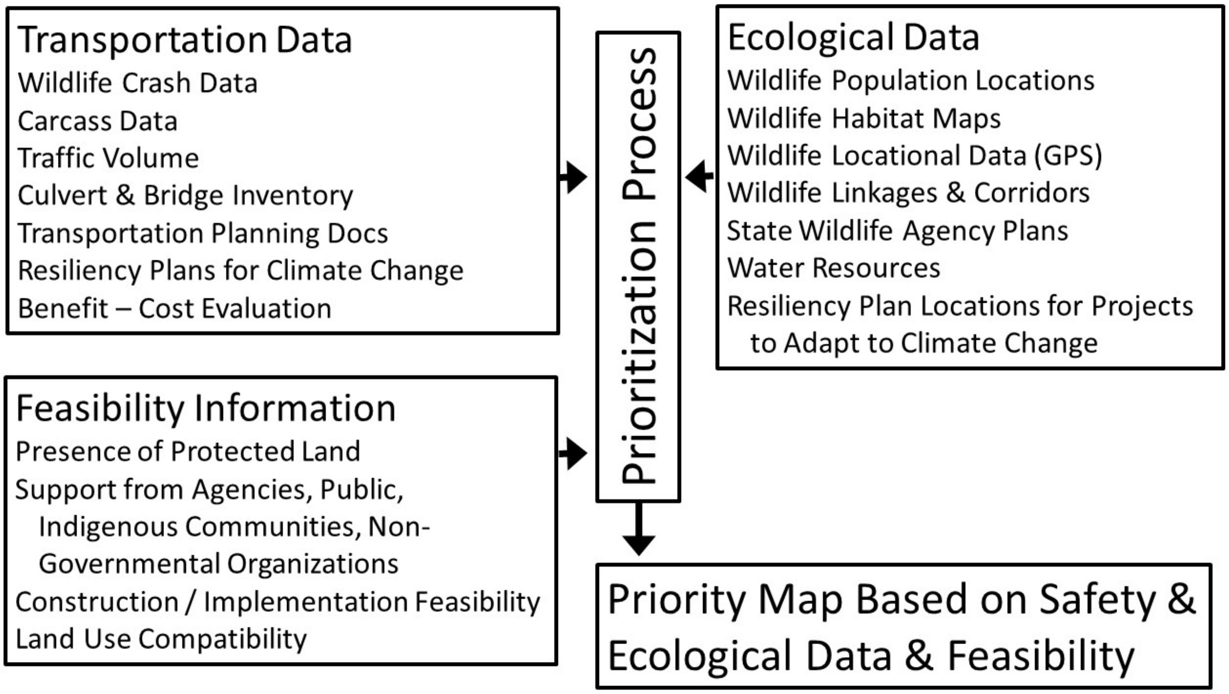

Figure 2-2. Data inputs to a prioritization process.

Identify the Objectives of Prioritization

If the prioritization is intended to find places where motorists are at greatest risk for crashes with animals, then a crash analysis alone can help to elucidate that goal. Crash analyses are often done to help support the justification or need for a project to receive U.S. Highway Safety Improvement Program (HSIP) funding from FHWA.

However, if the goal is to be proactive in identifying areas of potential conflict with wildlife of all kinds, not just those recorded in past accidents, then more information is needed. The majority of that information is usually GIS-based maps, such as wildlife habitat locations (distributions) known or modeled.

Not all information is geo-referenced in a GIS. Additional information may be derived from reports, public and professional support for actions in specific places, and other information that may not be quantified in a GIS analysis.

Many state, provincial, and regional prioritization studies are carried out with the objective to address both wildlife-vehicle collision reduction and wildlife and ecological goals using available spatial data combined with other data and information. The Nevada Wildlife-Vehicle Conflict Prioritization study provides an example of how multiple factors can be brought together to prioritize road segments for future wildlife mitigation (Cramer and McGinty 2018). It is presented as a case study with a more holistic approach to many factors in Appendix A. Case Studies.

Transportation Factors to Evaluate in a Prioritization

Introduction

Transportation data are important in identifying past problem areas of wildlife-vehicle conflict and the potential for where mitigation is most needed to ensure safety for the public traveling on roads and to keep wildlife moving.

Analyzing Crash Data for Hotspots

Crash data that include reports of collisions with large animals are the most important data source used to prioritize road segments based on transportation information. Traffic safety engineers evaluate crash data for upcoming transportation projects and can be strong allies in including wildlife concerns and wildlife-vehicle collisions into transportation planning. The engineers and planners can tap into various funding categories based on past crashes and the potential for future crashes.

Crash data included in prioritization score cards have included the number of crashes with animals or wildlife that were fatal to humans, and the number of wildlife-caused accidents which resulted in human injury, and the severity of those injuries. These analyses have also included scoring the percentage of total crashes that were wildlife-related (see Cramer et al. 2022b, Williams et al. 2021)

Analyses of reported crash data can help identify the extent of all animal collisions, specifically wildlife collisions, hotspot areas, species involved, and costs. Typically, crash data are analyzed in a hotspot modeling approach. See

PROFESSIONALS TO ENGAGE IN THIS APPROACH

- Transportation Agency Traffic Safety Engineers
- Transportation Agency Environmental Ecologists
- Transportation Agency Planners
- Transportation Agency Program Managers and Directors
- Transportation Agency District / Regional Engineer
- GIS Analysts in the transportation agency, wildlife agency, or other partners
- Consultant Ecologists

Appendix B. Data, section Crash Data on how these analyses have and could be conducted.

Evaluating Carcass Data

Carcass data are also important and may include smaller species not typically reflected in crash data. They can help identify the animals involved all kinds of collisions, not just reported crashes. These data have traditionally not been collected consistently over provinces or states, but may be well documented in a region or district. Thus, they are not typically used to prioritize wildlife mitigation over large areas. However, there are places where the number of carcasses reported can help in a combined score card of factors important to prioritization, see the Nevada example, Appendix A. Case Studies.

Carcass data can be important to a prioritization over smaller geographical areas, where the collection efforts are more standardized. This can be helpful to make prioritization decisions over a district or region, or even along a specific transportation corridor. Carcass data can be used to prioritize wildlife mitigation over these smaller areas using the same hotspot modeling as is used for crash data. Road segments can be ranked based on carcasses per mile, or for the presence of the more rare species and species of concern.

Traffic Volume Effects and Prioritization

Traffic volume, known as Annual Average Daily Traffic (AADT) data can inform prioritization as to where traffic volumes are too high for animals to navigate the traffic safely during the times of day and year they typically move (see Charry and Jones 2009). Higher traffic volume roads receive higher scoring in a prioritization, reflective of their barrier effect and lethality to wildlife. See Appendix B. Data, section Traffic Volume for more information on traffic effects and how to score roads based on AADT.

Culvert and Bridge Inventory and The Potential for Retrofits

Once priority areas are identified, bridge and culvert inventories can be consulted to identify where existing structures can be retrofitted cost-effectively to provide opportunities for wildlife to move beneath (and sometimes above) the road. A prioritization method could include a score for the potential for cost-effective easy measures to adapt existing culverts, bridges, fences and other infrastructure for use by wildlife in the road segment under scrutiny. For example, if there is a bridge over a flowing water body, there is potential to place an eight-feet (2.4 meter) fence to that bridge to guide large mammals and other wildlife to the bridge and allow them to cross beneath the road at that point. Tortoise and smaller animal fencing could be constructed to guide these animals to existing culverts as well. The design and extent of fencing on either side of the road would need to consider the local conditions and potential for additional wildlife collisions at the ends of the fencing.

Figure 2-3. Raccoon used a shelf placed in an existing culvert to pass beneath US 93 in Montana. Photo Credit: P. Cramer and Montana DOT**.**

The culverts could have wildlife shelves placed in them to allow these smaller animals to move beneath the road via the culverts when water is present (Figure **2-3**). Consideration of the continued function of the bridge or culvert to convey water must remain a paramount concern when considering retrofit options. See Appendix B. Data, section on Culverts and Bridges Inventory.

Prioritization Based on Transportation Planning Documents

Planning documents from the local, regional, and U.S. state and Canadian provincial/territorial transportation agencies can inform where future projects may be planned in areas where wildlife concerns should be considered. Long range transportation plans, state transportation improvement plans (STIPs), and Canadian transportation plans can be consulted to identify if any future transportation projects are in or near areas where wildlife crashes or wildlife connectivity issues have been identified. In a prioritization evaluation, segments of roads that have both a wildlife consideration and an upcoming project can be prioritized. These areas may not be the most urgent for wildlife, but can be mitigated opportunistically as projects come along. Many wildlife mitigation projects have occurred in both the U.S. and Canada this way **(Figure 2-4**). See

Figure 2-4. Mule deer move beneath US 97 in the Lava Butte Wildlife Mitigation Project area, south of Bend, Oregon. Wildlife-friendly crossing structures were placed in the road widening project. Photo Credits; Oregon DOT, Portland State University, P. Cramer.

Chapter 3 for more details on how wildlife concerns can be included in the planning and programming processes from their inception, rather than as an “add on” after the projects are formalized.

Prioritization in Tandem with Planning for Resiliency and Climate Change

The ongoing and future global changes in temperature, precipitation, sea levels, and disturbance processes mandate a broader approach to assessing transportation systems, especially with respect to wildlife connectivity. If the transportation agency has identified areas in need of improvements to adapt to climate changes, it could also become a place where wildlife movement is considered and integrated with the changed infrastructure. For example, bridges may need to be extended or enlarged to accommodate increased water flows (**Figure 2-5**). These bridge extensions or upgrades from a culvert to a bridge are the places where wildlife and fish can be accommodated to move beneath the roads. If the transportation agency is identifying these areas, and wildlife is present, the areas could receive a prioritization score to elevate these areas in a scorecard reflecting the potential for dual-purpose structures. It is not known if transportation agencies have begun using this as a prioritization factor in wildlife mitigation planning, but it is assumed and recommended that it will become an integral part of future planning. Learn more in the Appendix B. Data, Climate Change section.

Figure 2-5. A covered bridge in Vermont was almost washed away from the river surge due to Hurricane Irene in 2011. Photo Credit: P. Cramer.

Benefit Cost Considerations

The costs of wildlife mitigation actions, and potential funding sources can also be important in later stages of prioritization; however, the majority of prioritizations are based on the data and science first, and look at costs after priorities have been set. While some road segments may not rank as a high crash location priority, if there are upcoming projects and additional funding sources to build wildlife mitigation, these areas may rank higher in priority based on these opportunities. Chapter 3. Planning details a benefit-cost approach in the Economic Evaluations section. Appendix A. Case Studies presents a Colorado example of evaluating the benefits of wildlife mitigation.

The manual authors created a partner report to this manual that also details how benefit-cost analyses can be best conducted. See "The Strategic Integration of Wildlife Mitigation in Transportation Procedures: Practices, Partnerships, and Next Steps (Cramer et al. 2022a)."

Figure 2-6. Mule Deer use an existing culvert beneath I-25 in New Mexico. Photo Credit: New Mexico DOT, Arizona Game and Fish.

Combining Transportation Factors for Prioritization

A more highly informed method of prioritization includes combining many sources of data. Hotspot analyses are based solely on the number of reported crashes per mile per year. The multiple transportation factors discussed above can be combined in a scorecard to refine the prioritization based on many inputs. This helps create a more accurate representation of the problem areas than reported crash data alone. See Appendix A. Case Studies, for Nevada, and New Mexico's work (**Figure 2-6**) and the section on combining transportation and ecological data for how these transportation data are incorporated into a scorecard.

PROFESSIONALS TO ENGAGE IN THIS APPROACH

- Transportation Agency Environmental Ecologists
- Transportation Agency Planners – Headquarters and Local District/ Region
- Transportation Agency District / Regional Engineer
- Wildlife Agencies Ecologists
- GIS Analysts in the Transportation Agency, Wildlife Agency, or other partners
- Consultant Ecologists

Ecological Factors to Evaluate in a Prioritization

Introduction

Ecological concerns come from the perspective that wildlife and fish movement, and ecological processes need to continue unimpeded throughout the landscape, which were, are, and will be bisected by transportation corridors and human development. Identifying and then prioritizing these areas for potential wildlife mitigation across roads can be carried out based on a number of factors, such as: sheer numbers, as for example, deer populations' rank; or protected populations of species, such as an endangered turtle; or predicted areas where wildlife exists or needs to move across the road, such as wildlife linkages. The transportation agency Environmental Division staff at the headquarters and district / regional levels are the important staff to bring up pertinent data on ecological concerns and include them in prioritization processes, planning, and programming. Their partners at the district / regional level are important to prioritizing wildlife concerns into standalone or upcoming transportation projects. Wildlife professionals in the state or provincial agencies, and in the federal agencies are the "go-to" partners to help in the identification of these priority areas. The data and planning portals available in some areas are important places to locate the important data and plans to assist in these prioritizations.

Wildlife Locational Data and Habitat Maps

Figure 2-7. Florida panthers used a wildlife underpass in South Florida. Photo Credit: Florida Fish and Wildlife Conservation Commission.

There are apparent and subtler wildlife concerns that should be considered in a prioritization process for wildlife and transportation mitigation projects. The larger species of mammals that pose a risk to motorists are obvious candidates for evaluating associated ecological concerns. The listed wildlife species or candidates for listing for some level of state, provincial, or federal protection are also clear candidates for consideration (**Figure 2-7**). The concerns for many other species that lie outside these categories should also be included in a prioritization, but are often not, due in part to the complicated nature of adding multiple species for prioritization consideration. The species that are considered should represent various ecosystems and habitat types, and modes of locomotion to help broaden the prioritization.

It is critical to evaluate the full jurisdiction of an agency for wildlife presence and needs to move across transportation corridors. This could be the entire state, province, or Regional Planning area. These considerations will help avoid potential delays and cost for the transportation project, should they be considered later in the processes. Some state wildlife agencies have created assessment tools and guidance documents to help with this, such as New Jersey's CHANJ tools and guidance. See Appendix B. Data, Wildlife Locational Data section for the New Jersey case study and on how to access websites that help identify wildlife and ecosystems in need of protection. In turn, these data, maps, and other information can be used to prioritize areas with known wildlife populations that need to cross roads.

It is also important to work with the wildlife agency, and Indigenous Communities' wildlife professionals, and other researchers to learn of wildlife population and individual locations near roads to help determine those areas most important to wildlife. These interactions can save time and transportation project funding.

Listed Species

Listed protected species are transportation project red flags and their habitat and potential presence should be considered in tandem with any prioritization exercise. If these animals are not considered and planned for well in advance of any projects, the inclusion of their presence in or near a project can slow down and even halt transportation planning and construction. Listed species locations or habitats near roads are to be considered in a prioritization process (**Figure 2-8**). See Appendix B. Data the section on Listed Species for more information.

Figure 2-8. The U.S. federally threatened bog turtle. Photo Credit: G. Peeples, U.S. Geologic Service.

Wildlife Linkages

Prioritizing wildlife linkages is an acknowledgement that wildlife need to move across roads that bisect their habitats. A linkage is a landscape characteristic that provides enough natural habitat of an ecosystem that is used by the target species. The more narrowly defined areas where those linkages cross roads are more commonly referred to as corridors. Linkage and corridor reports should be considered and used as a screening tool to rank wildlife corridors across roads with higher priority than areas that are not identified as corridors. Typically, these maps can be developed in conjunction with the state or provincial wildlife agency, but there are also non-profit and academic efforts that have created linkages. See the Arizona Wildlife Linkages and Wildlife-Vehicle Conflict Case Study in Appendix B. Data, and reference to the Interior Secretarial Order 3362 for western state wildlife corridors, also in Appendix B. Data.

State / Province Wildlife Agency Plans and Assessments

U.S. State Wildlife Action Plans and Canadian Provincial Action Plans are blueprints for each state on the management goals for common and more rare species of wildlife, and their natural communities both terrestrial and aquatic, in the state or province into the next five years. These plans identify the species with the greatest conservation need and species the state (or province) would like to maintain or enhance their populations. These areas can be identified in a prioritization analysis. See Appendix B Data, section on Wildlife Action Plan and Species Recovery Plan for more details on these plans and links to websites.

The Locations of Water Resources and Ecological Processes as Priority Areas

The results of an on-line survey conducted in conjunction with the development of this manual, (see Strategic Integration of Wildlife Mitigation into Transportation Procedures: Practices, Partnerships, and Next Steps, Cramer et al. 2022a), found three states adhering to the guiding principle of restoring ecological processes in transportation projects and restoration. These areas are typically along waterways. In a prioritization process, the areas where water flow needs to be restored or is even just present could receive priority (**Figure 2-9**). Arroyos and washes in the west, and ephemeral water ways in the east could receive additional scoring to help protect those areas and the species that rely on them.

Figure 2-9. Mule deer doe, fawn, and buck moved beneath Interstate 80 at the Weber River Bridge which when replaced, was extended to accommodate wildlife along the river in Utah. Photo Credit: P. Cramer, Utah DOT, Utah Division of Wildlife Resources.

See the Minnesota Approach in the Case Study involving Best Management Practices Manuals in Chapter 3 and Appendix A. Case Studies for more information on how this approach has become part of standard operating procedure (also see Henrick et al. 2019, Leete 2014).

Resiliency, Climate Change, and Prioritizing Ecological Concerns

There are two approaches for including areas identified as subject to climate change concerns in a prioritization: areas where there are transportation concerns for protecting infrastructure, and areas of concern for species movement in the face of climate change.

Transportation planning will increasingly include resiliency plans for climate change. The locations identified for larger bridges and culverts replaced by bridges will be the target areas where such infrastructure can be planned to accommodate wildlife along with increased hydrologic flows, and thus receive a priority score.

At the same time, species and processes can become more vulnerable in the locations impacted by climate change. Priority can be given to areas important to wildlife movement in the face of climate change (**Figure 2-10**). See Appendix B. Data, Climate Change and Resiliency Plans for how these areas can be identified.

Figure 2-10. Pronghorn in New Mexico and Arizona will be heavily affected by ecosystem changes brought on by climate change as their grasslands turn to deserts in the coming years. Photo Credit: G. Andrejko, Arizona Game and Fish.

Combining Ecological Factors for Prioritization

Combining ecological data to prioritize wildlife mitigation along transportation corridors is an approach that is typically done as a step in a transportation agency's prioritization process. It would be then melded with the transportation priority areas to calculate final priority areas. This prioritization of multiple ecological and feasibility factors could also be a way to populate a dashboard portal into a web-based mapping and data resource for a transportation agency. Most state wildlife agencies have dashboard GIS websites for accessing such data. This is typically provided to transportation agency partners, but may not be readily accessible to the public. These ArcGIS dashboards can be a way to prioritize ecological data based on the users' various objectives.

Feasibility Factors

Data on transportation and wildlife related factors are paramount, but solutions to wildlife-vehicle conflict challenges are also based on the feasibility of options.

Feasibility as Learned from Agencies, Indigenous Communities, Non-profits, and the Public

Partners have an important role in prioritization. Prioritization for reduction of wildlife-vehicle crashes and increased wildlife connectivity is informed by transportation, wildlife, and ecological data, and feasibility for wildlife mitigation actions. The public, non-profit/non-governmental organizations, Indigenous Communities (Tribes and First Nations), and other entities have on the ground knowledge of land use practices, social acceptance of potential wildlife mitigation, science-based wildlife studies, and potential funding opportunities. When a jurisdiction or road is being prioritized, it is important to reach out to these partners for additional information that could be added in an evaluation of the feasibility and prioritization of a wildlife mitigation project. See the Colorado and Southern Ute Indian Tribe case study in Appendix A. Case Studies. The New Mexico Wildlife Corridors Action Plan used the information from agency, Tribal, non-profit organizations, and public comments to help score potential wildlife corridors for prioritization (Cramer et al. 2022b), see the New Mexico Case Study in Appendix A. Case Studies.

Feasibility of Construction and Land Use Compatibility

Additional factors of feasibility related to the topography, geology, land use, land ownership, and other factors and should be considered in the placement of culverts and bridges for wildlife. Private lands could be adjacent to future wildlife crossing structures if the landowners were willing to place conservation easements to assure future wildlife access to the area. However, geologic factors such as unstable soils, steep topography, and high water tables may preclude structures at those locations. Thus, feasibility factors can be added to the prioritization.

Prioritization Processes Based on Transportation, Ecological, and Feasibility Factors

The various methods (including those not mentioned here) will evolve in prioritizing areas for wildlife concerns in transportation. The basis for these prioritizations is based on: objectives, funding available, data available, and long term plans of the agencies involved. If funds are extremely restricted, a limited prioritization can be based solely on wildlife-vehicle crash data, as all western states and many others have done. If there is a collaborative process where expert opinion is sought at a workshop such as a transportation and wildlife summit, the maps can be better informed than when solely based on crash hotspot maps.

It is extremely important to combine multiple factors to identify priority locations within a jurisdiction to help elucidate where the most urgent areas are for wildlife mitigation. This holistic approach can help protect the safety of the public on roads, protect and restore ecological processes, maintain and restore wildlife populations that are not represented well by crash data, and help tap into multiple sources of funding from both the wildlife perspective and traffic safety. Various approaches several U.S. states have employed are presented below.

Priority Areas Based on Crash Hotspots

Wildlife-vehicle crash hotspot priority maps that have served as the base of priority areas for wildlife mitigation were conducted in:

South Dakota (Cramer et al. 2016).

Utah (Cramer et al. 2019).

https://drive.google.com/file/d/15K9yjM9kDRE8KVDvpUnFWn9RUyo1SkRL/view?fbclid=IwAR062_EPrlFmHPGc_uohMpEvoEsHNKWqVZGK5rnfGVlEkgzFwF-A4QwFhRk

Priority Areas Based on Crash Hotspots and Expert Opinion

Wildlife-vehicle crash maps with expert opinion input in a transportation and wildlife summit were created in Wyoming.

The Wyoming and Wildlife Roadways Initiative created an ArcGIS story map of the top wildlife-vehicle conflict priority areas. https://wgfd.maps.arcgis.com/apps/MapSeries/index.html?appid=ef666ba292b74c56a339efc10fca5332

The framework was described in a document, link below. https://drive.google.com/file/d/18R9mJzN6uiy5tTefUWptgri5GBhE4oFs/view

Priority Areas Based on Wildlife Corridors and Various Reports and Efforts

New Hampshire (New Hampshire Fish and Game 2018) identified wildlife corridors with a custom-made connectivity model, and added information on crash hotspots and many efforts underway to protect wildlife movement corridors. https://www.wildlife.state.nh.us/nongame/corridors.html

Priority Areas Based on Transportation and Wildlife Data and Risk Modeling

In Colorado, wildlife-vehicle crash data, carcass data, wildlife movement data and habitat maps were brought together in a risk model for the Western Slope Wildlife Prioritization Study and the Eastern Slope and Plains Wildlife Prioritization Study.

Kintsch et al. 2019, 2022.
https://www.codot.gov/programs/research/pdfs/2019/WSWPS

Prioritization Based on Omniscape Modeling and Best Culverts and Bridges

Prioritization of existing culverts and bridges for their value to wildlife connectivity were based on Omniscape Modeling (Landau 2020, McRae et al. 2016) of six mammal species potential movements in Vermont (Drasher and Murdoch. 2021).
https://vtrans.vermont.gov/sites/aot/files/Research/VTrans_Final_Report_2021_0001057-332.pdf

See Appendix A. Case Studies for more information on this study.

Prioritization Based on Omniscape Modeling on Species Connectivity Modeling

Oregon Department of Fish and Wildlife is leading the research and reporting for the Oregon Wildlife Corridors Action Plan, which was scheduled to be complete in 2023.

de Rivera et al. (2022) conducted initial modeling of species without roads.
https://www.frontiersin.org/articles/10.3389/fenvs.2022.757954/full#h3

Prioritization Based on Multiple Factors Brought Together in Matrix Scorecards in ArcGIS Modeling

Multi-factored prioritization approaches where a matrix of factors were brought together in a score card and through GIS modeling include the following:

Idaho (Cramer et al. 2014). https://rosap.ntl.bts.gov/view/dot/28515

Nevada (Cramer and McGinty 2018).
https://www.nevadadot.com/home/showdocument?id=16038.

See Appendix A. Case Studies

Arizona (Williams et al. 2021).
https://azdot.gov/sites/default/files/media/2021/08/WVC_Final_Report_July30_2021.pdf

New Mexico (Cramer et al. 2022b). https://wildlifeactionplan.nmdotprojects.org/. The New Mexico Wildlife Corridors Action Plan is presented as a case study for including these multiple factors and partners in a prioritization plan, See Appendix A. Case Studies.

When bringing together multiple factors to prioritize wildlife mitigation actions, the factors need to be quantified to create a transparent repeatable process. This can be done with a score card. One of the advantages of using a score card is that information not available in a GIS map can be incorporated, such as the support of local communities for various projects. It is important to understand the weighting of factors in a scorecard. To weigh all factors equally, the range of points within the categories such as transportation and ecology should all be the same. To weigh some factors more heavily, for instance, wildlife-vehicle crash hotspot rank, the range of points can be higher for this factor and thus more heavily important than others. A sample one-page scorecard based solely on GIS factors that can be adapted to rank priority road segments against one another to identify the top priorities based on different score weighting of these factors is presented in the Nevada example in Appendix A. Case Studies.

Taking it to the Next Step: Planning and Construction of Wildlife Mitigation

Once the transparent prioritization of wildlife-vehicle conflict areas is completed, the next step is to move these priority areas forward, depending on the location, species involved, safety factors, funding sources, politics, and upcoming transportation projects. Colorado standardized this next step with an Implementation Consideration Matrix, developed in the Western Slope Wildlife Prioritization Study (Kintsch et al. 2019). It focused the prioritization of highway segments on transportation safety and wildlife habitat, population, and connectivity factors. However, the study team also recognized that other factors such as urgency, opportunity and feasibility considerations may influence the likelihood of mitigation being implemented in a given highway segment and should be considered during project planning. See the Colorado case study “Implementing Wildlife Mitigation Priorities in Colorado” in Appendix A. Case Studies.

Recommendations for Prioritization

The following measures are based on the experiences of other agencies and researchers that have prioritized wildlife movement needs in transportation. The recommendations are provided to help transportation agencies and their partners plan for and prioritize wildlife mitigation.

1) Work with Traffic Safety of a transportation agency and their partners outside the agency to place a crash reporting form pull down menu of the species of animals most likely to be involved in an animal-vehicle collision. This allows analyses of the crash data to identify the species of animals most often involved in a crash hotspot, which then informs the best mitigation options. It also helps with prioritizing areas for species most at risk for the local population to become extinct due in part to collisions and habitat fragmentation.
2) Maintain a carcass data collection program with an on-line application to allow for identification of the many species of animals affected by traffic.
3) Wildlife agencies should make available to their transportation agency colleagues maps of habitat for smaller animals, and of movement data for GPS located animals of all sizes across the jurisdiction, such as the state or province. These maps in turn can help with the prioritization of road segments that may be bisecting and restricting wildlife movement.
4) Transportation agencies should meet at least annually with their wildlife professionals in the state and federal wildlife and natural resource agencies to review upcoming projects, and to create standalone wildlife mitigation projects. This is also important to placing priorities on different wildlife mitigation projects, based on these interactions and transportation and wildlife agency procedures.
5) The transportation agency can work to include a wildlife prioritization process in the long-range planning process. This would help to program in standalone wildlife mitigation projects in the long-range plan. It would also help the agency to have wildlife concerns considered early in the process to help avoid the need for wildlife mitigation or save time and money on wildlife mitigation later in the process.
6) The transportation and wildlife agencies should work together to create maps of known wildlife connectivity needs across roads. This can in turn be used in prioritization processes.
7) Prioritization processes should involve multiple transportation and ecological factors to more holistically identify top areas for wildlife mitigation, that in turn can best protect the motoring public from collisions with wildlife.
8) When creating a prioritization scorecard, it is important to try changes with different weighting factor values to see how the priorities can be affected by different scoring weights based on different objectives.
9) For a priority area of road to become a top wildlife mitigation project, it is important to also investigate the feasibility concerns that include how local landowners and users support the project prior to it becoming official.
10) These and other recommended actions can be standardized and institutionalized in Memoranda of Understanding (MOU). See Appendix C. Memoranda of Understanding for example MOU’s from several states.

Chapter 3. Planning, Project Development, and Everyday Operations

Introduction

Overview

Figure 3-2-1.Sandhill crane family used a wildlife underpass on US 93 in Montana. Photo credit: P. Cramer and Montana DOT.

This chapter focuses on PROCESS and demonstrates how wildlife connectivity and safety concerns can be part of the entire transportation process, from long-range transportation plans to everyday maintenance and operations. First the data requirements to inform the planning process are introduced. Then the overall planning process is presented to demonstrate and how various entities provide input as to what should become a transportation project, and how to include wildlife concerns into projects. These concerns consider wildlife-vehicle conflict which includes wildlife crashes, and the impacts roads and vehicles can have on all wildlife, including winged (**Figure 3-1**), finned, and four-legged animals. These recommendations stress the importance of consulting with wildlife professionals who are knowledgeable about wildlife present and how and where they move along transportation corridors. This chapter provides examples of how agencies and their partners can work together throughout the transportation process. **Figure 3-2** is the base diagram.

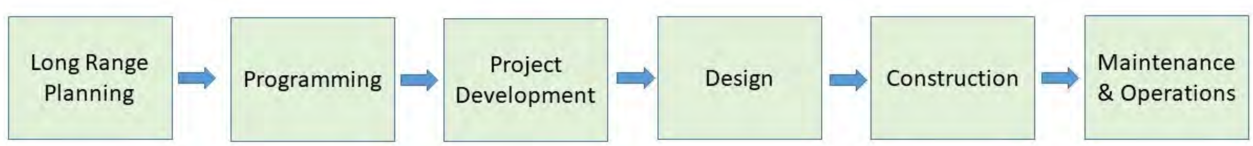

Figure 3-2. The transportation planning to maintenance and daily operations process.

How to Use This Chapter

Readers of this chapter can follow from the beginning or jump to a specific step in the transportation process, which are each represented by a section in this chapter. Appendices provide greater detail. Information is presented at a high level so it may be used by broad audiences across the U.S. and Canada. An objective is to help agency professionals institutionalize wildlife concerns in transportation procedures within the six-step transportation process. These procedures would be carried out with input from wildlife professionals and the public. This chapter is highly focused on the processes within the U.S. Departments of Transportation (DOTs) with reference to Canadian provinces and territories in several examples. The Canadian Ministries of Transportation (MoTs) each have their specific processes that are not fully presented here. However, the information is broad enough to be applicable to Canada and other nations.

Data to Establish the Need for Wildlife Considerations

Identification of the need for consideration of wildlife is necessary for transportation agencies to bring these concerns into procedures. This is established through systematic data collection and analyses to establish wildlife habitat areas near roads, where wildlife need to move, and overall wildlife-vehicle conflict areas for species of all sizes and locomotion abilities. **Figure 3-3** presents an overview of the various forms of data that feed into various points throughout the transportation process and procedures. All data inputs are presented in greater depth in Appendix B. Data.

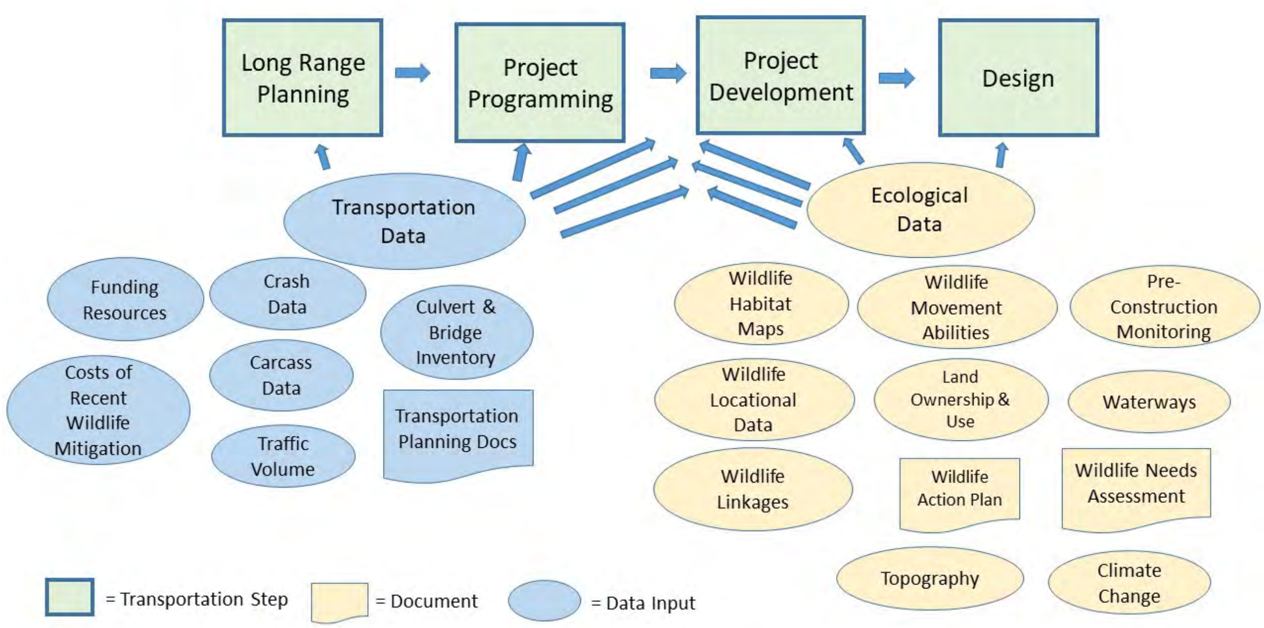

Figure 3-3. Flow diagram of how data inputs inform the transportation process of wildlife concerns.

Data on wildlife, habitat, and transportation factors will need to be brought together in ways that can address agency goals while protecting wildlife and reducing collisions with them. Data allow planners to develop objectives and performance measures that quantify how the policy, plan, program, or project will meet agency goals. Historically agency goals have seldom included concerns for wildlife connectivity or the reduction of wildlife-vehicle collisions. However, today wildlife-related objectives such as reduced collisions with wildlife are increasingly being acknowledged within agency goals. Data can also help identify funding resources that can be integrated during the planning process early on so that when programming and project development processes occur, funding is in place to include wildlife considerations, while meeting these agency goals.

Transportation agency personnel typically look at historic crash data in an upcoming project area to make recommendations to reduce crashes and can perform a benefit-cost analysis of the proposed project's potential ability to reduce these crashes and pay for itself. Wildlife-vehicle crash analyses help justify the use of traffic safety funds for wildlife mitigation. Please see the first report of this study (Cramer et al. 2022a), its Chapter 4 Data, the section on crash costs analysis for a more in-depth presentation.

Planning Overview

The transportation planning process is a set of steps that formulates the transportation agency's priority projects, from the long-range to the project level.

Transportation planners use many inputs to formulate long-range transportation plans (20 years). (See **Figure 3-4** for an example of how even smaller animals can be included in project plans).

Programming processes then prioritize and nominate long-range plan projects for the State Transportation Improvement Program (STIP) or a mid-term-10-year Development List which then leads to the STIP.

From the STIP, individual projects become programmed with funding obligations and begin the project development step, see **Figure 3-5**.

Figure 3-4. Utah DOT and Division of Wildlife Resources worked together to plan for and construct desert tortoise underpasses near St. George, Utah. Photo Credit: A. McLuckie, Utah Division of Wildlife Resources.

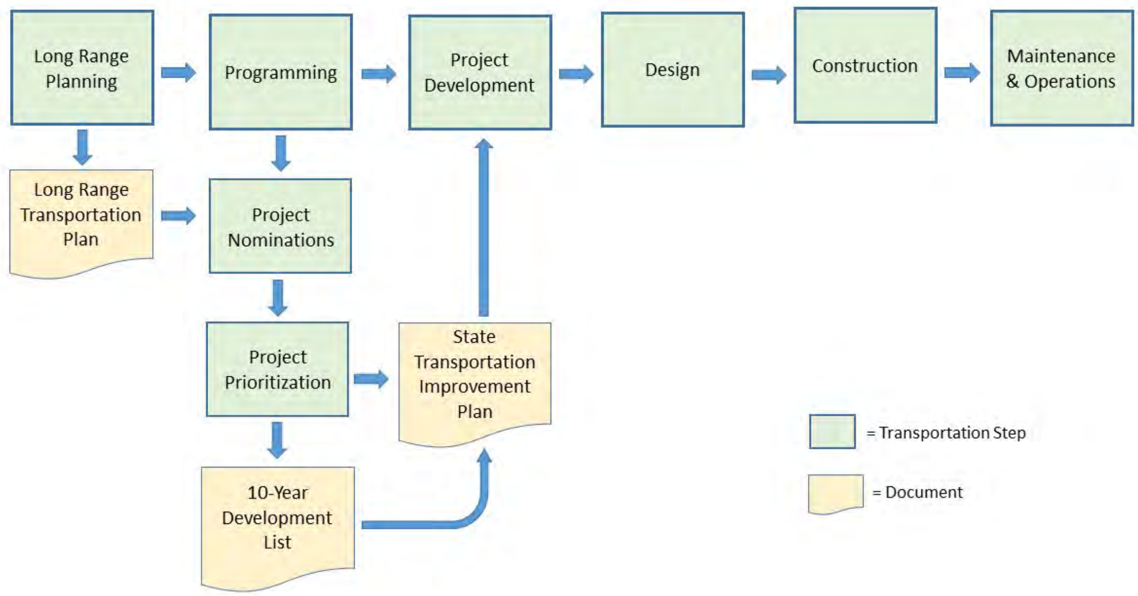

Figure 3-5. The steps for a project to become funded and begin project development. This is a generalized flow diagram that may be different for various jurisdictions.

These planning process steps require input from agencies, Indigenous communities, non-profit organizations, and the public to create a more integrated planning framework. Integrated collaboration and planning is part of the normal transportation planning process for wildlife and other ecological considerations. The guide for this integrated planning for two decades has been the Eco-Logical approach (Brown 2006), which guides interagency cooperation for the sake of wildlife. See Appendix A. Case Studies.

The important goal for protecting wildlife is for the programming process to consider wildlife so project budgets which are established at this stage, can include funding for wildlife mitigation. The programming process will need to evaluate wildlife presence near potential projects, if wildlife need to move across the existing road or future road, and what the potential measures are to help wildlife move and avoid collisions, measures which this manual calls wildlife mitigation. Wildlife mitigation can be included in upcoming projects or in standalone projects. It is important to a transportation agency that wildlife be considered at this programming stage. If wildlife considerations are not included in programming prior to projects being entered into the STIP, the projects may have to be reassessed because of species' presence, which could result in added costs and time for the projects, something most agencies do not want to incur. If an agency realizes there is an urgency to an area with wildlife-vehicle collisions and conflicts, it can create standalone wildlife mitigation projects within the STIP. At this level, the focus often is on highway safety, which can be tied to wildlife-vehicle reported crashes.

Recommendations

For wildlife to be considered in long-range planning and programming there needs to be three fundamental standardizations within the transportation agency:

1) Include reduction of wildlife-vehicle collisions and consideration of wildlife into the goals of the long-range plan;

2) Establish procedures that allow for wildlife mitigation standalone projects; and

3) Have processes in place that consider wildlife in the development of future projects.

The following sections delve more deeply into how these recommendations can be accomplished.

Long-Range Transportation Plans

Long-range transportation planning is the first step in the transportation process, (**Figure 3-6**).

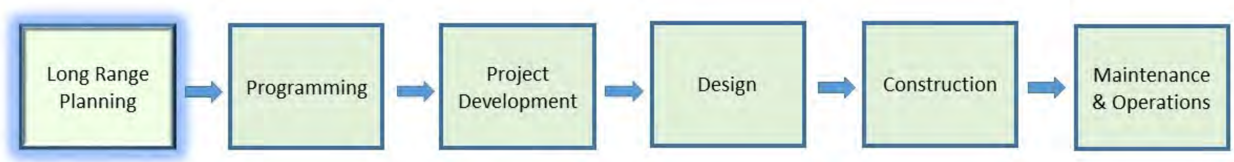

Figure 3-6. Long-range planning is the first step in the transportation process.

Long-range transportation plans define an overarching vision for the future of a transportation system, establish goals and objectives, and guide the selection of transportation policies, programs, and projects that meet those goals and objectives over a 20-year time frame (Waldheim et al. 2015). All state DOTs post their long-range transportation plans online. The Federal Highway Administration (FHWA) posts links to all DOTs at the website: https://www.fhwa.dot.gov/about/webstate.cfm.

The highest level of planning possible for wildlife is for consideration of wildlife connectivity and the reduction of wildlife-vehicle collisions to be part of the goals and objectives of a long-range plan. If an agency sets its long-range plan policy to include consideration of wildlife, it then sets the stage for staff to include these concerns in all subsequent levels of transportation processes. This approach is rare but is slowly becoming more incorporated into plans and missions. For example, the transportation plan for Northern Ontario includes a goal of maintaining a sustainable transportation system. This goal has helped support actions that include wildlife considerations.

A recommended approach to long-range planning and wildlife is to find a way to ensure wildlife concerns are part of a transportation agency's mission statement and goals of safety and environmental concerns. For example, the goal of "Zero Fatalities" cannot be achieved without addressing wildlife-vehicle crashes which result in annual human fatalities in 49 out of 50 U.S. states (see Chapter 1, Table 1-1). If a goal is "Environmental Considerations" then wildlife connectivity and wildlife crossing structures can be shown to be part of achieving this goal.

It should be an objective of long-range plans to follow the "Do No Harm" approach for new projects. This has been adapted by the U.S. Council on Environmental Quality (CEQ) to define mitigation: first avoid, then seek to minimize, and then finally mitigate and restore areas for wildlife if the project is unavoidable. Although mitigation is the last choice for action, it may be the only option considered once avoiding and minimizing road impact are no longer possible for projects on existing roads.

Although transportation agencies have designated planning departments and planning documents compiled in a central location, it is important for divisions within the agency and the headquarters and district/local levels of the organization to provide input on wildlife concerns in long-range plans. State and federal natural resource agencies can advocate for integration of wildlife-vehicle collision reduction and wildlife connectivity into long-range plans, as the state transportation agencies are mandated by Congress since 2005 to consult with them in the process of developing all transportation plans (since the passage of the Transportation Act known as Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, SAFETEA-LU).

PROFESSIONALS TO ENGAGE IN THIS APPROACH

- Transportation Agency Planners
- Transportation Agency District Engineers
- Transportation Traffic Safety Engineers
- Transportation Agency Programming Director
- Transportation Agency Environmental Ecologists
- Transportation Agency District Professionals
- Metropolitan Planning Organization Planners
- Wildlife Ecologists
- Fish Biologists
- Maintenance Staff
- Outside Agency Staff
- Experts in Wildlife

For wildlife concerns to be included in a long-range planning process, the agency must first be aware of the scope of the problem of wildlife-vehicle conflict, and secondly, there needs to be champions high enough in the political and transportation administrations to ensure these concerns become institutionalized. Identifying the problem with data, as described above and in Chapter 2. Prioritization, will help to bring these concerns to the highest levels of a transportation agency. The directors of U.S transportation agencies (however not Canadian agencies) are typically political appointees. They respond to Governors' directives which are influenced by the political pressure of the state constituents.

Long-range plans are to also include the concerns of communities. Wildlife advocates have helped secure legislation mandating concern of wildlife such as Wildlife Corridors Acts, (e.g., in New Mexico https://wildlifeactionplan.nmdotprojects.org/ and Oregon - https://www.oregonlegislature.gov/lpro/Publications/Background-Brief-Wildlife-Corridor.pdf), and governors' directives, such as Colorado's Governor J. Polis Executive Order to conserve big game winter range and migration corridors (https://drive.google.com/file/d/1HokP2Vsh749PpJtazPgldLgEjbYjypro/view).

These types of actions help to institutionalize these concerns. However, unless there is long-range planning policy that cannot be changed with political influence, these efforts could be short term.

For Parks Canada, the key has been to ensure that wildlife habitat and wildlife movement needs were identified as "valued components" of an environmental assessment for highway upgrades. Once these components are identified, the mitigation (fencing, crossing structures, etc.) tend to follow fairly directly from the evaluation of predicted impacts (**Figure 3-7**, T. Kinley, Parks Canada, personal communication 2020).

Figure 3-7. Parks Canada helped to incorporate wildlife overpasses and dozens of underpasses in Banff National Park and Kootenay National Park. Photo Credit: Parks Canada.

Recommendations on inclusion of wildlife concerns in these long-range plans are presented below.

Recommendations for Long-Range Transportation Planning

1) Transportation agencies should consider issues of wildlife-vehicle conflict in the development of long-range transportation plans. Ask the question: "Can the inclusion of

wildlife consideration be tied to the current goals and objectives of your agency's mission and long-range transportation plan?" If not, what needs to be changed to better align wildlife considerations and wildlife-vehicle reduction with the transportation agency objectives?

2) Develop a Memorandum of Understanding (MOU) between the wildlife agency and the transportation agency to work together in planning. See suggested wording in Appendix C. Memoranda of Understanding.

3) Each transportation agency and Metropolitan and Regional Planning Organization (MPO and RPO) shall prioritize locations where wildlife-vehicle conflict is a problem so the top priority areas can become candidate locations for future transportation projects in the long-range plan. See Chapter 2 Prioritization, and **Figure 3-8**.

Figure 3-8. Pima County in Arizona voted to tax themselves to help create projects to prioritize wildlife connectivity. Their Regional Transportation Authority creates projects for wildlife mitigation, such as the underpass on SR 86 where this bobcat was photographed. Photo Credit: Tohono O'odham Nation.

4) District/local level transportation agency engineers and planners should consult with local offices of the state/provincial and federal wildlife agencies on at minimum an annual basis to inform updates concerning wildlife to long-range plans.

5) Transportation agency environmental staff should review the long-range plan for potential conflict and opportunities to improve terrestrial and aquatic connectivity.

6) The transportation agency should build funding capacity to enable the environmental staff to participate in the development and review of the long-range plan.

7) Ask the question, "Can the wildlife consideration be tied to a safety goal?" Crash and carcass data can be analyzed to find hotspots, or the seriousness of the problem for specific roads. Traffic Safety engineers at the headquarters level should review wildlife and overall animal-vehicle crash data (this includes domestic species as well) annually to determine the top hotspots.

8) Develop a multi-disciplinary wildlife team within the transportation agency that helps the environmental staff to raise awareness of wildlife concerns, which in turn can help ensure wildlife considerations in long-range transportation plans. See British Columbia case study in Appendix A. Case Studies.

9) Establish a procedure for bringing wildlife concerns into transportation long-range plans. This would require the participation of planners, administrators, engineers, and

environmental staff in a transportation agency and their partners in wildlife agencies to create a step-by-step procedure, such as the example in **Figure 3-9**.

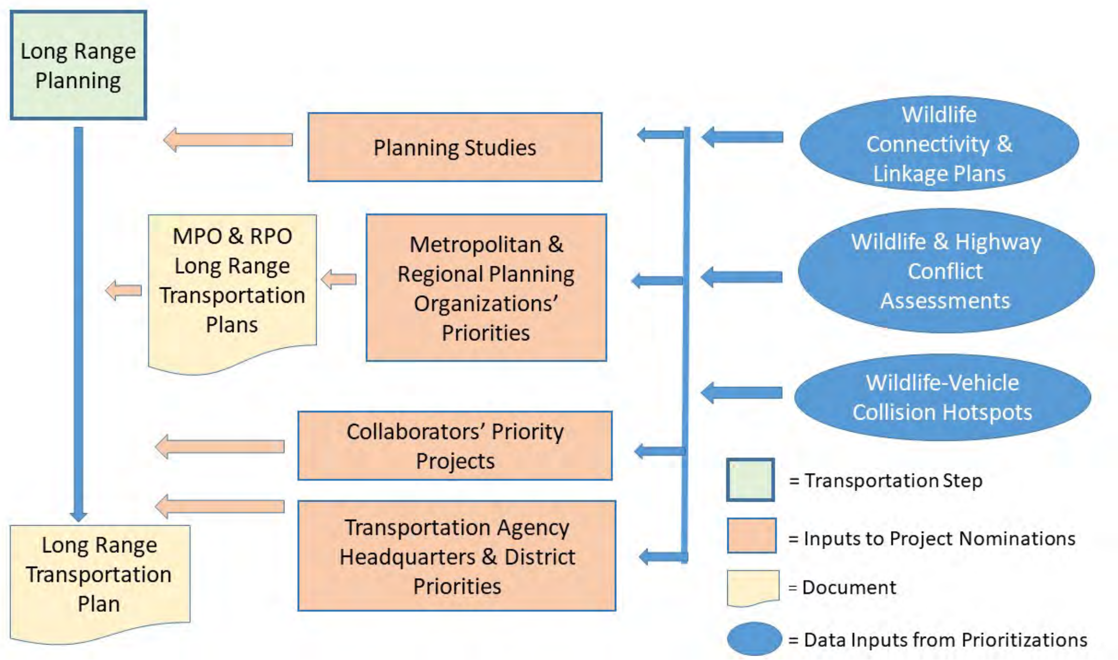

Figure 3-9. Range of inputs into the long-range transportation plan that could include wildlife considerations.

10) Consider a Wildlife Connectivity Policy, such that aquatic and or terrestrial connectivity are factors to consider in the long-range plans.

11) Consider legislation that institutes an annual or five-year review of transportation and ecological data to identify priority areas within a state or province. This has been done in Oregon and New Mexico with their Wildlife Corridors Acts, see Appendix A. Case Studies.

Suggested Resources

Incorporating Safety into Long-Range Transportation Planning. https://www.nap.edu/read/13891/chapter/2

The Eco-Logical Guide to Incorporating Wildlife and Ecosystem Concerns into Transportation Planning. https://www.environment.fhwa.dot.gov/env_initiatives/eco-logical/report/eco_index.aspx

Establishing Projects Through Programming

Once long-range transportation plan potential projects are identified, early stage planning efforts for developing priority projects begins in the programming step (**Figure 3-10**).

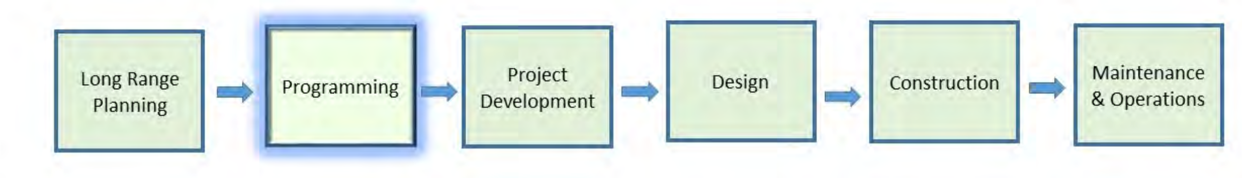

Figure 3-10. Programming is the second step in the transportation process.

This programming section describes the overall process for defining and prioritizing transportation projects put forward in the long-range plan that contain wildlife mitigation components or that have the potential for wildlife mitigation. The goal of the programming process is to prioritize the projects that move forward to the STIP (or the 10-year Development List in some states) with programmed funding. Understanding how these potential projects proceed through the programming phase is critical to bringing wildlife concerns into the transportation process and ultimately projects. The programming process varies in different places and agencies, but the overall process was summarized earlier in the chapter, in **Figure 3-5.** Programming is presented as having two steps: project nominations, and prioritization of those projects for the ones that proceed to the STIP.

PROFESSIONALS TO ENGAGE IN THIS APPROACH

- Transportation agency Planners
- Transportation Agency District Engineers
- Transportation Traffic Safety Engineers
- Transportation Agency Programming Director
- Transportation Agency Environmental Ecologists
- Transportation Agency District Professionals
- Metropolitan & Regional Planning Organization Planners
- Wildlife Ecologists
- Fish Biologists

The goal for wildlife mitigation efforts is to incorporate wildlife considerations into upcoming projects or create standalone wildlife mitigation projects. A transportation agency will need wildlife, safety, and other data to support proposed projects (**Figure 3-11**). These data are important for convincing decision-makers that the issue has sufficiently been analyzed and backed with data. The process can become complex when the priorities and information from various sources are brought together and are subjected to a scoring system, **Figure 3-12.**

Figure 3-11. Colorado's State Highway (SH) 9 Wildlife Mitigation Project was planned for and funded because of safety concerns for motorists, wildlife safety and connectivity, and committed partners with Colorado DOT. Black bear used this and most underpasses in the project. Photo Credit: Colorado DOT, Colorado Fish, Wildlife, and Parks, and ECO-resolutions. See this project in Appendix A. Case Studies.

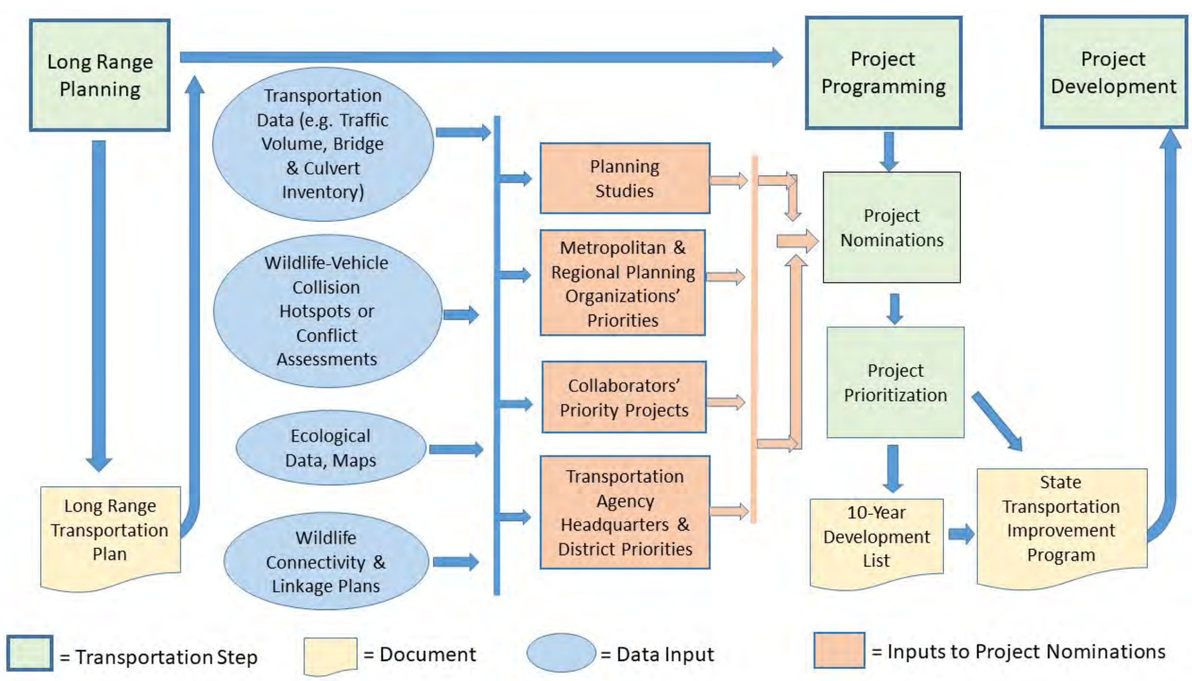

Figure 3-12. Inputs concerning wildlife that could be used in the programming process when projects are nominated and prioritized.

Project Nomination

Project nomination in both long range planning and programming can be done at the MPO and RPO levels (details on these planning agencies below), the transportation agency district or regional level, and at the transportation agency headquarters' level. Divisions within a transportation agency, such as the Traffic Safety division, Environmental division, and Maintenance and Operations division, can also nominate projects in the programming process. Sometimes potential projects can involve politicians' and national transportation agency funding and prioritization.

In Canada, the process for moving a transportation project forward is unique to each province/territory. For example, Ontario has the Northern and Southern Highways Program that lists funded highway construction projects, including expansion and rehabilitation projects, that are planned or underway. All expansion projects with construction funding are identified, while rehabilitation projects are focused on a four-year period. More information regarding Ontario's highway programs can be found through the following link: https://www.ontario.ca/page/ontarios-highway-programs.

Create Wildlife Mitigation Projects

Once priority areas for wildlife mitigation have been identified prior to programming, they can be incorporated into nominated transportation projects or defined as standalone wildlife mitigation projects. For example, Colorado prioritized the most important areas for wildlife mitigation in Western Colorado in a 2019 study (Kintsch et al. 2019), which they then used to develop standalone wildlife crossing projects and integrate mitigation for wildlife into upcoming projects in both the long-range plan and the STIP, see the Colorado case studies in Appendix A. Case Studies. In California, as of 2022, The Nature Conservancy was developing a study "The Transportation Climate Vulnerability & Wildlife Connectivity Assessment: An Assessment of the Nexus between Areas of Critical Transportation System Vulnerability Due to Climate Stressors and Wildlife Connectivity Restoration and Protection." The study results overlay wildlife movement maps over California highway segments considered most vulnerable to climate change processes. The hope is that the intersection points would be prime opportunities to both plan for resiliency and wildlife movement in the same future projects.

Bringing Metropolitan and Regional Planning Organizations on Board

Local and regional planning organizations, including MPOs and RPOs in the U.S. are critical to protecting wildlife on the majority of roads in North America. Of the 3.9 million miles (6.3 million km) of public roads in the U.S., 77 percent are owned by local towns, cities, and county governments (Federal Highway Administration 2010). In Canada, there 1,066,180 kilometers (662,492 miles) of public roads. Local entities there administer 73 percent of these roads (Statistics Canada 2018).

MPOs are federally created entities required for all metropolitan areas with populations greater than 50,000. Over half of the 440 MPOs in the U.S. operate within RPOs. RPOs deliver federal, state, and local programs including planning. They may be called regional councils, council of government's regional planning commissions or planning districts as well. MPOs must develop a 20-year Long-Range Transportation Plan (LRTP), and a Transportation Improvement Program (TIP) covering a period of no less than four years. These TIPs must be accepted without change by the state DOT and amalgamated into the STIP (23 United States Code, https://uscode.house.gov/browse/prelim@title23&edition=prelim, (U.S.C.) 134, 23 U.S.C. 150, and 49 U.S.C. 5303). See the MPO case study in Appendix A. Case Studies on how MPOs may address wildlife needs.

Collaborative Planning with Partners to Bring Projects to Fruition

Wildlife concerns can be translated into projects through collaboration with partners. Often the state or provincial wildlife agency has far more sway with transportation partners than any other agency, yet often these entities may be unaware of the critical role they play in assisting their transportation partners in planning for wildlife concerns. A successful recent model is for the transportation agency to partner with the wildlife agency in scheduling regular meetings about potential wildlife projects and planning, holding a summit to bring in the many partners, creating a MOU to codify how the agencies shall work together, and in developing funded projects for wildlife mitigation. See Appendix C. Memoranda of Understanding for several MOUs. See the Wyoming and Colorado case studies in Appendix A. Case Studies on how these states instituted working partnerships. MOUs between state DOTs and wildlife agencies institutionalize consideration of wildlife through coordination and collaborative planning between the two agencies. These documents instruct actions such as:

- Collection, storage, and mapping of carcass data;
- Meetings between the agencies and what positions within the agencies are responsible for setting up and guiding these meetings;
- Exchange of information on wildlife habitat and conservation and upcoming projects; and
- Planning coordination of long-range plans and the STIP.

Transportation Agency Headquarters and District Priorities

Professionals in most divisions (where similar professions work together) and districts within a transportation agency can nominate projects into and from the long-range plan to be put forth for prioritization for inclusion into the STIP. Traffic Safety engineers can be important allies in helping to elevate projects in wildlife-vehicle collision hotspots, using safety funds. Wildlife mitigation projects also need the support of the local engineers and environmental staff. Most wildlife mitigation projects have come about with the help of local champions at the district level. In fact, the projects need those champions to move forward (see Project Prioritization, below).

Project Prioritization

Prioritization of projects nominated to progress from the long-range plan to the STIP is something the planners and programming staff would best be able to explain for an agency. The process depends on quantifiable checklists of important input such as those listed below.

Funding Sources

Securing money from state and federal programs is critical. Typically, if there is a wildlife-vehicle crash hotspot that is targeted for wildlife mitigation, safety funds can be used toward the project. Other funding sources that can be used include replacing existing culverts and bridges through funding in the FHWA Bridge Investment Program and National Culverts Program; FHWA Tribal and Federal Lands programs that provide money for access to or on these lands (**Figure 3-13**); and through wildlife agencies, who have tapped into Pitman Robertson funding (a U.S. federal program to provide grants to wildlife agencies for specific projects to help wildlife), non-profit hunting group funds, and state funds approved by their wildlife commissions. Some western states are using governor assigned funds for wildlife crossing structures, and enacting laws to set aside certain amounts of DOT budgets for wildlife crossing structures. If partner agencies, the public, non-profits, Sovereign Nations (Tribes and First Nations), and other can bring matching

Figure 3-13. The Bureau of Land Management secured over one million dollars in federal funding for wildlife crossing structures on US 89 across the Grand Staircase Escalante National Monument in Utah. Photo Credit: P. Cramer, Utah DOT, and Utah Division of Wildlife Resources.

funds to potential projects, those efforts can go a long way to elevating a project into the STIP. See Appendix B. Data, section on Funding Resources.

Major Projects That Could Include Wildlife Mitigation

Often the largest wildlife mitigation projects have been incorporated into large multi-million-dollar transportation projects that are typically the four-laning of two lane roads (Arizona SR 260 and Montana US 93 for example), or adding climbing lanes in mountainous regions (Utah's Interstate 80 and the 2019 wildlife overpass), or brand new highways through prime wildlife habitat (Nevada's Interstate 11 Boulder City Bypass from Arizona to Las Vegas). These major projects typically have multiple sponsors within agencies and the legislative bodies and have high chances of becoming STIP projects. It is with these projects in wildlife habitat that wildlife crossings structures and other mitigation can be incorporated EARLY in the prioritization process, to make sure funds are secured for these features.

Transportation Department District Support

Projects with wildlife mitigation in them have to have the local transportation district's support to move forward into the STIP (**Figure 3-14**). These districts have limited allotments of the agency's funds, and the district administrator or engineer will need to support projects in their jurisdiction for the prioritization of those projects. Wildlife professionals and advocates will need to bring their concerns to these personnel at the local level if the wildlife mitigation project will have a chance of moving forward. After a project has become part of the STIP, these professionals and the project managers are very limited in their ability to find additional funding to add wildlife features.

Figure 3-14. Texas DOT Pharr District administrator and engineer support were crucial to creating wildlife crossings in their districts. Photo Credit: Texas DOT, U.S. Fish and Wildlife Service Laguna Atascosa National Wildlife Refuge.

The U.S. State Transportation Improvement Program - STIP

The STIP is an integral part of U.S. transportation agencies' programming. The statewide long-range transportation plan is implemented by programming projects into the STIP. Projects selected for the STIP support performance objectives. STIP projects include priority projects from rural and more urban MPOs and RPOs' Transportation Improvement Programs (TIPs). The STIP is typically updated very four to five years. All projects in the STIP have funding resources identified. Federal regulations require that a state's STIP be fiscally constrained, and all federally funded projects are included in the STIP. Getting the project into the STIP involves data, champions, and to some degree lobbying and persuasion during these programming steps.

Recommendations for Transportation Project Programming

1) Use a state or province-wide assessment to guide wildlife-highway mitigation project planning. Assessments such as those done by Arizona (See Appendix B. Data), Colorado (In Appendix A. Case Studies), New Mexico (In Appendix A. Case Studies) and other states and provinces provide the vital planning and prioritization needed to proactively integrate wildlife needs into the project programming process. See Donaldson (2022) for the Virginia wildlife considerations guidelines, and Suggested Resources below. Wildlife-vehicle collision hotspots, species habitats, and/or linkage/corridor maps can be overlaid with other project nomination studies and databases in a GIS to identify and nominate prioritized projects for inclusion in the STIP.

2) Hold periodic interagency coordination meetings. Headquarters and district level transportation agency professionals such as administrators, district engineers, traffic safety engineers, planners, environmental, and maintenance staff should be meeting regularly, such as annually, with wildlife agency professionals and other interested entities on what the transportation agency is considering in the long-range plan and programming in accordance with MOUs.

3) Wildlife and transportation professionals can present potential performance measures. These measures are what the potential wildlife mitigation project may help the transportation agency meet, such as a 75 percent reduction in crashes with large wild animals, and estimated costs savings to the public. This can help elevate a potential wildlife mitigation project based on cost savings.

4) Update transportation agency manuals to incorporate wildlife considerations. The manuals of all professions and divisions within a wildlife agency can be reviewed and recommended for revisions to include consideration of wildlife, wildlife-vehicle collisions, wildlife movement and habitat, biodiversity, ecological processes, and building resiliency for climate change along with restoring ecological connectivity. See the Texas Manuals case study in Appendix A. Case Studies for how this can happen.

5) Include costs of potential project mitigation prior to nomination. This can help program the funds needed for mitigation. This may entail some of the steps below in planning and design to get a better estimate of what mitigation costs would be.

Suggested Resources

The FHWA published a guide to transportation planning that explains the process (Transportation Planning Capacity Building Program et al. 2015). To learn more visit: https://www.fhwa.dot.gov/planning/publications/briefing_book/index.cfm

Non-profit organizations worked together to fund and create a film of Nevada's success at wildlife crossing structures, "Reconnecting Wild" which in turn helped to continue to raise public and political support for wildlife mitigation. See: https://vimeo.com/357164380

Virginia Department of Transportation's Policy for Determining Areas with High Risk of Large Animal-Vehicle Crashes and Guidance for Implementing Counter Measures in Projects (https://www.virginiadot.org/business/resources/LocDes/IIM/IIM262.pdf) is an excellent short state transportation agency driven guidance for the scoping process in Virginia (Donaldson 2022).

The Center for Large Landscapes has written a manual for helping to develop projects under the U.S. federal wildlife crossings pilot program of the Bipartisan Infrastructure Law (Paul et al. 2021).

Project Development

Once a project has been named in the short-term planning document, such as the STIP, it moves to the project development stage (**Figure 3-15**).

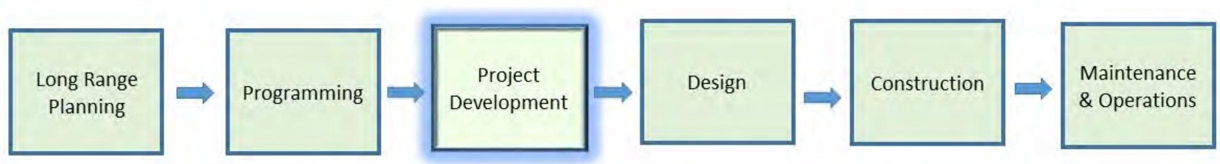

Figure 3-15. The project development stage of planning occurs once a project has an official place in the short-term (5-year) planning document.

The project development step creates the framework for a project, its schedule, milestones, and cost estimates. Once this framework is established, a project can then be budgeted. Project development stages have traditionally been where wildlife concerns were introduced to a transportation agency, yet it is critical that wildlife concerns are included in the project prior to this stage as described in the previous sections. Once the need for wildlife mitigation is established, the types and locations of mitigation features are established during project development.

Project development is completed through two steps presented in this section: Planning and Scoping. The project then moves on to the design step, and on to construction, (**Figure 3-16**).

PROFESSIONALS TO ENGAGE IN THIS APPROACH

- Transportation Agency Planners
- Transportation Design Engineers
- Transportation Agency Environmental Ecologists
- Transportation Agency District / Regional Engineer
- District Environmental Biologists
- Wildlife Ecologists
- Hydrologists
- Maintenance Staff
- Stakeholders

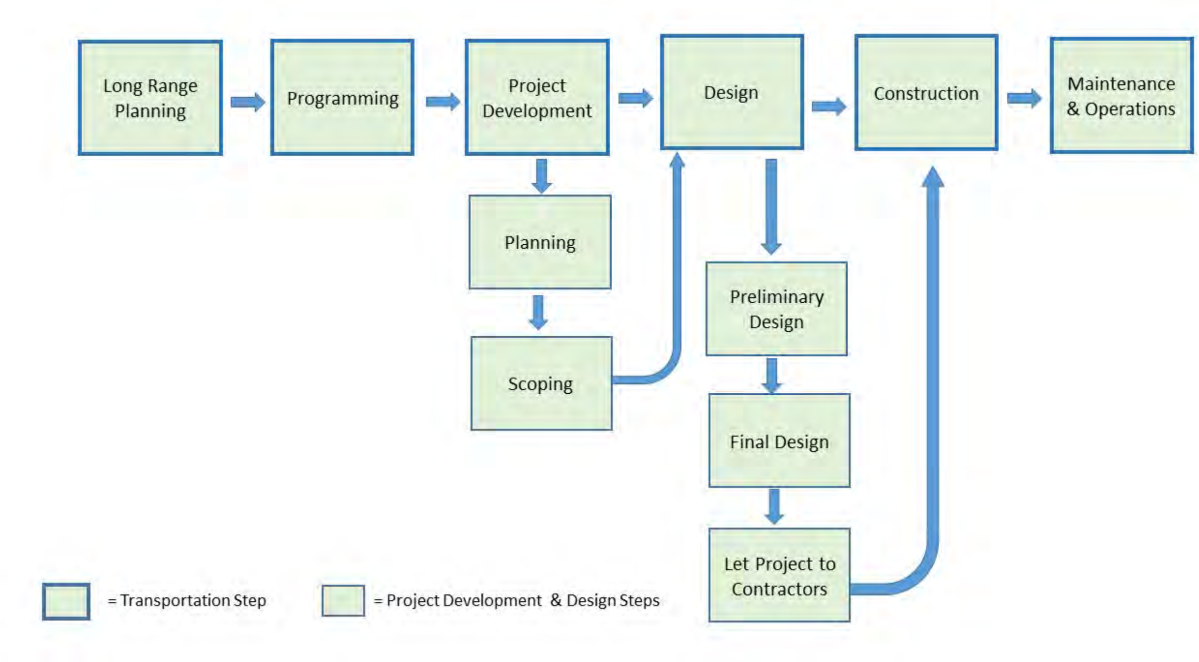

Figure 3-16. The transportation project development and design steps.

Project Planning

Project planning during the project development stage is where the general details of the wildlife mitigation and transportation project are refined enough to move to the scoping step. Wildlife considerations in this step include: identification of the regional and target species and their needs to move across roads; National Environmental Policy Act (NEPA) considerations; a review of the mitigation options; potential types and locations for wildlife crossing structures and other infrastructure; and benefit-cost analyses to understand how the project could pay for itself.

Wildlife professionals from a wildlife agency and other local experts should be consulted at this stage, along with data inputs derived from the prioritization process (Chapter 2). These project planning steps are briefly listed below, then described in this section.

- Identify appropriate project partners inside and outside the transportation agency.
- Determine the target species and their needs to move across the road.
- Identify pertinent policy, mandates, and mission statements.
- Determine National Environmental Policy requirements.
- Identify the objectives and goals of the wildlife mitigation components.
- Identify how those goals and performance measures will be monitored and reported.
- Evaluate road and traffic features to help determine appropriate mitigation.
- Assess other features and components that might influence the design and siting.
- Select the best mitigation for species and situation, based on science.
- Secure wildlife mitigation commitments.

Wildlife crossing structures and other wildlife mitigation strategies must address site-specific conditions and nearby wildlife population needs. Details of these steps are presented below.

Identify Partners

It is critical that transportation agency personnel consult with wildlife agency and natural resource agency professionals on any planning for wildlife mitigation. This includes fisheries biologists if water bodies are involved. These partners include non-governmental organizations, the public, Sovereign Nations (Tribes and First Nations), research institutions, and others who can help identify the locations of where wildlife need to move, the scope of the problem, potential solutions, and funding opportunities.

Determine the Target Species and Their Movement Needs

To determine an appropriate mitigation strategy, project planning teams must first confirm the suite of target species for the project area, including species identified through regional, province- or statewide prioritization plans as well as more localized species. Providing passage for all members of local populations of wildlife is important for functional connectivity (**Figure 3-17**). For example, crossing structures that are minimally effective may be used by lone or several males of the population, without being sufficient for females and young and perhaps greater numbers of the total population (see Kintsch et al. 2019 for pronghorn and elk examples, Gagnon et al. 2014 for bighorn sheep examples, and Cramer 2012, 2014 for elk examples).

Figure 3-17. North America's first wildlife overpass was placed over Interstate 15 in Utah in 1975. Monitoring found it was sufficient for successful passage by bull elk and a lone cow (female, above), but was not used by any other females or young. During monitoring It did not provide functional connectivity for herds of elk, rather minimal, genetic connectivity for males. Photo Credit: P. Cramer, Utah DOT, Utah Division of Wildlife Resources.

In the design of wildlife crossing systems, it is important to understand the local influences of natural and human landscape features on wildlife behavior and population dynamics including inter- and intraspecific species interactions. Conferring with wildlife professionals in the area of concern helps to determine these factors.

Identify Policies, Mandates, and Mission Statements

Proposing wildlife mitigation can be part of the environmental review process and documentation, but can also be mandated per an agency's guidelines that standardize how projects are put forward. For example, the Florida Department of Transportation has adopted guidelines to determine the appropriateness of wildlife crossing structures in proposed projects or standalone retrofit projects. https://www.fdot.gov/docs/default-source/content-docs/environment/pubs/WildlifeCrossingGuidelines_2018revisions.pdf

National Environmental Policy Act Considerations

The NEPA process is used to address the environmental impacts of a proposed project and is required for all transportation projects that receive federal funding. NEPA documents must:

- State the purpose and need for a project.
- Evaluate existing environmental conditions.
- Evaluate the environmental impacts of a proposed project.
- Evaluate alternatives to the proposed action that still meet the project's purpose and need.

Stand-alone wildlife mitigation projects often can proceed with a Categorical Exclusion because the mitigation offers substantial environmental benefits and, generally, this type of project does not result in significant environmental impacts. Mitigation projects that are included as part of a larger transportation project such as a roadway widening or realignment project will generally require an Environmental Assessment (EA) or Environmental Impact Statement (EIS). Involvement by wildlife biologists throughout these processes can help ensure wildlife mitigation is included where appropriate. It is important to include wildlife collision reduction and connectivity in environmental assessments. For some large transportation projects, the NEPA process may partially overlap with preliminary project design.

Planning and Environmental Linkages (PEL) is a collaborative approach to transportation decision-making that considers the impacts and benefits of a proposed transportation project to the environment and community. The process begins the evaluation of alternatives and incorporation of stakeholder interests and is used to inform a full NEPA process. It is referred to later in the scoping step as part of land use and planning. https://www.fhwa.dot.gov/federal-aidessentials/catmod.cfm?id=122.

Identify Objectives and Goals

The goals of the mitigation help to clarify the need for mitigation and the design of mitigation features. See Chapter 4 Monitoring for more details. There can be wildlife connectivity performance measures, with the highest goal being functional connectivity for entire populations of various species of wildlife (**Figure 3-18)**. This should be the goal, with evidence that all types of members of a population and members of different species were able to access habitat and resources on both sides of the road.

Figure 3-18. Functional connectivity addresses the ability of all genders and age classes of a species to use the wildlife crossing structure whenever they need to move to both sides of a road. A mother moose guides her calf through a wildlife crossing culvert in Utah. Photo Credit: P. Cramer, Utah State University, Utah DOT, Utah Division of Wildlife Resources.

Identify How the Goals and Performance Measures will be Monitored and Reported

To evaluate future success, specific mitigation objectives and performance measures for reducing collisions and improving species movement across a roadway should be defined at the outset of a project. These goals and objectives of wildlife mitigation are later woven into the monitoring phase of the project, where researchers evaluate if objectives are met, by evaluation of performance measures. These methods of evaluating performance measures should be included in the project plans, and a budget for these evaluations and monitoring studies should be included in the project cost. Chapter 4. Monitoring provides greater detail on these approaches.

Evaluate Road and Traffic Features

The lane configuration of the road dictates the crossing structure length. While some species are tolerant of longer structures, wider roads make for longer structure length, which increases ungulate rates of repellence at underpasses (Cramer 2014, Gagnon et al. 2006, 2011, Schwender 2013). Underpasses may need to accommodate two structures for opposing lanes of traffic, with an open median. Traffic volume also affects wildlife at the road. See further discussion in the Project Design step below.

Assess Other Features That Influence Design and Siting

The local terrain relative to a roadway is a practical consideration influencing the feasibility and cost-effectiveness of constructing a wildlife underpass. For more information, see the Project Design Step, Topography and Road Height sub-section.

Human activity at or adjacent to a wildlife crossing can negatively influence wildlife crossing success. While some wildlife crossing structures have been designed as multiuse structures which can help with funding sources, multiple studies have documented a negative correlation between human activity and wildlife use of crossing structures for many species (Clevenger and Barrueto 2014, Gagnon et al. 2011), particularly for un-habituated populations. Finding the right balance among various project components requires close coordination among biologists, engineers, and stakeholders to negotiate workable solutions. These concerns are further addressed with field visits by the team planning for the wildlife mitigation.

Select The Best Mitigation for The Target Species and Situation Based On Science

The science of transportation ecology has developed over several decades and the most cost-effective designs of wildlife crossing structures and other infrastructure are generally known for the more common large animals such as deer, moose, elk, bighorn sheep, pronghorn, black bear, mountain lion, medium-sized mammals such as red fox and badger, and smaller animals such as turtles and salamanders. **Table 3-1** provides a brief overview of different mitigation strategies for reducing wildlife-vehicle collisions and improving connectivity for wildlife. Additional detail about each of these mitigation strategies is provided in Appendix D. Wildlife Mitigation. In many cases, multiple mitigation strategies should be used in conjunction with each other.

Table 3-1. Overview of wildlife mitigation strategies to reduce wildlife-vehicle collisions (Adapted from Cramer et al. 2014, 2016, 2022).

Actions That Target Wildlife	**Actions That Target Drivers**
Retrofit-modify structures	Public education and awareness
Make roadside less attractive to wildlife	Signage
Deter wildlife from entering the road	Speed reduction zones
Exclude wildlife from road and provide wildlife crossing structures, fence, etc.	Animal detection driver warning systems
Reduce wildlife populations	Ineffective, inconclusive, or experimental driver approaches
Experimental, ineffective and inconclusive methods targeting wildlife	

Look for Retrofit and Existing Structure Opportunities

There may be existing culverts and bridges in the project area that could be retrofitted to facilitate wildlife movement or could be passing wildlife already. It is important to access GIS databases of culvert and bridge inventories, identify those locations, and go to the field to evaluate those structures. Washington DOT's Passage Assessment System (PAS, Kintsch and Cramer 2011) is a starting point to this type of evaluation. The most common retrofit is to place wildlife exclusion fence to existing structures to guide wildlife to use them rather than move up onto the roadway. Another is to remove gates from culverts and bridges (**Figure 3-19**).

Figure 3-19. In Idaho, monitoring culverts documented the need for Idaho Transportation Department (ITD) to work with adjacent landowners to pull private gates off of the ITD culvert to facilitate wildlife connectivity under Interstate 84. Photo Credit: P. Cramer, M. Schwender, and Idaho Game and Fish.

Terrestrial pathways along waterways or wildlife benches/terrestrial benches beneath bridges are easy options to providing movement opportunities for wildlife and humans amid the large rocks or boulders placed as rip rap to stabilize the embankment under a bridge. See the Minnesota Best Management Practices Manual (Leete 2014) in Appendix A. Case Studies for other small change ideas for smaller wildlife.

Determine Number of Structures

The number of wildlife crossing structures that would be part of the project is determined during the scoping process. This would entail the planning team to go out to the field to understand the lay of the land, where and how wildlife species are approaching the road, and various species' movement abilities to reach a structure if it came to the fence far from a structure. As mentioned above, Bissonette and Adair (2008), described that based on species daily movements and dispersal movements, 70 percent of North American mammals would need structures under one mile apart. This is important to consider. Most wildlife mitigation projects are based on deer and other ungulate needs. If these smaller animals can be accommodated with additional smaller and less costly culverts, the road's permeability for suites of species would be greatly increased over with a structure every half to one mile.

Fences

The placement of wildlife exclusion fence is something to consider in based on advice from wildlife professionals familiar with the species present preferences for types of structures. Some guidance can be taken from a Huijser et al (2015) guidance manual, but recent research into various fences has informed more effective designs. Length of fence is critical, but must consider wildlife of all sizes needs to move, which are typically well under one mile for species smaller than a deer. Traffic can also form a virtual fence, when daily traffic volumes exceed 12,000 vehicles per day (Charry and Jones 2009, **Figure 3-20**). Great detail can be found in Appendix D. Wildlife Mitigation.

Figure 3-20. An elk was photographed under an Interstate 90 bridge along the Cle Elum River, Washington, with no wildlife exclusion fence present. However, the Average Annual Daily Traffic was over 30,000 vehicles at the time, forming a virtual fence to wildlife movement. Photo Credit: P. Cramer, J. Kintsch, and Washington DOT.

Escape Ramps and Wildlife Deterrence

Wildlife fence will need to be placed with opportunities for animals trapped in the right-of-way to escape, thus wildlife escape ramps (or jump outs as they are also known) need to be placed. These earthen ramps along the fence line allow animals trapped in the right-of-way access to the wild area outside the fenced roadway. Greater detail can be found in Appendix D. Wildlife Mitigation.

Wildlife deterrence is created by guards at ingress and egress points along roads and driveways in the mitigated area, and gates at other low traffic volume and human access points. There are a variety of choices. See Appendix D. Wildlife Mitigation.

Maintenance Needs

The selection process for the most appropriate wildlife mitigation will include consideration of the maintenance needs of that mitigation. The willingness of the local maintenance crews to take on that responsibility is a concern that must be addressed in the final selection of mitigation options. Consultation with other colleagues that have created similar mitigation projects can help elucidate these needs and time costs.

Economic Evaluations (Benefit-Cost)

Economic evaluations are typically done through a benefit-cost analysis. The benefits of the reduced crashes with wildlife over the expected lifetime of the infrastructure, such as the culverts and bridges are divided by the cost of the mitigation and maintenance over time. Different sources of funding may have different benefit-cost analyses. Engineers and planners would know how to use the information and analyses. The Colorado DOT approach to analyzing wildlife-vehicle crash costs and benefits is further defined in Appendix A. Case Studies. Also see the first report in this study by Cramer et al. (2022a), Chapter 4 Data, the section on crash costs analyses, that presents methods on how to analyze crashes with wildlife and animals overall to estimate costs of reported wildlife and animal vehicle crashes which can be used in benefit-cost equations. In some states, crashes with wildlife are grouped with all animal types, which includes domestic animals, thus the analysis may have to include all animal crashes, not just wildlife. See Chapter 1 explanation of these approaches.

Determine Monitoring and Evaluation Plan

A wildlife mitigation project should have a pre-construction and post construction monitoring program for wildlife use and reduction of wildlife-vehicle crashes. See Chapter 4. Monitoring for greater details on how these plans are carried out.

Secure Wildlife Mitigation Commitments That Are Tied to Environmental Commitments and Project Funding

The NEPA process is an opportune time for solidifying wildlife mitigation commitments tied to project funding. These come about often with major transportation projects that require stakeholders' involvement in NEPA processes.

Once these steps have come to some fruition, and potential project needs to then go through the scoping process, below.

Project Scoping

The project scoping step is a more formal administrative step to identify the delivery plan with all project team members and stakeholders to ensure that a project can successfully achieve its goals. The scoping process further defines the boundaries and objectives of a project, it helps to refine the beginning and end points, the time frame, and gross estimate of the costs. The details of the wildlife mitigation and other parts of a project are brought together in the scoping report. An example of how FHWA requires these details to be presented is available at the website: https://highways.dot.gov/federal-lands/pm/cfl/scoping-outline. This document can help wildlife advocates demonstrate that these wildlife connectivity issues are part of the federal agency' priorities for projects.

Recommendations for Project Development

1) It is highly recommended that each agency specify how wildlife concerns are dealt with in the project development process so it is clear where and how these concerns are dealt with in the planning process. This is done through the creation of Best Management Practices manuals. See examples the next section, Project Design.

2) Success criteria need to be defined for potential wildlife mitigation projects. This will help to secure various funds, define benefit-cost analyses, help define a monitoring program, and help to have all parties in agreement on future performance measures.

3) Partners outside the agency need to be identified at the long-range plan stage and all along the planning continuum. This includes wildlife professionals, local communities, and the maintenance crews whom are important to understanding solutions.

4) Include the impacts of roads on wildlife connectivity and the effects of wildlife-vehicle collision in environmental documentation for EAs and EISs to assure these concerns are brought into this federally mandated process.

Project Design

Once a project's parameters have been defined, it progresses to the design step, **Figure 3-21**.

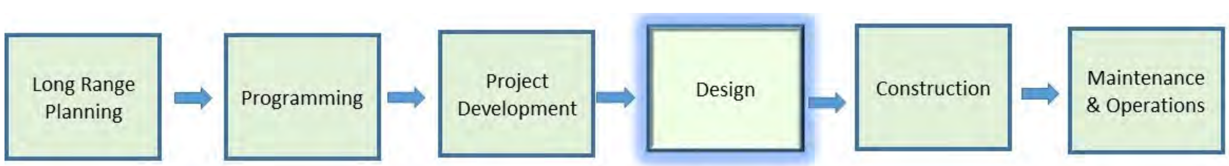

Figure 3-21. The project design phase comes after all major planning has occurred.

The design phase is where the ecological and engineering requirements of a wildlife mitigation project are brought together. Infrastructure designs can be new and unique or built upon past efforts that have been found to work that can be altered to accommodate site specific conditions or novel design elements. Previous designs offer a good starting point for developing new project designs but each project offers an opportunity to tailor the design to the project area and to integrate new research and data on the most suitable designs for the target species. This step in the manual will give some generalities, then set the readers on their way to finding past designs, manuals, and the best approaches for the situation in both the manual appendices and other resources.

Design Checklist

When designing culvert and bridge construction, consider designs that minimize impacts to fish and wildlife. A quick checklist of considerations is presented below and further defined in the matching sub-sections.

- Assess Site Conditions
  - Topography and Road Height
  - Presence of Water and Stream Geomorphology – mimic stream flow, use these structures to provide connectivity for terrestrial species too
  - Assess Retrofit Opportunities
  - Light and Noise Consideration
  - Human Use of Area and Possibly the Structure
- Identify Target Species Preferences for Structure Designs
  - Select and Design Crossing Structures Matched to Species Guilds (groups of animals with similar characteristics related to their ability to move across roads)
- Common Design Recommendations for Structures
  - Engineering Requirements
  - Dimensions
  - Materials
  - Bottom Surface

There are design manuals available from multiple organizations for terrestrial and aquatic fauna connectivity. A brief presentation of some of these guidance documents is provided at the end of this section.

PROFESSIONALS TO ENGAGE IN THIS APPROACH

- Transportation Agency Landscape Architects
- Transportation Design Engineers
- Transportation Agency Environmental Ecologists
- Transportation Agency District / Regional Engineer
- Wildlife Ecologists
- Fish Biologists
- Hydrologists
- Geologists
- Maintenance Staff

Assess Site Conditions

Placement of wildlife crossing structures is critical to ensure success. Project designs should include consultation with professional wildlife ecologists, fisheries biologists, hydrologists and geologists to assess these conditions.

Topography and Road Height

The elevation and topography of sites near and along the road are important for both bringing animals to the potential new structure, and for accommodating ecological processes such as the flow of water, which in turn affect the road infrastructure. Assessing Digital Elevation Maps (DEMs) with a GIS software tool can be an initial step, and a field visit to sites with the design team is critical to the final design selection (**Figure 3-22**).

Figure 3-22. Nevada DOT built a set of wildlife overpasses over Interstate 80 on the Pequop Summit ridge line to accommodate migrating mule deer, elk, and pronghorn. Photo Credit: Nevada DOT.

The position of the road relative to adjacent topography is important for deciding on final crossing structure options. It can be more cost-effective to build a wildlife overpass than an underpass in areas where the topography is above the road. Or if the water table is too close to the surface, underpass structures may be water logged during much of the year if placed in those spots. Road position and the topography help to dictate options. Field site visits are critical to the selection of most appropriate structures.

Presence of Water

Locations with permanent or ephemeral water can be perfect places where a bridge or larger culvert could accommodate both water and terrestrial wildlife. With the changes to the climate, these waterways could have greater pulses of water, mandating an "upgrade" of culverts and bridges to structures that could pass higher volumes of water. If climate change resiliency plans are including such enlargements to replacement structures, the water ways could then accommodate both aquatic and terrestrial wildlife if planned for correctly (**Figure 3-23**).

Figure 3-23. Washington DOT fish passage biologists enlarged the size of this fish culvert on US 101 to accommodate terrestrial wildlife for a small cost increase. Photo Credit: P. Cramer, J. Kintsch, and Washington DOT.

Stream geomorphology is important to consider in designs. Bridge and culvert designs should maintain the stream's dimension, pattern, and profile of the geomorphology, to minimize negative impact to the morphology. A culvert or bridge design should accommodate upstream fish movement, provide for terrestrial wildlife movements, and should be wide enough to maintain consistent flow within the stream. See guidance manuals below.

Assess for Retrofit Opportunities

The existing culverts and bridges on the road in the area of concern should be assessed for their potential to function for wildlife passage. These opportunities are given throughout this manual; see the Project Planning section above, in the Project Development sub-section. Assessment methods are reviewed in Kintsch and Cramer (2011).

Light and Noise Consideration

Areas with artificial lighting and traffic noise may deter nocturnal species. Selecting sites as close to the natural conditions near the highway is preferred. The traffic may pose serious noise deterrence to wildlife. Building material and earthen berms can be designed to help minimize the loud sounds. Placement of structures near areas away from noise, and in sections of roads with the traffic noise minimized is ideal. Wildlife overpasses can also be constructed with earth berms or concrete walls along the sides to shield wildlife of the traffic noise and light, **Figure 3-24**.

Figure 3-24. Washington DOT constructed a wildlife overpass on Interstate 90, and placed high concrete walls along the sides to shield wildlife from noise and light. The elk that use the structure are comfortable enough there to bed down above the highway. Photo Credit: Washington DOT.

Human Use of Area and Possibly the Structure

Humans can take advantage of bridges and culverts for their own use, which can deter wildlife. If the structure can be placed in areas away from human movement, camping, and squatting, it would be best for wildlife. There is potential for structures to also accommodate humans on trails, but evidence is mixed on the detrimental effects. However, if a structure has a better chance of being built if wildlife were to share it with trail users, it may be the best design possible under the circumstances.

Identify the Target Species Preferences for Structure Designs

The target species the wildlife crossing structure or other mitigation is to be built for will have already been selected in Project Development or earlier in the planning process. This step is when the final structure type is selected. What is important at this design stage is to really understand what designs work for that species (**Figure 3-25**). In **Tables 3-2** and **3-3**, generalities are provided for selecting the type of structure most appropriate for various North American species of mammals, amphibians, and reptiles. Appendix D. Wildlife Mitigation details the various structure types and how they would be effective for these various species based on past research.

Select and Design Crossing Structure Matched to Species Guilds

Figure 3-25. Desert bighorn sheep require overpasses to provide functional connectivity for entire herds. A desert bighorn ram used a bighorn overpass over US 93 in Arizona. Photo Credit; Arizona Game and Fish Department.

Although designing wildlife crossing structures for ecosystem function rather than individual target species is far more important, this approach can help readers understand the designs that are confirmed to work for different species groups and, in turn, how those design aspects may be combined to help pass a variety of wildlife and ecosystem processes such as the flow of water. Two classification systems are presented to achieve this: Structure Functional Classes, which classify culverts, bridges and large span viaducts based on size and how different species respond to them; and Species Movement Guilds, which organize wildlife into classes based on similar sizes and reactions to culverts and bridges. Tested wildlife crossings designs for the eight different Species Movement Guilds are presented.

Structure Functional Classes and Species Movement Guilds

The classification scheme provided for transportation infrastructure, 'Structure Functional Classes' provides an organization of the types of road crossing structures and types of wildlife for which each can provide safe passage under or over a roadway. Efforts were made to present dimensions commonly used in the U.S. for culverts. The critical dimensions defining the four classes of underpasses are based on heights and widths of structures, which are dictated by engineering design constraints as well as the characteristics that define individual species' willingness to move through a structure (**Table 3-2**). This classification was first proposed in Bissonette and Cramer (2008), was updated and modified in Kintsch and Cramer (2011), and further refined in a presentation to the International Conference on Ecology Transportation (Cramer et al. 2011). The term span refers to the width left and right. The term rise is the height. Lengths are much more varied and related to lanes of the road, and are not given here, but are discussed later in the section. Increasingly, wildlife crossings research is demonstrating that most species likely have an upper limit for structure length, beyond which crossing success declines (e.g., Australian Museum Business Services 2012, Cramer 2014).

Table 3-2. Structure Functional Classes. A classification system for transportation culverts and bridges as related to wildlife use.

Class Name	Approximate Dimensions (Span x Rise)	Typical Species the Structure Type is Known to Pass
Small Underpass	Metal pipe culverts or small box culverts 5' (1.5 meters, (m)) span or less	Amphibians, small mammals
Medium Underpass	Underpasses larger than 5' (1.5 m) span, to 8' (2.4 m) span x 8' (2.4 m) rise.	Coyote, bobcat
Large Underpass	Underpasses with minimum dimensions: 20' (6.1 m) span x 8' (2.4 m) rise, or 10' (3.1 m) span x 10' (3.1 m) rise, and open span bridges	Deer, elk, black bear
Extensive Bridge	Bridge extending over several spans. Designed for each site so dimensions vary. May allow more sunlight under structure than other types.	Most wildlife – including wary species
Wildlife Overpass	Overpass structure for wildlife to pass over roadway, as small as 22' (6.7 m) wide, but preferably > 164' (50 m) wide	Most wildlife, including birds and amphibians
Specialized Culverts	Current designs are small culverts less than 24" (0.5 m) span but could be larger structures	Reptiles & amphibians
Canopy Bridges	Adequate to cross all traffic lanes. May be connected to trees in the median	Flying squirrels, arboreal mammals

The Wildlife Crossing Guilds were originally created by Kintsch and Cramer (2011) to assist in identifying crossing structure dimensions and characteristics that influence wildlife passage. Terrestrial wildlife types were classified into eight Wildlife Crossing Guilds to assist in identifying crossing structure dimensions and characteristics that influence wildlife passage, **Table 3-3**. This synthesis was based on five primary behavioral and physiological factors: anti-risk behavior; the need for specialized habitat conditions; movement capacity and mode of locomotion; the need for cover or openness; and body size restrictions. These factors underlie a species' willingness to use crossing structures, ultimately determined by an animal's ability to minimize mortality risk when passing through a structure. The guilds combine the existing knowledge base on functional wildlife crossings with generalizations rooted in an animal's natural history and its unique anti-risk adaptations to inform the design of ecologically effective wildlife crossing structures.

Table 3-3. Terrestrial Species Movement Guilds. A functional categorization of terrestrial wildlife based on body size, predator avoidance strategies, and species behavior relative to road infrastructure, traffic and crossing structure characteristics. Taken from Cramer et al. 2011.

Species Movement Guild	Species Attributes & Examples	Preferred Passage Attributes	Preferred Structures
Low Mobility Small Fauna	Small, slow-moving species that require specific ambient conditions such as moisture and light. Frogs, toads, salamanders, ground insects.	Need species-specific habitat consistent with external conditions (light, moisture) throughout the entire structure.	Extensive bridges, wildlife overpasses, trench drains.
Moderate Mobility Small Fauna	Adaptable; can negotiate different types of structures. Small and meso-mammals, some salamanders, reptiles, some ground birds.	Variety of structure types. Water-free pathway preferred and usually required. Cover needed: rocks, vegetation etc.	Small to large culverts and bridges and larger: and overpasses.
Adaptive High Mobility Fauna	Medium-sized mammals that naturally use enclosed spaces for dens and can tolerate some enclosure. Black bear, bobcat, coyote.	May use a variety of structure types and prefer to have suitable habitat directly adjacent to the structure entrances.	Small to large culverts and bridges and larger: overpasses.
High Openness High Mobility Carnivores	Species that prefer good visibility in structure. Larger animals with larger minimum structure size requirement than Adaptive High Mobility Fauna. Wide ranging. Grizzly bear, puma, wolf.	Open structures that provide good visibility, can tolerate longer structures (>100’, 31m). Prefer more open structures but can be tolerant of enclosed structures.	Large bridge underpasses, extensive bridges, wildlife overpasses.
Adaptive Ungulates	Need good visibility on a horizontal plane and some cover. Prefer natural substrate, adjacent cover. Mule and white-tailed deer, moose, mountain goat.	Passages with good visibility in and around structure, clear lines of sight. Preferred structures are wider than they are tall and are less than 100’, 30m in length.	Medium to large culvert and bridge underpasses: larger: overpasses.
Very High Openness Fauna	Very wary of predators and require wide vistas and clear lines of sight.	Large passages with wide openings (at least 15’) that are less than	Large culvert or bridge underpasses,

Species Movement Guild	Species Attributes & Examples	Preferred Passage Attributes	Preferred Structures
Very High Openness Fauna	Prefer moderate hiding cover but still need to detect predators and escape. Elk, pronghorn, bighorn sheep, open-habitat grouse.	100' long, excellent visibility within and around the structure, and clear lines of sight from one end of a crossing structure to the other.	extensive bridges, preferred are wildlife overpasses.
Arboreal Fauna	Species that move primarily through the canopy. Flying squirrels, some bats, arboreal voles.	Features provide a continuous canopy-level structure across the roadway.	Treetop rope bridges, towers.
Aerial Fauna	Species who fly. Songbirds, raptors, bats, flying insects (including butterflies).	Features for these species aim to divert flying species out of the path of traffic.	Diversion poles, extensive bridges, wildlife overpasses.

The details of these types of structures and wildlife preferences are provided in Appendix D. Wildlife Mitigation. Exact structure dimensions are configured with inputs from the next step.

Common Design Recommendations for Structures

Each mitigation design must be tailored to site-specific conditions; thus detailed design information is not presented in this manual. Instead, this section outlines commonalities in the designs of effective wildlife crossing structures and retrofits of existing.

Engineering Requirements

Engineers will have design requirements based on the type of road, its lanes, the number of vehicles per day predicted to use the road, how much truck traffic occurs and is predicted, materials available and their current prices per square foot, the cost of re-routing traffic for placement of various types of structures which includes traffic control, off-site considerations (see Construction step), access to various funding sources, and many more factors that influence their decisions on the selection and the design of the structure. These all affect wildlife crossing structure selection and design.

Engineering constraints can very much drive the location, type, and number of wildlife crossing structures. Figure **3-26** illustrates a factor that both pushes up the cost of wildlife underpasses and limits options for them. Underpasses are commonly built as the elliptical multi-plate metal culverts because they can usually be built for about the same cost as smaller precast concrete box culverts. One disadvantage of multi-plate structures is that they normally need to be completed before supporting traffic. In contrast, traffic can be routed over the completed portion of box culverts when they are half built. As a result, two-lane temporary paved detours are typically required when building multi-plate structures. Detours increase the disturbed area, and a significant part of the construction budget is required to build and pave the detour lane then later remove it and revegetate the site. If the preferred site for an underpass is not suitable for a detour, the crossing location may need to be moved to a second-choice site. Alternatively, a box culvert may be selected to either avoid or reduce the size of the detour. (T. Kinley, Parks Canada, personal communication 2022).

Figure 3-26. Highway 93 through Kootenay National Park in Alberta Canada received the "Kootenay Pond" wildlife underpass in 2015. A 23 x 13 feet (7 x 4 m) corrugated steel pipe (culvert) was placed under three lanes of highway. Traffic was re-routed to one side of the highway. The detour and a former parking area to the right were later decommissioned and restored. Photo Credit: Parks Canada.

Dimensions

Wildlife underpasses have three dimensions to consider: height, width, and length. The most succinct recommendation for a wildlife crossing structure is to keep it as open, large, and as natural as possible. In general, larger structures can accommodate the greatest array of wildlife, including prey species such as ungulates that may be more reluctant to use a structure unless they perceive escape routes from potential predators. Larger structure may also include cover features to facilitate the passage of small prey species (**Figure 3-27**). We review these three dimensions in the order of importance some researchers have documented.

Length of the underpass, meaning the distance the animal travels below the lanes of traffic can be the most important configuration factor. The longer the length, the lower the success rate through the structures for mule deer and other ungulates, see **Figure 3-28**, and Cramer (2014). Keeping the length under the highway to a minimum, less than 200 feet (61 meters) long, results in higher success rates through the structure than rates of repellence away from the structure for white-tailed and mule deer and other prey species (Cramer 2014, Cramer and Hamlin 2017). Bellis (2008) found smaller carnivores will tolerate longer lengths. Other types of wildlife may have different length tolerances.

Figure 3-27. Additional small features can make the wildlife crossing structure function for smaller animals. These logs and stumps were placed under Oregon DOT's US 97 Bend wildlife crossings, and were used quickly by small mammals. Photo Credit: Oregon DOT, Oregon State University, P. Cramer.

Wide underpasses allow wildlife to have a broad area to view potential predators, and the width has been shown to be of importance for mule deer and elk, (**Figure 3-29,** Cramer 2014, Dodd et al. 2007, Gagnon et al. 2011), white tailed deer (Cramer and Hamlin 2017), and others.

Width should also be as wide as possible to accommodate 100-year and 500-year stream flows that are now and will be more common with climate change. These longer bridges and wider culverts can also then accommodate terrestrial pathways along the stream or river for terrestrial wildlife and humans moving along the water way.

Height of underpasses can be the least important structural dimension (Cramer 2014, Cramer and Hamlin 2017). The height can be the most difficult dimension to accommodate engineering-wise because it could mean raising the height of the road out in both directions from the structure, so this finding was welcome news in the design of wildlife crossing structures. Ungulates, including white-tailed deer, mule deer, moose, and elk, have been documented moving under and through structures 13 feet (4 meters) and shorter, (**Figure 3-30,** Kintsch and Cramer 2011, Cramer and Hamlin 2017, Gagnon et al. 2006, 2011).

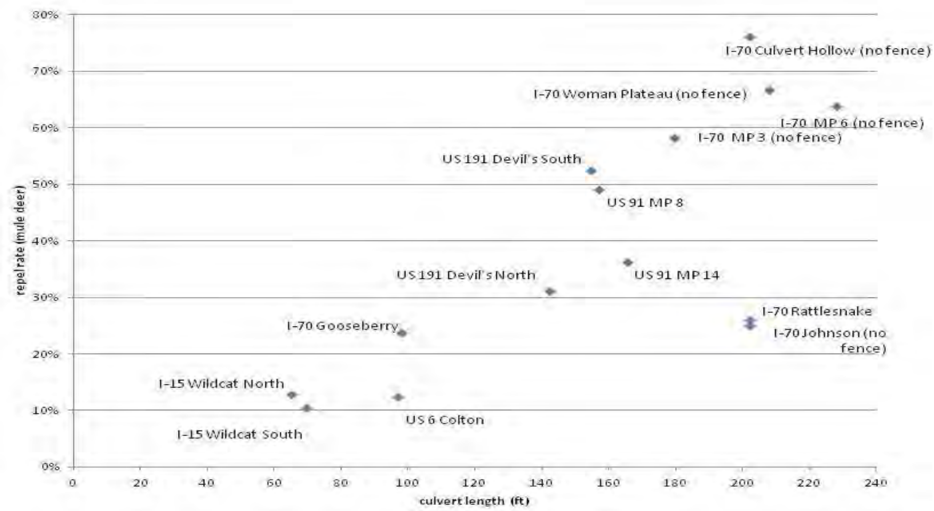

Figure 3-28. In Utah, Cramer (2014) found the longer the culvert, the higher the rate of repellence for mule deer.

Figure 3-29. Bull elk moved beneath Interstate 70 through pre-fabricated arch wildlife underpasses in Utah. However, only several female elk were compelled to do so, even with the arch widths of 60 feet (18 meters). Photo Credit: P. Cramer, Utah DOT, Utah Division of Wildlife Resources.

Figure 3-30. White-tailed deer moved beneath bridges less than five feet (1.5 meters) in height under US 93 in Montana. Photo Credit: P. Cramer, Montana DOT.

Materials

Wildlife crossing structures are typically constructed of the same materials used for culverts and bridges for other purposes. The bridges are typically made of concrete and or steel. Arch span underpasses and overpasses are made from pre-fabricated six-feet wide concrete arches, placed on pedestal supports and connected together. Culverts can be made of concrete or corrugated metal. New materials are anticipated in the coming years that could support the construction of wildlife crossing structures in a more cost-effective manner.

Bottom Surface

The bottom surface of any wildlife crossing structure should be of the natural materials present in the landscape. Animals can better move on a natural surface, which has less water collection water and freezing than human-made surfaces. Amphibians require natural substrate floors and ambient conditions (**Figure 3-31**).

c

Figure 3-31. Vermont Transportation Agency built an amphibian wall and crossing structure with a natural substrate to facilitate spotted salamander movement to breeding ponds. There were also native plants planted at both ends. Photo Credit: Vermont Transportation Department, and C. Slesar.

Best Management Practices and Design Manuals to Assist in Designs

Design manuals are essential for assuring institutional knowledge and practices that work best for wildlife, aquatic organisms, and ecological processes are readily available and are passed on. It is important for planners and designers to have an obligatory step in the development of wildlife mitigation to confer with wildlife biologists in state and federal agencies. The best management practices prompt transportation planners to confer with and receive approval from appropriate natural resource agencies. If no manual of wildlife mitigation designs exists, or the designs are not included in other common manuals, it is difficult to convince a designer to create something there is little institutional experience in building. It is important for these manuals to exist within an agency.

Design drawings from other transportation agencies that have been stamped by a professional engineer (PE) may or may not be permitted due to state registration issues. Some states have reciprocity for such designs, but if there is not an agreement among agencies, unapproved drawings could have legal ramifications. Any such designs provided with this manual are for guidance and information only.

Below are some of the U.S and Canada's top manuals for creating wildlife crossing structures and other mitigation efforts.

Ontario's "Best Management Practices for Mitigating the Effects of Roads on Amphibian and Reptile Species at Risk in Ontario," (**Figure 3-32**) by Gunson et al. 2016 is a stellar guide.

Ontario Ministry of Transportation's Environmental Guide for Mitigating Road Impacts to Wildlife (Ontario Ministry of Transportation 2017) provides guidance to mitigate the impacts of roads to terrestrial and semi-aquatic wildlife species. The guide recognizes how road design and landscape ecology are intertwined and considers road effects on wildlife and corresponding wildlife mitigation strategies.

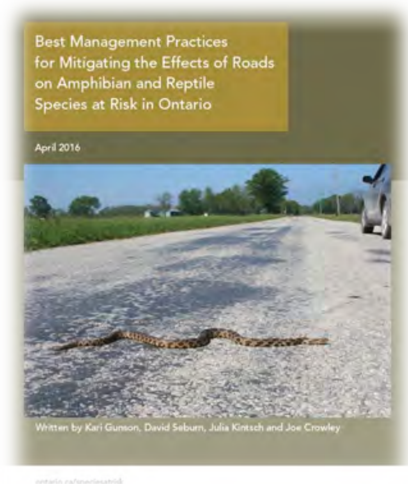

Figure 3-32. Ontario's best management guidelines for amphibians and reptiles.

The British Columbia Ministry of Transportation and Infrastructure created a similar manual based on the Ontario manual, titled, "Guidelines for Amphibian and Reptile Conservation During Road Building and Management Activities in British Columbia," (Ministry of Environment and Climate Change Strategy 2020).

California also has a best practices manual for amphibians and reptiles titled, "Research to Inform Caltrans Best Management Practices for Reptile and Amphibian Road Crossings" (Brehme and Fisher 2021).

There are cities and other municipalities that have also created best management practices manuals for incorporating wildlife crossing structures into future projects and maintaining those structures.

The city of Portland, Oregon produced "Wildlife Crossings, Providing Safe Passage for Urban Wildlife" (Metro 2009).

The City of Edmonton, Alberta also created a guidelines document titled, "Wildlife Passage Engineering Design Guidelines," (Chislom et al. 2010).

La Plata County, Colorado has also created a manual titled, "Best Management Practices for Wildlife and Roads in La Plata County," (Felsburg Holt and Ullevig et al. 2010).

FHWA produced an overall synthesis manual of how to plan for and create stream and river structures to facilitate aquatic species movement called, "Design for Fish Passage at Roadway Stream Crossings: Synthesis Report" (Hotchkiss and Frei 2007).

Massachusetts has developed a helpful series of websites, manuals, and tools for stream passage, restoration, and building and rebuilding infrastructure. The Stream Continuity website, www.streamcontinuity.org, is a good starting point, and the manual, Massachusetts Stream Crossings Handbook is updated regularly and at only 16 pages presents a concise series of steps, designs, and success stories to recreate (Singler et al. 2018).

Minnesota's "Guide for Stream Connectivity and Aquatic Organism Passage through Culverts" is a stellar example of how designs can be provided to planners and engineers who are designing new culverts and bridges to ensure aquatic organism passage through any waters flowing through and under these infrastructure (Hernick et al. 2019). The flow diagram from this design manual is presented in Appendix A. Case Studies, to give clarity to the design process for ensuring culverts and bridges over water bodies protect and restore ecological processes such as stream flow.

Virginia Department of Transportation created a policy and guidance manual (**Figure 3-33**) for planners, project managers, and traffic engineers to follow through the project scoping process on how and when to consider wildlife-vehicle collision counter measures. It can serve as a guide for other states and provinces to model. The Canadian agency, Environment and Climate Change Canada administers the Connectivity Toolbox.

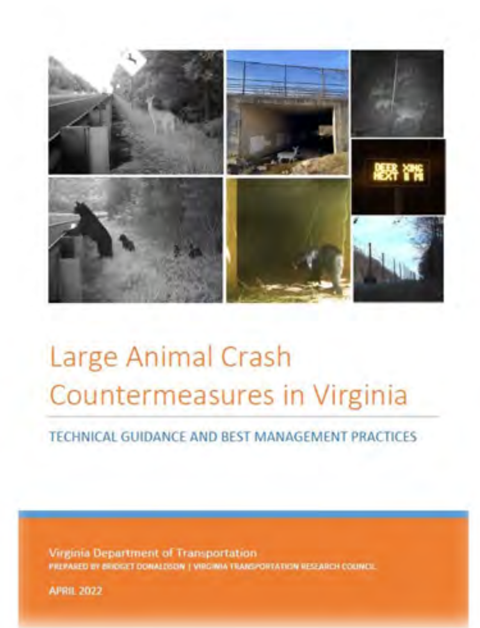

Figure 3-33. Virginia DOT's guidance manual for implementing wildlife mitigation for white-tailed deer and black bear. Donaldson 2022.

(https://www.conservation2020canada.ca/connectivity) that provides examples of guidance, policy, and research among other areas related to wildlife connectivity and climate change in Canada. There will be a forthcoming interactive map at the website. See Appendix A. Case Studies.

Recommendations for Project Designs

1) Standardize wildlife and ecological considerations into all project development. The transportation agency should work with natural resource professionals within and outside the agency to create a wildlife crossings design manual for terrestrial species, and if necessary, a manual for aquatic species, both based on the best available science and updated every two to three years. For example, in Minnesota, the plan sheets for project development have been standardized since 2011 to include standard wildlife benches and aggregate surfacing on large boulder rip rap for wildlife movement beneath bridges. These standards would have to be "opted out" rather than an "opt in" step, making them the default.

2) At minimum, the transportation agency shall have a checklist of professionals to confer with and factors to consider in the design of any wildlife mitigation. This checklist should be obligatory for designers to complete prior to final designs.

3) These manuals and checklists should also be mandatory for outside contractors to consider when designing wildlife infrastructure.

Construction

The construction step occurs once plans, funding, and contracts with construction contractors have been finalized, (**Figure 3-34**).

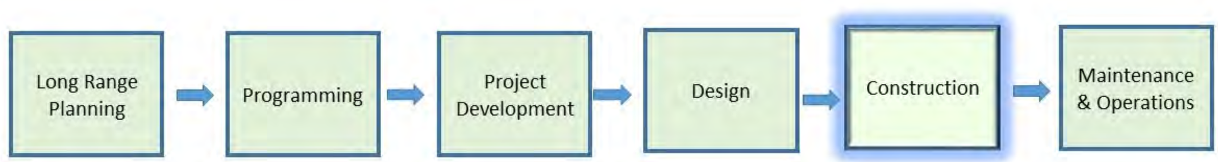

Figure 3-34. The construction step occurs once all planning and funding have been finalized.

The information for this step provides guidelines for construction of wildlife crossing structures and other projects with reference to ecological considerations. There are three areas of concern for the construction of wildlife crossing structures and other mitigation: contracts; ecological concerns; and construction impacts and site considerations.

Contracts and Contractors

Figure 3-35. The wildlife overpasses constructed over Interstate 80 in Nevada were so well placed and designed, a mule deer couldn't wait until construction was over to use the overpass during the last phase of construction. Photo Credit: Unknown Construction Personnel.

Attention to detail is the theme for this section. Wildlife cannot speak for themselves, so professionals must approach construction with what wildlife need in mind (**Figure 3-35**). The best management practices for implementation of wildlife concerns have all of the construction specifications and drawings accurate and up-to-date. Often mistakes in earlier drawings of projects were replicated because of lack of corrections for future uses. It is important for contractors and construction personnel to have the latest adapted wildlife mitigation drawings.

Major requirements such as adherence to migration schedules or breeding seasons are typically included in the environmental document and incorporated into the special provisions. Smaller items such as protection of native vegetation along the road right-of-way for visual and sound screening or other factors can be better addressed by cooperation and partnering with the transportation agency and the contractor.

Construction management and biological input on decisions and adjustments made in the field during construction are critical. There are always changes to designs during construction and it is important to keep the project wildlife-, vegetation-, and ecosystem-friendly. The biologists should be consulted on all changes that in any way could affect the mitigation effectiveness.

Ecological Concerns

When the contractors are in an environmentally sensitive site, there are ecological considerations in space and time. In space, the construction should not disturb or destroy ecological parts of the landscape. For time considerations, the construction activities should be timed to minimize disturbance to soil, water, plants, and wildlife (**Figure 3-36**). Below are specific recommendations.

Figure 3-36. Construction effects on smaller animals may not be immediately evident. Photo Credit: P. Leete.

- When constructing along water ways, the construction should take place during periods of low flow to minimize impacts to fish and wildlife and their habitat (Arizona Game and Fish Department 2008).
- Minimize disturbance to the length of the natural stream channel and the natural flow of water (Arizona Game and Fish Department 2008).
- Remove temporary fills and structures, fences, and debris when construction is complete (Arizona Game and Fish Department 2008).
- Do not use plastic erosion control devices. The plastic netting typically used to stabilize soils at construction sites entraps smaller wildlife that die in the plastic (**Figure 3-37**), and it delivers thousands of tons of plastic into the environment each year. The Minnesota Department of Natural Resources and Vermont Transportation Agency orchestrated a Peer Exchange on plastic alternatives in 2020. In 2022 the Transportation Research Board (TRB) posted a request for a synthesis research project put forth by the TRB committee AEP70 Environmental Analysis and Ecology to create a study on the potential alternative erosion control practices and products. This is a developing topic and users of this manual are encouraged to follow the progression of these alternatives closely.

Figure 3-37. A snake entrapped in plastic erosion control netting placed a decade earlier. Photo Credit: P. Leete.

- Timing of contract and contractors' adherence to ecological concerns are important. There should be provisions in the construction contract to make certain the project is completed either for the season or completely to avoid the next migration, or breeding season, or other wildlife factors that are sensitive to construction activities. It is especially important for timing of movements of Species at Risk (also referred to as SAR).

Construction Area Impacts and Site Considerations

The site impacts of construction activities and how to prepare for them in planning for construction are summarized in the Case Study of the Seven Dwarfs of Implementation in Appendix A. Case Studies.

Recommendations for Construction

1) The best management practices for constructing wildlife crossing structures and other mitigation have detailed specifications in the plans and drawings as to exactly how the structures, fences, escape ramps, wildlife deterrents, and other infrastructure are to be constructed and the timing of construction activities.

2) Consistent timely conferring with the project biologists should be a written part of contracts to assure any changes and incorrect construction are rectified to reflect what is best for wildlife.

3) Construction specifications should include: adherence to schedules that reflect wildlife needs to move into and through the area; protection of native vegetation and waterways; minimization of destruction of ecological parts of the landscape; use of natural fibers for erosion control and no use of plastics; exact specifications as to the footprint of the staging area(s); and working with private landowners nearby and maintenance staff.

Maintenance and Operations

The maintenance and daily operations step is the final part of the transportation process, where the maintenance staff cares for the infrastructure and assures a working wildlife mitigation system, and care for existing structures that wildlife can use to move beneath the road (**Figure 3-38**).

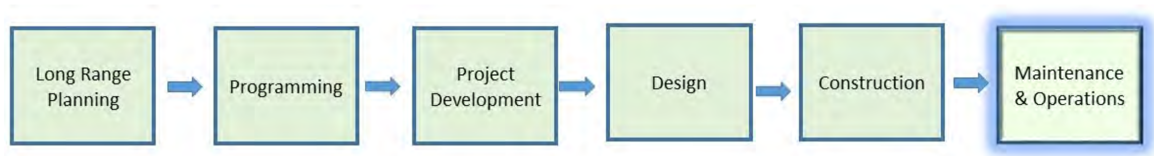

Figure 3-38. Maintenance and Operations is the final step of the transportation process.

Maintenance personnel and concerns are often overlooked in the planning and construction of wildlife mitigation. Yet these professionals are the very people whose attention to the mitigation is critical to the continued function of wildlife crossing structures, fence, wildlife guards, escape ramps, and driver warning systems (**Figure 3-39**).

Figure 3-39. Utah DOT Maintenance personnel were active partners in the mitigation maintenance and monitoring of the US 89 Paunsaugunt wildlife crossings. Photo Credit: P. Cramer

It is critical wildlife professionals and advocates learn more of the maintenance world and how funds are limited for added responsibilities, culvert maintenance schedules, collecting and reporting on carcasses, and how the adaptive management loop is only completed with the work of maintenance personnel.

The following sections detail how maintenance is critical to wildlife mitigation opportunities and how the consideration of wildlife can be incorporated into these activities.

Carcass Collection and Reporting Back

The collection of wildlife carcasses is often the responsibility of the transportation maintenance personnel (**Figure 3-40**). The problem of wildlife-vehicle collisions cannot be addressed unless the location and scope of the problem is documented. Adaptive management of wildlife mitigation cannot occur without the input of maintenance crews who can report on wildlife carcasses and the lack of them along roads. Keeping maintenance crews “in the loop” of what happens with wildlife crossing structures and other mitigation is important.

Figure 3-40. The Montana DOT Hamilton Maintenance crew’s morning haul in the Bitterroot Valley prior to wildlife crossing structures. Photo Credit: L. Frazier.

Cost of Maintaining Mitigation Infrastructure and Responsibilities

It is important Maintenance representatives are at the table from the beginning of long range planning to help elucidate the challenges and costs of maintaining the wildlife mitigation. This is especially important with new technologies. If there is a need to monitor and maintain solar panels, electric connections, cameras, electric signs, and other components of these technologies, and the Maintenance teams are not willing to take on these responsibilities, the technology should not be placed.

Culvert and Bridge Maintenance

If an existing culvert or bridge becomes a de facto wildlife crossing structure with retrofits of wildlife exclusion fence, or it is a wildlife crossing structure, maintenance will need to regularly check on them and make adjustments to make sure they are clear for wildlife. District level staff will need to be authorized by the district administrator or engineer to work with maintenance personnel to fix maintenance issues in these structures when requested.

Figure 3-41. Maintaining wildlife crossing culverts and other culverts used by wildlife to keep them free of ice buildup is a maintenance task that may be a new responsibility. Here mule deer fell on ice in a culvert. Photo Credit: P. Cramer, M. Schwender, and Idaho Game and Fish.

Monitoring of wildlife crossing structures and other existing structures can identify problems that need addressing, such as water build up, ice (**Figure 3-41**), snow from snow plows piled in front of structures, the erosion of wildlife pathways or aggregate fill in rip rap, and other issues. There should also be regular checking of these structures every season, to make sure they are functioning as intended.

Fence Maintenance

Wildlife exclusion fence can be the weakest link in a wildlife mitigation system. Fences come down from snow, falling trees, auto accidents, and other causes. Maintenance crews need to be committed to making these repairs within hours to days of these breaks in the system. Maintenance personnel may not want to maintain wildlife exclusion fence, and thus may not want to have a wildlife mitigation project in their district. A case has to be made as to how the decrease in animal carcasses to be collected is a greater benefit than the fence maintenance time. This will take “buy in” from district leaders to instill this fence maintenance policy to assure it happens.

Reporting Wildlife Problems

Maintenance personnel are at the front lines of what happens along transportation corridors. They need to have a way to inform interested parties as to what is happening with wildlife. A transportation – wildlife alliance, or a committee, or program within the agency is necessary to develop those lines of communication so Maintenance personnel know who to call and what to report. Establishing lines of communication are important. Carcass applications on smart phones can help with this as well.

Maintaining Wildlife Connectivity Through Vegetation Management

Maintenance mowing practices can affect wildlife and insect movement pathways. For example, if the right-of-way is planted in native flowers to facilitate pollinator movements and migrations, the mowing practices are critical to the timing and blooming of the flowers. It is necessary to work with the personnel to assure success of these efforts (**Figure 3-42**). Mowing practices will need to be codified.

Figure 3-42. Arizona DOT planted native flowers and maintained them to provide pollinator connectivity in southern Arizona. Photo Credit: K. Gade and Arizona DOT.

On the other side of vegetation management practices, keeping wildlife crossing structures free of dense vegetation at the entrances is also critical.

If native vegetation is planted at the entrance to structures, maintenance personnel will need to educated on the identification and management of these species.

Adaptive Management

Maintenance personnel are critical to the adaptive management of wildlife mitigation infrastructure. Culverts, bridges, wildlife guards (double cattle guards), and escape ramps are cared for by Maintenance personnel. Monitoring this infrastructure can help detect problems that arise. Maintenance personnel are critical to adapting these measures to help assure functionality. For example, double cattle guards can fill with snow when a plow comes over them, which then allows deer and other wildlife to walk into the right-of-way. It is critical the maintenance workers know this and possibly rectify the situation. Working with partners such as biologists of state and federal wildlife agencies has also resulted in teaming to adaptively manage the wildlife crossing structures and other parts of mitigation systems. Maintenance personnel also independently adapt infrastructure for the benefit of wildlife, from placing small fences to help guide nesting turtles to existing culverts to placing variable message board to warn drivers of wildlife near the road.

Recommendations for Maintenance

1) Maintenance personnel will need to be brought into the planning process from the long-range transportation plans all the way through the construction contracts.

2) Carcass data collection and reporting are important to rectifying wildlife-vehicle conflict. After wildlife mitigation has been placed it is important to report back to Maintenance personnel on how the structures are working, with maps and reports.

3) Maintenance personnel need a point person within a district/region or headquarters who they can contact to report problems with wildlife, or needed improvements to existing infrastructure.

4) Vegetation management practices should be conveyed to maintenance personnel annually in a formal workshop to update them on the latest practices, and the positive results of their past actions and future challenges.

Summary and Additional Recommendations

This chapter provided information on how the transportation process works and how wildlife concerns can be incorporated in the six major transportation steps: long-range planning; programming; project development; design; construction; and maintenance and operations. This chapter provided examples of how wildlife concerns are instituted and carried out within transportation procedures, and ends with a list of recommendations for future actions. In the U.S states and Canadian provinces where wildlife crossing structures and concerns are best addressed, these recommendations have been enacted, such as creating best management practices manuals to help professionals include wildlife concerns in their activities. The recommendations below have also been shown to help agencies instill an awareness and care for wildlife within agencies and within the public, which in turn help these people find ways in their positions and passions to help wildlife impacted by transportation. It is hoped these recommendations inspire readers to take action.

Recommendations

1) Instill Environmental Stewardship and Awareness Within Agencies

Awareness and a love of wildlife are key to helping institute the changes recommended in this manual. There are three approaches that have helped bring wildlife needs to this level in agencies: a within agency wildlife education program, within agency training workshops, and awards and recognition. The British Columbia Ministry of Transportation and Infrastructure (BCMOTI) Wildlife Program, and Vermont Transportation Department (VTrans) both instill an awareness and love of wildlife that then transcends disciplines with their education programs. See the case studies about these programs in Appendix A. Case Studies. Awards can affect change. Awards such as the U.S. Federal Highways Environmental Excellence Awards, and the International Conference on Ecology and Transportation Awards are an important way to instill a sense of pride for the job well done, and to continue achieving successful projects.

2) Engage Partners

Partnerships with others outside of transportation agencies can bring about change that helps to create mitigation for wildlife. Partners can bring information to the planning process, fundraise, bring in-kind actions, help adaptively manage the infrastructure, and raise awareness among the public and legislative bodies. For example, in western states, federal agencies (**Figure 3-43**), Tribes, and non-profits have helped create wildlife mitigation projects.

Figure 3-43. The Paunsaugunt US 89 Mitigation Project on the Utah-Arizona border came about through many partners' involvement. Photo Credit: P. Cramer, Utah DOT, Utah Division of Wildlife Resources, and Arizona Game and Fish Department.

3) Public Education

Public support for wildlife crossing structures and reducing wildlife collisions is crucial for planning for wildlife and spending tax payers' dollars. The transportation agency and its partners will need to update social media, meet with journalists and reporters, and have politicians go to bat for them in support of wildlife crossing structures.

These and other proactive steps will help the U.S. and Canada achieve greater successes in reducing wildlife-vehicle collisions and conflict, and in increasing connectivity for multiple wildlife populations across the continent.

Chapter 4 Monitoring Strategies

Overview

This chapter brings together all the components to a wildlife mitigation monitoring plan. The steps begin with setting objectives for the study, setting performance measures (**Figure 4-1**), and deciding how those objectives and measures will be evaluated. The main part of this chapter details how to set up a monitoring plan with pre and post construction tasks. After the monitoring has ceased, the analyses and reporting can be conducted with methods that have become standardized in the past decades. (**Figure 4-2**). More details are provided in Appendix E. Monitoring Plan Guide.

Figure 4-1. The monitoring for Colorado's SR 9 had set performance measures. Cameras measured wildlife use of escape ramps. Photo Credit: Colorado DOT, Parks and Wildlife, and ECO-resolutions.

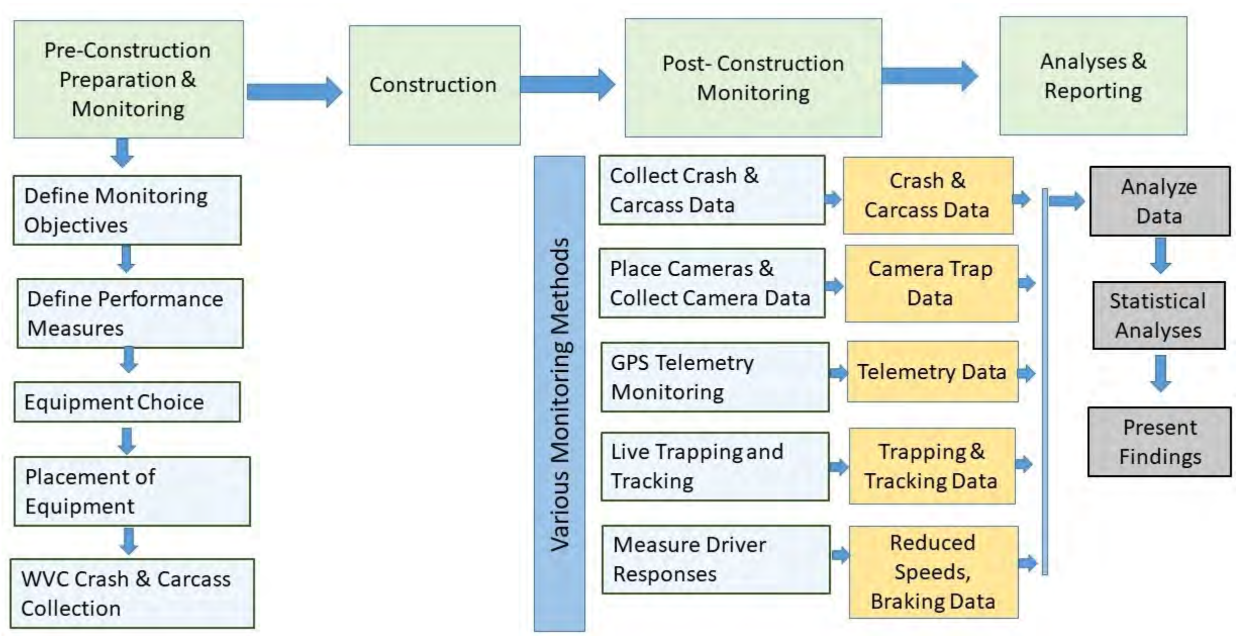

Figure 4-2. Flow of steps to a monitoring program for evaluating wildlife movements and wildlife-vehicle collisions in relation to transportation-wildlife mitigation.

The Value of Monitoring

Monitoring of wildlife mitigation created to reduce wildlife-vehicle collisions and minimize habitat fragmentation is essential to our understanding of successful and unsuccessful mitigation project components. Without monitoring, the iterative process of improving upon current projects through adaptive management and incorporating those modifications into future projects cannot occur (**Figure 4-3**).

The science and practice of transportation ecology has moved forward with success in large part because of the monitoring projects that allowed partners to choose the most cost-effective options for a variety of animal species in different geographic locations. There is more work to be done, more evidence to gather to support future efforts, and thus, monitoring should be considered part of mitigation efforts.

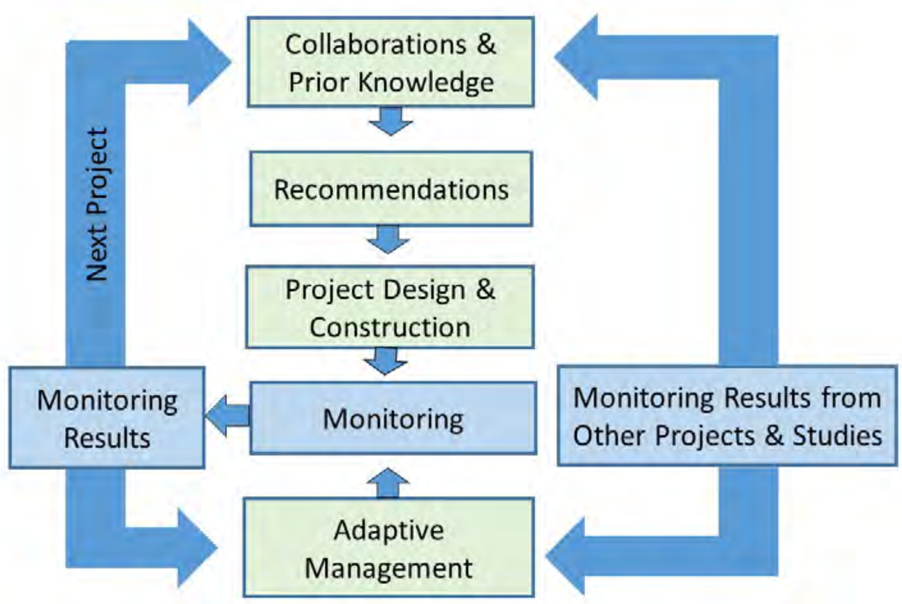

Figure 4-3. Flowchart showing the importance of monitoring in the iterative process of improving wildlife-vehicle collisions and habitat connectivity mitigation projects.

Evaluation of Wildlife Mitigation with Performance Measures

Define the Objectives

Figure 4-4. Monitoring is important to learn of carnivore species use of structures as well as ungulates. Carnivores typically are photographed much less frequently than ungulates. Mother black bear and three cubs used wildlife underpass on Highway 93 in Kootenay National Park. Photo Credit: Parks Canada.

Every monitoring project should begin with clearly defined objectives of the monitoring program. The objectives of the study determine the scientific approach, the performance measures, how the measures will be monitored, the equipment and its settings, the years of monitoring, the involvement of wildlife agencies, and other factors. Wildlife researchers know the various components of what makes a wildlife crossing structure or other mitigation important to wildlife connectivity (**Figure 4-4**). Engineers and planners in a transportation agency want to know how different infrastructure designs work and understand the importance of performance measures that document increased driver safety from reductions in collisions with wildlife. Monitoring projects bring together these two approaches in most transportation-wildlife mitigation monitoring.

The ecological objective of monitoring studies is often to determine how the wildlife crossing structures and retrofitting of existing structures functioned for different species of animals. The effectiveness of the structures is measured by the success and repel rates of various species through the structures, the average number of successful passages or movements through the structure annually for the species of interest, and the permeability of the mitigation project for multiple species. This permeability is defined as the structure allowing multiple members of multiple species to use it when they need to, meaning adult males, adult females, and young all use the structure in numbers representing a large portion of the populations of those animals that need to use the structure to access both sides of the road (**Figure 4-5**). This objective is often evaluated with camera traps but can also be partially evaluated with telemetry data of the species of concern.

A safety objective of mitigation and monitoring could be a reduction in wildlife-vehicle collisions. This can be evaluated with crash data and carcass data.

The list of standard objectives is provided in Appendix E. Monitoring Plan Guide.

Performance Measures

During project monitoring, performance measures are evaluated using data to determine whether the mitigation efforts accomplished the transportation and ecological goals. The five primary measures for assessing the success, or lack thereof, of wildlife mitigation measures are: amount of reduction in wildlife-vehicle collisions, use of structures by various species and the rates of success, successful passages per day on average, permeability for entire populations of target species, and driver responses. Specific performance measures are found in Appendix E. Monitoring Plan Guide.

Figure 4-5. Connectivity for all genders and age class is an important purpose of wildlife crossing structures. Overpass structures have shown to be the best structures to assure population level connectivity for bighorn sheep. Bighorn on the overpass along Boulder City Bypass, Interstate 11, Nevada. Photo Credit: Nevada DOT, Arizona Game and Fish Department.

Monitoring Techniques

There are five major monitoring techniques: collecting and analyzing crash and carcass data; evaluating mitigation effectiveness with camera traps; live capture and tracking of animals with Global Positioning System (GPS) collars and tracking devices; live trapping and marking animals; and measuring motorists' responses to driver warning systems. We present these below with an emphasis on the use of camera traps.

Wildlife-Vehicle Crash and Carcass Data Collection

Wildlife-vehicle crash data, also known as collision data in the Ministries of Transportation in Canada, reflect the combined effects of wildlife deciding to cross a road and motorists not responding in a manner that allows them to avoid the collision. Carcass data reflect the animals killed in the collisions with vehicles but may not be reported to law enforcement and traffic safety, and whose carcasses remain in the road and right-of-way area.

In most jurisdictions, wildlife-vehicle crash data are the most important metric to a Department or Ministry of Transportation (DOT, MoT respectively) because they are a measure of the risks to motorist safety. Most mission statements of transportation agencies reference providing safe transportation to the travelling public. This includes the reduction of wildlife-vehicle collisions, even if they are not mentioned directly. Crash data are available to analyze in a monitoring study. Greater detail on crash data can be found in Chapter 2. Prioritization, and Appendix B. Data.

Carcass data collection is a way to track smaller animal collisions and any animal collisions not reported as crashes to traffic safety. Carcass data (also called roadkill), can provide a more thorough evaluation of the number of animals actually getting killed on the road from larger sized animals such as elk, down to smaller animals such as amphibians, reptiles, and small mammals. Carcass tracking is helpful for any species that is small, and sometimes for more rare species that remain on the road long enough to be counted and not scavenged or taken by people. Professionals and the public may also track where live animals are observed near the road using phone apps and computer mapping programs. However, these efforts are opportunistic, preventing robust comparisons among locations. Researchers may also place cameras in targeted roadside locations to provide a limited snapshot of wildlife activity adjacent to a roadway.

The standardization of data collection methods is important during the monitoring. It is important for making relevant comparisons of carcass and crash data before and after the mitigation construction is completed.

Measuring Effectiveness of Mitigation Measures with Camera Traps

Monitoring of mitigation measures with cameras can help determine their success in functioning as intended. Cameras or camera traps, are the method most often used to capture wildlife presence and responses at wildlife crossing structures to cross under or above a road. While some agencies only tally wildlife presence at crossing structures, it is critically important and more informative to position cameras and analyze wildlife photos to evaluate each animal's response to the mitigation. These responses are tallied as success through the structure, repel movements from the structure, or parallel movements when the animal ignored the structure.

Camera traps can also evaluate other components of a mitigation system, such as how elk are breaching a wildlife guard or using an escape ramp by jumping on it in the wrong direction to enter the fenced right-of-way. In both cases monitoring helps learn of the mitigation successes and failures for future reference and helps feed into the incremental process of improvement and adaptive management over time (as seen in **Figure 4-3**). Details on how to set up cameras in a monitoring study are provided in Appendix E. Monitoring Plan Guide.

One monitoring mistake commonly made is collecting images of animals using a mitigation feature (successes), such as a culvert, and making assumptions and recommendations without a complete frame of reference regarding how many animals approached but ultimately did not pass through the structure (failures, **Figure 4-6**). This monitoring method can result in a misleading conclusion. For example, if four elk use a culvert but your monitoring does not record the 100 elk that did not, and these four elk movements are called a success, one may conclude the structure is effective for elk passages even though 96 percent of the herd did not use the structure. It is essential to collect success rates and repel rates of mitigation measures to accurately capture their effectiveness.

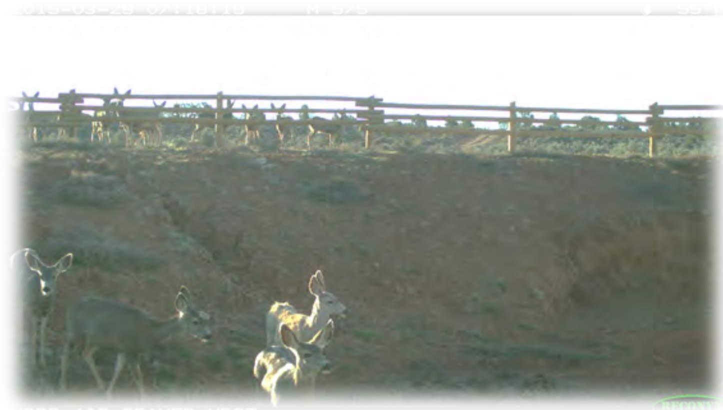

Figure 4-6. Not all animals that approach use the wildlife crossing structure. Mule deer herd approached a new wildlife crossing culvert under US 89 in Utah. Photo Credit: P. Cramer, Utah DOT, Utah Division of Wildlife Resources.

To measure success and failure rates (sometimes also called successful passage and repel rates, respectively), one must capture the number of animals that approach a feature and the number that actually use the feature. Dividing the number of uses by approaches calculates the success rate (successes/approaches = success rate). See Appendix E. Monitoring Plan Guide, for greater details and examples. These rates not only help normalize wildlife responses, they also provide a consistent comparison across different population densities of the same species.

It is also important to consider wildlife responses to the structure that are just parallel movements of animals that did not intend to use the structure. Although these rates are typically somewhat around 10 percent or less (Cramer and Hamlin 2019a, Kintsch et al. 2021), it is important to be able to classify activity by animals grazing or walking along the fence line adjacent to the structure rather than trying to move through a structure.

Success and failure rates are especially important for smaller structures or novel features where little to no prior research has been conducted on their success or failures for the target species or suite of species.

The number of successful movements per day on average is useful when evaluating the use of the structure by various species. While success rates are largely about structure dimensions and characteristics, the number of times animals use it can largely indicate if the location is important to animal movement. There can be instances where success movements per day may deem a structure not be cost-effective based on sheer numbers of times animals used it, such as large viaducts and bridges. In these instances, simple documentation of use still provides a relative measure of success that can be compared to nearby structures within the same wildlife population densities (**Figure 4-7**). Continued studies that bring together data from multiple monitoring studies rely on the results from monitoring these and other structures, and the greater number of similar types of structures, the stronger the statistical inferences we can make as to the most cost-effective crossing structure designs for various species (Basting et al. 2022).

Figure 4-7. Examples from New Mexico monitoring of smaller culvert (left) and of an existing bridge (right) to document success and repel movements. Photo Credit: New Mexico DOT, Arizona Game and Fish Department.

Another important part of monitoring is comparing structure use as gauged by the number of successful passages / movements by animals of a number of different species, relative to the species identified at a distance away from the road that may not be approaching the structures. For instance, if elk are known to be in the area, and preconstruction crash data document collisions with elk attempting to cross the roadway, but elk are not using the structure, then the structure did not function as providing connectivity for elk, that may or may not have intended to cross the road (**Figure 4-8**). One way to assess an area for the species present beyond the immediate vicinity of a structure is to place wild area or habitat cameras at the edge of the road right-of-way fence, facing out to the wild area. These cameras can then evaluate species of animal and numbers of those animals nearby that may be not using the structure. See Appendix E. Monitoring Plan Guide for greater details.

Figure 4-8. Elk were present outside the fenced right-of-way on US 160 east of Durango, Colorado. Despite 74 elk movements recorded over 2.5 years, none of the animals approached the wildlife crossing structure 130 feet (40 meters) away (Cramer and Hamlin 2021). This information greatly helped Colorado DOT better plan for future elk crossing structures. Photo Credit: P. Cramer and Colorado DOT.

Caution is warranted in placement of cameras in areas where the background setting may be private property. It is important to be cognizant of what activities the cameras may be perceived as documenting and the attitudes of landowners and potential vandals in an area toward a monitoring camera. It may be important to educate residents of an area and get some kind of local approval when placing these cameras that can cost thousands of dollars. The real-time uploads of photos and video can also play a role in law enforcement and “eyes on the ground” to help protect animals from poachers. Cameras can be placed in areas near crossing structures to monitor humans coming to kill or remove individual animals, and to identify the license plates of the poachers and vandals, as has happened in Minnesota, Arizona, Utah, and Washington. Instructions on protecting cameras from theft is presented in Appendix E. Monitoring Plan Guide.

Measuring Road Permeability with Camera Traps

Evaluating structures for functional connectivity or permeability is another step in the evaluation of wildlife crossing structure success. If just a few individuals of a species cross through the structure, and they are not representative of all age classes and genders, then there is low functional connectivity for the population of that species. If all ages and genders of a species have used the structure, and in proportions similar to the estimated population numbers of that species in the area, then the structure may be considered to be effective in providing functional connectivity.

It is also important to evaluate all the species and their age and gender classes for this functional connectivity (**Figure 4-9**). Recording the gender, age, and numbers of animals using the structure is critical to this evaluation. See Kintsch et al. (2021) for how these levels of connectivity were used as performance measures for multiple species for Colorado's SH 9 wildlife crossing structures.

Figure 4-9. Document multiple species' use of crossing structures to establish how the structure facilitates wildlife connectivity. Here a mule deer and javelina share the space under SR 77 wildlife underpass in Arizona. Photo Credit: Arizona Game and Fish Department.

Measuring Road Permeability with Telemetry Data

Even if mitigation projects both reduce collisions and have documented wildlife use of structures through monitoring, we cannot fully understand the positive or negative impact that a project may have on wildlife without looking at the overall changes in the location and ability of wildlife to cross the road once projects are completed. Telemetry data as taken from radio and GPS collars and devices mounted on the animals can help to determine the ultimate outcome by identifying shifts in movement patterns or levels of permeability across road barriers (**Figure 4-10**). If during post-mitigation, a large portion of the local wildlife population simply shift their movements to other non-mitigated areas along roads, or

Figure 4-10. Cameras on Arizona's SR 77 confirmed two GPS-collared mule deer movements over the wildlife overpass. Photo Credit: Arizona Game and Fish Department.

simply adjust their daily and seasonal migrations elsewhere then a project is not working as intended. Such shifts are best captured with the use of telemetry data.

Measuring highway permeability can help determine the success of a project in maintaining or restoring movements across roads. For example, if a project reduces accidents by 90 percent but in turn significantly reduces the ability of animals to cross the road then it may be considered a success from a motorist safety perspective but not from an ecological perspective as it leads to further habitat fragmentation.

If a road is a complete barrier to a species and no carcass data exists due to a lack of road crossing attempts, telemetry data can show whether the mitigation effort reconnected that population.

Historically, telemetry data was limited to larger species, however recent advances in technology have reduced GPS and very high frequency (VHF) transmitter telemetry units down to sizes small enough to fit reptiles and amphibians. GPS telemetry monitoring is the easiest to conduct because once the unit is attached to the subject, location data is provided remotely by satellite feed to the researcher. It is important however, to upload GPS locations from the collars more frequently to detect where animals cross the roads, than the time frequencies required for demographic research. For much smaller species VHF telemetry requires regular and consistent field visits to determine if those animals are moving across a mitigated area at different rates before and after construction.

Permeability for Smaller Species Measured with Camera Traps, Live Traps, and Telemetry

Smaller species typically cannot trigger camera traps as reliably as medium to large sized animals. Researchers documenting these animals' movements use innovative methods to detect and record small mammals, amphibians, reptiles, fish, and invertebrates inside and along wildlife crossing structures (**Figure 4-11**). Smaller animals can be photographed with camera traps that funnel them to small areas right under cameras, or cameras can take time lapse pictures. The former would census all animals that pass under the cameras, while the latter would survey. Small animals can be caught, marked, and recaptured using pitfall traps (recessed containers in the ground that the animals fall into when traversing a longitudinal barrier) and live traps. These methods help to detect animal movement

Figure 4-11. A Pacific Giant Salamander was photographed, using the Wolfe Creek wildlife crossing structure in Washington. Aquatic connectivity for smaller species is also an important objective of wildlife crossing structures. Photo Credit: P. James, Central Washington University.

through structures and across the landscape. Finally, animals as small as toads can be tracked with small GPS tracking devices. See the Smaller Animals section below and Appendix E. Monitoring Plan Guide for the story titled, “Monitoring smaller animals for connectivity across an interstate is possible.”

Evaluating Motorist Response to Mitigation

While most forms of wildlife-vehicle conflict mitigation projects such as wildlife crossing structures and fences are geared toward altering the behavior of the animals, other methods seek to alter motorist behavior. Mitigation methods such as signage, speed reduction zones, roadside vegetation removal to improve driver sight lines, and animal-activated detection systems (AADS) are intended to modify driver behavior in a manner that causes motorists to either avoid collisions completely or strike an animal at a slower speed reducing the potential for injury (Huijser et al. 2008). The “elk crosswalk” completed in 2007 along State Route 260 in Arizona is an excellent example of a mitigation measure designed to change driver speeds in response to wildlife activity detected on or adjacent to the roadway. This AADS uses software linked to thermal detection to identify animals large enough to potentially pose a safety concern to motorists (set at fox-sized or larger). Once an animal is detected, a series of signs are activated in an attempt to alert motorist to slow down in time to avoid a collision (**Figure 4-12**). Monitoring this mitigation system included evaluating if motorists brake lights came on when near an activated sign, if speeds were reduced in the section of the road with the sign, and if wildlife-vehicle crashes were reduced. Over nine years of monitoring motorist speeds were reduced by 13 percent and there was a five-fold increase in braking response with the signs on versus off, contributing to the 97 percent reduction in elk-vehicle collisions documented by the project monitoring program (Gagnon et al. 2019).

Figure 4-12. Example of thermal target
acquisition software used to activate motorist alert signs (left) and sign activated when a

target is identified as wildlife large enough to pose a safety concern to motorists. Photo Credit: J. Gagnon and Arizona Game and Fish Department.

Overall Tips for Setting Up Pre-Construction and Post-Construction Monitoring and Analyses

The following sections provide overview pointers for pre- and post-construction monitoring.

Pre-Construction

Prior to a mitigation construction project, wildlife professionals, engineers, and planners need to work together to determine multiple components of the study. This preparation may occur pre-construction but it is necessary for post-construction as well.

- Determine the location of crossing structures, escape ramps, and wildlife double cattle guards;
- Build structures for the inclusion of mounts for camera traps into the structures;
- Determine the objectives of monitoring and the performance measures, as outlined above and in Appendix E. Monitoring Plan Guide;
- Determine the number of cameras or GPS collars for monitoring animal movements;
- If wildlife will to be live-trapped or tagged, determine equipment needs;
- Determine if carcass collection surveys will be conducted and how often;
- Determine the time frame for pre and post-construction monitoring;
- Determine the budget for monitoring; and
- Build consensus on agreements on reporting and working together.

Pre-construction monitoring provides a baseline for evaluating the effectiveness of a mitigation project at the same location. When gathered consistently, occurrences of wildlife-vehicle crash and carcass data can be compared directly across pre- and post-construction to determine whether the mitigation project resulted in a reduction of reported crashes or carcasses, or if collision hotspots shifted.

Pre-construction telemetry movement data not only help to identify locations for the placement of crossings but can also provide baseline levels of roadway permeability and distributions of approaches and crossings.

Pre-construction camera monitoring is helpful in determining the species that are present near the road, their numbers, and if placed in opportune positions, the cameras may help evaluate how successful the animals were in crossing the road. If the pre-construction cameras can evaluate the success of the animals in crossing the road prior to construction, a base-line rate of successful crossing can be estimated and used as a performance measure for improvement with the mitigation. In Montana (Cramer and Hamlin 2017) the white-tailed deer crossed a two-lane control road and US 93 when it was two lanes pre-construction approximately 67 percent of the time they approached the edge of the road. This percent was used as a minimum target for the successful passage of white-tailed deer through the wildlife crossing structures.

In Colorado, Kintsch et al. (2021) evaluated the species present prior to SH 9 mitigation construction and set performance measures for species minimum numbers expected to use the crossing structures. This was especially useful for less common species such as pronghorn and mountain lion.

Post-Construction

Post-construction mitigation monitoring provides valuable insight into the effectiveness of implemented mitigation measures and is the most essential phase of monitoring. However, to best judge if the mitigation has worked at providing permeability for all the species present prior to construction and reduced wildlife-vehicle collisions it is important to try to pair this phase with a pre-construction monitoring phase.

The objectives of a monitoring effort drive the monitoring methods. The type of equipment, where it is placed, the settings, how often it is checked, the number of cameras or GPS collars, the length of the study, and the statistical analyses are all determined by the purpose of the study, which should always remain in the forefront of the approach scientists and their colleagues take when setting up the study. An important ecological component of this set up and reporting is to measure functional connectivity of populations for multiple species, not just the target large ungulates, which are often the most common species and frequently involved in wildlife-vehicle collisions. For greater details on the specifics of these components, see Appendix E. Monitoring Plan Guide.

Post-construction monitoring is used to assess the effectiveness of site-specific mitigation features such as wildlife crossing structures, escape ramps, wildlife guards, etc. that can be compared across the study area (**Figure 4-13**) or to results from other studies. If there is enough variation in feature design across the study, (e.g., multiple crossing structures of different types and sizes), valuable insights into the effectiveness of design variations can be gained and added to the field of knowledge.

Figure 4-13. Elk use the Gold Creek Bridge beneath Interstate 90 in Washington. This was one of over one dozen wildlife crossing structures built in this section of Interstate 90. Photo Credit: Washington DOT.

Long-term monitoring provides insights on the overall effectiveness of mitigation features, and provides opportunities for adaptive management to improve the mitigation project. Without long-term monitoring, researchers and managers are at risk of obtaining short-term inaccurate results that can lead to misinformed recommendations for future projects. In many instances, it takes wildlife several years to adapt to features and understand their utility.

For example, elk along Arizona SR 260 took approximately four years to fully adapt to wildlife crossing structures, which improved results from early assessments of some of the same structures (Dodd et al. 2007, Gagnon et al. 2011). U.S. Highway 89 in Utah showed similar learning curves for mule deer over the five years of monitoring (Cramer and Hamlin 2019a). In Colorado, Kintsch et al. (2021) found a small herd of elk adapted to an underpass crossing structure in the fourth winter after construction, and increased their use over time, **Figure 4-14**.

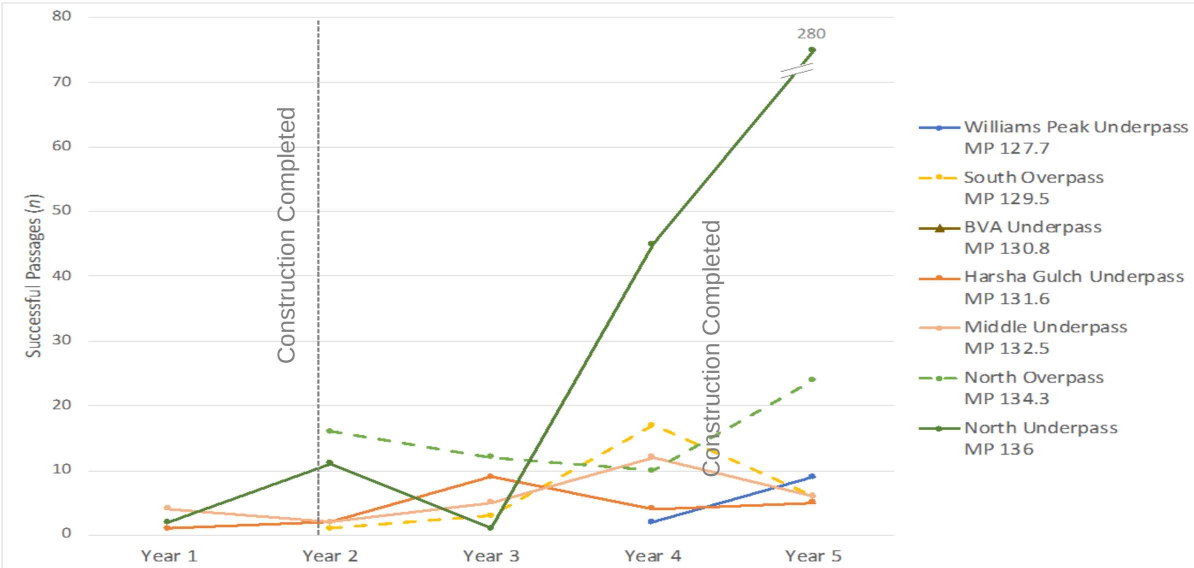

Figure 4-14. Elk successful passages through seven wildlife crossing structures per year, on Colorado's SR 9. Taken from Kintsch et al. 2021.

Smaller Animals

Monitoring for smaller animals both pre- and post-construction can be accomplished using species surveys that could involve pitfall traps, mark and recapture with Passive Integrated Transponders (PIT)-tags and telemetry tracking on animals as small as toads and fish, and cameras set to take pictures at regular times. Central Washington University has conducted some of the most extensive surveys of smaller wildlife along a transportation corridor, both pre- and post-construction. Their case study in Appendix E. Monitoring Plan Guide demonstrates some of these methods.

Gunson et al. (2016) created "Best Management Practices for Mitigating the Effects of Roads on Amphibian and Reptile Species at Risk in Ontario." It is a highly regarded guide and we refer the reader to use it if more interested in smaller animal monitoring. Appendix E. Monitoring Plan Guide provides greater detail on the various methods to monitor smaller wildlife.

For further reference, the book, Roads and Ecological Infrastructure: Concepts and Applications for Small Animals (Andrews et al. 2015) presents many ways to monitor, retrofit, and build crossing structures for smaller animals.

Analyses

Before After Control Impact (BACI) Study Design

The Before After Control Impact or BACI design is the most scientifically robust study design for isolating the effects of a mitigation project to determine how well the mitigation succeeded in achieving its objectives, typically in reducing wildlife-vehicle collisions (Rodenbeck et al. 2007, Rytwinski et al. 2016). This approach uses pre- and post-construction data on the mitigated section (Impact) and a control section of road where no changes occurred. This type of design provides the highest level of inferential strength to measure the ability of the study to detect changes in the parameters of interest (Gunson et al. 2016). With BACI approaches, the researchers can control for changes occurring over time, such as weather, traffic volume and wildlife numbers. For this type of analysis, a rate of something in the mitigated area or impact section of road is compared to rates in one or more control areas of the road nearby that have not been affected by the mitigation or road construction of the mitigation. The time periods of examination are the before and after mitigation periods.

Although a BACI study design is the "gold standard" for experimental research, it is not always possible in the applied world of transportation ecology. Most roads under examination do not have comparable control areas of road in similar habitat, used by the same wildlife population under similar conditions. Or there are no opportunities to collect pre-construction data on new roads where there were no roads to compare with pre-construction or as a control. Nevertheless, a before-after monitoring study can also be highly informative despite the lack of data from control segments.

Baseline and/or control data are necessary to determine the effectiveness of a mitigation project in reducing wildlife-vehicle collisions or maintaining or promoting habitat connectivity. Without these data there can be no comparison. For example, if monitoring of a mitigation project documented five wildlife-vehicle crashes in a year, it would be important to know if there were more or less than an average of five per year in the previous five years, or if that number is higher or lower than adjacent or control sections. Regardless of the comparisons used, consistent data collection is essential to these monitoring efforts.

Details on various types of data analyses for photos and telemetry data are presented in Appendix E. Monitoring Plan Guide in the Analyses section.

The Future

The future of monitoring wildlife mitigation along transportation corridors will be influenced by developing technology and climate change priorities. Several trends are described below to help the reader and agencies plan for the future of monitoring.

New Monitoring Methods

Technology to Identify Animals in Photos

Technology can help analyze the thousands to millions of pictures or videos generated by monitoring cameras, which can become onerous to review and analyze, especially if there are many pictures of objects other than animals, such as blowing vegetation or vehicles. Computer software can sort the images prior to analysis, by identifying animal pictures and those without animals. Artificial Intelligence (AI) has been trained to take this first “cut” on the pictures and sort them into pre-assigned folders and pull metadata from the images. There are currently no standardized AI systems for wildlife mitigation research and many researchers have concurrently developed their own AI photo processing systems. Some of the software available include:

ClassifyMe auto detects animal species and can be used by ecologists in the field and office (see Falzon et al. 2020).

Wildlife Insights is a platform based in the cloud (on-line) that uses machine learning to identify animals in camera trap images. Researchers can upload camera trap photos to store them and access them. The software in the platform identifies the species using machine learning and places a tag on the photo. This software was developed in conjunction with Google and the Smithsonian National Zoo, the Conservation Biology Institute, and other organizations (See Wildlife Insight 2022).

Technology to Identify Animals Along Road and at Structures

There are advances occurring with camera technology beyond the professional camera traps with batteries and SD cards that have traditionally been used to monitor wildlife at infrastructures. Advances in infrared, radar, LiDAR, electromagnetic, and thermal technologies and research methods have provided promising results for monitoring wildlife in field settings and in tandem with driver warning systems. However, in many instances cameras associated with driver warning systems should still be considered experimental until these systems have been successfully deployed and refined for their reliability. In 2022 at the time of this writing, several types of systems were being tested across North America. Camera systems used to monitor wildlife at infrastructure are however, advancing at fast enough rates that they can be considered potential alternatives for monitoring wildlife at structures. These are described below.

Radar-based cameras used to monitor animal movement and then warn drivers in animal activated detection systems showed promising results in Idaho (Huijser et al. 2017) and British Columbia (Sielecki 2016, 2017). Additional research and deployments are warranted.

Chen al. (2019) successfully utilized LiDAR technology to detect deer attempting to cross roads in Nevada. Recent research in Virginia by Druta and Alden (2019) has identified the advances of this technology in the animal detection realm with successful field deployments.

Figure 4-15. Elk movements were captured by thermal imaging video cameras at an underpass bridge on I-90 at Price Creek in Washington. Photo Credit: G. Kalisz, and Washington DOT.

Thermal technology is already delivering useable results that have become important to monitoring studies. Thermal video cameras can detect medium sized mammals up to 1200 feet (366 meters) away, which can replace over one dozen traditional cameras with infrared-heat-motion triggers (**Figure 4-15**). They have high detection reliability, and customizable software to help with such things as detection zones in animal activated detection systems.

Thermal video cameras used to monitor wildlife can be tied into the traffic and snow condition monitoring equipment electricity and fiber optic lines to send videos to an on-line server in real time. Se section below for more details. Thermal technology was also being used as of this writing in Idaho, New Mexico, and British Columbia, for both evaluating wildlife use of structures, and for driver warning systems.

Unlike thermal cameras, high definition (HD) digital cameras can provide full color videos that are helpful for public outreach as well as monitoring purposes. These cameras provide wide area of coverage, and can pan, tilt, and zoom. If connected to power and fiber optics, they can be wired together with the detection triggers of the thermal cameras to begin taping. They can allow real time monitoring with cell phone signals or Wi-Fi technologies, see below.

It is important these camera systems are regularly visited by researchers. Blowing vegetation, snow loading, vandals, nesting wildlife and insects, and other factors can all alter the accuracy and data load of the monitoring project.

Uploading Camera Data in Real Time

Real time photo and video uploads to email accounts and on-line servers are becoming more common in monitoring studies. The photos or videos are sent via a cell phone signal, or through a Wi-Fi network or a fiber optic cable system both of which will typically need to already exist to monitor traffic and road conditions. The time and effort saved by not having to visit the cameras regularly to change batteries and SD cards help the cameras pay for themselves over time. The person analyzing the video data can then download the information from anywhere and in real time without having to go in the field to retrieve the data. Cell phone enabled cameras need a cell phone signal. Wi-Fi communication is limited to highways that have these electricity and fiber optic or Wi-Fi systems in place that allow for the wildlife monitoring cameras to be connected. If the systems are not in place, the cost of connecting to adjacent power and fiber optic lines may be cost-prohibitive.

Not all cameras on a project need to be sending these videos and photos. One camera per location, or at key sites make the reception of photos daily less onerous, and can inform researchers and agency colleagues what is happening on the ground by the minute, while the cameras without such a connection are downloading their photos to SD cards to be gathered at a later time.

Another use of cell phone or Wi-Fi cameras is to monitor conditions at the wildlife crossing structures and fences. Dr. Sielecki of British Columbia MoT uses cell phone cameras set to a time lapse function to monitor snow accumulation on wildlife exclusion fence and at the entrances to wildlife crossing structures, which can alert the MoT to when maintenance is required.

New technology research can be tracked through the Transportation Research Board Transportation Information database website, which is a Transportation Information Services database joined with the International Joint Transportation Research Centre's International Transport Research Documentation database to form the Transportation Research Integrated Database (TRID) on-line database; https://trid.trb.org/. When projects are funded and underway, they will be listed here, even before final reports are available.

Climate Change and Resiliency

Monitoring programs can document changes in the landscape and wildlife activity over time, including range shifts and the timing of seasonal migrations, all with respect to climate change. Wildlife monitoring cameras can be positioned to detect wildlife movements and areas where snow levels can be measured, variations in tidal water levels, and be connected to weather monitoring equipment that measure temperatures and other weather parameters. Wildlife range shifts that are at least partially due to climate change are already being documented by wildlife cameras. These changes are best documented via long term studies or meta-analyses that can evaluate shifting patterns across multiple studies.

In Arizona for example, cameras are documenting javelina (or peccary, a type of native wild pig) and coati, generally desert species found in the more southern areas of the state, starting to become more common as far north as the Grand Canyon in northern Arizona. This is likely due to milder weather at these higher elevations than previous weather patterns.

Smaller animal species may be more affected by climate induced changes in weather and landscapes than larger animals. Medium- and small-sized animals such as porcupines and turtles are limited in their ability to access areas with the best climatic and ecosystem conditions. Planning for these types of adaptive shifts must begin now. Monitoring can help evaluate such efforts.

Summary

The various tested methods and future technologies are presented to help agencies and their partners select the most appropriate monitoring program to meet the objectives of both the wildlife mitigation and the monitoring objectives. See Appendix E. Monitoring Plan Guidelines for greater details.

Chapter 5. Summary and Recommendations for Incorporating Wildlife Mitigation into Transportation Processes

Summary

Figure 5-1. Parks Canada has created dozens of wildlife underpasses and overpasses and has been a national leader in consideration of wildlife and building wildlife crossing structures. Wolves used the Highway 93 wildlife crossing structure in Kootenay National Park. Photo Credit: Parks Canada.

In this manual, standardized approaches are presented to assess and address wildlife mitigation in transportation processes. The manual presents steps that should be taken to plan for and construct wildlife mitigation if the important wildlife areas cannot be avoided or effects minimized. This approach was based on the experiences of transportation agencies and other entities who have created standards and wildlife mitigation (**Figure 5-1**), a two-nation survey of transportation professionals, a literature review, case studies of partnerships and other efforts to reduce wildlife-vehicle collisions and accommodate wildlife movement, and the input of dozens of transportation and ecology professionals on the research team and the supporting agency Partners in this Pooled Fund Study.

The research team sent an online survey to 250 transportation agency and planning agency professionals in the U.S. and Canada. The responses from 57 respondents in 31 U.S. states, six Canadian provinces and territories, and 27 Metropolitan Planning Organizations (MPOs) in the U.S. included the following consistent themes.

1) The important information sources for integrating wildlife needs are wildlife-vehicle crash data and hotspot analyses of these data.

2) The most important parts of the planning process are collaboration with wildlife agencies and inclusion of wildlife mitigation plans into long-range plans.

3) The top four most common areas for improvement are: dedicated funding; legislative support to consider wildlife movement needs; partnering with wildlife agencies; and instilling environmental stewardship and awareness within agencies.

The wildlife professionals outside and inside a transportation agency are the key to inclusion of wildlife considerations in transportation processes. The importance of wildlife agency biologists and agency partnerships cannot be overstated.

Two forces outside the agency can also help this process: legislation and funding opportunities. If state/provincial/territorial and national legislation can give additional validity to consideration of wildlife at many levels of transportation planning, while also providing additional funding for wildlife mitigation, there may be a groundswell of change across the U.S. and Canada. This change could make wildlife considerations part of everyday business in all levels of transportation processes.

Important to all of this is change within transportation agencies to win the hearts and minds of personnel so they care about wildlife. Instilling environmental stewardship within transportation agencies and partner agencies such as Metropolitan Planning Organizations can come about with institutionalization of training programs and procedures. Wildlife awareness programs demonstrate how wildlife is affected by roads and traffic and what can be done. Wildlife can also be considered through procedures codified in transportation agency division manuals. Social media also helps to convince agency personnel and the public of the importance of wildlife in the face of roads and motor vehicles (**Figure 5-2**).

Figure 5-2. British Columbia Ministry of Transportation and Infrastructure's (BCMoTI) Wildlife Program consistently produces media and educational programs within and outside the agency to promote awareness of wildlife and the risks of wildlife-vehicle collisions and the benefits of wildlife crossing structures. Figure Credit: L. Sielecki and BCMoTI.

The intent of this manual is to help institutionalize change within the U.S and Canada with respect to wildlife and transportation. It is expected this manual will be updated in the coming years, to continue to inform transportation and wildlife professionals, their partners, and the public as to how they can help reduce wildlife-vehicle conflict and provide wildlife connectivity across the continent.

Recommendations

The integration of wildlife concerns into transportation procedures would be facilitated by the following recommendations. These are presented into two groups: transportation agency culture changes, and partnership opportunities.

Transportation Agency Culture Changes

The actions transportation agencies can do to help institutionalize wildlife concerns in the steps in the transportation process are included below.

Include Wildlife Connectivity and Reduction of Wildlife-Vehicle Collisions as Part of the Mission and Long Range Transportation Plan Objectives

It is important to link the transportation agency mission and long-range objectives with concerns for wildlife to begin the flow of information and considerations of wildlife-vehicle conflict.

1) Include reduction of wildlife-vehicle collisions and consideration of wildlife into the goals of the long-range plan. This can be done by linking the reduction of wildlife-vehicle collisions with safety goals, and wildlife connectivity as part of environmental concerns. These may already be included in some long-range transportation plans. These stated goals help wildlife considerations to become part of the planning process from the beginning.

2) Have processes in place that consider wildlife in the development of future projects. This includes check points in the programming process where wildlife is considered, and how potential standalone wildlife mitigation projects can be nominated for inclusion in the long-range plan and State Transportation Improvement Program (STIP).

3) Institutionalize a policy within the transportation agency to maintain and restore ecological connectivity. This is done in states such as Minnesota, where the DOT and Department of Natural Resources use a similar policy and methods to look at new and replaced transportation structures to maintain and restore ecological connectivity along streams and rivers. Washington replaces culverts and bridges for water and fish connectivity. States and provinces use stream simulation designs for aquatic and terrestrial connectivity in new and replaced culverts and bridges. With this policy, many wildlife considerations fall into place.

Educate About Wildlife

The transportation agency culture of caring for wildlife comes about with education.

4) Develop a multi-disciplinary team within the transportation agency that helps raise awareness among the various professions within the agency. This team, which helps support the environmental staff, develops outreach material for within the agency and the public, and acts as points of contact about wildlife and road issues. Make efforts to

identify and support champions within the transportation agency, especially at the district level that can help garner support for wildlife considerations.

5) All new hires and existing staff receive wildlife ecological training, either through a program such as Highways and Habitats offered in Vermont, or on a one-on-one basis, such as done with British Columbia's Ministry of Transportation and Infrastructure Wildlife Program.

Update Transportation Professional Manuals

6) The transportation agency can update manuals of all professions within the agency about their responsibilities to take wildlife into consideration. See **Table 5-1** for Texas DOT (TxDOT) manuals recommended for revisions (Loftus-Otway et al. 2019). See this TxDOT movie about the project: https://www.youtube.com/watch?v=YuCR-zGSbcA.

Table 5-1. Texas Department of Transportation manuals selected for revisions for consideration of wildlife-vehicle conflict. Taken from Loftus-Otway et al. 2019.

Access Management	Manual on Uniform Traffic Control Devices
Bridge Design	Plans, Specifications and Estimate Development
Bridge Project Development	Procedure for Establishing Speed Zones
Construction Contract Administration	Project Development Process
Design and Construction Information Systems	Roadside Vegetation Management
Highway Safety Improvement Program	Roadway Design
Landscape and Aesthetics Design	Traffic Safety Program
Maintenance Management	Transportation Planning
Maintenance Operations	Transportation Programming and Scheduling

Include Environmental Staff and Outside Agencies in Long-Range Transportation Planning and STIP

The development of the long-range transportation plan is where wildlife consideration needs to begin, and planners at this stage are not typically accustomed to tapping into the resources presented in the data section of Chapter 3. Planning, or the priority products described in Chapter 2. Prioritization.

7) Environmental staff within the transportation agency, and their partners in wildlife and natural resource agencies should be at the table during the development of long-range transportation plans. The goal is to incorporate wildlife concerns into any project that might affect wildlife, and to create standalone wildlife mitigation projects.

8) Build funding capacity to enable the environmental, traffic safety, and maintenance staff concerned with wildlife-vehicle collisions and wildlife connectivity to participate in the development and review of the long-range and other transportation plans as part of their division’s responsibility.

Create Manuals, Designs, Cost Estimates, and a Repository

Institutionalizing changes means standards are created with Best Management Practices manuals, and placed where all can have access. This helps level the playing field and to plan proactively for wildlife.

9) Create Best Management Practices manuals for the consideration of wildlife of all types and ecological connectivity in all steps of the transportation process. Standardize drawings and specifications for designs of crossing structures, escape ramps, deterrents, fences, etc., and place them in a repository for future projects. Update these regularly as research reveals how effectively they worked.

10) Keep a running list of recent mitigation projects and their costs. Provide annual updates of each project with an explanation of the topography, land use, land ownership, number of lanes, and whether the project was stand-alone or integrated into another transportation project. Identify the species, any monitoring projects, and costs.

Support Research

Research is crucial to learning how the transportation system is working and what can be improved. Whether it is from within the agency, such as Virginia’s Transportation Research Council program, or funded to outside agencies, such as Arizona’s Game and Fish Department Wildlife Contracts Branch, academic institutions, or consultants, ongoing research on wildlife-vehicle conflict can help assure the mitigation is effective, and new technologies and methods are tested. The top research topics are listed below.

11) Research species little studied with respect to transportation and mitigation.

12) Develop research and mitigation approaches that demonstrate the importance of wildlife crossing structures to listed species. Federal and state agency personnel can use tested and effective methods for promoting future wildlife crossing structures for these species.

13) Standardize methods for monitoring and researching wildlife-vehicle conflict and mitigation.

14) Study long-term effects of wildlife mitigation efforts – what are the positive and negative consequences?

15) Study wildlife mitigation infrastructure with new technologies and different species.

16) Regularly update Best Management Practices manuals with research information.

17) Initiate long-term studies on wildlife movement needs in the face of climate change and how the transportation infrastructure can be mitigated to help facilitate that movement.

Update the Agency on Knowledge of the Practice and Science

An agency and its partners will need to stay current in the science and practice of how roads and traffic can better accommodate wildlife.

18) Regular attendance at transportation conferences such as the U.S. Transportation Research Board (TRB) annual meeting in January each year, or the bi-annual International Conference on Ecology and Transportation, or regional wildlife and transportation conferences, such as the Northeast Transportation and Wildlife Conference are the best places to meet others with knowledge of wildlife-vehicle conflict solutions and upcoming research results.

19) It is also important to occasionally check the TRB Transportation Information database website, which is a Transportation Information Services database joined with the International Joint Transportation Research Centre’s International Transport Research Documentation database to form the Transportation Research Integrated Database (TRID), https://trid.trb.org/. Personnel who learn of these developments then have a responsibility to impart that knowledge to colleagues.

Institutionalize Climate Change Resiliency Planning

Transportation agency’s plans for resiliency as our climate changes can include concerns for wildlife movement.

20) Include approaches for helping wildlife movement in the face of climate change in agency resiliency planning. This includes placing structures large enough for various species to move up in elevation, north in latitude, and among ecosystems temperatures

and droughts intensify, and wildfires, floods, and rising sea levels further disrupt ecosystems.

Honor the Maintenance Personnel

Maintenance personnel are key to all transportation infrastructure and the transportation process to keep the roads safe for humans and wildlife.

21) Maintenance representatives should be at the table through all stages of the planning process, and be consulted in the design and placement of wildlife mitigation. They should also be kept abreast of the changes they helped create with their collection of wildlife carcass data, and adaptive management of infrastructure.

Partnership Opportunities

Partnerships are key to many state and provincial wildlife-transportation actions and programs.

Partnering with Agencies and Organizations

22) The state or provincial/territorial wildlife agency is the most important partner for bringing information to transportation and in helping to make decisions all along the transportation process. Partnerships with the transportation agency can become institutionalized with Memoranda of Understanding and Agreement. See Appendix C. Memoranda of Understanding.

23) Kick off a summit and form an alliance. Wildlife-transportation partners can raise awareness and enact change with a transportation and wildlife summit, and the resulting alliance or committee that brings about the changes prioritized in that meeting.

24) Transportation agency professionals need to stress to wildlife agency partners their information is crucial to transportation planning. There is a need for updated information on wildlife locations, habitat maps, wildlife linkages, and where wildlife movements are restricted by roads.

25) Bring personnel in MPOs and Regional Planning Organizations in the U.S. and regional planning organizations and Metropolitan Areas within the Canadian provinces and territories into the planning processes that involve looking at wildlife. Form informative alliances with these organizations so they have access to similar wildlife information and how they can process it with respect to their transportation plans. Also

change the regulatory code so these organizations can more formally include wildlife concerns in their transportation planning.

26) Welcome non-profit non-governmental organizations in the planning processes, and in seeking funding for wildlife mitigation.

Raise and Maintain Public Support

Public support of actions that help wildlife along transportation corridors is critical to maintaining a program of wildlife and roads research, wildlife mitigation, and continued consideration of wildlife in transportation procedures.

27) Partner with non-profit agencies to create stories, movies, and websites dedicated to telling stories about successful or upcoming wildlife mitigation projects and partnerships.

28) Regularly update social media personnel and spokespersons within the agency as to challenges, priority projects, and progress on wildlife research related to transportation. Provide pictures, maps, movies, and one-page media releases.

29) Use message boards along highways to educate drivers of wildlife migrations and wildlife on the road.

30) Utilize online resources to hold public meetings concerning wildlife and roads challenges overall, and in specific places.

31) Work with the WAZE company and other smart phone applications to utilize their platform for the public reporting of wildlife on the road (see Donaldson 2017).

Expand Knowledge of Funding Opportunities

Funding opportunities have been a major limiting factor in the establishment of wildlife crossing structures and other mitigation. There are several approaches to this that could occur to help make funding more available.

32) Change the way benefit-cost evaluations calculate the benefits of reductions in wildlife-vehicle collisions to account for the value of the animals not killed once mitigation is placed. This can help increase the benefits in the numerator, and up the benefit-cost ratio. See Chapter 3 Planning, the Programming Step, the Economic Evaluation Section.

33) Help various professionals inside and outside the transportation agency understand the most recent Transportation Act laws (in 2022 it was the Bipartisan Infrastructure Law) and funding sources. See Appendix D. Data, the funding section.

Legislate Actions to Consider Wildlife and Fund Mitigation

Legislation to support identification of areas important to wildlife in the face of roads, and to create wildlife mitigation to provide and restore connectivity can come at the national or state/provincial/territory level.

34) Support and promote changes to the next U.S. transportation act. The 2021 U.S. Bipartisan Infrastructure Law has several sections where consideration of wildlife and funding for actions are optional. This approach is probably the most preferred by transportation agencies, as it does not mandate wildlife considerations but rewards such considerations with grants to create wildlife crossing structures. See Appendix D. Data.

35) State, provincial, and territorial legislatures create acts and other legislation to consider wildlife connectivity in the process of transportation planning. As of 2022 this has already been achieved in as many as 14 states. These laws are typically written with input from the transportation agency. New Mexico developed the first completed Wildlife Corridors Action Plan (Cramer et al. 2022b). These acts and plans will be tested in the coming years to see if they result in actual new wildlife crossing structures.

These state and federal laws still do not change the overall transportation process. They rather give rewards for plans that include consideration of wildlife and potential projects. It is still up to the transportation agencies to change their considerations of wildlife from within.

In Summary

These are the highest priority recommendations as learned from the research conducted during the development of this manual. Many actions have been taken up by agencies most progressive on promoting wildlife in transportation.

As the science and practice of transportation ecology continues to grow and mature, this manual should be updated to remain current to the best practices and growing science, and new funding resources. The groundswell of support for wildlife within transportation agencies is also to be recognized and respected. This support varies considerably among agencies and even within districts and over time. A goal of this manual is to both inform readers of the need for wildlife to be considered in transportation procedures and to help inspire continuous efforts.

Chapter 6. Literature Cited

Adams, E. 2017. Volvo’s cars now spot moose and hit the brakes for you. Wired On-line Magazine. January 2017. https://www.wired.com/2017/01/volvos-cars-now-spot-moose-hit-brakes/.

Albright, W., Ament, R., Callahan, R., M. Frantz, M. Grabau, M. Ernest Johnson, T. Jones-Farrand, K. Malpeli, M. Milmann, N. Muenks, R. Quinones, B. Slys, and K. Tanggarjaja. 2021. Connectivity and Climate Change Toolkit. Prepared for the Climate Adaptation Committee of the Association of Fish and Wildlife Agencies. 56 pages. https://www.fishwildlife.org/application/files/9216/1582/0864/Connectivity_and_Climate_Change_Toolkit_FINAL.pdf

Allen, T. D. H., M. P. Huijser, and D. W. Willey. 2013. Effectiveness of wildlife guards at access roads. Wildlife Society Bulletin 37:402-408.

Amber, E.D., G. J. Lipps, Jr., and W.E. Peterman. 2021. Evaluation of AHDriFT camera trap system to survey for small mammals and herpetofauna. Journal of Fish and Wildlife Management 12:197-207. https://doi.org/10.3996/JFWM-20-016

American Association of State Highway and Transportation Officials Center for Environmental Excellence. 2022. Context Sensitive Solutions & Transportation. https://environment.transportation.org/education/practical-applications/context-sensitive-solutions/context-sensitive-solutions-overview/

Andreassen, H., H. Gundersen, and T. Storass. 2010. The effect of scent marking, forest clearing, and supplemental feeding on moose-train collisions. Journal of Wildlife Management, 69:1125-1132. https://doi.org/10.2193/0022-541X(2005)069[1125:TEOSFC]2.0.CO;2

Andrews, K.M., P. Nanjappa and S. P. Riely, (Editors). 2015. Roads and Ecological Infrastructure: Concepts and Applications for Small Animals. John Hopkins University Press, Baltimore, MD.

Arizona Game and Fish Department, Habitat Branch. 2008. Guidelines for Bridge Construction or Maintenance to Accommodate Fish and Wildlife Movement and Passage. https://www.azgfd.com/wildlife/planning/wildlifeguidelines/

Arizona Wildlife Linkages Workgroup. 2006. Arizona’s wildlife linkage assessment. Phoenix: Arizona Department of Transportation, Natural Resources Management Section.

Australian Museum Business Services. 2012. Investigation of the impact of roads on koalas. Report prepared for the New South Wales Roads and Maritime Services. Australian Museum Business Services, Sydney, Australia.

Barrett, S. and K.E. Gunson. 2013. MTO Wildlife Mitigation Strategy October 29th, 2013. Large Animal Expert Workshop Meeting Final report.

Basting, P., K. Bishton, K. Brown, T. Smthson, and G. Wooley. 2022. A literature analysis to determine optimal wildlife crossing structure size. Report to the Colorado Department of Transportation Applied Research and Innovation Branch. 105 pages.

Bellis, M. A. 2008. Evaluating the effectiveness of wildlife crossing structures in southern Vermont. Thesis. University of Massachusetts, Amherst, Massachusetts, USA.

Beier, P., D. R. Majk, and W.D. Spencer. 2008. Forks in the road: choices in procedures for designing wildland linkages. Conservation Biology. https://doi.org/10.1111/j.1523-1739.2008.00942.x

Bissonette, J.A., and W. Adair. 2008. Restoring habitat permeability to roaded landscapes with isometrically-scaled wildlife crossings. Biological Conservation 141:482-488. doi:10.1016/j.biocon.2007.10.019.

Bissonette, J. A., P. C. Cramer. 2008. Evaluation of the use and effectiveness of wildlife crossings. Report 615 for National Academies', Transportation Research Board, National Cooperative Highway Research Program, Washington, D.C. http://www.trb.org/Publications/Blurbs/160108.aspx

Brehme, C.S., and R.N. Fisher. 2021. Research to Inform Caltrans Best Management Practices for Reptile and Amphibian Road Crossings. USGS Cooperator Report to California Department of Transportation, Division of Research, Innovation and System Information, 65A0553. https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/final-caltrans-usgs-report-herproadresearch-rev.pdf

Brieger, F., R. Hagen, D. Vetter, C. F. Dormann, and I. Storch. 2016. Effectiveness of light-reflecting devices: A systematic reanalysis of animal-vehicle collision data. Accident Analysis & Prevention 97:242-260.

British Columbia Ministry of Transportation. 2020. Wildlife on B.C. Highways. https://www2.gov.bc.ca/gov/content/transportation/driving-and-cycling/traveller-information/routes-and-driving-conditions/wildlife.

Brown, J.W. 2006. Eco-Logical: An Ecosystems Approach to Developing Infrastructure Projects. Report to U.S. Department of Transportation. Report Number DOT-VNTSC-FHWA-06-01. 99 pages. https://www.environment.fhwa.dot.gov/env_initiatives/eco-logical/report/eco_index.aspx

Carruthers, B. and K. Gunson. 2015. Development of a province-wide wildlife mitigation strategy for both large and small animals on Ontario's highways. Proceedings of the 2015 International Conference on Ecology and Transportation. North Carolina State University. 16 pages. https://eco-kare.com/wp-content/uploads/2016/11/Carruthers_Gunson_2015_icoet_technical_paper_25-Sep-15_FINAL.pdf

Chapman, J. 2021. Activity patterns of bat species at interstate highway sites with and without wildlife underpasses. Presentation to the 2021 International Conference on Ecology and Transportation. On-line recorded presentation: https://www.youtube.com/watch?v=FPBdGdbTzIQ

Charry, B. and J. Jones. 2009. Traffic volume as a primary road characteristic impacting wildlife: a tool for land use and transportation planning. Proceedings from the 2009 International Conference on Ecology and Transportation. University of North Carolina, Raleigh. Center for Transportation Research. Pages 159-172. https://escholarship.org/uc/item/4fx6c79t#main.

Chen, J., H. Xu, J. Wu, R. Yue, C. Yuan, and L. Wang. 2019. Deer crossing road detection with roadside LiDAR sensor. IEEE Access 7:65944-65954.

Cheng, M. 2017. Volvo's New Pilot Assist II is designed to curtail animal collisions. Future Car. URL: https://www.futurecar.com/666/Volvos-New-Pilot-Assist-II-is-Designed-to-Curtail-Animal-Collisions.

Chisholm, M., A. Bates, D. Criend, and D. Cooper. 2010. Wildlife Passage Engineering Design Guidelines. Prepared for the City of Edmonton, Office of Natural Areas. 249 pages. https://www.edmonton.ca/city_government/documents/WPEDG_FINAL_Aug_2010.pdf

Clevenger, A. P., and M. Barrueto. 2014. Trans-Canada Highway wildlife and monitoring research, final report. part b: research. Prepared for Parks Canada Agency, Radium Hot Springs, British Columbia.

Clevenger, A. P., and M. Huijser. 2011. Wildlife crossing structures handbook: Design and evaluation in North America. Report # FHWA-CFL/TD-11-003. Federal Highway Administration, Washington, D.C. 223 pp. URL: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=134712

Clevenger, A. P., B. Chruszcz, and K. E. Gunson. 2001. Highway mitigation fencing reduces wildlife-vehicle collisions. Wildlife Society Bulletin 29:646-653.

Coe, P.K., R.M. Nielson, D.H. Jackson, J. B. Cupples, N. E. Seidel, B. K. Johnson, S. C. Gregory, G. A Bjornstrom, and D. A. Speten. 2015. Identifying migration corridors of mule deer threatened by highway development. Wildlife Society Bulletin 39(2):256-267; DOI:10.1002/wsb.544.

Colorado Department of Transportation. 2016. Wildlife on the Move! Website for driver awareness: URL: https://www.codot.gov/programs/environmental/wildlife/wildlifeonthemove.

Colorado Department of Transportation. 2021. Terrestrial wildlife and aquatic species technical report. I-70 Floyd Hill to Veterans Memorial Tunnels Environmental

Assessment. U.S. Department of Transportation Federal Highway Administration and Colorado Department of Transportation, Denver, CO.

Cramer, P., J. Kintsch, L. Loftus-Otway, N. Dodd, K. Andrews, T. Brennan, P. Basting, J. Gagnon, L. Frazier, and L. Sielecki. 2022a. Strategic integration of wildlife mitigation into transportation procedures: Practices, partnerships, and next steps. Report of the Nevada Department of Transportation and the Federal Highway Administration Pooled Fund Study: The Wildlife Vehicle Collision (WVC) Reduction and Habitat Connectivity Transportation Pooled Fund Project TPF 5(358). 242 pages. https://pooledfund.org/Details/Study/610

Cramer, P. J.L. Cartron, K. Calhoun., J. Gagnon, S. Cushman, H.Y. Wan, J. Kutz, J. Romero, T. Brennan., J. Walther, C. Loberger, H. Nelson, T. Botkin, and J. Hirsch. 2022b. Wildlife Corridors Draft Action Plan. New Mexico Department of Transportation and New Mexico Department of Game & Fish. Released for public review. https://wildlifeactionplan.nmdotprojects.org/

Cramer, P. and R. Hamlin. 2021. US 160 Dry Creek Wildlife Research. Final Report to Colorado Department of Transportation. https://www.codot.gov/programs/research/pdfs/2021-research-reports/us-160-dry-creek-wildlife-study.pdf.

Cramer, P. and R. Hamlin. 2019a. US 89 Kanab-Paunsaugunt Wildlife Crossing and Existing Structures Research Project. Final Report to Utah Department of Transportation, Salt Lake City, Utah. 77 pages. URL: https://www.udot.utah.gov/main/uconowner.gf?n=9353379532914605.

Cramer, P. and R. Hamlin. 2019b. US 189 Wildlife Crossing Structures and Escape Ramp Monitoring. Final Report to Utah Department of Transportation, 2019.

Cramer, P. and R. Hamlin. 2019c. US 191 Monticello Crossing Structure and Double Cattle Guard Monitoring Project. Final Report Submitted to Utah Department of Transportation. 21 pages. *In Press*.

Cramer, P., E. Vasquez, and A. Jones. 2019. Identification of wildlife-vehicle conflict priority hotspots in Utah. Final Report to Utah Department of Transportation. URL: https://drive.google.com/file/d/15K9yjM9kDRE8KVDvpUnFWn9RUyo1SkRL/view?fbclid=IwAR062_EPrlFmHPGc_uohMpEvoEsHNKWqVZGK5rnfGVlEkgzFwF-A4QwFhRk

Cramer, P. and C. McGinty. 2018. Prioritization of Wildlife-Vehicle Conflict in Nevada. Final Report to Nevada Department of Transportation. 264 pages. URL: https://www.nevadadot.com/home/showdocument?id=16038.

Cramer, P., and R. Hamlin. 2017a. Evaluation of Wildlife Crossing Structures on US 93 in Montana's Bitterroot Valley. MDT # HWY – 308445-RP. Final Report to Montana Department of Transportation. URL: http://www.mdt.mt.gov/research/projects/env/us93_wildlife.shtml

Cramer, P. and R. Hamlin. 2017b. Testing new technology to restrict wildlife access to highways: Phase 2. Final Report to Utah Department of Transportation. 35 pages. URL: http://www.udot.utah.gov/main/uconowner.gf?n=37026118257278521

Cramer, P. and J. Flower. 2017. Testing new technology to restrict wildlife access to highways: Phase 1. Final Report to Utah Department of Transportation. 70 pages. URL: http://www.udot.utah.gov/main/uconowner.gf?n=37026229956376505

Cramer, P., J. Kintsch, K. Gunson, F. Shilling, M. Kenner, and C. Chapman. 2016. Reducing wildlife-vehicle collisions in South Dakota, Final Report to South Dakota Department of Transportation, SD2014-03, Pierre, SD.

Cramer P.C., S. Gifford, B. Crabb, C. McGinty, D. Ramsey, F. Shilling, J. Kintsch, S. Jacobson, and K. Gunson. 2014. Methodology for Prioritizing Appropriate Mitigation Actions to Reduce Wildlife-Vehicle Collisions on Idaho Highways. Idaho Transportation Department, Boise, Idaho. August, 2014. https://rosap.ntl.bts.gov/view/dot/28515

Cramer, P. 2014a. Wildlife crossings in Utah: Determining What Works and Helping to Create the Best and Most Cost-Effective Structure Designs. Report to Utah Division of Wildlife Resources, Salt Lake City, Utah.

Cramer, P. 2014b. Culvert, bridge and fencing recommendations for big game wildlife crossing in western United States based on Utah data. Proceedings from the 2014 Transportation Research Board Meeting, Washington D.C. 11 pages, URL: https://fr.ail.ca/wp-content/uploads/2017/07/Utah-Wildlife-Paper.pdf

Cramer, P. 2012. Determining wildlife use of wildlife crossing structures under different scenarios. Final Report to Utah Department of Transportation, Salt Lake City, UT. 181 pages. http://www.udot.utah.gov/main/uconowner.gf?n=10315521671291686

Cramer, P. C., J. Kintsch, and S. Jacobson. 2011. Maintaining wildlife connectivity across roads through tested wildlife crossing designs. In: Proceedings of the 2011 International Conference on Ecology and Transportation, Seattle, WA, Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.

D'Angelo, G. J., J. G. D’Angelo, G. R. Gallagher, D. A. Osborn, K. V. Miller, and R. J. Warren. 2006. Evaluation of wildlife warning reflectors for altering white-tailed deer behavior along roadways. Wildlife Society Bulletin: 34: 1175-1183.

de Rivera, C.E., L. L. Bliss-Ketchum M. D. Lafrenz, A.V. Hanson, L.E. McKinney-Wise, A.H. Rodriguez, J. Schultz, A.L. Simmons, D. Taylor-Rodriquez, A. H. Temple and R. E. Wheat. 2022. Visualizing connectivity for wildlife in a world without roads. Frontiers in Environmental Science: Conservation and Restoration Ecology. February 2022. https://doi.org/10.3389/fenvs.2022.757954

DeVault, T. L., T. W. Seamans, and B. F. Blackwell. 2020. Frontal vehicle illumination via rear-facing lighting reduces potential for collisions with white-tailed deer. Ecosphere 11:e03187.

Dodd, K., W. Barichivich, and L. Smith. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation 111:619-631.

Dodd, N. L., J. W. Gagnon, A. L. Manzo, and R. E. Schweinsburg. 2007. Video surveillance to assess highway underpasses by elk in Arizona. Journal of Wildlife Management 71:637–645.

Dodd, N.L., J. W. Gagnon, S. Sprague, S. Boe, and R. E. Schweinsburg. 2010. Assessment of pronghorn movements and strategies to promote highway permeability: US Highway 89. Arizona Game and Fish Final Report to Arizona Department of Transportation. Report Number FHWA-AZ-10-619. 84 pages.

Dodd, N.L., J. W. Gagnon, S. C. Sprague, S. Boe, and R. E. Schweinsburg. 2012. Wildlife accident reduction study and monitoring: Arizona State Route 64. Arizona Game and Fish Final Report to Arizona Department of Transportation. Report Number FHWA-AZ-12-626. 118 pages.

Donaldson, B. 2022. Large animal crash countermeasures in Virginia. Technical guidance and best management practices. Virginia Department of Transportation. 27 pages. https://www.virginiadot.org/business/resources/LocDes/IIM/IIM262.pdf

Donaldson, B. M., and K. E. M. Elliott. 2020. Enhancing existing isolated underpasses with fencing to decrease crashes and increase habitat connectivity. Final Report 20-R28, Virginia Transportation Research Council, http://www.virginiadot.org/vtrc/main/online_reports/pdf/20-R28.pdf.

Donaldson, B. M., and Y. J. Kweon. 2018. Effectiveness of seasonal deer advisories on changeable message signs as a deer crash reduction tool. Final Report 19-R8, Virginia Transportation Research Council, http://www.virginiadot.org/vtrc/main/online_reports/pdf/19-R8.pdf.

Donaldson, B. 2017. Improving animal-vehicle collision data for strategic application of mitigation. Report Number FHWA/VTRAC 18-R16. Virginia Transportation Research Council to the Virginia Department of Transportation and Federal Highway Administration. 27 pages. http://www.virginiadot.org/vtrc/main/online_reports/pdf/18-r16.pdf

Donaldson, B. and N. Lafon. 2008. Testing an integrated PDA-GPS system to collect standardized animal carcass removal data. Virginia Transportation Research Council. http://www.virginiadot.org/vtrc/main/online_reports/pdf/08-cr10.pdf

Drasher, C.E., and J D. Murdoch. 2021. Improving roadway conservation investment in Vermont: Developing a prioritization screening framework for reducing wildlife mortality and improving wildlife movement through bridges and culverts. Report

Number 2021-05 to Vermont Agency of Transportation. 46 pages. https://vtrans.vermont.gov/sites/aot/files/Research/VTrans_Final_Report_2021_0001057-332.pdf

Druta, C., and A. S. Alden. 2019. Evaluation of a buried cable roadside animal detection system. Virginia Center for Transportation Innovation & Research. Final Report VCTIR 15-R25.

Druta, C., and A. S. Alden. 2015. Evaluation of a buried cable roadside animal detection system. Virginia Center for Transportation Innovation & Research. Final Report VCTIR 15-R25.

Eco-Kare International. 2020. Effectiveness monitoring of wildlife mitigation measures for large- and mid-sized animals on Highway 69 in Northeastern Ontario: September 2011 to September 2019. Submitted to the Ontario Ministry of Transportation, North Bay, Ontario, Canada, 73 pp. https://eco-kare.com/wp-content/uploads/2020/10/EcoKare-Final-Report2-to-MTO-Hwy-69-Effectiveness-monitoring-public-version-15Oct20.pdf

Eigenbrod, F., S. J. Hecnar, and L. Fahrig. 2008. The relative effects of road traffic and forest cover on anuran populations. Biological conservation 141:35–46.

Ernest, K., P. James, J. Irwin, A. Scoville, P. Garvey-Dada. 2021. Ecological connectivity and multi-taxa wildlife movement across I-90. Presentation to the 2021 International Conference on Ecology and Transportation. On-line recorded presentation: https://www.youtube.com/watch?v=-xuqhD5HccU.

Falk, N. W., H. B. Graves, and E. D. Bellis. 1978. Highway right-of-way fences as deer deterrents. The Journal of Wildlife Management 42:646-650.

Falzon G, Lawson C, Cheung K-W, Vernes K, Ballard GA, Fleming PJS, Glen AS, Milne H, Mather-Zardain A, Meek PD. *ClassifyMe:* A Field-Scouting Software for the Identification of Wildlife in Camera Trap Images. *Animals*. 2020; 10(1):58. https://doi.org/10.3390/ani10010058. https://wildlabs.net/resources/identification-wildlife-camera-trap-images#:~:text=We%20present%20ClassifyMe%20a%20software,field%20and%20in%20the%20office

Federal Highway Administration. 2010. The Highway System. https://www.fhwa.dot.gov/ohim/onh00/onh2p5.htm.

Federal Highway Administration. 2009. LED raised pavement markers. URL: http://safety.fhwa.dot.gov/intersection/conventional/unsignalized/tech_sum/fhwasa09007/.

Feldhamer, G. A., J. E. Gates, D. M. Harman, A. J. Loranger, and K. R. Dixon. 1986. Effects of interstate highway fencing on white-tailed deer activity. The Journal of Wildlife Management 50:497-503.

Felsburg Holt and Ullevig, Ecosphere Environmental Services, and Wildlife Consulting Resources. 2010. Best Management Practices for Wildlife and Roads in La Plata

County. Report to the La Plata County Planning Department, Durango, Colorado. 97 pages. URL: https://www.co.laplata.co.us/planning/Best%20Management%20Practices%20for%20Wildlife%20and%20Roads.pdf

Fiesta-Bianchet, M. and M. Appolonio, editors. 2003. Animal Behavior and Wildlife Conservation. Island Press, Washington, D.C., USA.

Flower, J.P. 2016. Emerging technology to exclude wildlife from roads: electrified pavement and deer guards in Utah, USA. Thesis submitted to Utah State University. 144 pages.

Found, R., and M. S. Boyce. 2011. Predicting deer-vehicle collisions in an urban area. J Environ Manage 92:2486-2493.

Fraser, D., and E. R. Thomas. 1982. Moose-vehicle accidents in Ontario: relation to highway salt. Wildlife Society Bulletin 10:261-265

Gagnon, J. W., C. A. Beach, S. C. Sprague, C. D. Loberger, and C. Rubke. 2020a. Evaluation of measures to reduce wildlife-vehicle collisions and promote connectivity in a Sonoran Desert environment - SR 77: Santa Catalina - Tortolita Mountain Corridor. Progress Report Presented to the Pima County Regional Transportation Authority; 24 pages.

Gagnon, J. W., C. D. Loberger, K. Ogren, C. A. Beach, H. D. Nelson, and S. C. Sprague. 2020b. Evaluation of effectiveness of wildlife guards and right of way escape mechanisms for large ungulates in Arizona. Final Report FHWA-AZ-20-729, Arizona Department of Transportation Research Center, Phoenix, AZ. 90 pages.

Gagnon, J. W., C. D. Loberger, and S. C. Sprague. 2020c. Oversight and evaluation of measures to promote desert bighorn sheep highway permeability - Boulder City Bypass Phase II. Progress Report Presented to Nevada Department of Transportation.

Gagnon, J. W., and C. D. Loberger. 2020. Determining wildlife-vehicle mitigation effectiveness. Progress Report Presented to New Mexico Department of Transportation Research Bureau.

Gagnon, J.W., N.L. Dodd, S.C. Sprague, K.S. Ogren, C.D. Loberger, and R.E. Schweinsburg. 2019. Animal-activated highway crosswalk: Long-term impact on elk-vehicle collisions, vehicle speeds, and motorist braking response. Human Dimensions of Wildlife: 1-16.

Gagnon, J. W., C. D. Loberger, S. C. Sprague, S. R. Boe, K. S. Ogren, and R. E. Schweinsburg. 2017a. Wildlife-vehicle collision mitigation on State Route 260: Mogollon Rim to Show Low. Arizona Game and Fish Report to Arizona Department of Transportation. Report Number FHWA-AZ-17-706. 94 pages.

Gagnon, J.W., C.D. Loberger, K.S. Ogren, S.C. Sprague, S.R. Boe, and R.E. Schweinsburg. 2017b. Evaluation of desert bighorn sheep overpass effectiveness: U.S. Route 93 long-term monitoring. Final project report 710, Arizona Department of Transportation Research Center, Phoenix, Arizona.

Gagnon, J. W., C. D. Loberger, S. C. Sprague, K. S. Ogren, S. L. Boe, and R. E. Schweinsburg. 2015. Cost-effective approach to reducing collisions with elk by fencing between existing highway structures. Human-Wildlife Interactions 9:248.

Gagnon, J.W., N.L. Dodd, S.C. Sprague, C.D. Loberger, S. Boe, and R. E. Schweinsburg. 2014. Evaluation of measures to promote desert bighorn sheep highway permeability: U.S. Highway 93. Final project report 677, Arizona Department of Transportation Research Center, Phoenix, Arizona.

Gagnon, J. W., N. L. Dodd, S. Sprague, R. Nelson, C. Loberger, S. Boe, and R. E. Schweinsburg. 2013. Elk movement associated with high-traffic highway: Interstate 17. Arizona Game and Fish Final Report to Arizona Department of Transportation. Report Number FHWA-AZ-13-647. 125 pages

Gagnon, J. W., N. L. Dodd, K. S. Ogren, and R. E. Schweinsburg. 2011. Factors associated with use of wildlife underpasses and importance of long-term monitoring. Journal of Wildlife Management 75:1477-1487.

Gagnon, J. W., Dodd, N. L., Sprague, S., Ogren, K., & Schweinsburg, R. E. 2010. Preacher Canyon wildlife fence and crosswalk enhancement project evaluation - State Route 260. Arizona Game and Fish Department, Research Branch, Phoenix.

Gagnon, J. W., N. L. Dodd, A. L. Manzo, and R. E. Schweinsburg. 2006. Use of video surveillance to assess wildlife behavior and use of wildlife underpasses in Arizona. Pages 534–544 in C. L. Irwin, P. Garrett, and K.P. McDermott, editors. Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, USA.

Grace, M. K., D. J. Smith, and R. F. Noss. 2015. Testing alternative designs for a roadside animal detection system using a driving simulator. Nature Conservation 11:61-77.

Grossman, P. D., J. A. G. Jaeger, P. M. Biron, C. Dussault, and J.-P. Ouellet. 2011. Trade-off between road avoidance and attraction by roadside salt pools in moose: An agent-based model to assess measures for reducing moose-vehicle collisions. Ecological Modelling 222:1423-1435.

Grubb, T. G., and R. G. Lopez. 2018. Winter scavenging of ungulate carrion by bald eagles, common ravens, and coyotes in northern Arizona. Journal of Raptor Research 52:471-483, 413.

Gustafson, A. 2018. Occupancy of stream-associated amphibians within the Interstate 90 Snoqualmie pass corridor. Central Washington University. All Master's Theses. 884. https://digitalcommons.cwu.edu/etd/884

Gunson, K.E., D. Ireland, F.W. Schueler. 2021. A tool to prioritize high risk road mortality locations for wetland-forest herpetofauna in southern Ontario, Canada. Northwestern Journal of Zoology 8:409-413.

Gunson, K. D. Seburn, J. Kintsch, and J. Crowley. 2016. Best Management Practices for Mitigating the Effects of Roads on Amphibian and Reptile Species at Risk in Ontario. Report to the Ontario Ministry of Natural Resources and Forestry. 112 pages. http://www.roadsandwildlife.org/Document/1041

Gunson, K. E., and F. W. Schueler. 2012. Effective placement of road mitigation using lessons learned from turtle crossing signs in Ontario. Ecological Restoration 30:329–334.

Hardy, A., S. Lee, and A. Al-Kaisy. 2006. Effectiveness of animal advisory messages on dynamic message signs as a speed reduction tool: case study in rural Montana. Transportation Research Record: Journal of the Transportation Research Board 1973:64-72.

Harmon, T. G. Bahar, and F. Gross. 2018. Crash Costs for Highway Safety Analysis. Final Report to the Federal Highway Administration Office of Safety. Washington DC. Report Number FHWA-SA-17-071. 108 pages.

Hernick, M. C. Lenhart, J. Kozarek, and J. Nieber. 2019. Minnesota Guide for Stream Connectivity and Aquatic Organism Passage through Culverts. Minnesota Local Road Research Board and Minnesota Department of Transportation. Report Number MN/RC 2019-02. 221 Pages. http://www.dot.state.mn.us/research/reports/2019/201902.pdf

Hirsch, J. G., L. C. Bender, and J. B. Haufler. 1999. Black bear, *Ursus americanus*, movements and home ranges on Drummond Island, Michigan. Canadian Field – Naturalist 113 (2): 221-225.

Hirsch, J. G., and J. B. Haufler. 1993. Evaluation of a forest habitat model for black bear. Proceedings of International Union of Game Biologists 21(1): 330-337.

Hobbs, M. T., and C. S. Breheme. 2021. An improved camera trap for amphibians, reptiles, small mammals, and large invertebrates. PloS ONE 12(10):e0185026. https://doi.org/10.1371/journal.pone.0185026

Hooghkirk, J. R. 2013. American pika (*Ochotona princeps*) home range use and habitat selection in relation to potential dispersal corridors. Master's thesis presented to the Graduate Faculty of Central Washington University. 66 pages.

Hotchkiss, R.H. and C.M. Frei. 2007. Design for fish passage at roadway-stream crossings: A synthesis report. Report Number: FHWA-HIF-07-033 June 2007. For Office of Infrastructure Research and Development. Office of Infrastructure

Research and Development. 280 pages. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/07033/07033.pdf

H.T. Harvey & Associates, HDR, Inc. 2021. Caltrans bat mitigation: a guide to developing feasible and effective solutions. Prepared for California Department of Transportation, Division of Environmental Analysis, Office of Biological Studies, Sacramento, California. 212 pages. https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/env/caltrans-bat-mitigation-guide-a11y.pdf

Huijser, M. P., E. R. Fairbanks, and F. D. Abra. 2017. The reliability and effectiveness of a radar-based animal detection system. RP 247 - Idaho Department of Transportation Research Program.

Huijser, M. P., W. Camel-Means, E. R. Fairbank, J. P. Purdum, T. D. H. Allen, A. R. Hardy, J. Graham, J. S. Begley, P. Basting, and D. Becker. 2016. US 93 North post-construction wildlife-vehicle collision and wildlife crossing monitoring on the Flathead Indian Reservation between Evaro and Polson, Montana. FHWA/MT-16-009/8208. Western Transportation Institute, Montana State University, Bozeman, Montana, USA.

Huijser, M. P., A.V. Kociolek, T.D.H. Allen, P. McGowen, P. C. Cramer, and M. Venner. 2015. Construction guidelines for wildlife fencing and associated escape and lateral access control measures. National Cooperative Highway Research Program 25-25, Project 84. Transportation Research Board, National Academies, Washington, D.C http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP25-25%2884%29_FR.pdf

Huijser, M. P., C. Haas, and K. R. Crooks. 2012. The reliability and effectiveness of an electromagnetic animal detection and driver warning system. Colorado Department of Transportation Applied Research and Innovation Branch. Final Report No. CDOT-2012-2.

Huijser, M. P., T. D. Holland, B. Matt, M. C. Greenwood, P. T. McGowen, B. Hubbard, and S. Wang. 2009. The comparison of animal detection systems in a test-bed: A quantitative comparison of system reliability and experience with operation and maintenance - final report. Prepared by Western Transportation Institute for Federal Highway Administration and Montana Department of Transportation.

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith, and R. Ament. 2008. Wildlife-vehicle collision reduction study. Report to Congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C. URL: https://www.fhwa.dot.gov/publications/research/safety/08034/

Huijser, M. P., and P. T. McGowen. 2003. Overview of animal detection and animal warning systems in North America and Europe. Pages 368-382 in C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the International Conference on Ecology and Transportation. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University, 2003.

Jacobs Engineering. 2022. Eastern Slope and Plains Wildlife Prioritization Study. Colorado Department of Transportation and Colorado Parks and Wildlife. Denver, Colorado. https://www.codot.gov/programs/research/pdfs/2019/WSWPS

Jacobson, S.L., L. L. Bliss-Ketchum, C. E. de Rivera, and W. P. Smith. 2016. A behavior-based framework for assessing the barrier effects to wildlife from vehicle traffic volume. Ecosphere 7(4):e01345.10.1002/ecs2.1345

Jaeger, J. and L. Fahrig. 2004. Effects of road fencing on population persistence. Conservation Biology, 18:1651-1657. https://doi.org/10.1111/j.1523-1739.2004.00304.x

Jared, D. M., D. Osborn, G. J. D'Angelo, K. V. Miller, and R. J. Warren. 2017. Understanding white-tailed deer sensory abilities, behavior, and movement ecology to mitigate deer-vehicle collisions: the value of long-term collaborative research. Proceedings of the Transportation Research Board Annual Meeting, National Academy of Sciences, Washington, D.C. http://amonline.trb.org/17-00809-1.3399777?qr=1

James, P.W., R.S. Wagner, K.A. Ernest, D. Beck, and J. Irwin. 2011. Monitoring fish and low-mobility vertebrates along a major mountain highway: a snapshot before construction of I-90 wildlife crossing structures. Pages 527-533 in P.J. Wagner, D. Nelson, and E. Murray, editors. Proceedings of the 2011 International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.

Kahn, R., and A. Kahn Goedecke. 2011. Roadway striping as a traffic calming option. ITE Journal 81, 30-37, Institute of Transportation Engineers, Washington, DC.

Kilgo, J. C., J. I. Blake, T. E. Grazia, A. Horcher, M. Larsen, T. Mims, and S. J. Zarnoch. 2020. Use of roadside deer removal to reduce deer-vehicle collisions. Human-Wildlife Interactions 14:87-95.

Kintsch, J., P. Basting, T. Smithson, and G. Woolley. 2022a. Eastern Slope and Plains wildlife prioritization study. Report No. 2022-03. Colorado Department of Transportation and Colorado Parks and Wildlife, Denver, CO.

Kintsch, J., P. Singer, A. Telander, and T. Prebyl. 2022b. I-25 South Gap wildlife study design technical memorandum. Unpublished Memorandum, March 21, 2022. Colorado Department of Transportation, Denver, CO.

Kintsch, J., P. Cramer, P. Singer, and M. Cowardin. 2021. State Highway 9 Wildlife Crossings Monitoring Final Report. Study Number 115.01. Report to Colorado Department of Transportation. https://www.codot.gov/programs/research/pdfs/2021-research-reports/state-highway-9-wildlife-mitigation-monitoring

Kintsch, J., P. Basting, M. McClure and J.O. Clarke. 2019. Western Slope Wildlife Prioritization Study. Report to Applied Innovation and Research Branch Colorado

Department of Transportation, Denver, CO. https://www.codot.gov/programs/research/pdfs/2019/WSWPS

Kintsch, J. and P. C. Cramer. 2011. Permeability of existing structures for terrestrial wildlife: a passage assessment system. For Washington Department of Transportation, WA-RD 777.1. Olympia, Washington. 188 pages. http://www.wsdot.wa.gov/research/reports/fullreports/777.1.pdf

Landau, V.A. 2020. Omniscape: An efficient and scalable implementation of the Omniscape algorithm in the Julia scientific computing language, v1.6.2, <https://github.com/Circuitscape/Omniscape.jl, DOI: 10.5281/zenodo.3955123>.

Langen, T. A., A. Machniak, E. K. Crowe, C. Mangan, D. F. Marker, N. Liddle, and B. Roden. 2007. Methodologies for surveying herpetofauna mortality on rural highways. The Journal of Wildlife Management 71:1361–1368.

Langton, T.E.S. and A.P. Clevenger. 2021. Measures to Reduce Road Impacts on Amphibians and Reptiles in California. Best Management Practices and Technical Guidance. Prepared by Western Transportation Institute for California Department of Transportation, Division of Research, Innovation and System Information.

Leete, P. and J. Alcott. 2011. Buckshot versus the silver bullet, a regulatory perspective: utilizing low cost wildlife friendly designs everywhere vs constructing a few expensive crossings. Proceedings of the International Conference on Ecology and Transportation, University of North Carolina, Center for Transportation Research, Raleigh, North Carolina. 7 pages.

Leete. 2014. Best practices for meeting DNR General Public Waters Work Permit GP2004-0001. Minnesota Department of Natural Resources and Minnesota Department of Transportation. Version 4. https://www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/gp_2004_0001_manual.html

Lehnert, M. E., and J. A. Bissonette. 1997. Effectiveness of highway crosswalk structures at reducing deer-vehicle collisions. Wildlife Society Bulletin 25:809-818.

Lemieux, Christopher J., Aerin L. Jacob, and Paul A. Gray. 2021. Implementing Connectivity Conservation in Canada. Canadian Council on Ecological Areas (CCEA) Occasional Paper No. 22. Canadian Council on Ecological Areas, Wilfrid Laurier University, Waterloo, Ontario, Canada. vi + 216 pp. https://ccea-ccae.org/publications/

Lewis, J. S., J. L. Rachlow, J. S. Horne, E. O. Garton, W. L. Wakkinen, J. Hayden, and P. Zager. 2011. Identifying habitat characteristics to predict highway crossing areas for black bears within a human-modified landscape. Landscape and Urban Planning 101:99-107.

Lister, N.M, M. Brocki, and R. Ament. 2015. Integrated adaptive designs for wildlife movement under climate change. Frontiers in Ecology: 13(9):493-502, doi:10.1890/150080.

Loberger, C.D., J.W. Gagnon, H.D. Nelson, C.A. Beach, and S.C. Sprague. 2020. Determining the effectiveness of wildlife-vehicle collision mitigation projects: Phase I Final Report. NM17ENV-01 Project Report. Prepared for the New Mexico Department of Transportation Research Bureau.

Loftus-Otway, L., N. Jiang, P. Cramer, N. Oaks, D. Wilkins, K. Kockelman, and M. Murphy. 2019. Incorporation of wildlife crossings into TxDOT's Projects and Operations. The University of Texas at Austin, Center for Transportation Research. Final Report, Technical Report 0-6971-1. 322 pages. https://library.ctr.utexas.edu/ctr-publications/0-6971-1.pdf

MacNeil, J. E., G. Dharmarajan, and R.N. Williams. 2011. Salamarker: A code generator and standardized marking system for use with visible implant elastomers. Herpetological Conservation and Biology 6:260-265.

Mastro, L. L., M. R. Conover, and S. N. Frey. 2008. Deer-vehicle collision prevention techniques. Human-Wildlife Conflicts 2:80-92.

Mastro, L. L. 2010. Factors influencing a motorist's ability to detect deer at night. Landscape and Urban Planning 94:250-254.

McDiarmid, R.W., M.S. Foster, C. Guyer, J.W. Gibbons, and N. Chernoff (Eds.). 2012. Reptile Biodiversity: Standard Methods for Inventory and Monitoring. Berkeley: University of California Press.

McRae, B. H., K. Popper, A. Jones, M. Schindel, S. Buttrick, K. R. Hall, R. S. Unnasch, and J. Platt. 2016. Conserving nature's stage: mapping omnidirectional connectivity for resilient terrestrial landscapes in the Pacific Northwest. The Nature Conservancy, Portland, Oregon, USA.

Meisingset, E. L., L. E. Loe, O. Brekkum, and A. Mysterud. 2014. Targeting mitigation efforts: the role of speed limit and road edge clearance for deer-vehicle collisions. Journal of Wildlife Management, 78:679-688. https://doi.org/10.1002/jwmg.712

Metro. 2009. Wildlife Crossings, Providing Safe Passage for Urban Wildlife. City of Portland, Oregon. https://www.oregonmetro.gov/wildlife-crossings-providing-safe-passage-urban-wildlife

Millward, L. S. and K. Ernest. 2018. Small mammal microhabitat use and species composition at a wildlife crossing structure compared with nearby forest. Central Washington University. All Master's Theses. 943. https://digitalcommons.cwu.edu/etd/943.

Millward, L. S., K. A. Ernest, and A. G. Scoville. 2020. Reconnecting small mammal populations in the Cascade Range across an interstate highway: an early look at use of a wildlife crossing structure. Western Wildlife 7:9-21.

https://wwjournal.org/wp-content/uploads/sites/9/2021/05/Millward_etal_WW_2020.pdf

Ministry of Environment and Climate Change Strategy. 2020. Guidelines for Amphibian and Reptile Conservation during Road Building and Maintenance Activities in British Columbia. Version 1.0., March 30, 2020.

Ministry of Transportation. 2016. Environmental Guide for Mitigating Road Impacts to Wildlife. Updated final report submitted by Eco-Kare International to the Ministry of Transportation, St. Catharines, Ontario, 107 pages. http://www.roadsandwildlife.org/data/files/Documents/4123298b-fbd6-4558-94e7-c50e940eda65%20%20.pdf

Montgomery, R. A., G. J. Roloff, and J. J. Millspaugh. 2012. Variation in elk response to roads by season, sex, and road type. Journal of Wildlife Management 77:313–325.

Mullen, K. 2020. Environmental DNA is an effective method to monitor species in various freshwater habitat. Master's Thesis. Central Washington University. https://digitalcommons.cwu.edu/etd/1381/

Muller, L. A. Hackworth, N. Griffen, J. Evans, J. Henning, G. Hickling, and P. Allen. 2014. Spatial and temporal relationships between deer harvest and deer-vehicle collisions at Oak Ridge Reservation, Tennessee. Wildlife Society Bulletin, 38: 812-820.

Myers, A. 2020. Toadal isolation: Genetic connectivity of the Western toad (Anazyrus boreas) along I-90 in the Snoqualmie Pass Area of Washington State. Central Washington University. All Master's Theses. 1371. https://digitalcommons.cwu/etd/884

National Academies of Sciences, Engineering, and Medicine 2006. Incorporating Safety into Long-Range Transportation Planning. Washington, DC: The National Academies Press. https://doi.org/10.17226/13891. https://www.nap.edu/read/13891/chapter/2

National Fish, Wildlife and Plants Climate Adaptation Network. 2021. Advancing the national fish, wildlife, and plants climate adaptation strategy into a new decade. Association of Fish and Wildlife Agencies, Washington, DC. 93 pages. https://toolkit.climate.gov/sites/default/files/Advancing_Strategy_Report_FINAL%20%281%29.pdf

New Hampshire Fish and Game. 2018. New Hampshire Wildlife Corridors Report. Report on Senate Bill 376. June, 2018. 56 pages. https://www.wildlife.state.nh.us/nongame/corridors.html

Nichols, A. P., M. P. Huijser, R. Ament, S. Dayan, and A. Unnikrishnan. 2014. Evaluation of deer-vehicle collision rates in West Virginia and a review of available mitigation techniques. Report to the West Virginia Department of Transportation. Charleston, WV.

Normandeau Associates, Inc. 2012. Deer-vehicle crash, ecological, and economic impacts of reduced roadside mowing, Final Report to the Federal Highway Administration. Washington D.C. R-19977.003. https://intrans.iastate.edu/app/uploads/sites/10/2018/11/DVC-Mowing.pdf

North Carolina Department of Transportation. 2019. Project ATLAS. https://connect.ncdot.gov/resources/Environmental/EAU/Project-Atlas/Pages/default.aspx. Also see: https://www.youtube.com/watch?v=-lHxe05HpmI

Olson, D. 2013. Assessing vehicle-related mortality of mule deer in Utah. PhD Dissertation, Graduate School of Utah State University. Paper 1994. http://digitalcommons.usu.edu/etd/1994.

Ontario Ministry of Transportation 2017. Environmental guide for mitigating road impacts to wildlife. Update final report submitted by Eco-Kare International to the Ontario Ministry of Transportation, St. Catherines, Ontario. http://www.roadsandwildlife.org/Document/1063

Pagnucco, K. S., C. A. Paszkowski, and G. J. Scrimgeour. 2012. Characterizing movement patterns and spatio-temporal use of under-road tunnels by long-toed salamanders in Waterton Lakes National Park, Canada. Copeia 2012:331–340.

Paige, C. 2012. A landowner's guide to fences and wildlife: practical tips to make your fences wildlife friendly. Wyoming Land Trust, Pinedale, Wyoming. 52 pages.

Paige, C. 2008. A landowner's guide to wildlife friendly fences. Landowner/Wildlife Resources Program, Montana Fish Wildlife and Parks, Helena, Montana. 44 pages.

Paul, K., A. Wearn, R. Ament, E. Fairbank, and Z. Wurtzebach. 2021. A toolkit for developing effective projects under the federal wildlife crossings pilot program. Published by the Center for Large Landscape Conservation. 26 pages. https://largelandscapes.org/wp-content/uploads/2021/12/Crossing-Toolkit_Final.pdf and https://doi.org/10.53847/PZNN2279

Penrod, K., R. Hunter, and M. Merrifield. 2001. Missing linkages: restoring connectivity to the California Landscape Meeting Proceedings. Co-sponsored by California Wilderness Coaltion, The Nature Conservancy, U.S. Geological Survey, Center for Reproduction of Endangered Species, and California State Parks. http://www.scwildlands.org/reports/Missing_Linkages.pdf.

Peterson, M. N., R. R. Lopez, N. J. Silvy, C. B. Owen, P. A. Frank, and A. W. Braden. 2003. Evaluation of deer-exclusion grates in urban areas. Wildlife Society Bulletin 31:1198-1204.

Pither, R., P. O'Brian, A. Brennan, K. Hirsh-Pearson, and J. Bowman. 2021. Areas important for ecological connectivity throughout Canada. Doi: https://doi.org/10.1101/2021.12.14.472649.

Pojar, T. M., R. A. Prosence, D. F. Reed, and T. N. Woodard. 1975. Effectiveness of a lighted, animated deer crossing sign. The Journal of Wildlife Management 39:87-91.

Reed, D. F., and T. N. Woodard. 1981. Effectiveness of highway lighting in reducing deer-vehicle accidents. The Journal of Wildlife Management 45:721-726.

Robertson, C., N. Richards and M. Karch. 2013. Standard turtle handling and research practices and protocols. Prepared for the Ontario Turtle Conservation Group.

Romin, L, and L. Dalton. 1992. Lack of response by mule deer to wildlife warning whistles. Wildlife Society Bulletin 20:382-384

Root, R. B. 1967. The niche exploitation pattern of the blue-gray gnatcatcher. Ecological Monographs 37:317-350.

Roedenbeck, I. A., L. Fahrig, C. S. Findlay, J.E. Houlahan, J. A. G. Jaeger, N. Klar, S. Kramer- Schadt and E. A. van der Grift. 2007. The Rauischholzhausen agenda for road ecology. Ecology and Society 12: 11. http://www.ecologyandsociety. org /vol12/iss1/art11/

Rotalec. 2022. Case Study: Roadside Wildlife Warning System. https://www.rotalec.com/us/achievements/roadside-wildlife-warning-system/

Ryckman, J. 2020. Ecological and genetic connectivity of shrews (Sorex spp.) across Interstate 90 in the Washington Cascade Range. Central Washington University. All Master’s Theses. 1436. https://digitalcommons.cwu.edu/etd/1436.

Rytwinski, T., K. Soanes, J. A. G. Jaeger, L. Fahrig, C. S. Findlay, J. Houlahan, R. van der Ree, and E. A. van der Grift. 2016. How effective is road mitigation at reducing road-kill? A meta-analysis. PLoS One 11:e0166941.

Rytwinski, T., and L. Fahrig. 2012. So species life history traits explain population responses to roads? A meta-analysis. Biological Conservation 147:87-98.

Sawyer, H., C. Lebeau, and T. Hart. 2012. Mitigating roadway impacts to migratory mule deer-A case study with underpasses and continuous fencing. Wildlife Society Bulletin 36:492-498.

Sawyer, H., P. A. Rodgers, and T. Hart. 2016. Pronghorn and mule deer use of underpasses and overpasses along U.S. Highway 191. Wildlife Society Bulletin:n/a-n/a.

Schwender, M. 2013. Mule deer and wildlife crossings in Utah, USA. Thesis. Utah State University, Logan, Utah, USA.

Seiler, A. 2003. The toll of the automobile: Wildlife and roads in Sweden. PhD Dissertation, Swedish University of Agricultural Sciences, Uppsala, Sweden.

Sielecki, L. E. 2016. Behind the Scenes: BC Wildlife, Trucks Saved from Collisions. British Columbia Ministry of Transportation.

https://www.tranbc.ca/2016/07/27/behind-the-scenes-bc-wildlife-trucks-saved-from-collision/

Sielecki, L. 2017a. TAC 2017 Environmental Achievement Award Submission for the Wildlife Detection Systems, Highway 3, British Columbia Real-time warning systems for protecting wildlife and drivers. British Columbia Ministry of Transportation and Infrastructure. 11 pages. https://www.tranbc.ca/2015/10/21/on-the-case-for-safety-wildlife-detection-systems-on-highway-3/

Sielecki, L. E. 2017b. The deer-vehicle collision phenomena in the United States. Dissertation submitted to the University of Victoria, Department of Geography. 374 Pages. https://dspace.library.uvic.ca/handle/1828/7740?show=full.

Sielecki, L. 2020. It is amazing to see wildlife crossings like never before. Website. https://www.tranbc.ca/2020/08/13/its-amazing-to-see-wildlife-crossings-like-never-before/

Simpson, N.O., K.M. Stewart, C. Schroeder, M. Cox, K. Huebner, and T. Wasley. 2016. Overpasses and underpasses: effectiveness of crossing structures for migratory ungulates. Journal of Wildlife Management. Doi: 10.1002/jw.21132.

Singler, A., B. Graber, and C. Banks. 2018. The Massachusetts Stream Crossings Handbook. Second Edition, reprinted 2018. Department of Fish and Game, Division of Ecological Restoration. http://www.roadsandwildlife.org/Document/1054

Smith, D. J., D. Marsh, K. E. Gunson, and S. Tonjes. 2015. Monitoring and adaptive management of road impacts and mitigation. Pages 240-261 in K. M. Andrews, P. Nanjappa, and S. P. D. Riley, editors. Roads and Ecological Infrastructure: Concepts and Applications for Small Animals. Johns Hopkins University Press, Baltimore, MD.

Southern Rockies Ecosystem Project (SREP). 2005. Linking Colorado's landscapes: a statewide assessment of wildlife linkages. Phase 1 Report, Denver, CO.

Sparks, J.L. and J. E. Gates. 2012. An investigation into the use of road drainage structures by wildlife in Maryland, USA. Human-Wildlife Interactions 6(2):311-326. JSTOR, www.jstor.org/stable/24874104.

Sprague, S., J. Gagnon, S. Boe, C. Loberger, and R. Schweinsburg. 2013. A evaluation of pronghorn (Antilocapra americana) permeability associated with transportation right-of-way fence characteristics in northern Arizona. Presented at the 2013 International Conference of Ecology and Transportation. North Carolina State University, Raleigh. https://trid.trb.org/view/1345790

Statistics Canada. 2018. Canada's Core Public Infrastructure Survey: Roads, bridges, and tunnels, 2018. URL: https://www150.statcan.gc.ca/n1/daily-quotidien/201026/dq201026a-eng.htm.

Sullivan, T. L., A. F. 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. Wildlife Society Bulletin 32:907-915.

Theimer, T., S. Sprague, E. Eddy, and R. Benford. 2012. Genetic variation of pronghorn across US Route 89 and State Route 64. Final Report 659 for the Arizona Department of Transportation. 43 pages.

Transportation Planning Capacity Building Program, Federal Highway Administration, and Federal Transit Administration. 2015. The Transportation Planning Process Briefing Book: Key Issues For Transportation Decision Makers, Officials, and Staff. 84 pages. https://www.fhwa.dot.gov/planning/publications/briefing_book/index.cfm

Ujvari, M, H. Jorgen Baagoe, and A. Bo Madsen. 2004. Effectiveness of acoustic road markings in reducing deer-vehicle collisions: a behavioral study. BioOne Complete. Wildlife Biology, 10:155-159. https://doi.org/10.2981/wlb.2004.011

Valitzski, S. A., G. J. D'Angelo, G. R. Gallagher, D. A. Osborn, K. V. Miller, and R. J. Warren. 2009. Deer responses to sounds from a vehicle-mounted sound-production system. The Journal of Wildlife Management 73:1072-1076.

van der Ree, R., D. J. Smith, and C. Grilo. 2015. Handbook on Road Ecology. 1st edition. John Wiley and Sons Ltd., John Wiley and Sons Ltd.

van Riper, C. and R. Ockenfels. 1998. The influence of transportation corridors on the movement of pronghorn antelope over a fragmented landscape in northern Arizona. Proceedings of the 1998 International Conference on Wildlife Ecology and Transportation. Federal Highway Administration. https://trid.trb.org/view/639959

Waldheim, N., E. Wemple, and J. Fish. 2105. Applying Safety Data Analysis to Performance Based Transportation Planning. Federal Highway Administration Report Number FHWA-SA-15-089. 100 pages. https://safety.fhwa.dot.gov/tsp/fhwasa15089/chap3.cfm

Waller, J.S. and C. Servheen. 2010. Effects of transportation infrastructure on grizzly bears in northwestern Montana. Journal of Wildlife Management 69:985-1000. https://doi.org/10.2193/0022-541X(2005)069[0985:EOTIOG]2.0.CO;2

Wickem, C. and K. Ernest. 2016. Testing the forage preference of the American pika (Ochotona princeps) for use in connectivity corridors in the Washington Cascades. Central Washington University. All Master’s Theses. https://digitalcommons.cwu.edu/etd/452

Wildlife Insights. 2022. Wildlife Insights Artificial Intelligence Models. Webpages. https://www.wildlifeinsights.org/about-wildlife-insights-ai#model-performance, https://venturebeat.com/2019/12/17/googles-ai-can-identify-wildlife-from-trap-camera-footage-with-up-to-98-6-accuracy/

Williams, T., N. Dodd, P. Cramer, S. Kundur, M. Gomez, and J. Rybczynski. 2021. Arizona statewide wildlife-vehicle conflict study. For Arizona Department of Transportation. 315 pages. https://azdot.gov/sites/default/files/media/2021/08/WVC_Final_Report_July30_2021.pdf

Wilson, J. B. 1999. Guilds, functional types and ecological groups. Oikos 86(3):507-522.

Wood, P., and M. L. Wolfe. 1988. Intercept feeding as a means of reducing deer-vehicle collisions. Wildlife Society Bulletin 16:376-380.

Young et al. 2016. NatureServe Species Climate Change Vulnerability Index. https://www.natureserve.org/ccvi-species

Appendix A. Case Studies

Overview

This appendix presents case studies from states and provinces that created methods to bring wildlife concerns into transportation processes. The case studies are supplemental to the information presented in the main body of the manual. The authors believe the information will help inform others interested in taking similar actions in their jurisdictions.

Table A-1. The case studies presented in this appendix and challenges they address.

Case Study Title	Challenge Addressed	Approach
Nevada Prioritization Process for Wildlife Conflict	How to prioritize areas for animal crashes plus ecological and transportation factors	Geo-referenced data placed in a GIS and scored to rank top one-mile areas for transportation & ecological factors
The New Mexico Wildlife Corridors Action Plan	How to identify top areas for wildlife movement based on modeling, crash and other data	An approach with several ways of identifying where wildlife need to move across roads
An Example Prioritization Scorecard for Transportation and Ecological Factors	What factors are important in prioritization of areas for wildlife connectivity?	The scorecard presents multiple factors used by various U.S. states for prioritization of areas along roads for wildlife connectivity
Canadian Partners Prioritize Wildlife Connectivity Across Canada	How to prioritize the many lands and roads across a nation for wildlife crossing structures and other mitigation efforts	Modeling with Circuitscape, using examples of success stories, and mapping plans for the future
Vermont Prioritizing Screening Framework for Existing Bridge and Culverts	Identify the most important existing bridges and culverts for wildlife movement	The assessment tool modeled where wildlife need to move and the structures important to those movements
Integrated Planning through the Eco-Logical Approach	Agencies have not typically worked collaboratively to plan for wildlife	Integrated planning with partners is presented in an overview with case studies
Colorado’s Wildlife Mitigation Project on the	Identify wildlife migration and movement pathways	GPS collaring of mule deer and elk located exact places where

Case Study Title	Challenge Addressed	Approach
Southern Ute Indian Tribe Land	across roads on Tribal / Indigenous lands	Colorado DOT placed crossing structures
Wyoming's Wildlife and Roadways Initiative	Agencies and partners were interested in the WVC problem and solution and needed to work together	The transportation and wildlife agencies worked with partners to identify top areas for wildlife mitigation, and secure funding annually
Colorado's Wildlife and Transportation Alliance	Agencies and partners all had pieces of the problem and solution and needed to work together	The transportation and wildlife agencies and partners developed an action plan to educate, create policy, exchange data, and fund wildlife crossings
Implementing Wildlife Mitigation Priorities in Colorado	There was a need for a decision support tool to identify most urgent areas for wildlife mitigation	The support tools developed identify crash areas, mule deer migration areas, and pinpoint areas for new projects for wildlife
Changing Texas Department of Transportation Manuals	Most professions do not consider wildlife needs to move in their transportation division	If the professional manuals in a transportation agency give specific instructions on how to plan for, construct, and maintain for wildlife movement, there is a better chance these actions will be institutionalized
How MPOs Can Be Compelled and Rewarded to Consider Wildlife Concerns	MPOs and RPOs typically do not consider wildlife concerns in transportation planning	Changing the federal regulations to include wildlife concerns in the environmental review and to work with partners
Colorado's Interstate 70 Floyd Hill Realignment – When to Invest in Mitigation Outside Project Boundaries	Wildlife mitigation projects are often opportunistic and chiefly occur within transportation projects, rather than urgent areas	The Context Sensitive Solutions process can be used to consider wildlife needs to move outside of transportation project boundaries
Colorado's Interstate 25 South Gap Project Environmental Assessment and Wildlife Mitigation Commitments	Funding for wildlife mitigation is often not incorporated into environmental planning for transportation projects	Detail specific mitigation commitments in the Environmental Assessment
Minnesota Best Management Practices	Construction plans often do not include specific	The permitting process for transportation construction

Case Study Title	Challenge Addressed	Approach
Manual Leads to Everyday Low Cost Wildlife-Friendly Designs Across the State	details on the small and large changes that can be made to accommodate wildlife movement	around and in waters of the state requires plans to be reviewed and updated by wildlife professionals in the Department of Natural Resources
Colorado's Western Slope Wildlife Prioritization Study Benefit-Cost Analysis	Most federal and state benefit-cost analyses do not consider the value of wildlife saved from collisions with wildlife mitigation	A hybrid benefit-cost technique was developed to allow for transportation safety and development methodologies to be combined to account for wildlife values
Construction Project Impacts and the Seven Dwarfs of Implementation	Construction impacts to a wildlife mitigation area may negate all efforts to draw wildlife to that area	The larger area outside of the road itself need to be accounted for in the environmental documents when planning for construction activities
British Columbia Ministry of Transportation and Infrastructure's Wildlife Program Instill the Love of Wildlife	How to have many different professionals in transportation agencies care about wildlife and be aware of what they can do	In the agency, have a Wildlife Program, and an active social media presence to instill pride in what they do for wildlife
Vermont Transportation Agency's Highways and Habitat Program Instill Ecological Knowledge in Agency Personnel	How to have many different professionals in transportation agencies care about wildlife and be aware of what they can do	Create an education program to give transportation professionals ecological knowledge of what wildlife need with respect to roads
Monitoring Smaller Animals for Connectivity Across an Interstate is Possible	Assessing a project's success in providing permeability for smaller terrestrial and aquatic animals is difficult	Multiple survey methods were and are carried out by a university's scientists to monitor fish, amphibians, reptiles, small mammals, and bat movement along an interstate
Monitoring Wildlife Crossing Structures for Eight Years in Ontario	Long-term studies take time and resources, and often don't include monitoring smaller animals	This study was eight years long and included monitoring of how well the mitigation efforts were to larger and smaller animals

Nevada Prioritization Process for Wildlife-Vehicle Conflict

In 2018 Nevada DOT (NDOT) published the study "Prioritization of Wildlife-Vehicle Conflict in Nevada" (Cramer and McGinty 2018), which identified areas of animal-vehicle conflict of highest priority for mitigation alternatives to reduce these collisions and make roads safer for travelers as well as providing connectivity for large mammals. It included wild animal species, horses, and cows in the analyses, since this open range state has livestock and wildlife crashes.

Figure A-1. Mule deer exit a wildlife crossing built by Nevada DOT. Photo Credit: N. Simpson, Nevada DOT.

The animal-vehicle collision (AVC) hotspot map was created using the Getis-Ord Gi* Optimized Hot Spot Analysis tool in ArcGIS, based on crashes/mile/year. Additional transportation factors were added (see **Table A-2**) to create a transportation-safety map of top hotspot road segments. An ecological map was created with GIS information on wildlife corridors, wildlife GPS locational data, and areas where horses and cows were involved in collisions. This was the ecological hotspots map, which gave priority to areas with the highest scores based on various wildlife species' presence and habitat. These two maps were brought together to score every one-half mile of Nevada roads for all these factors for potential animal-vehicle conflict, not just reported crashes. This resulted in the Nevada Cumulative Safety and Ecological Priority Road Segments for Wildlife Vehicle Conflict (**Figure A-2**).

Table A-2. GIS score card for safety-ecological priority hotspots.

Information-GIS Layer to Evaluate a Half-Mile Segment of Road for Scoring	Range of Values	Range of Points	Max Points
GIS Safety Information			
Number of Animal Crashes/mile/year	From < 0.65 to ≥ 1	0 - 20	20
Number Human Fatalities from AVC	From 0 to 1	0 - 7	7
Number of Human Injury AVC Crashes	From 0 to > 1	0 - 5	5
Number of Carcasses/mile/year	From 0 to > 1	0 - 3	3

Average Annual Daily Traffic	From < 2,000 to >9,999	0 - 10	10
Percentage of Crashes = AVC	From <2.4 to >10.6	0 - 5	5
Total for Safety map			50
GIS Wildlife-Livestock Information			
Mule deer habitat	From 0 to Habitat Present	0 - 5	5
Mule deer movement corridors	From 0 to Habitat Present	0 - 5	5
No. of horse-vehicle crashes/mile/year	From 0 - > 0.11	0 - 10	10
No. of cattle-vehicle crashes/mile/year	From 0 - > 0.11	0 - 10	10
Elk habitat	From 0 to Habitat Present	0 - 5	5
Pronghorn habitat	From 0 to Habitat Present	0 - 5	5
Bighorn sheep habitat	From 0 to Habitat Present	0 - 3	3
Bighorn movement corridors	From 0 to Habitat Present	0 - 5	5
Black bear habitat	From 0 to Habitat Present	0 - 2	2
Total Points for Ecological Map		50	50
Total points		100	100

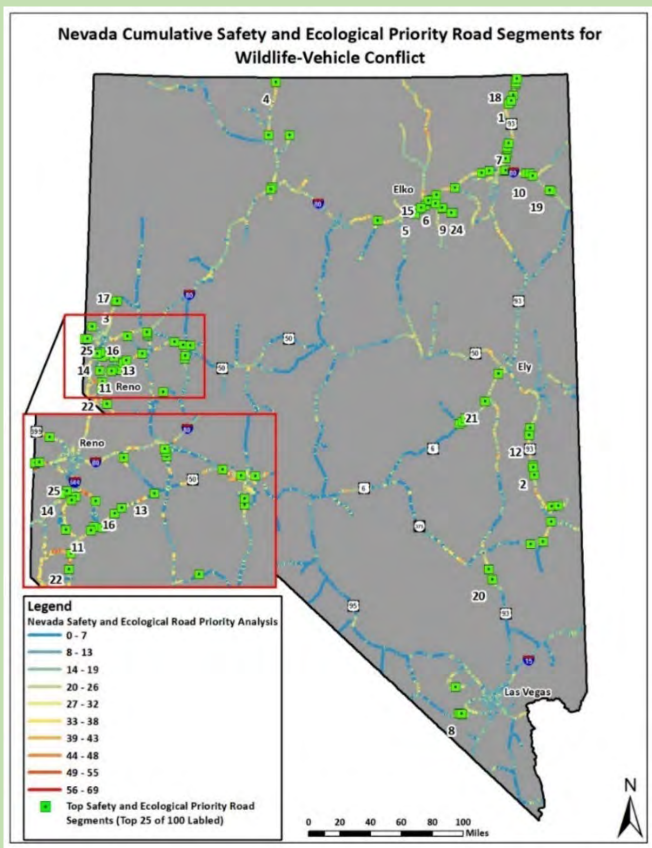

Figure A-2. Priority road segments for wildlife-vehicle conflict based on ecological and safety maps combined. Top 25 Listed, Top 100 road segments presented in green boxes. Modeled on data from 2007-2016.

See: Cramer and McGinty (2018).
https://www.nevadadot.com/home/showdocument?id=16038

The New Mexico Wildlife Corridors Action Plan is the first such plan completed in the U.S. Prioritization of both wildlife-vehicle collision hotspots and wildlife corridors as separate entities were central to this prioritization, as was public, agency, Tribal, and non-profit input.

The New Mexico Wildlife Corridors Action Plan

In 2019 New Mexico signed into law the U.S.'s first Wildlife Corridors Act. It instructed the DOT and New Mexico Department of Game and Fish to work together to identify the top 10 areas where wildlife need to cross New Mexico highways, and propose recommended projects to mitigate those roads for wildlife connectivity. In 2022 the New Mexico Wildlife Corridors Action Plan was released (**Figure A-3**). It selected top priority areas for wildlife mitigation based on two different sets of criteria: Wildlife-vehicle crash hotspots based largely on transportation data, and wildlife corridors based on GPS locational data on the six species listed in the act, modeling of those data, species of special concern, wildlife agency input, the input of Tribal wildlife managers and other officials, non-profit organizations, and the public. The Plan received public input at the beginning of the research and at the release of the draft Action Plan. It is a model for other states and entities in the scope of the scientific approach, and the inclusivity with which it was developed with partners.

Figure A-3. New Mexico Wildlife Corridors Action Plan Cover.

In 2022 the New Mexico State Legislature debated funding the proposed top 11 projects the Plan identified. With the support of politicians, the transportation and wildlife agencies, Tribes, non-profit organizations and importantly the public, this Plan will assist in the creation of wildlife mitigation projects in the state's priority locations.

See: Cramer et al. 2022b. https://wildlifeactionplan.nmdotprojects.org/

An Example Prioritization Scorecard for Transportation and Ecological Factors

The scorecard below (**Table A-3**) lists a number of factors that can be considered in a matrix of data and factors in a prioritization of wildlife mitigation for transportation. The factor entries also list states that have used that factor in their prioritization.

Table A-3. Transportation, ecological, and feasibility factors for potential use in transportation prioritization scorecard of areas most important for wildlife mitigation.

Factor	Range of Points	Total Potential Points
Transportation Factors		
Rank in hotspot prioritization – based on crashes/mile/year = weighting top hotspots more heavily, must decide on range of points. *States that have used this: AZ, NM, NV, UT, ID, SD* Or – Use a traffic and safety analysis that predicts the expected number of wildlife-vehicle collisions on a road based on its number of lanes, topographic location, sinuosity, traffic volume, etc. and how much more the wildlife-vehicle crashes are than expected. See Colorado's Kintsch et al. (2019)		
Score for number of carcasses reported per mile per year. *States that have used this: NV*		
Fatality Score = (Fatal crashes / number of miles in hotspot) x 10. *States that have used this: AZ, NV*		
Serious Injury Score = (Number of severe injury wildlife crashes per mile per 10 years of data) x 10. *States that have used this: AZ, NV, NM*		
Percentage of all crashes in segment that are wildlife related. *States that have used this: AZ, NM, NV*		
Average annual daily traffic (AADT): 0 < 2,000 AADT= 0; 2,000–7,500 = 3; 7,501–15,000 = 5; > 15,000 = 7. *States that have used this with various points: AZ, NM, NV*		
Score for an upcoming STIP project in the segment = 5. *States that have used this: NM*		

Score for an upcoming transportation project in the road segment or nearby, such as those in the STIP. *States that have used this: AZ, NM*		
Score for location importance to resiliency plans to adapt infrastructure to climate change. *No known usage by states in wildlife mitigation plans*		
Total Transportation Score		
Ecological Factors		
Deer Habitat. *States that have used this: NV, NM, AZ, CO, ID*		
Identified wildlife linkage or corridor within 1,000 feet of road segment. *States that have used this: AZ, ID, NM, CO*		
Magnitude of winter range use by deer, elk, and other ungulates. *States that have used this: NV, ID, CO*		
Identified critical habitat for protected species. *States that have used this: AZ, ID, NM, CO*		
Number of crashes/mile/year for an identified species not as fully represented in the overall crash data as deer and other more numerous species. This can be bighorn sheep, pronghorn, carnivores, endangered species, etc. St*ates that have used this: NV, AZ, NM*		
Target Species Migration Corridor. St*ates that have used this: NV, AZ, NM, ID*		
Known or modeled impacts of wildlife-vehicle collisions on a population of a species. This can also be quantified as an urgency factor for populations that are close to becoming extirpated. *States that have used this: CO*		
Target Species 1 Habitat		
Target Species 2 Habitat		
Additional Species and Population Data		
Water resources within set distance		

Total Ecological Score		
Feasibility Factors		
Percentage of the road segment that has public land on both sides, or conservation easement on both sides, lower points if protected land is on just one side. Assign more points for higher range of percentages. *States that have used this: NM*		
Agency/Tribal/Citizen Support. One point for each entity that has documented this area as important, up to a certain limit. *States that have used this: NM*		
Constructability of the area for construction of wildlife mitigation. *States that have used this, CO (as a secondary criteria)*		
Total Feasibility Score		
Final Score		

References:
Arizona – Williams et al. 2021;
Idaho – Cramer et al. 2014;
Colorado – Kintsch et al. 2019;
Nevada – Cramer and McGinty 2018;
New Mexico – Cramer et al. 2022b;
South Dakota Cramer et al. 2016;
Utah – Cramer et al. 2019.

Prioritization of top areas for wildlife mitigation can include data, resources, and partnership with other entities outside the transportation agency, as the below case study of the Colorado DOT and Southern Ute Indian Tribe partnership demonstrates.

Colorado's Wildlife Mitigation Project on the Southern Ute Indian Tribe Land

Colorado Department of Transportation (CDOT) worked closely with the Southern Ute Indian Tribe and Colorado Parks and Wildlife (CPW) to identify where mule deer and elk needed wildlife mitigation across US 160 in southern Colorado. The Tribe's biologist placed GPS collars on mule deer and elk that migrated into and then off the Tribal lands seasonally. The resulting movement maps (**Figure A-4**) helped to pinpoint the priority areas for mule deer and elk mitigation. In turn, CDOT, CPW, the Southern Ute Indian Tribe, and partners in the Mule Deer Foundation were able to invest $11 million on the US 160/SH 151 Wildlife Mitigation Project. In 2021 and 2022 an overpass and underpass were constructed to facilitate these migratory movements. CDOT needed these partners to prioritize and complete the project, and in the future, monitor its success.

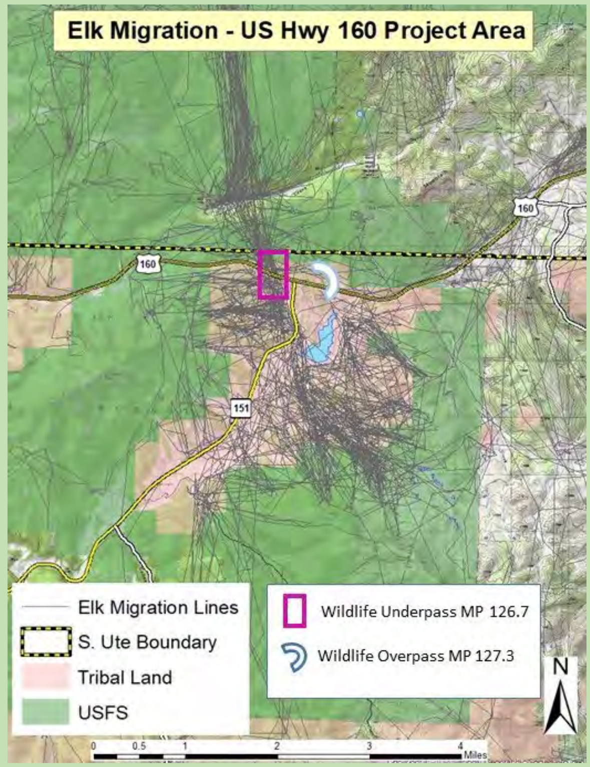

Figure A-4. Southern Ute Indian Tribe map of elk movements and new wildlife crossing underpass and overpass. Map credit: A. Johnson, Southern Ute Indian Tribe.

Canadian Partners Prioritize Wildlife Connectivity Across Canada

The Environment and Climate Change Canada sponsored the Canadian Council on Ecological Areas to produce a study focused on connectivity across Canada for terrestrial wildlife with the report, "Implementing Connectivity Conservation in Canada" report (**Figure A-5**). The focus of the report was to identify areas to protect and restore connectivity for wildlife within Canada's terrestrial ecosystems. It presents a modeling strategy that was applied across the country, identifying top areas for various wildlife species' movement corridors. It presented 10 case studies on how wildlife connectivity is being protected and restored, with many examples from transportation systems. The report also presents an Organizational Capacity and needs assessment, and ends with how agencies and partners can work together to increase protection and restoration of important natural areas, with instructions on setting goals and milestones. The sheer enormous scale of this undertaking is an inspirational example of how nations can identify and set priorities.

Figure A-5. Canada's recent research and compilation of work to protect and restore wildlife connectivity in Canada. Figure Credit: Canadian Council on Ecological Areas.

The Environment and Climate Change Canada also administers the Connectivity Toolbox (https://www.conservation2020canada.ca/connectivity) that provides examples of guidance, policy, research among other areas related to wildlife connectivity in Canada. There will be a forthcoming interactive map at the website.

There are also provincial members of the Connectivity Working Group who are very active in identifying areas of wildlife connectivity and collaborating to place wildlife mitigation along Canada's highways. These include Parks Canada, which has a new Ecological Corridor Program to identify priority areas for wildlife connectivity in Canada's national parks.

References: Prither et al. 2022., and Lemieux et al. 2021. Implementing Connectivity Conservation in Canada: https://ccea-ccae.org/publications/

Vermont's prioritization study took a slightly different approach by modeling wildlife connectivity and identifying the important bridges and culverts that were located where the wildlife linkages and corridors were bisected by roads.

Vermont Prioritization Screening Framework for Existing Bridges and Culverts

Vermont Agency of Transportation (VTrans) and partners in the Vermont Fish and Wildlife Department, The Nature Conservancy, and the University of Vermont developed an assessment methodology to evaluate the value of VTrans transportation structures for terrestrial mammal connectivity and a Terrestrial Passage Screening Tool that ranks each of almost 6,000 structures with respect to terrestrial species connectivity. This tool prioritizes the most important structures for predicted wildlife movement for: moose, white-tailed deer, black bear, coyote, bobcat, red fox, raccoon, and striped skunk. Those movements were predicted with the Omniscape modeling program (Landau 2020, McRae et al. 2016) that uses electrical circuit theory approach to predict species movements. The resulting spreadsheet of structures allows for structures to be ranked according to constraints, which then allows users to find the best structures to prioritize mitigation and retrofits for specific objectives defined in the spreadsheet by the user. There is a top 100 structures priority map for users to view (see **Figure A-6**). These priority structures were ranked in areas of concentrated wildlife movements as predicted by the Omniscape analyses and have lower levels of human development influence.

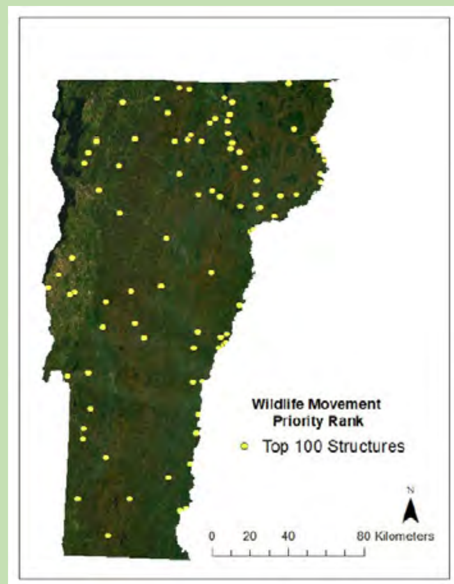

Figure A-6. Vermont's top 100 transportation structures identified by the wildlife movement priority rank. From Drasher et al. 2021.

See: Drasher and Murdoch (2021).
https://vtrans.vermont.gov/sites/aot/files/Research/VTrans_Final_Report_2021_0001057-332.pdf
For a 2021 International Conference on Ecology and Transportation Presentation, see Dr. Drasher present this study at: https://www.youtube.com/watch?v=hXVovP139Ow

Integrated Planning Through the Eco-Logical Approach

"Integrated planning for transportation agencies attempts to provide a method for the collection, sharing, analysis, and presentation of data contained in the agencies' plans. Through the collaborative efforts of field-level experts, partners, and the public, a single framework for appropriate strategies can be devised." (Eco-Logical, Brown 2006, **Figure A-7**). The various approaches to this integrated planning for wildlife and natural processes is documented in the Ecological document: Eco-Logical, an Ecosystems Approach to Developing Infrastructure Projects. See:

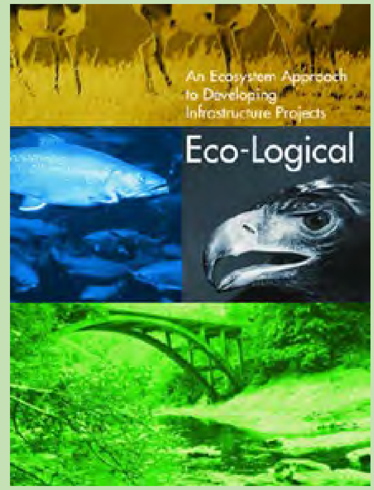

Figure A-7. Eco-Logical manual cover.

https://www.environment.fhwa.dot.gov/env_initiatives/eco-logical/report/eco_index.aspx

Wyoming's collaborative and integrative planning has been brought together for several years through the efforts of Wyoming DOT, Wyoming Game and Fish, and multiple partners. These cooperative efforts were crystallized in 2017 with the Wildlife and Roadways summit and the partnerships continue beyond this and a second summit, see below.

Wyoming's Wildlife and Roadways Initiative

In 2017, the Wyoming Department of Transportation (WYDOT) and Wyoming Game and Fish hosted the nation's first of its kind Wildlife and Roadways Summit, where officials met to discuss ways to improve safety on Wyoming's road, reduce loss of lives and property due to wildlife-vehicle collisions, and reduce impacts to the state's wildlife heritage. The event was a unique opportunity for state agencies, non-government organizations, members of the public, and other stakeholders to come together to actively discuss these critical issues and identify opportunities to mitigate these conflicts. Through a collaborative, expert knowledge-based process, summit participants identified areas across the state that were particularly problematic for various ungulate species (see **Figure A-8**).

Figure A-8. Pronghorn moved over a wildlife overpass placed above US 191 in Pinedale, Wyoming. Photo Credit: West, Inc., and Wyoming DOT.

Following the summit, an implementation team was formed to develop a framework for priorities the top roadway-wildlife projects. This framework consists of three steps: 1) set the top priorities with high wildlife-vehicle collisions that also present the greatest barriers to wildlife movement, 2) modify priorities based on the feasibility and effectiveness of mitigation solutions, and 3) evaluate other considerations to further modify priorities, such as funding availability or an upcoming roadway project. The resulting priorities list is now guiding mitigation project priorities and funding across the state. See the websites:

Wyoming's Wildlife and Roadways Initiative

See: https://www.dot.state.wy.us/wildlife-initiative

Story Map:

https://wgfd.maps.arcgis.com/apps/MapSeries/index.html?appid=ef666ba292b74c56a339efc10fca5332

Colorado followed Wyoming's lead and created the Wildlife and Transportation Summit also in 2017. This led to their Wildlife and Transportation Alliance, which has brought Colorado to the head of leadership in mitigating roads for wildlife.

Colorado's Wildlife and Transportation Alliance

In 2017 Colorado DOT, Parks and Wildlife (CPW), the Federal Highway Administration (FHWA) and other partners joined forces to host a two-day Wildlife and Transportation Summit (**Figure A-9**). As a result, the Colorado Wildlife and Transportation Alliance was formed to carry forward the momentum generated by the summit. The Alliance is led by an inter-organizational Steering Committee composed of representatives from CDOT, CPW, FHWA, the USDA Forest Service, the Bureau of Land Management, the Southern Ute Tribe, Rocky Mountain Elk Foundation, and the Mule Deer Foundation. The initial tasks of the committee were to define a mission and vision, and to develop an action plan. The action plan identifies specific goals, actions and timelines, and led to the formation of technical teams to broaden the capacity of the Alliance. The primary goals and associated technical teams are focused in four areas: 1) education and outreach, 2) partnerships and funding, 3) policy, and 4) data coordination and planning. In 2019, Colorado Governor Jared Polis signed an Executive Order on Big Game Winter Range and Migration Corridors and Wildlife Crossings, reinforcing the ongoing work of the Alliance, including revising an interagency MOU to streamline collaboration between CDOT and CPW. See: https://www.coloradowta.com/home/

Figure A-9. Participants in the Colorado Wildlife and Transportation Summit visit SR 9 wildlife mitigation. Photo Credit: P. Cramer.

Once priority areas for wildlife mitigation have been identified, it is important that the information be taken to the next steps of beginning wildlife mitigation standalone projects and as part of planned projects. The Colorado case study below is an important example of how priority locations then became wildlife mitigation projects.

Implementing Wildlife Mitigation Priorities in Colorado

The Colorado DOT (CDOT) and Colorado Parks and Wildlife (CPW) funded the Western Slope Wildlife Prioritization Study with the objective of strategically identifying wildlife-highway conflict areas where targeted mitigation could have the greatest impact on reducing wildlife-vehicle collisions and enabling wildlife movement across Colorado's Western Slope (WSWPS: Kintsch et al. 2019). Prior to this research, CDOT addressed wildlife-vehicle problem areas largely on a project-by-project basis, integrating mitigation as transportation projects arose. However, this approach often did not capture areas outside of project limits where mitigation could have the greatest impact, and largely relied on state safety funds or regional discretionary funding.

The outcomes of the WSWPS and accompanying decision-support tools now drive mitigation project planning and budgeting for new wildlife-highway mitigation projects across the Western Slope. CDOT began presenting the prioritization results to transportation planners and stakeholders across the state and added the highest wildlife mitigation priorities to the recently updated Statewide Long Range Transportation Plan. These efforts led to the prioritization of 17 wildlife mitigation projects across the Western Slope for funding within the next 10-years. CDOT staff are now able to identify priorities and budgetary needs at the beginning of the planning cycle and more efficiently direct funding towards mitigation projects. The study in 2022 was expanded for a complete statewide prioritization (see Kintsch et al. 2022a).

Figure A-10. Colorado US 160 wildlife overpass under construction. Photo Credit: A. Johnson.

Additionally, the outcomes of the WSWPS have pinpointed priority projects for state and federal grant opportunities and other partnerships and supported CDOT's requests for mitigation funding from non-traditional sources. Multiple WSWPS priorities have since received project funding.

The number four ranked priority in southwest Colorado highlights a strong partnership with the Southern Ute Tribe and was awarded funding from the National Fish and Wildlife Foundation with supplementary funding from the Rocky Mountain Elk Foundation (**Figure A-10**).

See: Kintsch et al. 2019, 2022a. https://www.codot.gov/programs/research/pdfs/2019/WSWPS

Another important way to institutionalize concerns for wildlife is to insert wildlife concerns into the professional manuals of various transportation agency professions.

Changing Texas Department of Transportation Manuals

Figure A-11. Bobcat used the wildlife crossing underpass in southern Texas. Photo Credit: Texas DOT, University of Texas Rio Grande Valley, U.S. Fish and Wildlife Services.

One way to enact change across transportation agencies is to provide instructions for that change in the manuals of the dozens of divisions and professions within the agency. In 2017 Texas Department of Transportation (TxDOT) with the University of Texas, Center for Transportation Research led a research project to update TxDOT division manuals with recommendations based on the state of the science and practice on wildlife crossing structures and mitigation across the U.S. (Loftus-Otway et al. 2019, **Figure A-11**). The project recommended specific language modifications to 18 TxDOT manuals to help ensure that consideration of wildlife-vehicle conflict and wildlife connectivity became standard business procedure, see **Table A-4** below. Recommended changes included: definitions of terms, such as wildlife corridors; how to include wildlife crossing structures in the planning process; the reporting of carcasses by maintenance staff; maintenance and repair of structures and fences for wildlife; consideration of wildlife when establishing speed zones; the review of animal-vehicle conflict in project planning; and the examination of wildlife-vehicle crash hotspots for transportation programming, along with dozens of other recommendations.

Table A-4.Texas Department of Transportation manuals selected for revisions for consideration of wildlife-vehicle conflict and habitat connectivity.

Access Management	Manual on Uniform Traffic Control Devices
Bridge Design	Plans, Specifications and Estimate Development
Bridge Project Development	Procedure for Establishing Speed Zones
Construction Contract Administration	Project Development Process
Design and Construction Information Systems	Roadside Vegetation Management
Highway Safety Improvement Program	Roadway Design
Landscape and Aesthetics Design	Traffic Safety Program
Maintenance Management	Transportation Planning
Maintenance Operations	Transportation Programming and Scheduling

See: Loftus-Otway et al. 2019. https://library.ctr.utexas.edu/ctr-publications/0-6971-1.pdf

Metropolitan Planning Organizations (MPOs) are important allies in institutionalizing wildlife concerns in planning processes.

How MPOs Can Be Compelled and Rewarded to Consider Wildlife Concerns

The major barrier to MPOs creating a process to consider wildlife is that the current purpose section of the U.S. federal regulations does not mentioned the terms 'wildlife,' 'enhancing biodiversity,' or 'wildlife crossings,' nor is there any mention of the environment within the purpose section (23 Code of Federal Regulations (CFR) § 450.300). An initial recommendation is to include environment at 23 CFR §450.300 so that environment is given a seat at the table along with the other policy components detailed in this paragraph.

MPOs are political bodies, with policy and planning boards comprised of elected officials. MPOs and RPOs can take the initiative to protect wildlife connectivity, as the residents of Pima County, Arizona voted to do (**Figure A-12**). However, if federal regulations required consideration of wildlife this would afford politicians political cover to count "environmental protection" as part of the range of components they are required to consider.

Section 450.318 (a) (4) and (5) could be amended to state: (4) Basic description of the environmental setting *including any wildlife vehicle crash hot spots*; and/or (5) Preliminary identification of environmental impacts, *for example wildlife vehicle crash hot spots* and environmental mitigation *including installation of wildlife crossing structures*.
Section 450.320 (a) (1) (ii) could be amended so that the term wildlife habitat is instead termed 'wildlife habitat *and connectivity'*.

Section 450 324 (f)(10) could be amended to: A discussion of types of potential environmental mitigation activities and potential areas to carry out these activities, including activities that may have the greatest potential to restore and maintain the environmental functions affected by the metropolitan transportation plan, *and reduce wildlife-vehicle interaction*. The discussion may focus on policies, programs, or strategies, rather than at the project level. The MPO shall develop the discussion in consultation with applicable Federal, State, and Tribal land management, wildlife, and regulatory agencies. The MPO may establish reasonable timeframes for performing this consultation.

Figure A-12. A bobcat used the SR 86 underpass paid for by tax funds from Pima County residents, and administered by the Regional Transportation Authority. Photo credit: J. Gagnon, Arizona Game and Fish Department.

The following case study from Colorado demonstrates how the transportation agency worked across jurisdictional boundaries to make wildlife crossing structures part of construction projects.

Colorado's Interstate 25 South Gap Project Environmental Assessment and Wildlife Mitigation Commitments

The Interstate 25 (I-25) South Gap Project was a major highway widening project to reduce congestion and improve safety between Denver and Colorado Springs. The Environmental Assessment (EA) process identified wildlife-vehicle collisions as a safety problem for motorists and transportation infrastructure and traffic as a major barrier to wildlife movement and population health. The EA was multi-year process to meet the requirements of the National Environmental Policy Act (NEPA) and involved numerous stakeholders, including cities, counties, other local government entities, the state wildlife agency, and private economic development organizations.

This section of I-25 travels through natural grasslands and forested habitat, much of which has been protected through extensive land protection efforts by Douglas County over 25 years. Due to the ecological values of this landscape, the safety concerns resulting from wildlife-vehicle collisions and the presence of federally threatened species, the Preble's meadow jumping mouse*,* the EA specifically identified the need for wildlife-highway mitigation, including four underpasses, a major bridge replacement, wildlife exclusion fencing, escape ramps, and wildlife guards (**Figure A-13**). These mitigation commitments capitalized on CDOT's partnership with Douglas County and the county's previous investments in habitat conservation along this corridor, and by detailing specific mitigation commitments in the EA, funding for mitigation was included in the project budget from the outset.

Figure A-13. A Black Bear used a new wildlife underpass on I-25. The woody material was placed along the structure for small mammals. Photo Credit: Colorado Parks and Wildlife.

Minnesota's approach to consideration of wildlife in transportation projects is to standardize the methods that the Minnesota DOT and consultants need to use to assure that all planning and construction activities consider wildlife concerns, particularly along water ways. The below manual is a stellar example of providing a standardized approach that all agencies and partners understand will be enforced with every project. It also considers small changes to curbs and gutters that could trap smaller animals in a roadway.

Minnesota Best Management Practices Manual Leads to Everyday Low Cost Wildlife-Friendly Designs Across the State

The Minnesota Department of Transportation (MnDOT) and the Minnesota Department of Natural Resources (DNR) developed a Best Practices guidance manual for meeting state environmental regulations (**Figure A-14,** Leete 2014). It is an incentive based guidance document and is utilized as a comprehensive communication tool and an implementation guide for transportation designers, construction managers, and contractors (Leete and Alcott 2011).
The manual includes simple engineered design modifications to allow for riparian continuity at roads, as well as curb and storm drain designs to reduce animal mortality on curbed roads, selection of native vegetation for roadsides, invasive species control, and hydrologic improvements.

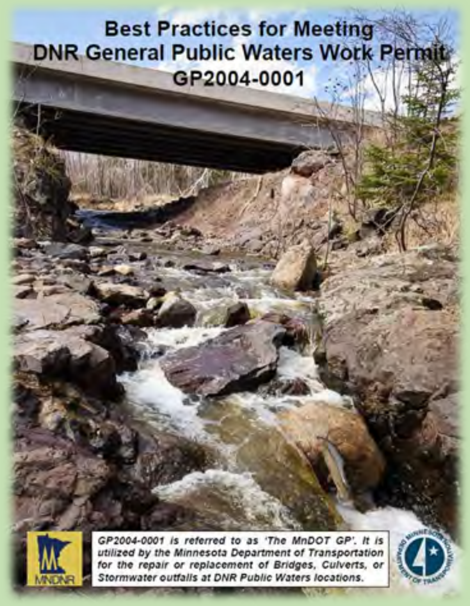

Figure A-14. Minnesota's Best Practices Guidance Manual.

The manual offers pre-approved designs for various way to provide connectivity and protection for species of various sizes and modes of locomotion. An ArcGIS Story Map from Arc Solutions: https://storymaps.arcgis.com/stories/005f9937f2e34685811c7b930f259954 describes the Minnesota approach.

The best practices manual is continually updated at the site: https://www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/gp_2004_0001_manual.html

Minnesota's Stream Design Manual presents a flow diagram (**Figure A-15**) on how to proceed with the best stream flow approaches for a transportation project involving a culvert or bridge.

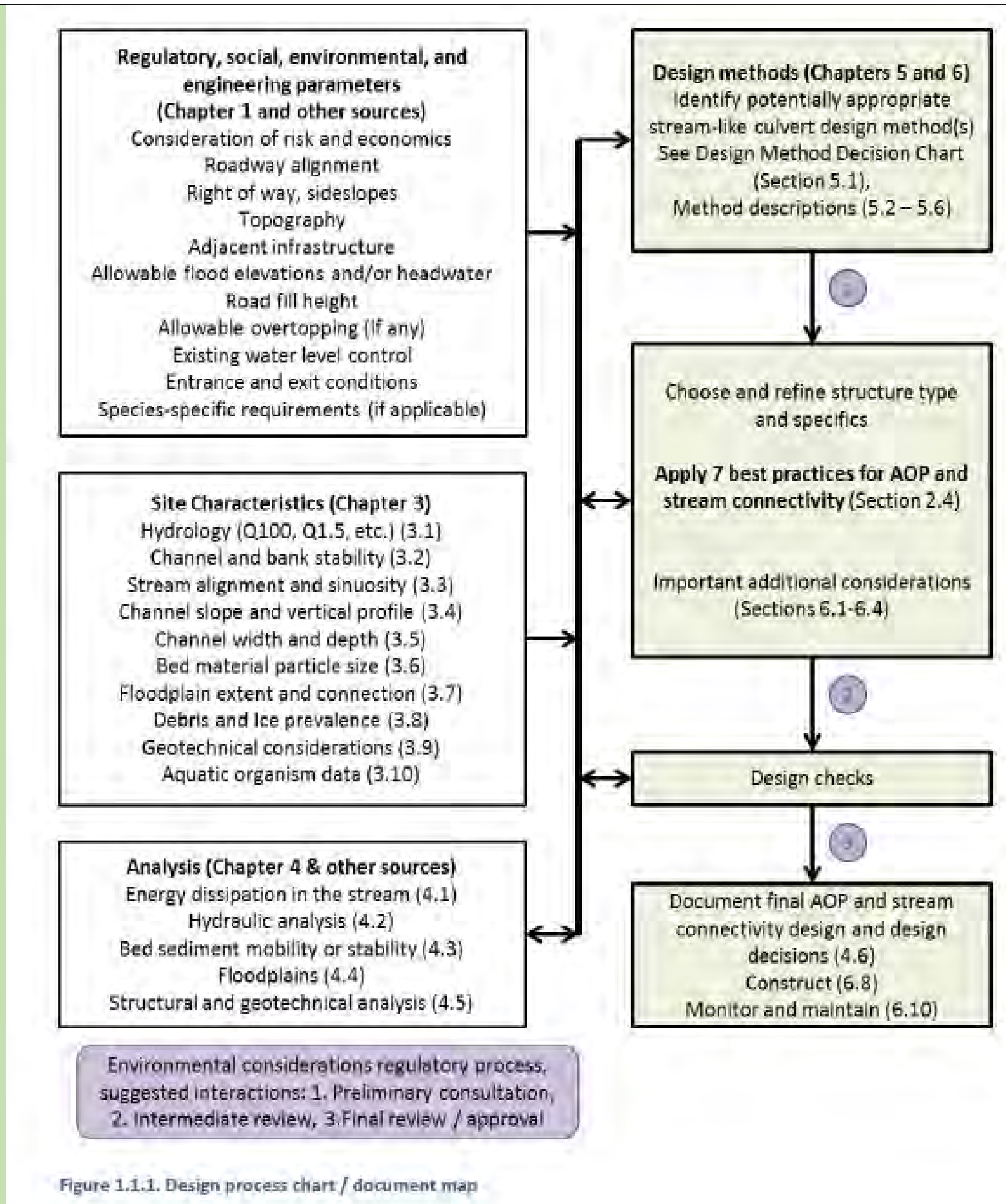

Figure A-15. Minnesota's stream design process flow diagram. Borrowed from Henrick et al. 2019.

A more comprehensive approach to benefit-cost analyses was developed with Colorado DOT in the research project “Western Slope Wildlife Prioritization Study.” This case study is presented as the preferred manner to conduct a benefit cost analysis of wildlife mitigation. The study provided an Excel spreadsheet that helps users automatically calculate costs and benefit-cost ratios.

Colorado's Western Slope Wildlife Prioritization Study Benefit-Cost Analysis

The Colorado DOT (CDOT) and Parks and Wildlife (CPW) sought a more comprehensive approach to assist in evaluating potential wildlife-highway mitigation projects. The West Slope Wildlife Prioritization Study developed a hybrid benefit-cost technique, drawing from both CDOT Traffic and Safety Engineering and CDOT's Division of Transportation Development methodologies to allow potential wildlife-highway mitigation projects across the Western Slope to be compared (Kintsch et al. 2019, **Figure A-16**). This hybrid approach is designed to provide a more comprehensive evaluation of the value of reduced wildlife-vehicle collisions than is currently possible with the formula used by CDOT Traffic and Safety Engineering. This approach was based on the accepted economic theory of contingent valuation, which is used to assign dollar values to nonmarket resources, such as wildlife or other environmental values. A deer lost to a crash was valued at $2,178, elk = $2,537, pronghorn = $2,106, and bighorn sheep = $7,533. This approach also accounted for the residual value of crossing structures (75-year life span or more) beyond the 20 to 30-year analysis period typically used in benefit-cost equations in Colorado.

Figure A-16. Colorado's Western Slope Wildlife Prioritization Study.

The team developed an Excel tool that prompts any user to input the number and type of mitigation items, the number of wildlife-vehicle collisions in the project and their severity, and the wildlife involved. Users can find the tool at: https://www.codot.gov/programs/research/pdfs/2019/WSWPS/view

An example is given to elucidate a benefit-cost analysis (BCA) with this tool.

U.S. Highway 160 is a two-lane road in southwest Colorado; the segment from mileposts 104.5 to 113.5 was identified a high priority segment for wildlife-highway mitigation (Kintsch et al. 2019). The following user-defined inputs were entered into the tool: 2 wildlife underpasses suitable for elk; 4 wildlife underpasses suitable for deer; 9 miles of wildlife exclusion fencing; 36 escape ramps; and 52 deer guards. The costs for these mitigation items were calculated as $9,969,685, including 30 percent contingency costs and 22.1 percent construction engineering and direct charges. The cost of ongoing maintenance was assumed at 1 percent of the mitigation cost. There were 129 wildlife-vehicle crashes in this segment from January 1, 2006, to December 31, 2015, including one human fatality, 13 injury accidents, and 115 Property Damage Only crashes resulting in 119 mule deer and 10 elk mortalities. Using an 87 percent crash reduction rate, the average annual cost savings of the mitigation was calculated as $409,340. **Table A-5** summarizes these inputs and baseline calculations. The tool then automatically calculates BCA ratios:

- Using CDOT methods for federal Highway Improvement Safety Program (HSIP) and state FASTER Safety Mitigation grants: 0.59
- Using the guidance for federal TIGER and FASTLANE grants: 2.62
- Using the hybrid approach developed for Colorado's wildlife prioritization studies: 1.38

A BCA ratio greater than one is generally considered the threshold where the benefits of a project exceed the costs of investment. However, grant requirements vary, and these ratios are provided for planning and identification of potential funding source purposes only.

Table A-5. Wildlife-vehicle crash costs and wildlife values used to calculate benefit-cost.

Cost Description	Unit Cost Source	Units	Unit Cost (2021 $)	Total Cost
Fatality accident	Crash data and costs from CDOT Traffic and Safety (2021); Wildlife values derived from the Eastern Slope and Plains Wildlife Prioritization Study (Kintsch et al. 2022a).	1	$1,820,600	$1,820,600
Injury accident		13	$101,800	$1,323,400
Property damage only accident		115	$11,100	$1,276,500
Value of deer killed in reported accidents		119	$2,178	$259,182
Value of elk killed in reported accidents		10	$2,537	$25,370
Total 10-year Cost of wildlife-vehicle crashes				**$4,705,052**
Average Annual Cost of wildlife-vehicle crashes				**$470,505**
Total Mitigation Project Cost (including maintenance)				**$10,032,494**
Average Annual Cost Savings (87 percent Crash Reduction)				**$409,340**

Based on these inputs, users may also calculate a payoff period, or the number of years that it will take for the anticipated benefits of the mitigation to exceed the upfront cost of the mitigation. The payoff period for this example is 24.5 years.

The Colorado BCA tool only utilizes reported accident data from law enforcement agencies responding to crashes. It does not include values for wildlife killed in collisions but only recorded in CDOT's maintenance carcass data. However, if one were to include maintenance carcass data (178 deer and 11 elk carcasses) in addition to reported wildlife-vehicle collisions crashes for this highway segment, the projected timeframe the mitigation would pay for itself would be 22.5 years.

The construction of wildlife crossing structures in standalone projects or part of larger projects can incur severe damage to the sites as the road is re-worked or created in an area rich with wildlife and ecological processes. There are seven factors to consider when writing construction contracts and making sure the sites are restored back to pre-construction levels of ecological integrity. See the Seven Dwarfs case study below.

Construction Project Impacts and the Seven Dwarfs of Implementation

The reference to seven dwarfs is an analogy to Snow White's seven dwarf friends, making the seven points easier to remember. The environmental documents for construction impacts of road projects often do not take into account many off-site activities and land disturbance that are necessary for road construction (**Figure A-17**). The larger area impacts of construction activities must be identified and be a part of the planning process for construction and reconstruction projects to allow for the smooth construction implementation to take place, and to build or reconstruct a linear feature that has the least impact on the natural environment.

Figure A-17. Contractor use area, Arizona's State Road 260, on the Tonto National Forest. Photo Credit: T. Brennan**.**

Most, if not all, of the following items are necessary for any construction project implementation, not just for wildlife related projects. These concerns need to become part of the construction contract and NEPA planning documents well before the project is begun. The contractor's possible need for use or access areas outside the road right-of -way, are a part of the construction activity. Rather than try to identify these impacts during the construction activity, it is often better for all concerned partners to identify the areas, plan for their use in the construction plans and specifications, and then identify how the area is remediated at project completion.

The Seven Dwarf impacts to consider include:

1. Borrow and waste sites, material balance - look for alternate borrow or waste sites outside the immediate project limits, and preserve a set aside area for topsoil and soils with native seed embedded in them.
2. Contractor use/staging areas need to be identified and minimized placement outside of the right-of-way, or the contractor rehabilitates the area afterward.
3. Water for construction needs to be planned for in storage areas nearby.
4. Contractor access and detours need to be carefully considered so there are limitations to additional unnecessary disturbance or provide for an additional old project impact that needs healing and closure.
5. Geotechnical investigation access will need to be restricted as to where subsurface investigations for design parameters can occur to help save existing vegetation that may be critical wildlife habitat.
6. Preparing for relocation of utilities and their impacts is necessary to minimize the area and location of the disturbance.
7. Document required mitigation of impacts either in the original NEPA document with identification of locations, or add the costs to a pre-approved mitigation banking program to the project.

British Columbia Ministry of Transportation and Infrastructure has created a successful Wildlife Program that helps it personnel and the public to better appreciate wildlife and the need to mitigate roads and traffic for their survival into perpetuity. See the case study below.

British Columbia Ministry of Transportation and Infrastructure's Wildlife Program Instills the Love of Wildlife

The British Columbia Ministry of Transportation and Infrastructure (BCMOTI) Wildlife Program began in the late 1990's and is funded through the agency's rehabilitation budget. The Wildlife Program is BCMOTI's approach to wildlife-vehicle collision monitoring and mitigation and provides a single point of contact for all wildlife/highway related issues. A growing component of the program is communications, and outreach within the agency and with the public. Early engagement of new agency employees to help raise wildlife awareness is a critical role of the Wildlife Program personnel. The Wildlife Program gives presentations to agency staff, ranging from administrative and financial staff to planners and engineers to help establish a common wildlife appreciation and awareness mindset (**Figure A-18**). Presentations to professional engineer associations, and to the non-engineering branches of BCMOTI are also regularly scheduled. These and other efforts have helped instill the needed environmental stewardship and awareness the agency has to support wildlife mitigation efforts.

Figure A-18. Outreach concerning wildlife was extended to senior BCMOTI executives. Photo Credit: L. Sielecki.

Vermont Transportation Agency has implemented training programs to help instill ecology knowledge and a deep appreciation of wildlife among all its personnel, see the case study below.

Vermont Transportation Agency's Highways and Habitats Program Instills Ecological Knowledge in Agency Personnel

The Vermont Transportation Agency (VTrans) created an agency slow wave of change for concern for wildlife by inspiring its people. The Highways and Habitats program for VTrans personnel has been successful in bringing transportation professionals from all disciplines into the road ecology conversation (**Figure A-19**).

Figure A-19. Participants in the Highways and Habitats course learn about wildlife tracks. Photo Credit: VTrans.

VTrans regularly offers three-tiered series of trainings and seminars to help VTrans staff better understand the relationship between transportation and wildlife connectivity and habitat needs. In turn, personnel from every division within VTrans have learned of the needs of wild animals of all sizes to move to critical habitat and their vulnerability to traffic and roads. As course graduates move into higher positions within VTrans, they become more empowered to implement programmatic changes and project improvements that affect wildlife connectivity and habitat. The cultural changes from these trainings have occurred over decades, and from the highest levels of VTrans to the local maintenance personnel, in effect, creating an intangible magic within the agency.

Monitoring for small wildlife and fish in the face of transportation has traditionally been much more difficult than monitoring for larger animals. Washington DOT worked with Central Washington University scientists to monitor all forms of vertebrate life along the I-90 wildlife mitigation corridor. These studies have been in progress for over a decade, from pre-construction to post-construction years. The professors involved have graduated multiple graduate studies whose theses were based on these research projects. The methods used by this group can be replicated in other places where small animal connectivity is studied along roads. See the case study below.

Monitoring Smaller Animals for Connectivity Across an Interstate Is Possible

Washington's Snoqualmie Pass East Project created ecosystem passages, (rather than just calling them wildlife passages) on 15 miles (24 kilometers) of Interstate 90 (I-90). The project included two overpasses, 18 large underpass bridges, and over 100 small and medium sized culverts and small bridges. Monitoring for smaller animal movement across these passages continues to be conducted by researchers at Central Washington University and other partners with the support of Washington DOT. Of special importance with respect to smaller animals are the low mobility species that were and are monitored.

Dr. Paul James and his students, through PIT-tag monitoring, found cutthroat trout and bull trout re-inhabiting streams formerly blocked by insufficient culverts (**Figure A-20**). They also found benthic macroinvertebrates moving through new crossings structures to upstream areas within one year of new culvert and bridge placement in areas where they were previously missing. Environmental DNA analyses in water has also been used to detect fish movement through these streams (Mullen 2020). The overall results are showing the streams that have been reconnected through the new structures are returning to normal and healthy levels of fish and invertebrate populations.

Figure A-20. Bull Trout used the new wildlife underpass bridges and culverts to access streams along I-90. Photo Credit: P. James.

Dr. Jason Irwin works with students to monitor 14 reptile and amphibian species in the study area. Among the different species they study, PIT-tags are used to mark costal giant salamanders, and radio telemetry is used to track western toads (**Figure A-21**). Results demonstrate amphibians using new structures and even inhabiting them. The toads are breeding in created ponds at the entrances to an overpass, and even using it to cross I-90. (see Gustafson 2018).

Figure A-21. Western toads were radio-tracked crossing under and over I-90 using new crossing structures. Photo Credit: J. Irwin.

Dr. Kristina Ernest has been working with Washington DOT for over a decade to detect the movements of smaller animals restricted by I-90 prior to construction of wildlife crossing structures, and movements post-construction. Dr. Ernest and her students study the American pika, to learn if created rock piles near the highway will suffice for pika habitat, and if the animals will use the crossing structures. Camera traps at the crossing structures have captured several pika moving through the structures. In studying small mammals, they employ live traps (**Figure A-22**) placed in a grid pattern at wild areas away from the highway (forest reference sites), and at wildlife crossing structures pre- and post-construction. Animals are marked for recapture with PIT tags and radio collars.

They find small mammals crossing under and even over the highway at the structures, where there can be as much as eight lanes of roads. They use pitfall trap arrays to also sample amphibians, reptiles, and small mammals overnight at the overpass and other crossing structures as well as both sides of the highway adjacent to the structures. Genetic samples are collected for population genetic structuring studies. Cameras are used to monitor the structures for larger animals. (See: Hooghkirk 2013, Wickhem 2016, Milward and Ernest 2018, Millward et al. 2020, Ryckman 2020, and Chapman 2021).

Figure A-22. A pika in a live-trap in the Snoqualmie Pass East Project. Photo Credit: C. Ernest, Central Washington University, and Washington DOT.

Dr. Ernest and her colleagues' presentation for International Conference on Ecology and Transportation (see Ernest et al. 2021) stressed the need for multidisciplinary and multi-agency teams to collaborate and coordinate with one another to assure goals are met of both monitoring studies and the wildlife mitigation.

Ontario Ministry of Transportation sponsored a monitoring study that lasted for eight years, an unusual amount of time for transportation mitigation studies. It helped Ontario better plan for large and small animal wildlife crossing structures.

Monitoring Wildlife Crossing Structures for Eight Years in Ontario

In 2012 Ontario's Ministry of Transportation constructed a dedicated wildlife overpass and five wildlife underpasses on Highway 69. It was part of a multi-pronged approach to prevent vehicle collisions with wildlife on the four-lane highway.

Figure A-23. Black bear used an underpass on Highway 69. Photo Credit: K. Gunson, Ontario MoT.

Monitoring data were collected for one year prior to and seven years post-construction. Multiple cameras at each entrance and the middle of each structure allowed successful passages to be confirmed The monitoring study showed that wildlife such as moose, deer, and lynx successfully used the crossing structures. Monitoring results show overpass was used primarily by deer in addition to moose, bear (**Figure A-23**), and wolf. Wildlife collisions with large mammals within this section of highway decreased by 73 percent post-construction (Eco-Kare International 2020).

The monitoring report is available at: https://eco-kare.com/wp-content/uploads/2020/10/EcoKare-Final-Report2-to-MTO-Hwy-69-Effectiveness-monitoring-public-version-15Oct20.pdf.

Appendix B. Data

Introduction

This appendix describes the different data sources used in consideration of wildlife in transportation procedures and plans (**Figure B-1**). Data can help first establish the need to consider wildlife in long term planning documents, and then how considerations of wildlife can be carried out with these data to inform processes from project planning and development through maintenance and operations, **Figure B-2**.

Figure B-1.Data on desert tortoises and other federally and state protected species' locations and habitat are mandated to be considered during the development of transportation plans. Photo Credit: K. Nussear, U.S. Geologic Service.

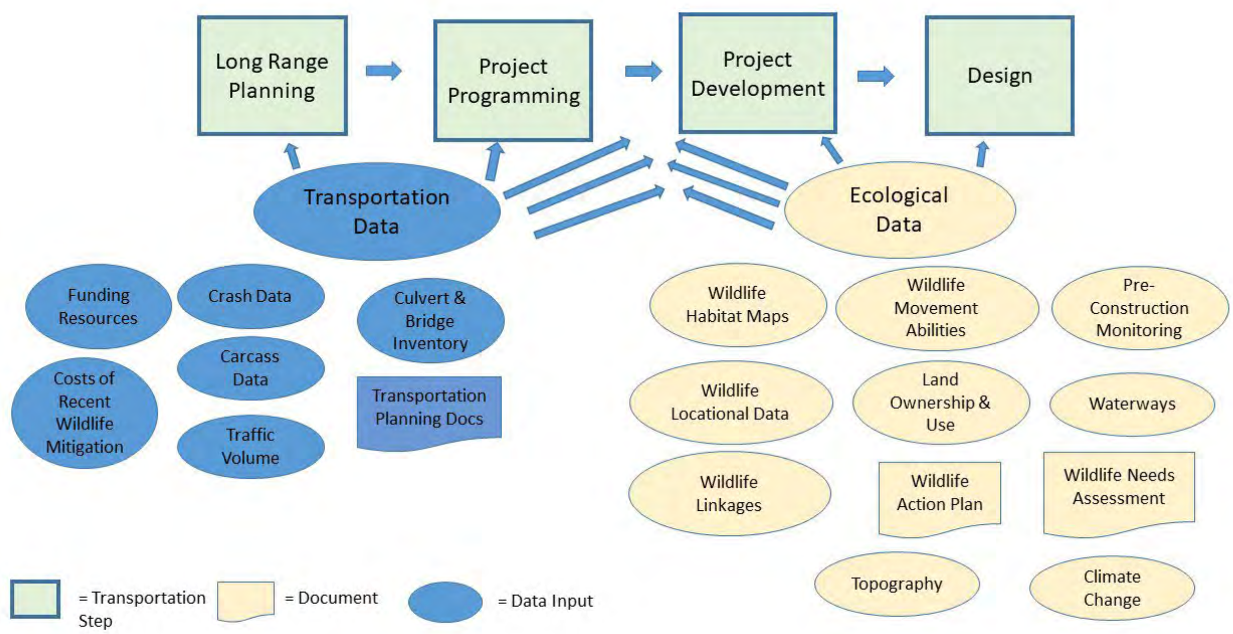

Figure B-2. Flow diagram of how data inputs inform the transportation process of necessary wildlife concerns.

Data allow agencies to develop goals, objectives, and performance measures that quantify how the policy, or program, or project will meet the agency goals. It is important that any consideration of wildlife in planning be supported with data. Data can help identify funding resources that can be integrated during the planning process early on so that when programming and project development processes occur, funding is in place to include wildlife considerations, while meeting these agency goals.

Transportation Data

Transportation data help traffic safety engineers and others establish how wildlife-vehicle collisions are a threat to the traveling public. Safety funding sources can be used to remedy these problem areas. Transportation data can also help planners evaluate if and how wildlife mitigation is necessary, based on traffic volume, the potential for retrofitting existing structures, and other actions.

Crash Data

Analyses of reported crash data, which are also known as collision data in Ministries of Transportation, can help identify the extent of all animal and specifically wildlife collisions, hotspot areas, species involved, and costs. Reported crash data are the only data on collisions with animals that are consistently collected across time and space, in the U.S. and Canada. These data are from traffic safety personnel, such as highway patrol, police, sheriff, wildlife conservation officers, etc. when they are called to report a crash. Of course these crash entries only represent crashes where a traffic safety officer was called to the scene and the vehicle damage was over a threshold amount, typically about US$1,000 to US$1,500. Crashes with tractor trailer trucks that haul commercial goods are not typically recorded because these incidents generally do not result in damages worthy of reporting, and it can be against the driver's best interest to report such collisions. The lack of wildlife-vehicle collision reporting hampers our efforts to identify the most urgent areas to implement wildlife mitigation. In fact, in Utah, Olson (2013) found 5.6 more large animal carcasses along the road and right-of-way on various Utah DOT highways than were reported in the crash data. There is even a greater challenge to identify areas of crashes with smaller animals.

While some locations within a state or province/ territory may have robust carcass collection reporting, this is typically not the case across entire states, provinces, and nations. Reported crash data are thus the most appropriate crash data type to use to analyze the magnitude and scope of crashes with animals over a broad region, despite these data underrepresenting the full magnitude of wildlife-vehicle collisions.

Quantifying Costs to Society from Wildlife and Animal Crashes

Examining the extent of animal and wildlife crashes can help place a figure on the societal cost of crashes. Each crash is coded as to its severity, as either: property damage only (PDO), injury crash with three different levels of injuries or if it was a fatal crash. If the crash types for a specific location, such as a road, district, or even a country can be tallied and averaged over a year, the magnitude of wildlife crashes can be realized on an average annual basis. All transportation departments estimate the value of crashes to society for each crash type, from the property damage only crashes to fatality crashes. The data on crashes can be queried for the severity of the crashes, and calculated for crash costs over a jurisdiction, average over a year, and other rates of cost.

The researchers of this study contacted the traffic safety engineers of all 50 state DOT’s to secure five years of all crash data, wildlife crashes, and animal crash data as of 2018 crash numbers. They also obtained each DOTs crash cost estimates. The total crashes, animal crashes, numbers of each crash type for animal and wildlife crashes, fatal crashes, and costs using the states’ values and the Federal Highway Administration values (Harmon et al. 2018) were calculated for every state. There are 11 states that did not delineate if a crash with an animal was with wildlife or a domestic animal. Therefore, animal crash data for all 50 states was used rather than leave out those 11 states’ crashes that did not delineate wildlife. The analyses resulted in a national estimate of the magnitude of animal-vehicle crashes, not just wildlife crashes.

Annually there were on average, a minimum of 345,000 reported crashes with all animals. Some states do not record wildlife separately, so this the most accurate estimate to the extent of the problem. There are on average 201.8 fatal crashes with animals annually. The societal cost of all these crashes, based on severity of injuries, fatalities, and property damage only, is over $10 billion annually, using the Federal Highway Administration (FHWA) 2018 estimates for crash costs (values were not adjusted beyond the 2018 values given in Harmon et al. 2018), see **Figure B-3**.

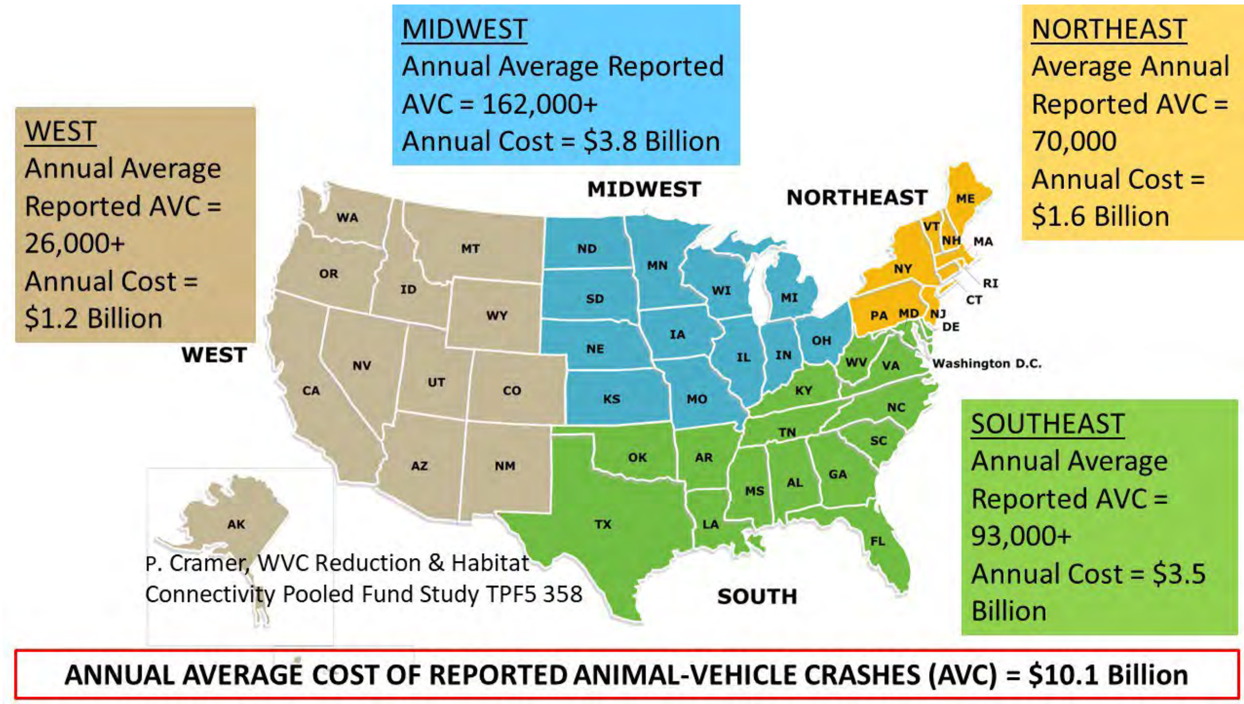

Figure B-3. The annual average number of reported crashes with animals in U.S. regions, and the societal cost of those crashes, based on census of all Departments of Transportation conducted in 2020.

The annual average cost to society of crashes with animals in each U.S. state were calculated based on each agency's own crash numbers over five years, and costs values for the various severities of crashes and the FHWA cost estimates. These are presented along with the annual average: number of crashes with all animals; the percentage of all the crashes that were animal-related; and number of fatal collisions with animals, **Table B-1**.

The state with the greatest number of reported animal-vehicle crashes was Michigan, with over 54,000 annually reported. New York was second, with over 40,000.

The state with the highest percentage of all crashes that were animal-related was South Dakota, with over 25 percent. Wyoming was second with over 20 percent.

The state with the greatest annual average of fatal accidents was Texas, with over 30 fatal animal-vehicle crashes per year. Michigan was second with over 18.

The state with the greatest cost to society based on FHWA crash values was Michigan, with over one billion dollars in costs to society for their animal-vehicle crashes. Texas was second with over 900 million dollars in costs to society for animal-vehicle crashes.

Table B-1. Annual average number of crashes with animals, the percentage of all crashes that were animal crashes, the state crash costs, and the Federal Highway Administration crash costs of those animal crashes. Based on data from 2014-2018.

State	Annual Average Number of Animal-Vehicle Crashes	Percentage of Total Crashes	Annual Average Number of Fatal Crashes	Societal Cost Using State's Crash Costs	Societal Costs Using FHWA Crash Costs*
Alabama	2,424	1.59	1.40	$100,946,835	$89,537,280
Alaska	685	6.51	1.60	$46,472,960	$47,750,540
Arizona	2,117	1.74	1.80	$72,641,014	$77,466,560
Arkansas	2,495	3.20	3.67	$64,581,667	$104,943,533
California	2,131	0.45	4.80	$251,844,156	$149,765,700
Colorado	4,326	3.62	4.80	$87,695,460	$197,031,540
Connecticut	434	0.16	0.00	$4,108,000	$11,598,280
Delaware	1,531	5.87	0.40	$33,709,140	$33,709,140
Florida	✧	✧	✧	✧	✧
Georgia	14,489	3.77	4.80	$851,731,800	$428,343,420
Hawaii	36	0.37	0.20	$4,537,440	$4,537,440
Idaho	1,542	6.31	1.80	$47,538,374	$74,580,420
Illinois	16,245	5.18	5.80	$330,197,028	$403,181,180
Indiana	16,362	7.62	6.00	$359,596,580	$324,639,740
Iowa	6,915	12.91	2.60	$83,528,000	$175,772,240
Kansas	9,846	15.65	4.2	$166,192,800	$219,511,100
Kentucky	6,565	4.80	5.2	$158,227,125	$193,327,720
Louisiana	2,222	1.34	1.2	$73,233,190	$73,979,540
Maine	5,671	16.51	1.40	$103,153,400	$127,922,720
Maryland	1,936	1.73	1.00	$72,912,340	$72,912,340
Massachusetts	2,969	2.12	0.80	$90,119,680	$65,057,420
Michigan	54,328	17.30	18.75	$720,359,950	$1,122,628,350
Minnesota	1,944	2.33	6.00	$26,780,020	$153,436,320
Mississippi	4,222	5.30	2.80	$85,626,500	$110,992,380
Missouri	4,550	3.05	6.60	$186,598,040	$221,883,880
Montana	3,450	15.14	4.20	$100,302,700	$157,838,360
Nebraska	2,659	7.52	2.00	$95,103,644	$94,967,760
Nevada	625	1.30	1.80	$27,065,597	$44,770,940
New Hampshire	1,536	4.51	0.60	$39,879,780	$34,038,560
New Jersey	10,015	3.65	2.60	$156,111,786	$209,053,000
New Mexico	1,615	4.24	1.60	$27,209,440	$62,592,060
New York	40,465	8.19	6.20	$292,698,853	$757,995,900
North Carolina	21,658	7.15	3.60	$424,460,520	$509,066,100

State	Annual Average Number of Animal-Vehicle Crashes	Percentage of Total Crashes	Annual Average Number of Fatal Crashes	Societal Cost Using State's Crash Costs	Societal Costs Using FHWA Crash Costs*
North Dakota	2,749	18.84	1.20	$56,551,220	$56,551,220
Ohio	20,990	7.03	6.80	$296,927,145	$525,951,680
Oklahoma	1,451	2.08	5.40	$214,329,840	$154,712,880
Oregon	1,679	3.07	1.60	$115,306,260	$134,632,140
Pennsylvania	4,121	3.24	12.40	$327,329,692	$304,875,400
Rhode Island	989	2.02	0.00	$10,212,014	$22,345,080
South Carolina	3,151	2.30	6.20	$124,648,200	$182,486,240
South Dakota	4,845	25.97	2.00	$126,407,780	$99,953,980
Tennessee	8,967	4.37	5.00	$285,109,100	$285,109,100
Texas	11,614	0.02	30.80	$2,043,960,200	$917,888,680
Utah	3,374	5.68	3.00	$137,637,220	$121,227,460
Vermont	324	2.82	0.60	$9,653,686	$15,307,540
Virginia	6,405	4.99	2.20	$133,999,660	$195,799,100
Washington	1,665	3.17	0.80	$79,308,460	$62,114,420
West Virginia	1,795	5.15	3.20	$62,499,883	$107,399,960
Wisconsin	20,710	16.48	8.80	$416,241,806	$443,596,260
Wyoming	2,958	20.84	1.60	$157,765,296	$71,447,360
Total	345,795	5.14	201.82	$9,783,051,280	$10,056,229,963

* = Harmon et al. 2018 FHWA estimated societal costs. ✦= Numbers and Costs could not be calculated due to reporting complexities in different data worksheets

Hotspot Modeling of Wildlife-Vehicle Crash Data

Crash data can also be mapped and modeled to prioritize areas with the greatest concentrations of crashes with wildlife. The prioritized crash locations can then be used as an input into the planning and programming processes. Crash data have been analyzed in multiple U.S. western states to identify top hotspot areas for wildlife-vehicle collisions and to evaluate how past mitigation efforts have worked. These analyses include the 2022 New Mexico Wildlife Corridors Action Plan (Cramer et al. 2022b), the 2021 Arizona Statewide Wildlife-Vehicle Conflict Study (Williams et al. 2021), Colorado's West and East Slope Studies (Kintsch et al. 2022a, 2019), Nevada's Prioritization of Wildlife-Vehicle Conflict in Nevada (Cramer and McGinty 2018) the Utah Identification of Wildlife-Vehicle Conflict Hotspots (Cramer et al. 2019), Texas'

Incorporating Wildlife Crossings into TxDOT's Project Development, Design and Operations (Loftus-Otway et al. 2019), South Dakota's Reducing Wildlife-Vehicle Collisions in South Dakota (Cramer et al. 2016), and Idaho's Identification and Prioritization Method to Mitigate Idaho Roads for Wildlife (Cramer et al. 2014).

Some states and provinces allow for identification of the species involved in the crash reports. For example, New Mexico and Nevada both have species lists in pull down menus in the software for the reporting officers. This level of detail helped enormously in the mapping of these states' crash locations by species. These maps in turn assist in developing the appropriate mitigation strategies for the target species most involved in crashes. Crash data can also be modeled in a GIS and a hotspot map created of the most intense crash areas for animal or wildlife collisions.

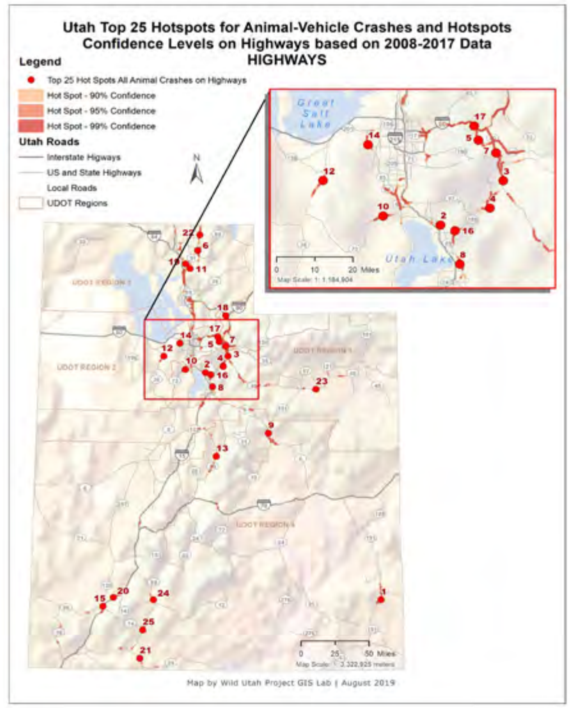

Figure B-4. Utah's animal-vehicle crash hotspots from Cramer et al. 2019.

Hotspot modeling typically evaluates road segments based on the number of animal or wildlife crashes per mile per year. The more recent hotspot analyses have used the ArcGIS Optimized Hotspot Modeling Analysis tool with the Getis-Ord GI* statistic to scientifically identify these wildlife-vehicle crash hotspot areas.

Utah's hotspot analysis of wildlife and animal crashes is presented in **Figure B-4**, and can be accessed the link below (Cramer et al. 2019).

https://drive.google.com/file/d/15K9yjM9kDRE8KVDvpUnFWn9RUyo1SkRL/view?fbclid=IwAR062_EPrlFmHPGc_uohMpEvoEsHNKWqVZGK5rnfGVlEkgzFwF-A4QwFhRk

These priority hotspot maps in turn help traffic safety engineers, planners, and professionals at the headquarters' and local level identify where their next wildlife mitigation projects could be located, and with possible Highway Safety Improvement Program (HSIP) funds. These efforts help agencies identify the areas that are most important for action, and help to create a scientific standardized method of prioritization that can be less subject to political persuasion.

If these crash data are used to base priority areas for mitigation through the above hotspots analyses or other similar modeling, it should be noted that solely basing priorities on past reported crashes favors areas where there are deer, which are the most numerous large bodied wildlife in most states and provinces. It also skews hotspots to areas where crashes are reported, which tend to favor areas where large 18-wheel trucks do not use, because the drivers of these vehicles tend not to report crashes with wildlife. Basing priorities on crash hotspots should be considered for largely safety reasons, and where deer and other large ungulates such as elk are most often reported to be involved in collisions.

Carcass Data

Figure B-5. Mule deer carcasses along US 191 in Utah. Photo Credit: P. Cramer.

Carcass data typically reveal more than crash data do about the animals killed, such as their species, gender, age, and numbers killed at a location. However, carcass data are not consistently collected in space and time in almost all locations in the U.S. and Canada. Typically, agency maintenance personnel or outside contractors collect the carcasses that pose additional risk to motorists (in the road or on the shoulder) and are required to report that carcass data (**Figure B-5**). These personnel are most recently using phone and computer applications to record the carcass data. Carcasses are ubiquitous enough that transportation, wildlife, and law enforcement personnel can report their locations. Citizens are also becoming more involved in carcass data reporting, on both phone and computer systems, however precautions and liability must be considered and understood by citizens and transportation agencies before promoting this type of data collection. In states and provinces where there is a fully functioning computer system for inputs and immediate mapping of carcass data, users can map the carcass data to learn of the hotspot locations, species most often killed along specific road stretches, and other important facts and trends. Mapping these carcass data demonstrate the problem areas regardless of whether the collisions were reported, and identify the species involved, which then helps determine the best mitigation strategies. Several state examples of carcass collection recording and mapping websites are presented in **Table B-2**.

Table B-2. Examples of state carcass collection websites.

State and Program	Website
Utah Wildlife-Vehicle Collision Data Collector for State Employees and Contractors	https://mapserv.utah.gov/wvc/desktop/
Idaho Game and Fish	https://idfg.idaho.gov/species/roadkill/add
University of California Davis, Road Ecology Center	https://roadecology.ucdavis.edu/hotspots/map
South Dakota Map of carcasses collected	https://sdbit.maps.arcgis.com/apps/webappviewer/ index.html?id=e87e8054b7964f5ba5f1ad105998882e
Maine Audubon's Road Watch	https://www.wildlifecrossing.net/maine/maps/observations

Traffic Volume

Traffic volumes are important indicators of the ability of various species of animals to get across a road. Transportation agencies publish estimated average annual daily traffic volumes (AADT) for roads they administer. Traffic can cause a barrier effect and thus looking at crash and carcass data in higher traffic volume areas does not address the problem of vehicles for the animal populations that do not even attempt to cross a road or highway. For example, pronghorn in northern Arizona are nearly completely fragmented by fenced right-of-ways with high traffic (**Figure B-6**) to the point where genetic consequences were notable (Theimer et al. 2012).

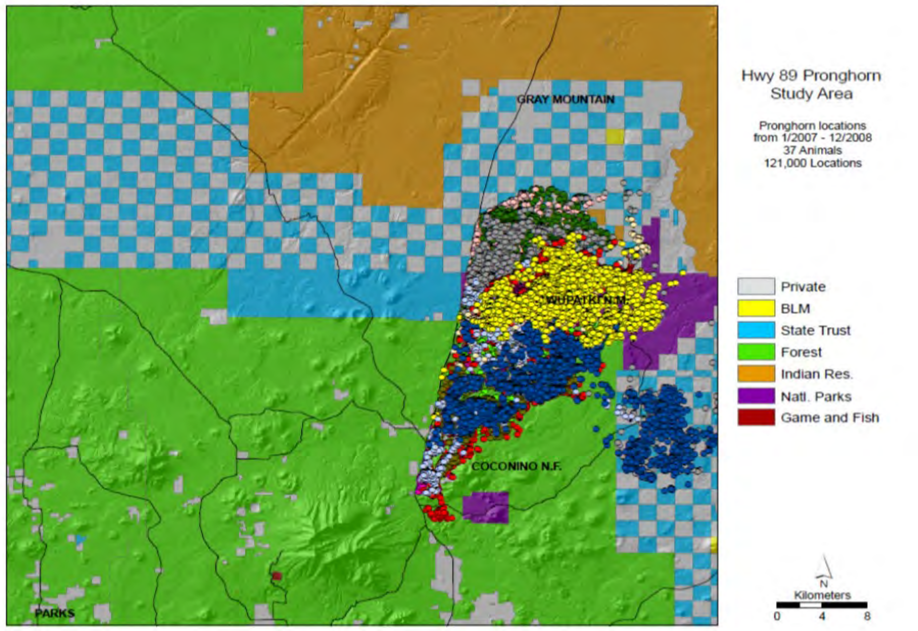

Figure B-6. Fragmentation of GPS collared pronghorn along US 89 (Average Annual Daily Traffic = 8,000) in Northern Arizona. Figure Credit: Arizona Game and Fish Department.

Charry and Jones (2009) presented traffic volume thresholds as guidance as to the effect of traffic volume on wildlife abilities to get across roads. A short summary of the traffic thresholds is presented in **Table B-3**. This method of valuing a road with higher traffic volumes to give it a higher priority in a statewide prioritization was used for Arizona (Williams et al. 2021), and New Mexico (Cramer et al. 2022b). At some point in moderate traffic volumes between 4,000 and 7,500 Average Annual Daily Traffic (AADT), large mammal crashes and animals reach a peak in numbers. After 10,000 AADT, typically animals are less willing to try and cross roads due to high vehicle numbers, or their populations have been killed off and the remaining animals, if any, do not try to cross (Seiler 2003), see **Figure B-7**.

Table B-3. Traffic volume thresholds for wildlife ability to cross roads, based on Charry and Jones 2009.

Annual Average Daily Traffic Volume	**Comments**
Less than 2,000	Low volume, minimal effect on ungulates, still lethal for smaller animals, moderate to high wildlife-vehicle collisions
2,000 - 7,500	Medium volume, moderate lethality, increasing barrier effect, high wildlife-vehicle collisions
7,501 – 15,000	High volume, high lethality for all species, near total barrier, moderate to high wildlife-vehicle collisions
Greater than 15,000	Extremely high volume, barrier for over 90 percent of terrestrial species and members of most mammal, reptile, and amphibian populations, low to moderate wildlife-vehicle collisions because animals either stopped trying to cross, or have all been killed out in the area

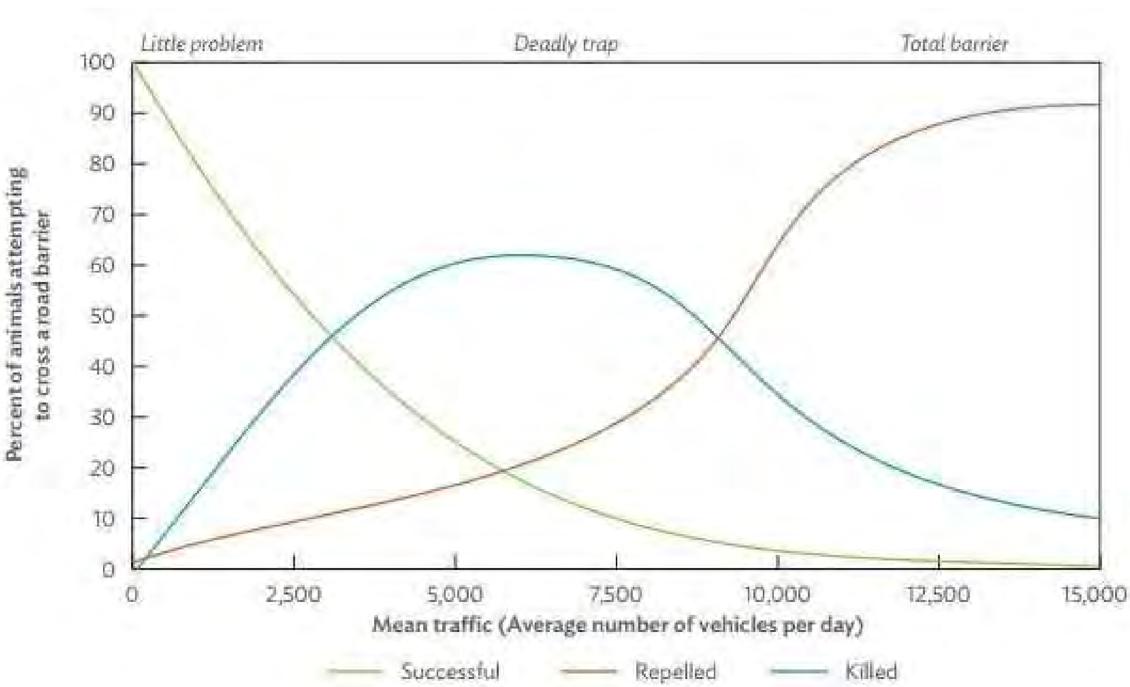

Figure B-7. Relationship Between Traffic Volume and Barrier Effect with Wildlife Crossing the Road (Taken from Seiler, 2003).

Traffic also creates greater habitat fragmentation than roads alone, thus higher volume roads are most problematic for wildlife. Ecologists working with engineers and planners can consider a species' risk-avoidance response to traffic. Risk avoidance is an animal's instinct about how to react to a threat. It can freeze, move in a zig zag pattern, turn and confront the source of risk, run quickly in front of the risk, etc. These behaviors affect how the species will fare in the face of vehicles and traffic volumes of a specific road. These behaviors help to make appropriate decisions on mitigating the road and traffic impacts on wildlife movement (Jacobson et al. 2016).

For example, in Oregon Coe at al. (2015) found that mule deer-vehicle collisions increased with AADT, but peaked at 8,000 vehicles per day. Once the AADT went over that threshold, mule deer-crash records decreased, due in large part to fewer deer attempting to cross the highway. This was true of those higher traffic volume locations, as well as in the historic mule deer migration pathways.

Culverts and Bridges Inventory

Databases of existing culverts and bridges are resources to use for examining the potential for retrofits of infrastructure for wildlife. Having that information on hand when looking at problem areas for wildlife-vehicle conflict will help evaluate lower cost potential solutions rather than a need for new structures. See Kintsch and Cramer (2011) for Washington DOT's standardized method for evaluating these existing structures for retrofitting for different types of wildlife (**Figure B-8**).

Figure B-8. Washington DOT biologists work with wildlife and transportation researcher to assess an Interstate 90 bridge for wildlife connectivity. Photo Credit: P. Cramer.

Knowledge of the existing culverts and bridges that could potentially be used by wildlife is also important in working with maintenance crews in helping to keep these areas cleared of debris and human encampments. However, human encampments are something for law enforcement to eliminate and problems in these areas should be referred.

Transportation Planning Documents

> "*Road Projects are like trains – slow to get rolling, averse to getting off track, and hard to slow down.*" Tonjes et al. 2015

State and provincial long-range plans, State Transportation Improvement Plans (STIP), Improvement Plans, transportation project plans, and Metropolitan Planning Organization (MPO) transportation plans, are all important to evaluating where future projects could impact and potentially mitigate for wildlife (**Figure B-9**). The upcoming projects may not be in the direct area where specific wildlife-vehicle conflict has been identified, but if there is a project within several miles of the wildlife-vehicle collision high priority area or where wildlife are known to need to cross the road, the information from these planning processes could inform the future project.

Figure B-9. A mountain lion moves beneath US 89/91 in Utah using a wildlife underpass that was placed when the road was widened from two to four lanes. It was an early wildlife mitigation project in Utah, constructed in 1995. Four wildlife crossing structures were included in the project, which took early planning efforts to integrate into the project. Photo credit: P. Cramer, Utah DOT, Utah Div. of Wildlife Resources, Utah State University.

It is essential that transportation agency environmental staff are involved in shaping long range transportation plans through integration of wildlife prioritization studies into the planning and project development processes and provide relevant updates. Some U.S. state wildlife agencies provide input on the long-range plans and STIPs as to where they think wildlife will be affected and should be mitigated for conflict. These documents are critical to proactive measures to plan for wildlife and if not included at this planning stage reduce the potential for mitigation once funding is identified.

Costs of Recent Wildlife Mitigation

Most potential wildlife mitigation projects need to be evaluated with respect to the cost of the mitigation measures. If transportation agency staff can have the costs of the structures, fences, escape ramps, wildlife deterrents, driver warning systems, variable message board signs, and other measures that the agency or others nearby have recently priced readily available and kept up to date, the case for creating additional measures could be quickly and efficiently made. It is important that these past projects be referenced as to where they occurred, and the year they were installed, also if they were standalone projects or incorporated into a new or reconstruction project, and the breakdown of costs for wildlife mitigation items included in those projects.

Unfortunately, this is not as easy as it sounds for many DOTs. If the mitigation measures are included into a larger construction project, many of the costs are bundled together and classified into typical costs, such as the mobilization of the project. Thus it is difficult to distinguish exact costs of the added mitigation. However, if the project is a stand-alone wildlife mitigation project, the mitigation costs can be more clear (see **Figure B-10**). With a lump-sum system it is hard to define exact costs associated with individual mitigation measures and the estimated prices can vary wildly.

Figure B-10. Mule deer moved across Colorado's State Highway 9 wildlife overpass. This project was largely built for wildlife, and Colorado DOT placed the values of all mitigation components into institutional documents to help with future project cost estimates. Photo Credit: Colorado DOT, Colorado Parks & Wildlife, ECO-resolutions.

Funding Resources

All transportation-based funding opportunities for projects are tied to transportation planning and benefit cost analyses. Early integration of wildlife mitigation into the transportation planning process helps to determine the funding needed and possible sources for those funds, such as the U.S. Highway Safety Improvement Program (HSIP, https://safety.fhwa.dot.gov/hsip/), federal grants, and state or provincial/territory discretionary funding. The typical funding sources have standardized benefit-cost analyses that state and possibly provincial agencies have to develop. In the U.S., there is a strict traffic safety HSIP funds benefit cost analysis. These analyses have typically not included the benefits of the animals saved from wildlife mitigation projects, in terms of the value of the animals, or the value of a connected landscape for water flow, adaptation to climate change, or the value of stream connectivity for fish and aquatic life. See the Colorado case study for a Benefit-Cost analysis in Appendix A. Case Studies for greater detail on how these benefit-cost analyses can be adapted to better support wildlife mitigation.

The HSIP is an important funding source and the program has a standard benefit-cost analyses to evaluate a potential project. The program and budget are identified with the purpose to achieve a significant reduction in traffic fatalities and serious injuries on all public roads, including non-State-owned roads and roads on Tribal lands. The HSIP requires a data-driven, strategic approach to improving highway safety on all public roads with a focus on performance. The elimination of animal vehicle collisions fits into this program very well. New ways to access that money for wildlife mitigation are presented below under the U.S. 2021 Infrastructure Law details in this subsection.

Cost is the number one reason given in this study's survey as to why transportation agencies do not construct more wildlife crossing structure mitigation (see Cramer et al. 2022a for details in the first report from this study). Preparing a case for wildlife consideration in transportation processes will have to include potential funding sources. Having that data/information will be valuable in how to build partnerships and present the information. **Table B-4** below lists potential sources of funding for wildlife mitigation.

Table B-4. Potential Funding Sources for Wildlife Mitigation in the U.S. Adapted from Cramer and McGinty 2018. These Do Not Include Sources Newly Available in 2022.

Funding Source - Partner	**Comments**
Local Governments	Counties and cities can conduct surveys, build cattle guards, and raise funds for wildlife mitigation. See Colorado Case Study in Appendix A. Case Studies, and Kintsch et al. 2019.
State and Provincial Wildlife Agencies	These agencies can tap into state, provincial, and federal funding sources, such as Pittman-Robertson Funds in the U.S.
State/Provincial Traffic Safety Funds	This has traditionally been the main source of funding wildlife crossing structures for larger animals that cause more severe crashes with human safety concerns.
Federal Highway Safety Improvement Program	In the U.S. this is the HSIP fund that is available for projects that achieve significant reduction in traffic fatalities and serious injuries.
Federal Tribal Transportation Program	In the U.S. TTP is the largest program within the Office of Federal Lands Highways and is to address the need of Tribal Governments for safe transportation.
Federal Nationally Significant Federal Lands and Tribal Projects	NSFLTP was established with the 2015 Transportation Act provides funding for construction and rehabilitation of nationally significant projects on federal and tribal lands.
Federal Lands Transportation Program for Federal Lands	FLTP funds projects that improve access to federal lands. Within each transportation act, each federal land agency is allocated a set amount for the coming five years. These funds can be accessed for projects on the specific agency's lands.
Federal Lands Access Program	FLAP or Access Program provides for projects on areas that are facilities that are located adjacent or in federal lands. FLAP calls out wildlife passage as a standalone category for funding.

Funding Source - Partner	Comments
Federal Transportation Alternatives Program	TAP was eliminated with the 2015 Transportation Act (FAST Act). It was replaced with set aside Surface Transportation Block Grants Program for transportation alternatives.
Federal Transportation Investment Generating Economic Recovery	TIGER funds for transportation projects are highly competitive and have not typically been used to fund wildlife mitigation projects, but they are not excluded from potential funding.
Non-Profit Organizations	Conservation organizations and sports people groups have helped dedicate funds to wildlife mitigation projects and will continue to do so in areas they deem important to their constituents.
Citizens Organizations and Private Funding	In multiple cases, private citizens have created non-profit organizations and raised tens of thousands to hundreds of thousands of dollars for wildlife mitigation.
Taxation	Citizens have voted to tax themselves for wildlife connectivity and the money has been used to create wildlife crossing structures. See the Pima County Case Study Cramer et al. 2022a.
License Plates	Since 2017 the Wyoming wildlife crossing license plate has raised over $300,000 as of early 2021, dedicated to the construction of wildlife crossing structures and other mitigation options. See URL: http://wildlifecrossingswork.com/

The 2021 U.S. Transportation Infrastructure Law, also known as the Bipartisan Infrastructure Law, (BIL, https://www.fhwa.dot.gov/bipartisan-infrastructure-law/) provided several opportunities to fund wildlife crossing structures and other mitigation with federal funds that will be available for these programs in 2022 as a pilot program that may someday become standard in future transportation acts.

A manual for helping to develop projects under the federal wildlife crossings pilot program is available at: https://largelandscapes.org/wp-content/uploads/2021/12/Crossing-Toolkit_Final.pdf. See Paul et al. (2021).

There are ten potential areas of funding at the U.S. federal level that can be tapped in to for building wildlife crossing structures.

1. The Wildlife Crossing Pilot Program supplies $350 million toward wildlife mitigation over five years.

2. The Surface Transportation Block Grant Program with $12 billion over five years.

3. Nationally Significant Freight and Highway Projects (INFRA)

4. Federal Lands Transportation Program with $12.2 billion over five years.

5. Bridge Investment Program provides $12.5 billion over five years.

6. Program to Protect Resilient Operations for Transformative, Efficient, and Cost-saving Transportation (PROTECT) helps with climate change adaptations.

7. The National Culverts Program supplies $5 billion over five years.

8. Forest Service Legacy Roads and Trails Program funds $250 million, focusing on fish passage.

9. Ecosystem Restoration Program, includes Tribal funding, and funding for fish passage projects.

10. Pollinator-Friendly Highways provides $10 million over five years, up to $150,000 grants.

The reader is encouraged to pursue these programs in the coming years.

Figure B-11. Ocelot inspected a wildlife crossing structure in Texas Department of Transportation's (TxDOT) Pharr District wildlife crossing on the Laguna Atascosa National Wildlife Refuge. Photo Credit: U.S. Fish and Wildlife Service and TxDOT.

Ecological Data

Ecological data are important for determining where wildlife need to move. However, transportation data may be more important to most engineers within a DOT / MoT. Ultimately, if the connection between where wildlife need to move can be made to safety and other engineering concerns, such as safety risks to motorists, costs for maintenance personnel to pick up carcasses, or the identification of protected species locations (**Figure B-11**) and needs to move long before a project is finalized, then the ecological data will be more widely accepted outside of those who know to include ecological concerns. It is also important to enlighten transportation personnel such as engineers, planners, and administrators of the benefits to proactively identifying areas where wildlife need to be concerned. Money and time, the important considerations of transportation agencies, can be saved if wildlife concerns are considered proactively.

Wildlife Habitat Maps

Species habitat maps are typically compiled by wildlife agencies and consulted by transportation agency personnel. The most common habitat maps examined by DOTs/MoTs are for larger wildlife such as deer, moose, and elk that when involved in collisions, cause the serious animal crashes. Their habitat is typically mapped in large polygons representing seasonal ranges and the areas they need to migrate through to access those ranges. These data are typically coarse and only general approximations. However, they can still be helpful at a coarse scale analysis.

Figure B-12. The Arizona State Wildlife-Vehicle Conflict Study presented two species of desert tortoises' habitat maps to help Arizona DOT planners and environmental staff include tortoise concerns in upcoming projects. Figure Credit: Arizona DOT, Williams et al. 2021.

There are also traffic and road conflicts with smaller animals such as reptiles (**Figure B-12**) and amphibians, and even some larger animals (pronghorn) all of which are poorly represented in the crash database. While these species' populations are worthy of saving from vehicle collisions and habitat fragmentation, it is often the protected and listed species of reptiles, amphibians, small mammals, and invertebrates that warrant a habitat needs analysis in transportation departments. The maps of occupied habitat for smaller protected species are based largely on field location data, and habitat modeling, rather than telemetry data, but these trends are changing (see Chapter 4 on Monitoring).

All these habitat maps would need to be gathered in consultation with state/provincial, local, non-profit, indigenous, and military wildlife professionals in the areas under consideration. An early start on this process could begin with reviewing the State Wildlife Action Plan, or Provincial Wildlife Action Plan (see below).

Wildlife Linkages

A wildlife linkage is a landscape characteristic that provides enough natural habitat of an ecosystem that is used by the target species and possibly others. The more narrowly defined areas where those linkages cross roads are more commonly referred to as corridors.

Wildlife linkage and corridor assessments are typically based on expert opinion, landscape modeling (least-cost path, Omniscape (Landau 2020, McRae et al. 2016), or other approaches) and modeling telemetry data of target species. However, these linkages are only a snapshot of the larger landscape where wildlife move. The maps of linkages and corridors represent human hypotheses on how animals move across the landscape and may not fully reflect the complexity of factors contributing to corridors. In the case of corridors based on Global Positioning System (GPS) data, these areas are where collared or other tracked individuals moved. These linkages while helpful and based on true data, do not fully take into consideration what we do not know. Nonetheless, they represent important planning tools. Typically, wildlife linkages and corridors reports are published in conjunction with the state or provincial/ territorial wildlife agency, but there are also non-profit and academic efforts that have created linkage and corridor maps.

Among the earliest efforts to map where target wildlife species may need to move across areas bisected by roads were the Linking Colorado's Landscapes (Southern Rockies Ecosystem Project 2005), the Southern California Linkages (Penrod et al. 2006), and the Arizona Wildlife Linkage Assessment (Arizona Wildlife Linkages Workgroup 2006), see the case study below.

A more recent study was conducted in Vermont, using circuit theory in Omniscape software to identify the most important areas of wildlife movement across the state (Drasher and Murdoch 2021).

The New Jersey Division of Fish and Wildlife maintains an interactive website that helps identify key areas and actions needed for wildlife habitat connectivity, see the case study below.

Arizona Wildlife Linkages and How They Helped Plan for Wildlife Mitigation

Arizona was one of the first states to map wildlife linkages. The Arizona Wildlife Linkages Report was released in 2006 (**Figure B-13**). The assessment identified 152 potential wildlife linkage zones and prioritized them. The maps provided a starting point for detailed Arizona DOT consultation and coordination with various stakeholders.

Figure B-13. The Arizona's Wildlife Linkage Assessment.

This led to six refined county level linkage analyses. The goal of these maps was to further refine the statewide linkages for county level planning. The development of these linkages helped build collaborative partnerships with local jurisdictions.

Individual linkage-scale corridor modeling assessments were formalized with a Northern Arizona University research project (Beier et al. 2008) in partnership with the Arizona Game and Fish Department. The resulting maps identified multi-species corridors that would best maintain wildlife movements among wildland blocks, and highlighted specific planning and road mitigation measures to maintain connectivity within these corridors.

In 2020 Arizona released its State Action Plan for the Interior Secretarial Order 3362, "Improving Habitat Quality in Western Big Game Winter Range and Migration Corridors," https://wafwa.org/so3362/. The plan identified the top five wildlife migration corridors for mule deer, elk and pronghorn identified with the use of GPS-telemetry tracking data.

In 2021 Arizona commissioned a comprehensive "Arizona Statewide Wildlife-Vehicle Conflict Study" (Williams et al. 2021) which further identified wildlife corridors, wildlife-vehicle collision hotspots, and wildlife habitats Arizona DOT should consider in all future planning and upcoming projects. Analyses were conducted based on reported crashes with wildlife and the severity of those crashes, ecological factors such as connectivity, and habitat of desert tortoise, and then the factors were combined.

The combined project maps, mapping tools, data, and reports provide ample data-based evidence for Arizona DOT and Arizona Game and Fish to orchestrate a new program of data-driven wildlife mitigation based on solid wildlife habitat and movement data.

New Jersey's CHANJ Website

In New Jersey, the Division of Fish and Wildlife created the "Connecting Habitat Across New Jersey" (CHANJ) program, a strategic plan to make the New Jersey landscapes and roads more permeable for terrestrial wildlife by identifying key areas and actions needed to achieve habitat connectivity across the state. (**Figure B-14**). The website provides tools to bring up interactive maps and a guidance document to help prioritize land protection, inform habitat restoration and management, and guide mitigation of road barrier effects on wildlife and their habitats. (https://www.state.nj.us/dep/fgw/ensp/chanj.htm). An instructive video for the public helps to educate on the efforts: NJDEP Division of Fish & Wildlife-Tools of CHANJ (https://www.state.nj.us/dep/fgw/ensp/chanj_tools.htm).

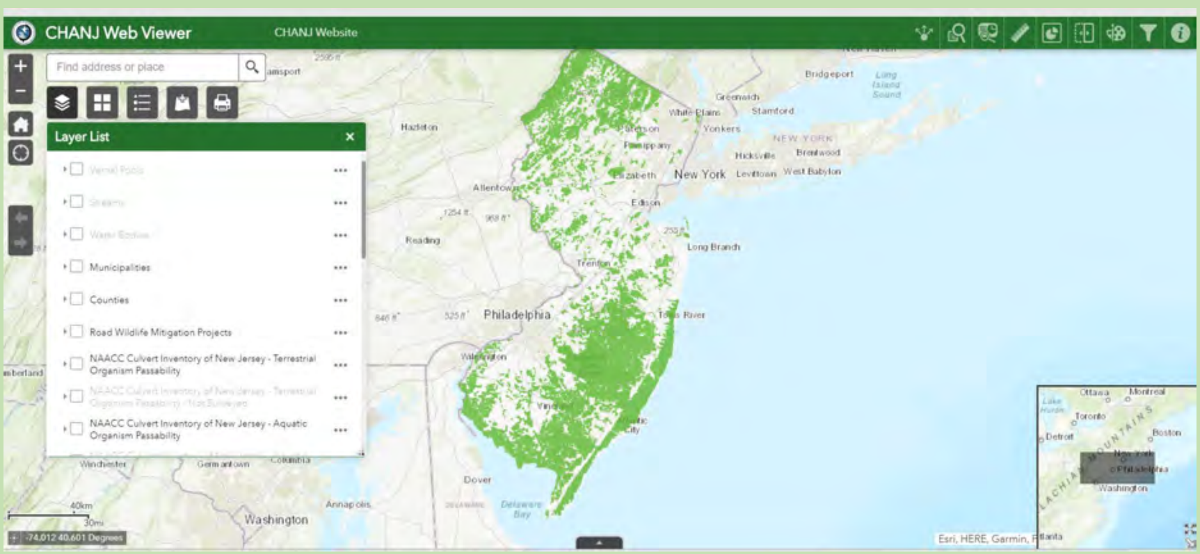

Figure B-14. The New Jersey CHANJ Web Viewer for wildlife connectivity.

A major piece of policy in the second decade of the 21st Century was the U.S. Secretarial Order 3362 (SO 3362), Improving Habitat Quality in Western Big Game Winter Range and Migration Corridors. (See https://www.doi.gov/sites/doi.gov/files/uploads/so_3362_migration.pdf). The funding that came with this order assisted 11 western states with applying GPS collars on dozens to hundreds of mule deer, elk, pronghorn and mapping of the ranges and movements of the herds where those animals belonged. Each of the western states was to develop a list of two to three priority wildlife corridors for those three species, as well as a SO 3362 Wildlife Corridors Action Plan. Every state included statements and maps of how roads were a major threat to these populations' movements.

See the following website for SO 3362 state wildlife action plans and the maps of the top priority wildlife corridors that in turn should be prioritized in assessments for the 11 states – Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Wyoming, and Washington: https://www.nfwf.org/programs/rocky-mountain-rangelands/improving-habitat-quality-,western-big-game-migration-corridors-and-habitat-connectivity/state-action-plans

Wildlife linkages for smaller animals are typically developed through habitat modeling. The various types of ecosystems and features within those systems that are important to target species are mapped and coded for importance. These maps can be used to prioritize areas along or near roads where transportation agencies can better plan for these species.

Figure B-15. Mule deer migrate through a new wildlife crossing structure for the first time under US 89 near Kanab Utah at the Arizona – Utah border. Photo credit: P. Cramer, Utah DOT, Utah Division of Wildlife Resources, Arizona Game and Fish Department.

A valuable resource in Utah is the Utah Division of Wildlife's (UDWR) Wildlife Migration Initiative (https://wildlifemigration.utah.gov/). This program documents wildlife species movement with GPS tracking, and gives users the ability to see the movements of not only large ungulate species but white pelicans, toads, trout, and other species on an interactive map. The data are helping UDWR work with Utah DOT plan the priority areas for wildlife crossing structures (**Figure B-15**).

The University of Wyoming's Wyoming Migration Initiative has completed databases, maps, and tools that have helped the university, multiple agencies, the public, and non-profit organizations work together to help Wyoming become a leader in the nation for planning for, funding, and building wildlife crossing structures (see: https://migrationinitiative.org/).

Wildlife Locational Data

Telemetry data on collared wildlife and survey data on wildlife locations are important data points to evaluate where wildlife need to cross roads. **Figure B-16** displays a map of GPS collar locations where a grizzly bear attempted to cross Interstate 90 in Montana over 40 times before it found a bridge over a river to move beneath the highway.

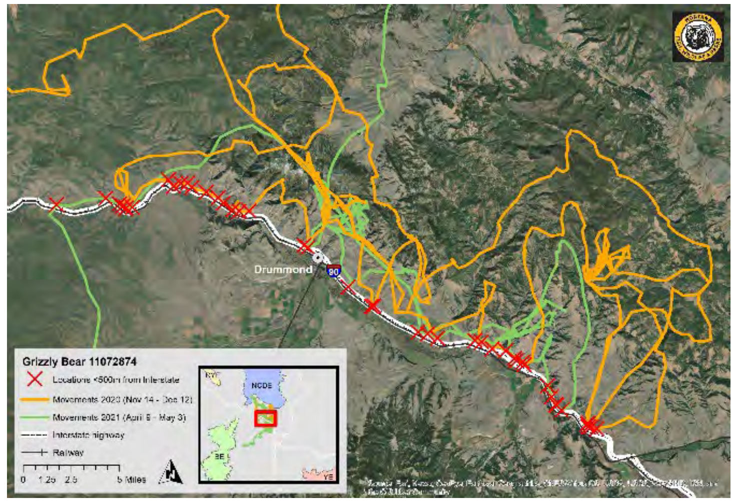

Figure B-16. A grizzly bear's movements in relation to Interstate 90 south of Missoula, Montana. The bear crossed the highway where the green line crosses the interstate. Figure Credit: C. Costello, Montana Fish, Wildlife and Parks.

Sometimes movement data can be sensitive information that need to be presented to the public in a manner that does not reveal exact locations of where individual animals were/are in order to prevent harassment or hunting. Locational data are collected from the state/provincial wildlife agency, universities with wildlife research programs, military bases wildlife research programs, county and regional agencies, Indigenous wildlife programs, and non-profit organizations. Locational data can be used in point form – as GIS shape files of specific locations, they can be modeled to present home range polygons to demonstrate where wildlife are known to reside, and these points and polygons can be clipped to be represented in maps to only reveal where wildlife are within a certain distance from the road. It is important to always work with the wildlife professionals familiar with the data and maps to best understand the circumstances and implications for other animals not tracked.

NatureServe is a go-to on-line resource (https://explorer.natureserve.org/) for information on rare and endangered species and ecosystems in the U.S. and Canada. Their online guide provides information on over 100,0000 species and ecosystems. The NatureServe Network is a hub for the Natural Heritage Program in all U.S. states (https://www.natureserve.org/natureserve-network). Contact between agency personnel and a state Natural Heritage Program Office directly can reveal more detailed records of species' occurrence than are available to the public (https://www.ncnhp.org/contact).

Listed Species

Natural resource agency and non-profit partners are important allies in the maps of where listed species may reside and could be used in a prioritization of locations for wildlife mitigation. Inclusion of Natural Heritage data in the U.S., species of concern maps and data, and professional opinion is critical to long term and project planning. The presence of these species needs to be available to transportation agencies on easily accessed databases and mapping websites. Listed species and species of concern were included in the prioritization of wildlife-vehicle conflict top areas in New Mexico (Cramer et al. 2022b), Arizona (Williams et al. 2021), and Colorado (Kintsch et al. 2019). Since these species can help drive mitigation, their presence can be weighted more heavily in a prioritization scoring.

In the U.S., NatureServe maintains a national database on the locations of species and ecosystems in North America with an interactive map called NatureServe Explorer: https://explorer.natureserve.org/.

Canadian species at risk can be identified with a review of species recovery plans at the Wildlife Preservation Canada Conservation Action Plan, https://wildlifepreservation.ca/conservation-action-plan/ and the Canadian Government Species at Risk Range maps, https://open.canada.ca/data/en/dataset/d00f8e8c-40c4-435a-b790-980339ce3121.

Parks Canada also maintains a web explorer that identifies information about species at risk, in conjunction with NatureServe. https://www.pc.gc.ca/en/nature/science/especes-species/ewb-bwe.

Ontario is a leader in mapping habitat for high risk areas for protected species of turtles, see the case study below.

Case Study – Ontario Mapping, Citizen Science, and Working Groups

The Ontario Ministry of Transportation (MTO) has sponsored workshops, working groups, and research studies to help delineate the priority areas for mitigating roads for smaller animals. Ontario has eight species of turtle and all are listed as Species at Risk federally, and road mortality is listed as a threat for six of these (Gunson and Schueler 2019). A 2012 study mapped turtle and amphibian baseline habitat along roads (Gunson et al. 2012) to prioritize high risk road mortality locations. In 2016 Gunson et al. published a Best Management Practices manual for mitigating the effects of road on amphibians and reptiles in Ontario (Gunson et al. 2016).

Ontario is also an example of how locations of species can be learned from the public through citizen science. The Ontario "Wildlife on Roads INaturalist" project is based on citizen scientists submitting their observations of live and dead small animals on the road to an online website: https://inaturalist.ca/projects/wildlife-on-roads-in-ontario. In the first year there were over 2,000 observations recorded (**Figure B-17**).

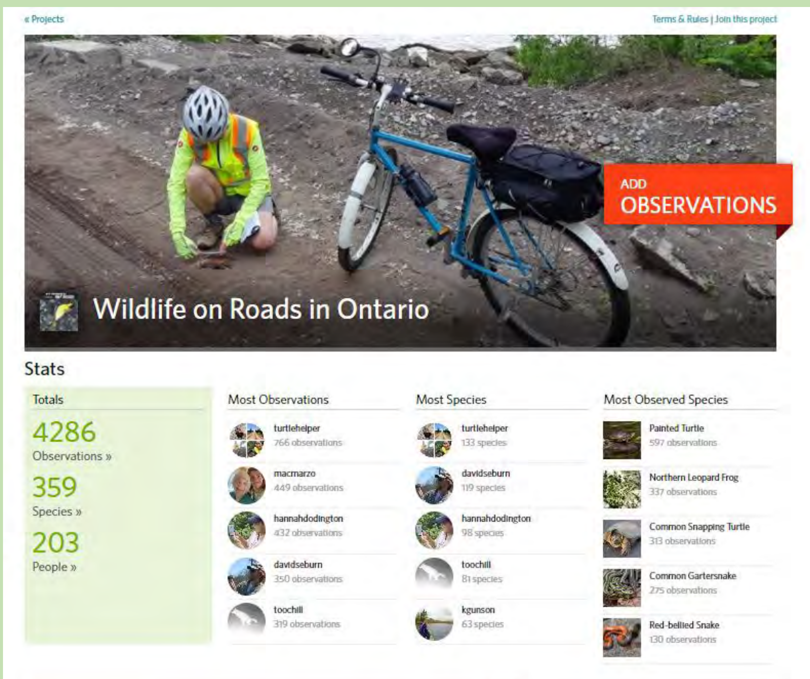

Figure B-17. Ontario's INaturalist website.

The MTO also sponsored many workshops and research studies to help delineate the priority areas for mitigating roads for smaller animals. The MTO Wildlife Mitigation Strategy Working Group of 2013 resulted in a report (Barrett and Gunson 2013) that developed a strategy to prioritize mitigation efforts for small and large animals in the Province.

Wildlife Movement Needs and Abilities

Locating where wildlife crossing structures should be placed, the spacing distance between them, and what species should be accommodated are very dependent on the target species' movement abilities and needs. Data on species' movement distances near the area of interest are important to determine placement of structures that wildlife can find in normal movements.

Bissonette and Adair (2008) estimated the distances between structures for mammals should be based on the average daily movements of the species, animal size, and dispersal distances of the young adults when they leave their maternal home ranges. Daily home range distances are less than one mile (1.6 kilometers, km) for 71 percent of 72 mammal species in North America they examined. This means structures for most mammal species need to be spaced less than one mile (1.6 km) apart. This statement represents the scientific data. However, practitioners in an agency world understand that this may not be possible with various cost and logistical constraints.

Data on how the individuals of the species of interest in an area move and how far they typically move in their daily and dispersal movements should all come into play when locating where wildlife crossing structures are placed, and how many are needed to promote connectivity.

Animal movement abilities are also important. Data on the target species' mode of locomotion, its anti-predator response, and ability to move the distances needed to get across roads and highways all play into how to create the most appropriate structures.

Jacobson et al. (2016) proposed four categories of animal behavioral responses on the perceived danger of traffic: Nonresponders- those that continue their movements without apparent reactions to approaching vehicles, Pausers- those that stop or freeze in response to approaching vehicles, Speeders- those that move faster with nearby vehicles approaching, and Avoiders- animals that stay away from vehicles on the roads all together. Animal types of movement, from those that are semi-aquatic animals and may need water bodies to move beneath roads, to butterflies and other aerial invertebrates that may need to be diverted up above the flow of traffic to fly safely across a highway, all need to be considered when proposing the types and locations of mitigation. Working with wildlife experts who understand and study these movements is critical to placing the correct structures.

Pre-Construction Monitoring

Pre-construction monitoring is instrumental in both the long-term planning of wildlife crossing structures, and in evaluating how well they work in comparison to pre-construction conditions. If wildlife species have been monitored in an area near proposed transportation projects, their movements near the areas of the road are instrumental in determining where the populations of animals need to cross the road.

For a stellar example, the Arizona Game and Fish Department with funding from Arizona DOT utilized GPS location and movement data to help identify locations for wildlife crossing structures. This is especially important for animals that do not cross roads or are inhibited by high traffic volumes, as carcass data become less accurate or non-existent for some of these species. This is especially true for pronghorn, which can stand at right-of-way fences and never move across the roads they need to traverse. Arizona Game and Fish Department's monitoring of ungulate populations with GPS collars prior to road projects have been instrumental in locating and designing the best wildlife crossing structures and fences for elk (Dodd et al. 2012) bighorn sheep (Gagnon et al. 2017b), and pronghorn (Sprague et al. 2013).

Examples of these Arizona projects can be found at the following links:

Elk movements associated with a high-traffic highway: Interstate 17 (Gagnon et al. 2013).

https://apps.azdot.gov/files/ADOTLibrary/publications/project_reports/pdf/az647.pdf

Wildlife-vehicle collision mitigation on State Route 260: Mogollon Rim to Show Low, (Gagnon et al. 2017a).

https://apps.azdot.gov/files/ADOTLibrary/publications/project_reports/pdf/spr706.pdf

Wildlife accident reduction study and monitoring: Arizona State Route 64 (Dodd et al. 2012b).

https://apps.azdot.gov/files/ADOTLibrary/publications/project_reports/pdf/az626.pdf

Assessment of pronghorn movements and strategies to promote highway permeability: US Highway 89 (Dodd et al. 2010).

https://apps.azdot.gov/files/ADOTLibrary/publications/project_reports/pdf/az619.pdf

Wildlife Action Plan & Species Recovery Plan

U.S. State Wildlife Action Plans are blueprints for each state on the management goals for common and more rare species of wildlife, and their natural communities both terrestrial and aquatic, in the state into the next five years. These plans identify the species with the greatest conservation need and species the state would like to keep common. The plans are starting to focus on promoting actions that can be applied at a large scale, rather than on specific species. Any type of infrastructure project planning should cross reference these plans and their maps to help identify if species of some type of concern or if greater conservation actions are located in the project area that the state wildlife agency would want to see take place.

All U.S. State Wildlife Action Plans can be accessed at: https://www.fishwildlife.org/afwa-informs/state-wildlife-action-plans.

Note: The Washington State Wildlife Action Plan Link at the above site did not work at this writing, thus Washington's Plan is available at: https://wdfw.wa.gov/species-habitats/at-risk/swap

In Canada, the federal action plans listed on the Species at Risk Public Registry are developed in coordination with provinces/territories. They can be accessed through the Canadian Federal Government website: https://species-registry.canada.ca/index-en.html#/documents?documentTypeId=11&sortBy=documentTypeSort&sortDirection=asc&pageSize=10

The Ontario equivalent are the Species at Risk (SAR) Recovery Strategies. They can be accessed through the Provincial website: https://www.ontario.ca/page/species-risk

Needs Assessment from the Wildlife Agency

Habitat and locational maps of wildlife created in GIS are limited in their ability to show areas important to wildlife with respect to roads. There may be specific populations of wildlife that are in danger of being extirpated in part due to collisions with vehicles or the effects of roads causing complete fragmentation. Geo-referenced data typical of habitat maps and hotspot modeling may not highlight these populations due in part to their low numbers, and also potentially their small size. It is critical that any transportation planning in areas where wildlife still exist also include conversations with wildlife professionals in the state/provincial/territorial, federal, and Indigenous agencies.

These conversations can alert the transportation department to potentially important areas for wildlife, that if not accounted for, could be the cause of later delays and increased costs to a transportation project that belatedly incorporates mitigation for these animals.

Land Ownership and Use

Data and planning for wildlife will need to examine the potential for installing wildlife crossings, fencing and other mitigation in an area based on land ownership. While some road mitigation such as driver warning systems may work on private land stretches, wildlife crossing structures are typically placed in areas where development will not negate their effectiveness. This does not preclude placing mitigation efforts adjacent on private land, but it is important that the land be protected from development in perpetuity if this option is pursued. Counties may be important in future zoning actions in areas where wildlife connectivity across roads is crucial. States such as Montana, Idaho, and Colorado have worked with land conservation groups to help secure conservation easements on such places. It is also possible to arrange land purchases or swaps as a tool to ensure protection in perpetuity for infrastructure and wildlife. As an example, Nevada DOT purchased private land along US 93 to protect continued wildlife movements to a wildlife underpass (N. Simpson, Nevada DOT personal communication, 2020).

To help determine if there are protected areas involved in the review of the area of concern, check the USGS National Landcover Database: https://www.usgs.gov/centers/eros/science/national-land-cover-database?qt-science_center_objects=0#qt-science_center_objects

Parallel highways, rail lines, energy extraction and transmission lines and corridors, water transmission canals, and even right-of-way fences can also pose a land use consideration for placement of wildlife crossing structures for wildlife connectivity. Mitigation placement will need to be created with thought as to how wild animals can also navigate these nearby impediments (van Riper and Ockenfels 1998, Sprague et al. 2013).

It is also necessary to determine if Indigenous lands are present or near the area of concern for wildlife movement. Indigenous governments and wildlife agencies within the Indigenous peoples will need to be notified, and coordinated in the planning stages. The U.S. Bureau of Indian Affairs published a map of federally recognized Indian Lands in the U.S. URL: https://www.bia.gov/sites/bia.gov/files/assets/public/webteam/pdf/idc1-028635.pdf

In Canada, the Aboriginal and Treaty Rights Information System may be used to locate Indigenous groups and become familiar with each group's established or asserted Aboriginal or treaty rights, URL: https://www.cirnac.gc.ca/eng/1100100014686/1609421785838

A map of Ontario treaties and reserves can be accessed through the Provincial website: https://www.ontario.ca/page/map-ontario-treaties-and-reserves

It is also important to ask, "Does future development, energy extraction, transmission lines and corridors, and other human infrastructure possibly threaten the wildlife population in the near future that would exacerbate the wildlife-vehicle collision problem?" These possibilities need to be incorporated into the placement of wildlife crossing structures.

Permanent and Perennial Water Sources and Flows

To assess for the presence of wetlands, riparian areas, dry washes, and other areas where there is short or long term water with reptile, amphibian, mammal, bird or aquatic species' populations that need to move across the landscape and would be affected by a road or railway across their home ranges, check the U.S. Fish and Wildlife Service National Wetlands Inventory: https://www.fws.gov/wetlands/.

Ontario's Natural Heritage Information Centre (NHIC) also maintains data on Ontario's wetlands throughout the province. The NHIC Make-A-Map: Natural Heritage Areas application allows users to view an online map with a provincial wetland data layer and natural heritage information, and can be accessed via the link below:

https://geohub.lio.gov.on.ca/datasets/areas-of-natural-and-scientific-interest-ansi/explore?location=49.261000%2C-84.732500%2C5.46

The presence of wetlands and riparian areas can also provide a convincing strategy to bridge the wetlands entirely for the road infrastructure, thus eliminating wetland mitigation and permitting, while providing terrestrial connectivity along the sides of the aquatic connectivity. You may also find that your state and provincial resource agencies have additional GIS data on aquatic resources that are more detailed and have finer mapping than the typical databases that might help further define your area of interest.

Topography

Many wildlife mitigation solutions are dependent on topography. Some terrestrial animals follow ridge lines, while others may follow natural draws and riparian habitat along water ways. Smaller animals such as turtles also follow topographic features, such as when females lay nests of eggs in terrestrial areas free of water. With the expected and unexpected changes that are to come with climate change, topographic features are less likely to change in 20 to 50 years than the ecosystem successional stages near the highway. Placing wildlife crossing structures in topographic features that animals can follow to access new resources will become even more critical. The topographic features could initially be located remotely with GIS technology, and more importantly, through field visits. In fact, field visits are a necessity. Sections of road with fill or cut slopes that fall in priority areas should be evaluated for underpass and culvert or overpass opportunities, respectively. It is critical that wildlife professionals, which could include wildlife agency personnel, locate appropriate ridges, ravines, riparian corridors, and access points where multiple wildlife species could be expected to approach the road and find crossing structures.

Climate Change and Resiliency Plans

The current and future global changes in temperature, precipitation, sea levels, and disturbance processes mandate a broader approach to assessing transportation systems with respect to wildlife connectivity. Climate change necessitates a macro level – landscape perspective in space and over greater time scales than human careers. Data requirements to assess the risks to wildlife movements, and overall ecosystem resilience go beyond the scope of this report, but warrant serious consideration.

The U.S. FHWA provides a climate change adaptation guide for transportation systems. The process of using this guide could help transportation planners and environmental staff consider how wildlife can be accommodated in the decision matrix. https://ops.fhwa.dot.gov/publications/fhwahop15026/index.htm#toc

Lister et al. (2015) argue that planning for climate change with infrastructure should emphasize innovative designs for infrastructure that can potentially be flexible or moved and transferred from one locations to another as climate changes local conditions.

The goal for planning for climate change should be maintaining or restoring ecosystem resilience to these multiple stressors. A primer on these changes is presented by the National Fish, Wildlife and Plants Climate Adaptation Partnership (National Fish, Wildlife, and Plants Climate Adaptation Network, 2021). In a 2021 manual, the Association of Fish and Wildlife Agencies produced a toolkit to ensure climate change considerations are being accounted for and incorporated in the planning and implementation of terrestrial and aquatic connectivity initiatives (see Albright et al. 2021). These considerations for wildlife should be incorporated into every upcoming transportation project.

NatureServe produced a guide to estimate species' vulnerability and responses to climate change with a climate change vulnerability index (see Young et al. 2016). This guide is for use of a Microsoft Excel workbook that helps identify key factors to a species' vulnerability to climate change. It is important to predict future scenarios of how the world will change climate wise, and human population and infrastructure build up wise as well.

Climate change has already been documented in the U.S. **Figure B-18** displays some of the Environmental Protection Agency (EPA) maps of changes in precipitation, temperature, river flooding, and sea level changes already documented.

While these maps and documents help with the information that could inform long term and STIP plans, it should be acknowledged that there is uncertainty as to what will happen. However, the authors want to stress that planning for 100-year or even 500-year flood events, which could possibly be more expensive with larger bridges and culverts, would also help transportation agencies prepare for the instabilities with climate change.

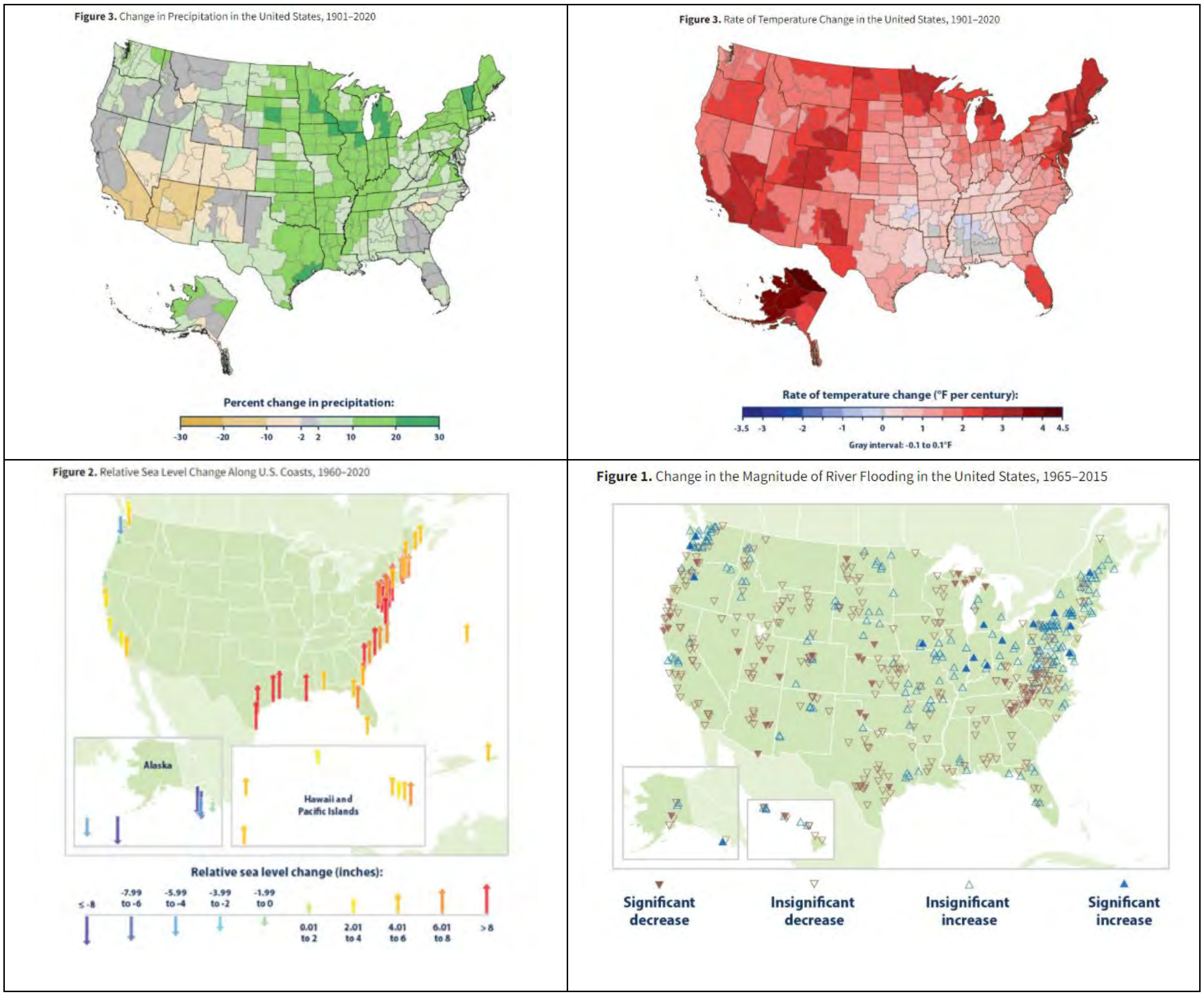

Figure B-18. U.S. Environmental Protection Agency maps of climate change indicators in the U.S.: changes in precipitation, temperature, river flooding, and sea level rise. See https://www.epa.gov/climate-indicators.

For more information on identifying these areas, see the following two references:

- Connectivity and Climate Change Toolkit (https://www.fishwildlife.org/application/files/9216/1582/0864/Connectivity_and_C limate_Change_Toolkit_FINAL.pdf). Prepared for the Climate Adaptation Committee of the Association of Fish and Wildlife Agencies. (Albright et al. 2021).

- Advancing The National Fish, Wildlife, And Plants Climate Adaptation Strategy Into a New Decade (National Fish, Wildlife and Plants Climate Adaptation Network 2021) https:\toolkit.climate.gov\sites\default\files\Advancing_Strategy_Report_FINAL (1).pdf).

Appendix C. Memoranda of Understanding and Agreement

This appendix presents three Memorandum of Understanding (MOU) and Agreement (MOA) from Colorado, Montana, and Utah. The MOU and MOA are between the state transportation and wildlife agencies, spelling out how they will work together to minimize wildlife-vehicle collisions and provide connectivity for wildlife.

COLORADO MEMORANDUM OF UNDERSTANDING

BETWEEN THE COLORADO DEPARTMENT OF TRANSPORTATION AND THE COLORADO DEPARTMENT OF NATURAL RESOURCES DIVISION OF PARKS AND WILDLIFE

Whereas, the Colorado Department of Transportation, hereinafter referred to as CDOT, is charged under the laws of the State of Colorado with the construction and maintenance of the state's highways, and

Whereas, a significant number of aquatic and terrestrial wildlife inhabit or cross highway rights-of-way under the administration of CDOT, and

Whereas, the Department of Natural Resources Division of Parks and Wildlife, hereinafter referred to as CPW, is charged under the laws of the State of Colorado with the management and enhancement of the state's wildlife resources, and

Whereas, it is the mutual desire of these agencies to manage aquatic and terrestrial wildlife within highway rights-of-way in a cooperative manner to satisfy their respective charges for the best interests of the people of Colorado and its visitors, and

Whereas, on August 21, 2019, Colorado Governor Jared Polis signed Executive Order D 2019 011, Conserving Colorado's Big Game Winter Range and Migration Corridors directing CDOT and CPW to develop and Memorandum of Understanding (MOU) outlining their collaboration and support for the Wildlife and Transportation Alliance and the implementation of big game crossings over and under roadways in Colorado.

Now Therefore, CDOT and CPW agree:

Background:

CDOT exists to ensure that Colorado has a safe and efficient highway system by building and maintaining interstates, U.S. highways and state highways. CPW's mission is to perpetuate the wildlife resources of the state, to provide a quality state parks system, and to provide enjoyable and sustainable outdoor recreation opportunities that educate and inspire current and future generations to serve as active stewards of Colorado's natural resources. It is for the economic, social, cultural and recreational benefit of Colorado's citizens and visitors that CPW and CDOT collaborate for the common purpose of maintaining and improving Colorado's transportation systems while simultaneously protecting and managing Colorado's fish and wildlife resources and their associated habitats. This MOU embodies the idea that these goals are not mutually exclusive and so establishes a program of cooperation between the agencies.

This MOU supersedes the previous MOU (198), entitled, "Memorandum of Understanding between the State of Colorado Departments of Highways and Natural Resources Divisions of Highways and Wildlife." It does not invalidate any other MOUs or other agreements between CPW and CDOT regions.

Authority:

This MOU is entered into pursuant to the authority of Colorado Revised Statutes Sec. 331-105(e) & 43-1-105, and Colorado Governor Executive Order (EO) D 2019 011.

SPECIFIC AREAS OF COLLABORATION:

Implementation of EO D 2019 011, Conserving Colorado's Big Game Winter Range and Migration Corridors

Both parties agree:

1. To cooperate to determine possible mitigation for Wildlife-Vehicle Collisions (WVCs) during all phases of transportation planning and transportation project implementation.
2. To Identify priority areas for the implementation of big game crossings over and under roadways in Colorado using the best available science.
3. To continue to support the Wildlife and Transportation Alliance (Alliance), and to use the Alliance to raise awareness, forge partnerships, and identify potential public and private funding opportunities to construct new wildlife crossing structures.

Wildlife/Vehicle Collisions (WVC)

CDOT shall:

1. Have primary responsibility for removal and disposal of roadkill elk, deer, and antelope from federal and state highways in Colorado (see CDOT Procedural Directive 1005.1).
2. Remove from the road prism to avoid attracting public attention roadkill bear, mountain lion, bobcat, lynx, bighorn sheep, mountain goat, moose, wolverine and wolf. Within 24 hours of removing one these species from the road prism and prior to moving the carcass off site, CDOT maintenance staff shall report to local CPW

staff the species and location, and coordinate with CPW on proper carcass disposal.

3. Report animals killed on the roadway to the nearest 1/10 mile by the most efficient and accurate means available, and entered into its statewide database quarterly.
4. Encourage a photo be taken of unknown, but identifiable, roadkill and sent to CDOT's Regional or HQ biologist for positive identification, particularly if one of the aforementioned species is suspected.
5. Provide CPW Regional Managers and Terrestrial Section Manager (Appendix B Contacts) an electronic copy of CDOT's Quarterly Roadkill Report.
6. Inspect and repair any deficiencies found in existing wildlife fencing or other wildlife mitigation feature within 30 calendar days or as conditions allow.

CPW shall:

1. Remove from federal and state highways roadkill elk, deer and antelope first discovered by CPW staff that present a clear hazard to human health and safety. Locations of roadkill elk, deer and antelope removed by CPW staff shall be reported to CDOT to the nearest 1/10 mile for its statewide roadkill tracking database.
2. Coordinate with local CDOT staff on reports of roadkill bear, mountain lion, bobcat, lynx, bighorn sheep, mountain goat, moose, wolverine and wolf.
3. Inform the appropriate CDOT Region or HQ Biologist of deficiencies in existing wildlife fencing or other wildlife mitigation feature(s).

Data Access and Information Sharing

CDOT shall:

1. Respond to individual requests from CPW for transportation system information within 30 calendar days unless otherwise coordinated.
2. CDOT HQ biologist will respond to individual requests from CPW for roadkill information collected by CDOT's maintenance crews and law enforcement agencies within 2 weeks unless otherwise coordinated.
3. upon request, include individuals from CPW on the distribution of quarterly and annual roadkill reports.
4. Map and share individual requests for animal/vehicle conflict areas.
5. Inform the appropriate CPW Regional Manager, or designee, of future projects which have the potential to obstruct wildlife movement beyond current baseline levels, and provide the opportunity to comment or advise on possible measures to mitigate the impacts.
6. Comply with the terms of the data sharing agreement provided in Appendix A when utilizing project-specific data provided by CPW.

CPW shall:

1. When information or data is available, identify and share wildlife seasonal ranges and migration corridors that may affect CDOT activities on a statewide basis.
2. Upon request, cooperate in the development of best-management-practices to minimize CDOT's impact on wildlife and their habitat.

3. Respond to individual requests from CDOT for wildlife related information within a reasonable time, not to exceed thirty calendar days. Unless otherwise coordinated, these requests will not pertain to currently unpublished data, on-going research data, or other data with restricted access as noted by CPW.
4. Upon request, CPW shall provide CDOT with annual GIS-based maps of known raptor nests and necessary buffer zones. Given the statutory duty under CORA to protect information related to private lands that would identify, or allow to be identified, landowners or lands, CPW will share the requested data related to private lands with CDOT because, as a state agency, it shares with CPW the duty to protect such information.
5. Respond to CDOT's request for comment on future projects, which have the potential to obstruct wildlife movement beyond current baseline levels within a reasonable time not to exceed thirty calendar days. An indication of 'no comment' is acceptable.

Both parties agree:

1. Unless impractical, sharing data electronically is preferred over hard copy.

Communication and Coordination

Both parties agree:

1. Meet annually to discuss topics of mutual concern. Potential substantative topics include but are not limited to vegetation management, fencing, SB40, Statewide Transportation Improvement Program (STIP), carcass removal, and habitat connectivity.
2. A principle representative(s) will be appointed for each agency and will be responsible for the coordination and continuation of the meetings throughout the lifespan of this MOU.
3. Review and update on an annual basis, a roster of relevant Agency contact information, as listed in Appendix B.
4. Meeting notes will be taken and distributed to CDOT RPEMs, CDOT Maintenance Superintendents, CDOT HQ wildlife program, CPW Regional Managers, Terrestrial and Aquatic section heads and CPW Statewide PIO.
5. Continue to champion the Colorado Wildlife and Transportation Alliance as co-chairs. Both agencies will identify resources to ensure its momentum, relevance and success.
6. Look for opportunities to coordinate at both a regional and statewide basis.

Public and Media Relations

Both parties agree:

1. When issuing a press release which may impact or affect the other agency, the affected agency will be given advance notice and provided an opportunity to offer input on the draft press release, before it is released to the public.
2. In situations where media contact is immediate and does not afford communication with the other agency, any statements given in respect to the other agency will be relayed to that agency and an opportunity to clarify those statements to the press will be given.

3. Both agencies agree to use common language and overall speaking points to provide consistency and continuity with the Colorado Wildlife and Transportation Alliance efforts.
4. If promoting work, outreach or information through a variety of communication channels to include social media, traditional press and/or web platforms the primary agency will tag, mention or link to the partnering agency's platforms when appropriate.
5. For all of the above, both parties will coordinate with their respective Director of Communications or designee. See Appendix B.

Training

CDOT shall:

Consider training CPW employees who interact with CDOT on topics that would improve communication and understanding (e.g. development and review of transportation construction plans and specifications, efficacy of wildlife crossing structures for various species, etc.).

CPW shall:

Consider training CDOT employees who interact with CPW on topics that would improve communication and understanding (e.g. track identification).

Nothing in this MOU by and between CDOT and CPW shall be construed as limiting or expanding the statutory or regulatory responsibilities of either agency or any involved individual acting on behalf of the agency or in performing functions granted to them by law; or as requiring either agency to expend any sum in excess of its respective appropriation. Each and every provision of this MOU is subject to the laws and regulations of the State of Colorado and the United States.

Nothing in this MOU shall be construed as expanding the liability of either party. In the event of a liability claim, each party shall defend their own interests. Neither party shall be required to provide indemnification of the other party. This MOU does not in any way restrict any entity from participation in similar activities with other public or private agencies, organizations, and individuals.

The memorandum of understanding shall become effective when signed by the designated representatives of the parties hereto and shall remain in force until terminated by mutual agreement, or by any party upon thirty days notice in writing to the others of its intention to do so. Amendments to and deviations from this agreement may be proposed by any party and shall become effective upon approval of written supplemental agreements by all parties.

This MOU shall remain in force for ten years from the date of the last signature unless it is mutually extended or formally terminated by either party after thirty (30) calendar days written notice to the other party.

Colorado Department of Transportation

By ______________________

Chief Engineer

Date ______________________/

Colorado Parks and Wildlife

By ______________________

Director

Date ______________________

Colorado MOU Appendix A:

Agreement allowing use of Colorado Parks and Wildlife Information by the Colorado Department of Transportation for Conservation Purposes

1) Colorado Parks and Wildlife (CPW) will provide information on wildlife locations and migration, as requested by Undersigned, to the Colorado Department of Transportation (CDOT) for the purposes of planning for the avoidance of impacts and mitigating the effects of project-specific transportation infrastructure projects on wildlife, wildlife migration and wildlife habitat connectivity.

Data to be provided by CPW upon request (to the extent available) includes:

- GPS and/or satellite telemetry data from research previously published by CPW and from previous and ongoing unpublished management studies statewide;
- census data and/or density mapping (where available);
- big game, small game, and other fish and wildlife resource areas of occurrence, seasonal habitats, and known migratory movements and migration routes mapped by CPW; and
- other data as requested and determined to be a necessary part of CDOT project planning by CDOT and CPW.

CPW will provide data in raw and/or processed form (e.g., Brownian bridge movement models, etc.), as available and as determined in consultation with CDOT and its subcontractors.

This information will be used solely by CDOT, its employees, and subcontractors employed specifically to work on planning transportation infrastructure projects and for no other purpose, and are not to be distributed to any other party, including other governmental entities. Any information transmitted by CPW will be labelled "confidential" and "do not distribute" by CDOT and its subcontractors.

2) CPW considers this information confidential and sensitive due to the species' vulnerability to intentional or unintentional disturbance, or due to state statutory requirements and agreements made with individual landowners to protect their privacy. With specific regard to information collected or maintained by CPW per CR.S. S 24-72204(3)(a)(XXl), CPW is prohibited from disclosing all records, including, but not limited to, analyses and maps, compiled or maintained pursuant to statute or rule by the department of natural resources or its divisions that are based on information related to private lands and identify or allow to be identified any specific Colorado landowners or lands; except that summary or aggregated data that do not specifically identify individual landowners or specific parcels of land shall not be subject to disclosure.

However, the Colorado Open Records Act (CORA) defines "official custodian" as "any officer or employee of the state ... or political subdivision of the state and the definition of "political subdivision" in CORA includes "every county, city and county, city, town, school district, special district, public highway authority, regional transportation authority and housing authority within the state. Given the statutory duty under CORA to protect information related to private lands that would identify or allow to be identified landowners or lands, CPW will share the requested data related to private lands with CDOT because, as a state agency, it shares with CPW the duty to protect such information.

3) CPW will participate with CDOT, its employees and subcontractors in determining the scope of intended uses of, and use limitations prior to providing data, and will be allowed to review draft products developed from these data.

4) I, the Undersigned, represent that I am authorized to bind CDOT and on behalf of CDOT acknowledge that the information noted above is sensitive and confidential, and agree to the terms and conditions set forth herein:

- The raw and/or processed information described above will be accessible only to CDOT, its employees and subcontractors working on the project described above, and to no other party; nor will it be made available in any manner for public viewing or distribution. CDOT represents that it and its employees and subcontractors working for them are not subject to the federal Freedom of Information Act or that it, its employees or subcontractors could otherwise be required to disclose the information to any other part.

- The raw information may not be transcribed or reproduced in any manner, unless authorized in writing by CPW. CDOT, and/or its subcontractors, may display locations spatially only if necessary to the stated conservation purpose or as part of an internal process. CDOT, and/or its subcontractors, may display point locations spatially if necessary to their stated conservation purpose, but agrees to do so in a manner and at a scale where specific locations cannot otherwise be derived.

- The raw information will be used for the conservation purpose described in the data request and for no other purpose. The information provided through this agreement will be immediately returned (and all copies destroyed) upon completion of the applicable project and purpose described above or upon termination of this Agreement. This Agreement is terminable at will by CPW. CDOT will require its employees and subcontractors to comply with the terms and conditions listed herein.

- Requests involving biological interpretation or use of the information beyond the stated conservation purpose will be referred to CPW.

- CDOT acknowledges that the information represents data and features that are variable both over time and over the landscape and that CPW makes no warranties, express or implied, regarding the use of the information for any particular purpose.

Remedies and Enforcement

This Agreement shall be governed by Colorado law and CPW has all remedies available to it in law or equity to enforce the terms and conditions of this Agreement.

Colorado Department of Transportation

Signature

Title

Please Print

Date

Colorado Parks & Wildlife

Signature

Title

Please Print

Date

Colorado Memorandum of Understanding Appendix B

Agency Contacts

CDOT

Subject Matter	Name	Title	Email	Phone
Communications	A current list of CDOT Regional Communication Managers can be found at https://www.codot.gov/news/documents/region-communication-managers			
Biologists	Jeff Peterson	HQ Wildlife Program Manager	jeff.peterson@state.co.us	303-5124959
	A current list of CDOT Regional Biologists can be found at: https://www.codot.gov/programs/environmental/contacts-region.html			
Regional Planning & Environmental Managers	A current list of CDOT Regional Environmental Staff can be found at: https://www.codot.gov/programs/environmental/contacts-region.html			

CPW

Subject Matter	Name	Title	Email	Phone
Communications	Ferrell, Rebecca	Public Information & Website Manager	rebecca.ferrell@state.co.us	303-866-3203 X4604
NW Region	JT Romatzke	NW Region Manager	jt.romatzke@state.co.us	970-255-6179
SW Region	Cory Chick	SW Region Manager	cory.chick@state.co.us	970-375-6710
NE Region	Mark Leslie	NE Region Manager	mark.leslie@state.co.us	303-291-7203
SE Region	Brett Ackerman	SE Region Manager	brett.ackerman@state.co.us	719-227-5209

Terrestrial Biologist	Brian Dreher	Terrestrial Section Manager	brian.dreher@state.co.us	303-291-7461
Aquatic Biologist	Matt Nicholl	Aquatic Section Manager	matt.nicholl@state.co.us	303-291-7356
GIS	Seth Mclean	GIS Unit Supervisor	seth.mcclean@state.co.us	303-291-7163

MONTANA MEMORANDUM OF AGREEMENT

FOR

COORDINATION OF WILDLIFE AND TRANSPORTATION ISSUES

BETWEEN

MONTANA DEPARTMENT OF TRANSPORTATION

AND

MONTANA FISH, WILDLIFE AND PARKS

This Memorandum of Agreement (MOA) is entered into by the Montana Department of Transportation (MDT) and Montana Fish, Wildlife, and Parks (FWP) (collectively "Parties" and singularly "Party") to institutionalize continued communication, cooperation, and collaboration with the intent of providing for a safe, efficient, and environmentally sensitive transportation system while also stewarding the state's wildlife resources.

Wildlife refers to terrestrial species. A Memorandum of Understanding (MOU) outlining procedures between the Parties for Stream Protection Act coordination and compliance is currently in place.

RECITALS

WHEREAS, the Montana Constitution grants the authority for MDT and FWP to coordinate on wildlife and transportation issues; and

WHEREAS, MDT's authority is defined by USC Title 23 and MCA Title 60; and

WHEREAS, FWP's authority is defined by MCA Titles 23 and 87; and

WHEREAS, MDT is committed to serving the public by providing a transportation system and services that emphasize quality, safety, cost effectiveness, economic vitality, and sensitivity to the environment; and

WHEREAS, FWP is committed to providing for the stewardship of the fish, wildlife, parks, and recreational resources of Montana, while contributing to the quality of life for present and future generations; and

WHEREAS, Montana's transportation system and wildlife resources provide economic, social, cultural and recreational benefits to Montana's citizens and visitors; and

WHEREAS, the state transportation system and wildlife movements and habitat intersect, leading to wildlife-vehicle conflicts and habitat fragrnentation; and

WHEREAS, the Montana Wildlife and Transportation Summit was held in December 2018 where state, local, federal, tribal government, and non-governmental organizations gathered to collaboratively address challenges and develop strategies to work together on wildlife and transportation issues; and

WHEREAS, MDT and FWP cooperate with each other and collaborate with other stakeholders for the common purpose of delivering a safe, efficient, and environmentally sensitive transportation system while simultaneously stewarding the state's wildlife resources.

NOW, THEREFORE, the Parties agree as follows:

1. <u>FWP agrees as resources allow and priorities dictate to:</u>

    a. Commit to and make appropriate staff and resources available to coordinate and collaborate with MDT at regular intervals on wildlife and transportation issues.

    b. Inform MDT of FWP's research and habitat conservation programs and engage MDT early when there is a wildlife-transportation nexus to ensure MDT can understand and provide input on wildlife and transportation-related concerns.

    c. Provide biological expertise, knowledge, and applicable data on wildlife for MDT highway planning, projects, design, studies, and transportation research.

    d. Consider wildlife and transportation needs and recommendations from MDT in wildlife research prioritization, data collection, and analysis products, habitat prioritization, and land conservation.

    e. Coordinate with MDT on press releases or other external releases of information; submitting grant or award applications; or responding to third party initiatives and requests related to wildlife and transportation issues, as appropriate, to promote the cooperative relationship between the agencies.

2. <u>MDT agrees as resources allow and priorities dictate to:</u>

    a. Commit to and make appropriate staff and resources available to coordinate and collaborate with FWP at regular intervals on wildlife and transportation issues.

    b. Inform FWP of new project proposals and engage FWP early when there is a wildlife-transportation nexus in research, planning, and design phases of transportation projects to ensure FWP can understand and provide input on wildlife-related concerns.

c. Consider wildlife information and recommendations from FWP in MDT highway planning, projects, design, studies, and transportation research regarding wildliferelated concerns.

d. Provide wildlife and transportation expertise, knowledge, and applicable data for FWP consideration in wildlife research prioritization, data collection, analysis products, habitat prioritization, and land conservation.

e. Coordinate with FWP on press releases or other external releases of information; submitting grant or award applications; or responding to third party initiatives and

requests related to wildlife and transportation issues, as appropriate, to promote the cooperative relationship between the agencies.

3. <u>The Parties mutually agree as resources allow and priorities dictate to:</u>

a. Build upon existing work and relationships between MDT and FWP to maintain a solid foundation to address wildlife and transportation issues. Acting together, the agencies will continue building relationships with Montanans for Safe Wildlife Passage (MSWP) and other stakeholders to ensure broad engagement in wildlife and transportation issues.

b. Commit to and make appropriate staff available to engage in the Montana Wildlife and Transportation Steering Committee and Planning and Implementation Team (PIT Crew) made up of MDT, FWP, and MSWP representatives with support from other key staff.

c. Share data and information to define key areas of wildlife-vehicle conflict and important areas for wildlife movement.

d. Work together to investigate and implement wildlife accommodations to minimize safety risk associated with wildlife-vehicle conflicts and highway impacts to terrestrial wildlife movement and wildlife habitats.

e. Further develop methods and measures of success for monitoring and evaluating the success of wildlife accommodations measures to determine their effectiveness in facilitating safe wildlife movement across highways. Collaborate to identify and implement mutually agreed upon adaptive management strategies, which will improve the effectiveness of constructed wildlife accommodations.

f. Further elevate public awareness of wildlife and transportation issues through a mutual communication strategy for public education and outreach.

g. Work together to engage landowners in wildlife and transportation issues.

h. Evaluate the agency partnership and discuss matters affecting this MOA at the director level on no less than an annual basis.

i. Coordinate biennial meetings with relevant agency staff, including FWP regional and MDT district staff, to review highway projects and other wildlife and transportation issues at the regional/district scale.

j. Explore funding opportunities and new funding mechanisms for wildlife and transportation research, education and outreach, land conservation, wildlife accommodation projects, operations and maintenance, and monitoring and adaptive management. Work with MSWP and other stakeholders to identify and develop these funding efforts.

k. Develop the agency staff knowledge and skills needed to efficiently and effectively address wildlife and transportation issues.

l . Provide information and report on the progress of wildlife and transportation efforts via the Montana Wildlife and Transportation website.

4. <u>Agency Management Involvement/Conflict Resolution</u>

   a. The Parties will make every effort to expeditiously resolve outstanding issues at the lowest possible staff level of their respective agencies. If the Parties' staff and supervisors cannot reach agreement on any issue, the Parties agree to elevate the decision to successively higher and corresponding (e.g., bureau chief to bureau chief) staff levels within each Party until a course of action is agreed upon. Each level will be given 15 working days to make a mutually agreed upon decision or elevate to the next higher level.

   b. The Parties may elevate the issue to their respective director or director's designee with appropriate decision-making authority.

5. <u>Effective Date Duration and Amendments.</u>

   a. This MOA is effective as of the last signature date.

   b. The Parties will review this MOA for needed amendments every five (5) years.

   c. Amendments to this MOA may be proposed by either Party at any time and shall become effective upon signature by both Parties.

6. <u>Termination Generally.</u> Either Party may terminate this MOA for any reason upon thirty

(30) days written notice to the other Party.

IN WITNESS WHEREOF, the Parties hereto have executed this Memorandum of Agreement.

MONTANA DEPARTMENT OF TRANSPORTATION

By:______________________________

Mike Tooley, Director

____

MDT Legal Counsel

MONTANA FISH, WILDLIFE AND PARKS

By:______________________________

Martha Williams, Director

____

FWP Legal Counsel

Date 2/21/2020

UTAH MEMORANDUM OF UNDERSTANDING

Statewide Coordination and Cooperation between the Utah Department of Transportation And Utah Division of Wildlife Resources

Under the authority of Utah Code Ann. §23-22-1 and §72-1-201, and in furtherance of the objectives and goals identified in House Concurrent Resolution 13, Concurrent Resolution Supporting the Protection and Restoration of Wildlife Corridors, adopted in the 2020 General Session, the Utah Department of Transportation (UDOT) and Utah Division of Wildlife Resources (UDWR) enter into this Memorandum of Understanding ("MOU") in order to fulfill their respective mission statements and provide long-term guidance in agency interactions and project planning. Fulfilling the objectives identified in this MOU will assist the parties in accomplishing mutually beneficial goals and in serving the citizens of Utah.

Agency Mission Statements

UDOT's mission is "Enhance quality of life through transportation." UDWR's mission is "to serve the people of Utah as trustee and guardian of the state's protected wildlife."

It is for the economic, social, cultural, and recreational benefit of Utah's citizens and visitors that UDOT and UDWR collaborate for the common purpose of maintaining and improving Utah's transportation systems while also protecting and maintaining Utah's wildlife populations and habitats.

This MOU is entered into by and between UDOT and UDWR to institutionalize continued cooperation and collaboration with the intent of providing for a safe, efficient, and ecologically sustainable transportation system while also stewarding Utah's wildlife resources.

Both parties acknowledge that:

- The collaboration and processes described in this MOU are designed to enhance the efforts of the agencies within their regulatory and statutory obligations.
- Increasing public safety by reducing wildlife-vehicle collisions, enabling safe wildlife passage, and maintaining wildlife habitat connectivity will require financial support from both agencies. However, this MOU will not bind either agency to specific funding obligations beyond their statutory requirements.
- Coordination early in a project's planning timeline and prior to project design and development can reduce costs and provide more meaningful opportunities for collaboration.

Needs of UDOT and UDWR for an MOU

Utah continues to be one of the fastest growing states in the country, and the state's population is projected to nearly double in the next 50 years. Population growth is resulting in large-scale changes to the landscape as roads are built and expanded, housing developments are constructed, and water is diverted to accommodate growth. Rapid change can result in the degradation, fragmentation, and in some cases the complete loss of wildlife habitat. Without careful planning and active mitigation efforts, these changes to Utah's landscape could have real and lasting consequences for wildlife. To the extent it is feasible and appropriate, UDOT and UDWR intend to collaborate and cooperate on project planning, developing appropriate mitigation, streamlining project completion, data sharing, and other topics identified in this MOU.

Planning

Statewide transportation planning is required by federal and state regulations and provides a direction and framework for decision-making at UDOT. In recent years, UDOT has stressed the importance of considering the communities and lands through which highways pass, seeking to balance the need to move people efficiently and safely while improving the quality of life. Coordination during the planning process can lead to early identification of wildlife challenges and provide opportunities for UDOT and UDWR to collaborate in finding solutions.

UDOT will:

- Involve UDWR as a stakeholder in UDOT's corridor planning process. This process identifies the unique context of an area or corridor and develops a set of solutions to meet its transportation needs. UDWR will have an opportunity to discuss wildlife and other biological concerns in the corridor and participate in developing appropriate solutions.
- Provide opportunities for UDWR to provide feedback on criteria used to evaluate transportation projects that will improve or optimize the capacity of the transportation system.
- Invite key staff members identified by UDWR to participate and/or coordinate at a Regional level with UDOT as recommendations for the Statewide Transportation Improvement Program (STIP) are developed.
- Include UDWR data resources, such as the Wildlife Migration Initiative, in UDOT's Long Range Plan, a planning document that identifies future transportation-related needs outside of urbanized areas across the entire state.
- When appropriate, coordinate during individual project design, construction, and operations so that UDWR may provide substantive wildlife resource recommendations to UDOT.
- Coordinate strategically with UDWR on a statewide list of potential animal vehicle conflict mitigation projects.

UDWR will:

- Provide UDOT with the biological expertise, knowledge, and applicable wildlife and wildlife habitat data for conducting investigations or research.
- Provide recommendations and strategies to reduce impacts to wildlife populations and habitats, identify key wildlife and wildlife habitat connectivity areas, identify best management practices during planning and project design to reduce impacts to wildlife and their habitat from transportation infrastructure, and suggest mitigation alternatives.
- Respond to individual requests from UDOT for wildlife related information on current and future projects.
- Provide species-specific expertise to assist with UDOT consultation with federal agencies, including species locations and relevant habitat requirements, and suggest compensatory mitigation alternatives where mutually beneficial.

Both agencies mutually agree to:

- Utilize existing transportation planning processes and tools to facilitate regular coordination during the planning process.

● Participate in joint agency meetings. ○ District/Region Level: Meet annually at minimum to discuss issues of mutual concern and upcoming projects. Responsibility for these annual meetings will be assigned by the Region Directors of each agency.
○ Headquarters Level: Meet annually to discuss issues of mutual interest and assure the MOU is operationalized. Provide an annual summary report of accomplishments to each respective Director's office on the implementation and success of this MOU. Responsibility for these meetings and annual report will be with the UDOT Program Development Director and the UDWR Director or their designees.

● Jointly develop methods and performance measures for monitoring and evaluating wildlife infrastructure mitigations to determine their effectiveness in facilitating safe wildlife movement across highways.
● Collaborate to identify and implement mutually agreed upon adaptive management strategies, which will improve the effectiveness of wildlife infrastructure.
● Develop the agency staff knowledge and skills needed to address wildlife and transportation issues efficiently and effectively.

Data Sharing

Both parties acknowledge the following:
● Both agencies collect high quality data across the state. The information is used to inform planning and project management for both agencies.
● Both agencies collect and store substantial quantities of wildlife-related data. This data must be efficiently stored and easily retrieved by both parties in order to inform their respective decisions.
● Both agencies are subject to the Utah Government Records Access and Management Act, Title 63G Chapter 2 of Utah Code "GRAMA." This Act governs how state agencies share records with the general public and amongst themselves. Both agencies support openness and transparency in the collection and distribution of biological records. UDWR classifies records as "public," "private," or "protected."

Public records can be freely shared with public customers and between the agencies. UDWR will strive to make public records easily accessible through online applications and reports that provide self-serve access to view, explore, and download records.
UDWR and UDOT recognize that greater conservation and collaboration can occur when important data and information is shared. A separate record-sharing agreement that is consistent with GRAMA should be executed if this type of record-sharing becomes necessary.
UDWR has identified categories of biological records that are classified as "protected" due to the potential threats public disclosure may have on the resource. UDWR may choose to share some protected data sets through an additional data sharing agreement with UDOT that could include protected Natural Heritage Program (UNHP) data. These data sets would include and be limited to non-game sensitive species data locations as currently included in the UNHP.
UDWR and UDOT will undertake the following actions to facilitate regular sharing and exchange of information:
• Creation and utilization of derived products and other types of generalized depictions that help indicate important areas of wildlife habitat and usage.
• Joint database access with login credentials and view-only capability.
• Data sharing on a predetermined schedule (monthly/quarterly/yearly).

Efficient Funding

Both agencies agree to seek opportunities for funding of cooperative projects and activities dealing with highway and wildlife issues. The parties will utilize, to the extent feasible and appropriate, interagency funding transfers and simple project funding justification statements to reduce administrative burdens and expedite project completion. Both parties agree to utilize electronic signatures and transfer of electronic records when possible. 5

Mitigation and Management

During roadway project design and development, impacts to wildlife and wildlife habitat may require a mitigation commitment before a project may secure the appropriate state or federal approvals. In addition, new highway construction or retrofitting existing infrastructure may fragment wildlife habitat or negatively impact wildlife populations.

UDOT will:

- Consult with UDWR when mitigation is necessary and assess potential habitat improvement opportunities on UDWR or other lands.
- Include UDWR experts on mitigation projects when those resources/species are identified by federal agencies as necessary for project success.

UDWR will:

- Serve as a liaison between UDOT and federal land management agencies to explore improvements on federal or private lands through the Watershed Restoration Initiative (WRI) that may satisfy UDOT mitigation requirements.
- Assist, when appropriate, in monitoring success of UDOT mitigation efforts on UDWR or other lands.
- Suggest mitigation alternatives or opportunities to minimize impacts to wildlife and wildlife habitats.

Both agencies will:

- Explore opportunities where land acquisition and long-term management associated with mitigation meets the needs of both agencies as well as federal requirements.
- Coordinate on wildlife crossing structures and other associated infrastructure to engage in early discussion about long-term land ownership and open space to maintain wildlife connectivity and perpetual open space on either side of structures.
- Assess effectiveness of wildlife mitigation measures based on past performance and assure flexibility in future policies and practices through data and expertise.

Public and Media Relations

Both agencies mutually agree:

- When issuing a press release which may impact or affect the other agency, the affected agency will be given advance notice and provided an opportunity to offer input on the draft press release before it is released to the public. When advance notice is not possible, each agency will notify the other agency as soon as possible and the media will be instructed to contact the other agency.
- Each agency will speak only for its respective agency upon media or legislative inquiry except for joint initiatives when designated spokespersons and speaking points are agreed upon prior to such inquiry.

● Contracted private parties shall not communicate on behalf of either agency unless appointed to do so under joint agreement.
● If promoting work, conducting outreach, or disseminating information through a variety of communication channels to include social media, traditional press and/or web platforms, the primary agency will tag, mention, or link to the partnering agency's platforms when appropriate and approved by the other agency.
● During all of the above, both parties will coordinate with their respective Director of Communications or designee.

____
____
Teri Newell Date
Deputy Director
Utah Department of Transportation

____
____
Rory Reynolds Date
Interim Director
Utah Division of Wildlife Resources

Rory Reynolds

Appendix D. Types of Mitigation

Introduction

Disclaimer: This document provides basic information on the types of wildlife mitigation opportunities that are available to modify driver or wildlife behavior and is meant to be a resource for transportation department highway planners, maintenance personnel, engineers and wildlife professionals. This document is not all-inclusive guide but touches on each option and provides relevant or recent literature if available. For an all-inclusive list of mitigation options refer to 2008 FHWA Report to Congress (Huijser et al. 2008).

This monitoring plan has been adapted from the New Mexico Wildlife Corridors Action Plan (Cramer et al. 2022a).

The various mitigation measures to help reduce wildlife-vehicle collisions and help wildlife move beneath or above a road are presented in this appendix. They are organized into actions that target wildlife, and actions that target drivers. Below, **Table D-1** presents these actions with hyperlinks to the sections. Table D-1 also presents the difficulty to deploy level, effectiveness and use across the U.S. along with generalizations about costs.

Table D-1. Overview of wildlife mitigation strategies to reduce wildlife-vehicle collisions (Adapted from Cramer et al. 2014, 2016). Blue-highlighted text is hyperlinked to section in this appendix.

Measure	Difficulty in Effort and Time to Deployment	Effectiveness	Use Across U.S.	Cost to Agency
Actions That Target Wildlife				
Retrofit – Modify Existing infrastructure				
Place fence to existing structures	Moderate	High	Common	Moderate
Retrofit culverts and bridges	Low	Moderate	Common	Low
Adapt fences and gates	Low to Moderate	High	Common	Low

Measure	Difficulty in Effort and Time to Deployment	Effectiveness	Use Across U.S.	Cost to Agency
Facilitate wildlife movement across road	Low	High	Low	Low
Make Roadside Less Attractive to Wildlife				
Supplemental feeding/salt /water at a distance from road	Low	Unknown	Low	Low
Deter Wildlife from Entering Road				
Place exclusion fence and deterrents	Moderate	Moderate	Low - Moderate	Moderate - High
Facilitate Wildlife Movement Across the Road				
Lay down Right-of-Way fence	Low	Moderate	Low	None
Exclude Wildlife from Road and Provide Wildlife Crossing Structures, Fence, Escape Ramps, Guards				
Wildlife crossing structures, fence, fence end treatments, escape ramps, gates, guards,	High	High	High	High
Place Escape Mechanisms for Smaller Animals				
Give wildlife a way to escape road right of way	Low	High	Low-Moderate	Low
Prevent Wildlife Entrapment in Erosion Control Blankets				
Design infrastructure to allow smaller animals a way up and out of road	Low	High	Low	Low
Use only biodegradable erosion control matting	Low	High	Moderate	Low
Reduce Deer Populations				
Sharpshooting deer	Low-Moderate	Moderate-High	Moderate	Low
Experimental, Ineffective, and Inconclusive Methods Targeting Wildlife				

Measure	Difficulty in Effort and Time to Deployment	Effectiveness	Use Across U.S.	Cost to Agency
Vegetation Management	Low	Low-Moderate	Moderate & Unknown	Low
Devices intended to elicit behavioral response through wildlife senses: tags, whistles	Low	Unknown	Low	Low
Reflectors and Noise	Low-Moderate	Inconclusive	Low	Low-Moderate
Olfactory	Low	Inconclusive	Low	Low
Painted White Lines	Low	Low	Low	Low
Actions That Target Drivers				
Public Education and Awareness Campaigns				
Public awareness campaigns	Moderate	Largely Unknown	High	Low
Signage				
Static driver warning signs and signs with lights	Low	Low	High	Low
Variable message boards	Low	Low-Moderate	High	Low
Speed Reduction Zones				
Wildlife crossing zones	Low - Moderate	Low- Moderate	Low	Low
Animal Detection Driver Warning Systems				
Animal Activated Detection Systems	Moderate-High	Low - Moderate	Low	High
Animal detection systems, no exclusion fence	Moderate-High	Low - Moderate	Low	High
Animal detection system with exclusion fence, crosswalks or fence ends	Moderate - High	Moderate - High	Low	High
Ineffective, Inconclusive, or Experimental Driver Methods				
Traffic Calming	Moderate	Low - Moderate	High	Moderate

Measure	Difficulty in Effort and Time to Deployment	Effectiveness	Use Across U.S.	Cost to Agency
Reduce Roadside Vegetation	Low	Unknown to Low	Unknown	Low
Wildlife crosswalks and animal activated crosswalks	Moderate	Low	Low	Low-Moderate
Roadside lighting	Moderate	Unknown	High	Moderate - High
In road lighting – solar pucks	Moderate	Unknown	Low	Moderate
On-vehicle lighting	Low	Unknown	Low	Low
Driver phone applications	Low	Unknown	Moderate	Low
In vehicle warning systems	High	Unknown	Low	Moderate
Self-Driving vehicles	Low	Unknown	Low	Low

Actions that Target Wildlife

Actions that target wildlife are specific to convincing animals to move either above or below the road, or to not enter the road right-of-way at all. This can be done by retrofitting existing structures, making the roadside less attractive to wildlife, placing deterrents, placing wildlife crossings along with exclusion fences, placing escape mechanisms for wildlife, preventing wildlife entrapment, reducing wildlife populations, and several experimental or ineffective practices to be aware of when considering the choices. These actions are detailed below.

Retrofit- Modify Existing Structures

Objective

Many existing culverts and bridges may allow wildlife to pass beneath roads with small modifications at a lower cost and on shorter time frames than needed for new wildlife crossing structures. In this context, retrofit is defined as an action to existing infrastructure that helps to encourage wildlife movement and thus makes the existing culvert or bridge functional for wildlife connectivity. See the Washington DOT Passage

Assessment System (PAS) for how to evaluate existing infrastructure for potential retrofitting for all taxa of wildlife (Kintsch and Cramer 2011). Retrofits include: 1) Fence placement to existing structures to encourage animals to move beneath or above roads; 2) Retrofit of culverts and areas under bridge to encourage wildlife movement; 3) Adapt fences and gates to facilitate wildlife movement beneath the road; and 4) Adapt fencing to facilitate wildlife movement across the road. These are further detailed below.

Place Fence to Existing Structures

Most U.S. Departments of Transportation (DOT's) and Canadian Ministries of Transportation (MoTs) place eight-foot-high (2.4 meters) fence along the right of way to channel ungulates and other wildlife to existing bridges and culverts so animals can move through them to pass beneath highways. Amphibian and reptile fence can be placed along the right of way fence to guide turtles, snakes, salamanders, tortoises, and other small animals to use existing culverts and bridges.

For example, New Mexico has created multiple projects where retrofits of existing bridges, culverts and fences have created deterrence to wildlife movements over roads, and encouraged movement to existing structures to move below the road (see **Figure D-1** for an example).

Arizona used a similar approach to reduce elk-vehicle collisions along Interstate (I) 17. Gagnon et al. (2015) documented a 97 percent reduction in elk-vehicle collisions in a road section where existing bridges that were placed originally for water flow had right-of-way fence extended upwards to eight feet (2.4 m) high placed to and between the bridges. Use of the structures by elk increased by as much as 217 percent.

Figure D-1. Bridge under Interstate 40 in New Mexico, with wildlife exclusion fence placed to guide wildlife to the existing bridge. Photo Credit: J. Hirsch and M. Watson.

Retrofit Modifications to Culverts and Areas Under Bridges

If culverts and areas under bridges are similar to nearby natural conditions, wildlife will have more of a tendency to use them. The most common methods to make culverts and areas under bridges more suitable for wildlife use are:

- Cleaning of culverts so wildlife can better use them;
- Placement of natural substrate in culverts to mimic natural soil-like conditions;
- Placement of a shelf to allow small animals to move above water (see **Figure D-2**);
- Addition of crusher fines or other materials onto existing rip rap rocks to create a 5 to 20 feet wide pathway through the boulder field that would facilitate wildlife and human movement (**Figure D-3**);
- Placement of a natural substrate path alongside asphalt pavement to facilitate safe wildlife passage underneath bridged vehicle interchanges (**Figure D-4**);
- Placement of stumps and logs and natural vegetation under bridges and in wildlife crossing structures including overpasses, to promote small animal movement along the passage (**Figure D-5**); and
- Modification of pedestrian underpasses and overpasses for use by wildlife.

Figure D-2. A small mammal shelf was placed in a Montana US 93 culvert to facilitate movement of raccoons and other wildlife. Photo Credit: P. Cramer and Montana Department of Transportation.

Figure D-3. New Mexico Tijeras Canyon retrofit of Public School interchange under Interstate 40 with a natural substrate path to the side of the paved surface to facilitate wildlife movement beneath the highway bridge. There are no known successful passages by wildlife. Photo Credit: J. Gagnon, Arizona Game and Fish Department.

Figure D-4. Minnesota passage bench (left) and aggregate surfacing (right) to treat rip rap to provide soil structure for wildlife and human passage. Photo Credits: Minnesota Department of Natural Resources, courtesy of P. Leete.

Figure D-5. Oregon's US 97 Lave Butte Wildlife Mitigation Project placed stumps, logs, and rock along a wildlife underpass set of bridges for small animal movement. Photo Credit: Oregon Department of Transportation, Portland State University, P. Cramer.

Adapt Fences and Gates

It is important to remove or modify fences and gates that are located at the entrances of culverts and bridges. Fences and gates near the entrances of these structures can impede wildlife movement. Place wildlife-friendly rail fence as far back along the right-of-way line as possible, see **Figure D-6**, Paige 2012, and the section Wildlife Exclusion Fence, below.

Figure D-6. In New Mexico, a gate located at a culvert prevented nearby livestock and wildlife from moving beneath the road, (left). When the gate was removed and a right-of-way fence installed 40-feet (12 meters) from the culvert entrance, mule deer began moving through, with over 880 mule deer successful crossings, (right). Photo Credit: Arizona Game and Fish Department and New Mexico Department of Transportation.

Make the Roadside Less Attractive to Wildlife

Objective

Draw wildlife away from roads and roadside habitat by providing resources away from the road. It is important wildlife professionals judge the reasons why animals may be coming to the road surface, foraging in the road right of way, or crossing the road to access resources. There may be different incentives and motivations for wildlife on different sides of the road. For example, while access to water on one side of the road may be an apparent motivator for wildlife to cross the road, other factors of heterogeneous habitat features may be drawing animals across the road. It is important to assess animals' motivation for various resources to find the potential actions to reduce movement near or across the road.

Options

Potential measures include:

Provide supplemental feeding (intercept feeding) and salt-mineral sources at locations away from road (Wood and Wolfe 1988, Grossman et al. 2011).

Use road de-icing agents that don't attract wildlife and/or replace the use of sodium chloride roadway salt with products such as ethylene glycol, calcium chloride, or other acceptable alternatives (Fraser and Thomas 1982);

Plant right-of-way with native vegetation that is unpalatable and of low nutritional value to wildlife (Mastro 2008);

Remove roadkill carcasses promptly to avoid attracting eagles and other scavengers (Grubb and Lopez 2018);

Place water resources, such as water guzzlers or water catchments away from the road to attract thirsty animals there and to keep them on one side of the road (**Figure D-7**).

 

Figure D-7. Left, pronghorn at a water guzzler in Utah. Photo Credit: R. Larson, Bringham Young University. Right, mule deer at water guzzler Arizona. Photo Credit: Arizona Game and Fish Department.

Deter Wildlife from Entering Road

Objective

Keep wildlife off the road but do not provide any wildlife passage.

Options

This is done by erecting wildlife exclusion fence with no options for wildlife to move beneath or over the road to access both sides. Wild ungulate exclusion fence is typically eight feet high (2.4 meters), metal fence material that is supported with metal or wooden poles, t-posts, or combinations of these supports. It is placed along the right-of-way fence line along roads and highways. It can also be of woven or welded wire, v-mesh wire, chain link, electrified strands of wire or rope embedded with conductive material such as copper, or a combination of these materials. In some instances, smaller gauge mesh can be included to simultaneously address smaller wildlife species or options that use smaller openings at the bottom to exclude small wildlife and graduate to large openings at the top to exclude large wildlife (van der Ree et al. 2015)

Exclusionary fence can be an effective tool to reduce wildlife-vehicle collisions (Clevenger et al. 2001). However, the use of fence as a standalone measure to reduce wildlife-vehicle collisions is not recommended in most instances as it can be detrimental to some wildlife populations (Jaeger and Fahrig 2004).

Additionally, wildlife that have an incentive to access a specific location, such as a preferred food source or migration route, and if an option for crossing is not provided can lead to animals attempting to finding ways under, over or through the fence and in turn increased fence maintenance efforts. Early attempts to block deer access to roads with fence without connectivity options were unsuccessful and in most cases this practice has been largely discontinued (Falk 1978, Feldhamer 1986). Anytime exclusionary fence is used, with or without wildlife crossing opportunities it should include wildlife guards also known as double cattle guards, basically deterrents at vehicle access points to deter wildlife from entering the right-of-way, along with escape ramps that allow animals entrapped within fenced areas to safely exit the roadway (see sections on Escape Ramps and Guards below for more details).

Facilitate Wildlife Movement across Road

Objective

There are some places where wildlife movements are predictably limited in space and time, where wildlife crossing structures are not yet an option, and where traffic volumes are still well below 2,000 Annual Average Daily Traffic (AADT) during times of wildlife movement. In these areas, where there may be sheet flow of hundreds to thousands of animals.

Options

Laying down right of way fence during movement periods (typically migrations) is an option to facilitate faster ungulate herd movements across the road. This is possible when livestock are not in the area.

Facilitating wildlife movement can also include temporary road closing, temporary dynamic signs, or reduced speed limits during peak movement times, and other actions.

It should be noted that these actions may not reduce wildlife-vehicle collisions, but rather facilitate wildlife movement and connectivity across the road. This is done on the Bureau of Land Management lands on the Rio Grande Del Norte National Monument along US 285 in New Mexico (**Figure D-8**). The fences are then placed back to upright positions during periods when cattle are in the area.

Figure D-8. Lay-down fence in erect setting with permanent metal posts supporting wooden lay-down posts, on the Rio Grande Del Norte National Monument, Tres Piedras, New Mexico. Photo Credit: P. Cramer.

Exclude Wildlife from Road using Fence and Provide Wildlife Crossing Structures, Escape Ramps, and Wildlife Guards

Objective

Wildlife exclusion fences placed to guide animals to wildlife crossing structures substantially decrease wildlife-vehicle collisions and are an important part of providing wildlife connectivity when there are structures provided or available for wildlife movement. These structures and fence are also concurrently placed with escape ramps to allow trapped wildlife to escape and wildlife guards or double cattle guards to keep wildlife from entering the roadway at ingress and egress points, see **Figures D-9** through **D-13** for examples of some of these measures.

Figure D-9. Montana's US 93 wildlife overpass, a wildlife underpass, and wildlife exclusion fence. Photo Credit: P. Cramer.

Options

Wildlife Crossing Structures

There are two different wildlife crossing structures; there are overpasses where wild animals move above the road and traffic, and underpasses where they move beneath the road. Below, each type is presented with variations of types of structures used for these tested designs.

Overpasses

Overpasses are proven to work for all ungulates found in North America with the exception of mountain goats, which have not been located in locations where studied overpasses have been placed. Mountain lions, grizzly and black bears also use overpasses, perhaps to a lesser degree. Overpasses have worked for: desert bighorn in Arizona (Gagnon et al. 2017b), Nevada (Gagnon et al. 2020c), Rocky Mountain bighorn in Colorado (Kintsch et al. 2021); for pronghorn in Wyoming (Sawyer et al. 2016) and Nevada (Simpson et al. 2016); elk in Utah (Cramer 2012, 2014a,b), and Colorado (Kintsch et al. 2021); and mule deer in Arizona (Gagnon et al. 2020a), Utah (Cramer 2012, 2014a,b), Colorado (Kintsch et al. 2021), Wyoming (Sawyer et al. 2016), Nevada (Simpson et al. 2016), and Montana (Hujiser et al. 2016). Moose have also used overpasses in Colorado (**Figure D-10**, Kintsch et al. 2021).

Overpasses are typically the most expensive option of all wildlife crossing structures, but can be the best option for certain landscapes, types of roads, and specific ungulate species. In particular, bighorn sheep subspecies and pronghorn have proven this is the most viable option for facilitating movement of entire herds of mixed genders and ages (**Figure D-10**, Gagnon et al. 2017b, Kintsch et al. 2021). See **Figures D-10 through D-13**.

Figure D-10. Left moose used the Colorado SH 9 overpass the first fall after completion. Right, bighorn sheep use another SR 9 overpass. Photo Credit: J. Richert, Blue Valley Ranch (l), and ECO-Resolutions, Colorado Department of Transportation, and Colorado Parks and Wildlife.

Figure D-11. Mule deer used Arizona SR 77 overpass. Photo Credits: Arizona Game and Fish Department.

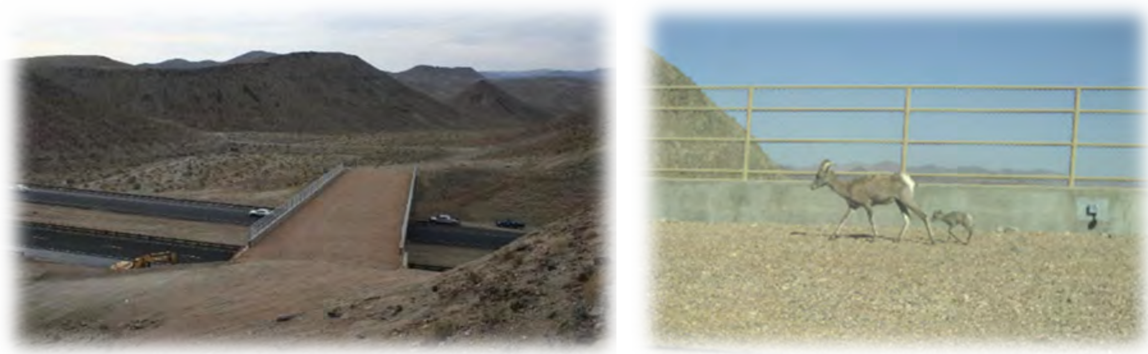

Figure D-12. Desert bighorn sheep use US 93 overpasses in Arizona. Photo Credit: Arizona Game and Fish Department.

Figure D-13. Mule deer and elk used the first overpass built in North America over Interstate 15 in Utah. Photo Credit: P. Cramer, Utah Department of Transportation and Utah Division of Wildlife Resources.

Bridged Underpasses

Bridges are commonly used as wildlife underpasses, in part because studies have shown mule deer, elk, and other ungulates have higher success rates moving through these types of structures than most culverts (Cramer 2012, Cramer 2014a, b, Dodd et al. 2007, Gagnon et al. 2011, Simpson et al. 2016). When a river or wetland is involved, these can be the most logical choice, helping to avoid wetland building permits, and allowing for natural terrestrial and aquatic wildlife movement (**Figure D-14** through **D-18**).

Figure D-14. Mountain lions use wildlife underpass bridges in California (left) and Washington. The Washington picture was taken with a thermal imaging video camera. Photo Credits: California – W. Vickers, University of California Davis Wildlife Health Center; Washington – Washington DOT.

Figure D-15. In Oregon, mule deer used one of two bridge wildlife underpasses at Lava Butte under US 97. Photo credit: Oregon DOT, Portland State University, and P. Cramer.

Figure D-16. In Montana, black bear and white-tailed deer used bridged wildlife crossing structures with water features. Photo Credit: P. Cramer and Montana Department of Transportation.

Figure D-17. In New Mexico, left, elk moved beneath the US 550 bridge near Cuba, and right, in Tijeras Canyon mountain lion walked below the bridge under Interstate 40. Photo Credit: Arizona Game and Fish Department and New Mexico Department of Transportation.

Figure D-18. A desert tortoise moved beneath a wildlife crossing bridge erected less than three feet (1 meter) above the landscape for tortoise passage in St. George, Utah. Photo Credit: A. McLuckie, Utah Division of Wildlife Resources.

Arch Underpasses

These structures are created with pre-fabricated concrete arches that are each typically about six feet (2 meters) wide, of various heights, with the arches placed on a concrete foundation. The prefabrication of underpasses with these arches, and with overpasses created in the same way, help reduce the traffic detours and congestion associated with large infrastructure placement in the road. They allow for a high amount of vertical and horizontal space to accommodate wildlife. Mule deer success rates at these structures have been over 90 percent in Utah (Cramer 2014a, b), and Colorado (Kintsch et al. 2021) and other states (**Figures D-19** through **D-20**). However, they are still a limited option for elk movements. While elk have been present at the locations monitored at the above Utah and Colorado studies, years of research and dozens of elk approaches at these structures have either been limited to several dozen successful passages by elk, or higher numbers after the initial five years post construction (Kintsch et al. 2021).

Figure D-19. Mule deer used the arch underpass under I-70 in Utah. Photo Credit: P. Cramer, Utah Department of Transportation, and Utah Division of Wildlife Resources.

Figure D-20. Bobcat, mule deer, and javelina were just a few of many species documented using the arched underpass on Arizona's SR 86 (left) and SR 77 (right). Photo Credit: Arizona Game and Fish Department.

In Colorado, the full diversity of ungulate and carnivore species present in the area monitored were documented using the five arch underpass structures on SR 9, including: mule deer, limited numbers of elk and moose, singular bighorn sheep, singular pronghorn, black bear, coyote, bobcat, and medium sized mammals (**Figure D-21**, Kintsch et al. 2021).

Figure D-21. Black bear used several arch underpasses under Colorado's SR 9. Photo Credit: ECO-Resolutions, Colorado Department of Transportation, and Colorado Parks and Wildlife.

Concrete Box Culvert Underpasses

Concrete box culverts have been used to accommodate wildlife of all sizes and movement capabilities (Sparks and Gates 2012). As long as the culverts are less than 200 feet (61 meters) long, and are at least 13 feet (4 meters) high and wide, mule deer and white-tailed deer may use them over time as they adapt to them (**Figure D-22**). For example, from 2017-2019, researchers with Arizona Game and Fish Department documented more than 6,000 mule deer successful movement through box culvert wildlife underpasses installed along US 550 near Aztec, New Mexico (Gagnon and Loberger 2020). They are not recommended for elk, bighorn sheep, and pronghorn: these species have rarely used this type of structure in numbers greater than singular or several animals. Carnivores, such as mountain lion and black bear have used these structures regularly in Montana (Cramer and Hamlin 2017), Utah (Cramer 2012, 2014, **Figure D-23**), and Colorado (Kintsch et al. 2021). In New Mexico Gagnon and Loberger (2020, **Figure D-24**) documented black bear use of existing concrete box culverts.

In Florida, small and medium sized mammals, snakes, turtles, frogs, alligators, and fish were among the 51 vertebrate species documented using medium sized concrete box culvert wildlife underpasses (see **Figure D-25**, Dodd et al. 2004).

Figure D-22. In Utah, once wildlife exclusion fence was placed along this USDA Forest Service road that encompassed a pair of concrete box culverts, mule deer began using these to pass beneath Interstate 70, with hundreds of successful mule deer movements through the pair of culverts each year (Cramer 2012, 2014). Photo Credit: P. Cramer, Utah Department of Transportation, Utah Division of Wildlife Resources.

Figure D-23. Mountain lions used a ranch operations concrete box culvert under Interstate 70 in Utah. Photo Credit: P. Cramer, Utah Department of Transportation, and Utah Division of Wildlife Resources.

Figure D-24. In New Mexico, black bear have regularly used existing box culverts to cross under Interstate-25 near Raton. Photo Credit: Arizona Game and Fish, New Mexico Department of Transportation.

Figure D-25. Alligator used a box culvert placed as a wildlife crossing structure under US 441 Paynes Prairie, Florida. Photo Credit: L. Smith, J. Barichivich, and K. Dodd.

Corrugated Steel Culverts

Corrugated steel culverts, also known as squash pipes, metal plate pipes, or corrugated metal pipes (CMP) are used by DOTs and MoTs to accommodate wildlife across western North America. As long as they are high, wide, and short enough, mule deer will use them (Cramer 2012, 2014, Cramer and Hamlin 2017, 2019a, b, c, **Figure D-26**) as will multiple wildlife species (Clevenger 2001, Cramer and Hamlin 2019a). However, elk, bighorn sheep, and pronghorn will typically not use them in herds. Smaller wildlife and carnivores have been proven to use these culverts as well (**Figure D-27**).

Figure D-26. In Utah, mule deer use a large corrugated steel culvert underpass in Deer Creek State Park under US 189. Photo Credit: P. Cramer, Utah DOT.

Figure D-27. In Colorado, SR 9, a black bear exits an existing corrugated steel six feet by six feet (2 meters x 2 meters) culvert. Photo Credit: ECO-Resolutions, Colorado Department of Transportation, and Colorado Parks and Wildlife.

Wildlife Exclusion Fences

There are field fences with welded wire to deter ungulates, mesh fence to deter smaller animals, and electric fences of woven materials (Electrobraid fence), or a combination of these types of fences to deter large mammals. Wild ungulate exclusion fence is used to prevent wildlife in general, access to the road area. It is described in better detail above in the section Deter Wildlife from Entering the Road. The multiple types of fences are presented in **Figures 28-29** below.

Figure D-28. Fence types: left – traditional right-of-way fence eight feet (2.4 meters) high, right – woven wire mesh fence for smaller wildlife. Photo Credits: Arizona Game and Fish Department.

Wildlife also need to access wildlife crossing structures and existing culverts and bridges in the presence of fences that allow them this access. If there is a need to keep domestic livestock out of the structures, it is important to place rail fence, 18 inches (46 centimeters) above the ground and back at the right of way line of fence to accommodate wildlife trying to use the structure while deterring livestock from entering the crossing. Wildlife friendly fence options are detailed in two manuals from Montana and Wyoming (Paige 2008, 2012).

Figure D-29. Utah wildlife rail fence at a wildlife crossing structure under Interstate 15. The intent was to keep out livestock but allow wildlife access. Photo Credit: P. Cramer.

Fence may also need to be placed to deter motorized vehicles, particularly off highway vehicles (OHV), while still allowing wildlife access to the area. See Arizona's approach to this challenge in **Figure D-30** below.

Figure D-30. Arizona placed a steel rail fence at a wildlife underpass structure to deter motorized vehicle use. Photo Credit: Arizona Game and Fish Department.

Fence is also used to channel smaller animals to crossing structures. These fences can be made from plastic, such as a plastic-based drift fence/wall, (permanent or temporary), or High Density Polyethylene (HDPE) half pipes (Heaven et al. 2019), (**Figure D-31**), or concrete, or metal fence products (**Figure D-32**). A company specializing in small animal fences has proven very helpful in all kinds of ecological and taxa-specific situations, Animex Wildlife Fencing, and can be found at: https://animexfencing.com/permanent.

Figure D-31. Two types of small animal fences: Top, plastic drift fence-wall, bottom, half pipe barrier wall. Photo Credits: Top B. Zarate, New Jersey Division of Fish and Wildlife, Bottom, taken from Heaven et al. 2019, Ontario.

Figure D-32. Types of fences and wall to keep amphibians, reptiles, and small animals off the road and moving toward wildlife crossings. Top, Paynes Prairie Preserve, Florida, concrete wall for reptiles and amphibians prior to construction completion in 1999, Photo Credit, P. Cramer; Middle, chain link fence for turtles, in Minnesota, Photo Credit, C. Smith, Minnesota DOT; Bottom, small grid metal fence to guide tortoises to crossing structures in southern Utah, Photo Credit, P. Cramer.

Fence End Treatments

The fence ends typically have movements around the end of the fence (end runs, **Figure D-33**) by wild animals that either did not find structures to move beneath the road, or that will not use those structures. Over time, after fence placement and existing crossing structures become more highly used by wild animals, there is typically a reduction in numbers of animals that move around fence ends, as long as the wildlife crossing structures or existing structure are maintained to promote wildlife movement (Cramer and Hamlin 2019a).

Figure D-33. Elk moved around fence end on SR 9 in Colorado. Photo Credit: Colorado DOT, Colorado Parks and Wildlife, and ECO-resolutions.

There have been concerns by state DOTs that the wild animals that move around fence ends will move back into the fenced part of the road. In Utah (Cramer and Hamlin 2019a) and Colorado (Cramer and Hamlin 2021, Kintsch et al. 2021) research revealed that approximately 10 percent of the animals detected by cameras at fence ends move back into fenced areas; 90 percent move to the other side of the road, or escape out of the fenced areas. In Arizona, the rate of ungulates into the fenced area was 19 percent (Gagnon et al. 2010). Therefore, fence end treatments across roads with deterrents such as electric pavement may not be necessary if the 10-19 percent generalization is acceptable. It is a judgement call that will need to be made by the transportation agency professionals evaluating the situation, along with wildlife professionals who can help estimate the numbers of animals crossing the roads at those points.

Fences can also be angled toward the road at the fence ends, to deter animals that move around the ends from moving into the fence right of way.

Fence ends can be placed at natural breaks in the landscape that are difficult for wildlife to maneuver, such as steep cliffs and rock walls, human dominated areas, or attached to bridge abutments and culvert bases.

There are fence end treatments that can help prevent animals that move around the fence end from entering the fenced right of way from the natural areas at the fence ends up to the pavement. These include an experimental Enviro-grid that is used to secure erosion-prone slopes (Cramer and Hamlin 2021) but may not be effective (see **Figure D-34**).

Figure D-34. Erosion control webbing was used to potentially deter animals from entering fenced right-of-way. Photo Credit: P. Cramer.

Another right-of-way treatment is boulders. Boulder fence is a wide stretch of riprap boulders extending out from the pavement that in theory cannot be traversed by hooved animals and are likely completely ineffective for padded animals. In Arizona boulder fence was used along SR 260 in Arizona and over time ungulates and livestock learned to negotiate it leading to regular occurrences of wildlife in the right-of-way at these locations. In 2015 standard eight feet (2.4 meters) high woven wire fence was placed on the backside of the boulders and incidence of animals in the roadway was significantly reduced. It is not recommended as a standalone measure or over an extended stretch of roadway, and may increase the barrier effect for many species, and present a potential safety hazard for drivers.

Animal detection systems placed at fence ends alert motorists of the presence of wildlife providing the opportunity to avoid collisions at these locations. See animal detection systems driver warning systems below for details.

Right of Way Escape Mechanisms

In the event animals are trapped within the fenced right of way, options to allow them to escape are needed. Options include escape ramps, one-way gates, and slope jumps (lowered sections of fence on a slope). To date the only effective escape mechanisms are escape ramps, sometimes referred to as “jumpouts” and are the only measures covered in this section.

Escape Ramps

Escape ramps are mounds of earth placed in the right-of way along the exclusion fence to provide an area animals trapped in the right of way can use to jump out of the area. Escape ramps should be placed with local wildlife biologist input to maximize use by trapped wildlife. In Utah and Colorado, the standard is four escape ramps per mile of wildlife exclusion fence. Experiments with various ramp designs have found that the most effective designs include:

- Integration into the topography so that animals encounter them without having to climb a steep slope;
- If integration into the topography is not possible, then provide ramp access with no steeper than 3:1 slopes (Kintsch et al. 2021) and preferably 4:1 or even less steep (Gagnon et al. 2020b); a nominal four feet (1.2 meters) wide flat area at the top of the ramp to facilitate jumping out into the wild area can be created;
- In Colorado (Kintsch et al. 2021) and Utah (Cramer and Hamlin 2019b) researchers recommend no center fences (**Figure D-35**), while Arizona does not have this preference;
- A minimum ramp opening in the fence line of 10 feet (3 meters) at the top, but wider gaps are preferred to further encourage prey species like ungulates to use them rather than perceiving the opening is too confined to enter;
- In Utah, Cramer and Hamlin (2019b) found that placement of ramp at a slight angle of approximately 150 degrees, or at an inflection point in the fence to draw the animals inward and over the ramp to the wild side worked best (**Figure D-36**);
- The landing pad on the wild side should be flat and clear of vegetation, rocks, and debris;

- There are several different escape ramp designs. There can be one, two or even three ramps tied together at an opening in the fence location (**Figure D-37**). These multiple ramp entries improve the chances wildlife will find and use them.
- The height of the ramp will be dependent on species, for example a ramp height of six feet (1.8 meters) is recommended for elk but a ramp for deer should be in the five to six feet (1.5-1.8 meters) range (Kintsch et al. 2021). If there are elk present in the same area as mule deer, then ramps should conservatively be placed at six feet high (1.8 meters) due to the safety concerns caused by larger bodied elk jumping up the ramp and into traffic along the fenced area (**Figure D-38**, Gagnon et al. 2020c). Bighorn sheep require a crossbar set at 18-20" (45-50 centimeters) above the lip of the ramp to reduce entry into the right-of-way while still allowing them to go over or under the ramp to exit (Gagnon et al. 2017, 2020c);


Figure D-35. Left, Colorado SH 9 most successful escape ramp type with a 3:1 slope and no center fence. Photo Credit: P. Cramer. Right, mule deer used an escape ramp with center fence in Colorado, SR 9. Photo Credit: Colorado DOT, Colorado Parks and Wildlife, ECO-resolutions.

Figure D-36. Angle of escape ramp in fence along Utah’s US 189. Red fox on Utah escape ramp on US 189. Ramp is approximately at a 150-degree angle to fence line. Photo Credit: P. Cramer, Utah Department of Transportation.

Figure D-37. A Utah high migration escape ramp on US 91. Three sides provide three escape opportunities. Photo Credit: P. Cramer. Photo on Right, Mule deer uses a high migration escape ramp in Utah, US 91. Photo Credit: P. Cramer, Utah DOT, Utah Division of Wildlife Resources.

Figure D-38. Left, elk used escape ramp and right, desert bighorn sheep used a six feet (1.8 meter) high escape ramp, both in Arizona. The bar on the desert bighorn ramp was placed higher than six feet (1.8 meter). Photo Credit: Arizona Game and Fish and Arizona DOT.

Gates, Guards, and Electrified Barriers

When utilizing fence to exclude wildlife from roads there must also be provisions for preventing wildlife from entering the roadway through open turnouts, driveways and lateral roads. Options include gates, wildlife guards, double cattle guards, and electrified barriers.

Gates

For lateral access roads with low traffic volumes, gates that are eight feet high and made of chain link or other sturdy fence material should be included. Educational signs can help alert motorists, recreationists, and land users of the risks of leaving gates open (**Figure D-39**). Although gates are cost effective, there is the risk that gates will be left open and allow wildlife to enter the roadway. Gates that automatically close using internal spring mechanisms should be a consideration in design to minimize the chances of gates being left open. If a project budget allows, other robust measures besides gates should be utilized.

Figure D-39. Educational signs on gates in wildlife fence in Utah (left) and Arizona (right). Photo Credits: Left, P. Cramer, right, J. Gagnon.

Guards - Wildlife Guards, Double Cattle Guards and Electrified Guards

In situations where gates are not feasible, guards should be used to allow vehicle access and limit wildlife access. Single cattle guards are the typical guards placed to keep cattle from entering roads. Paired single cattle guards are typically called wildlife guards or double cattle guards and are used for deterring wildlife from entering roadways at egress and ingress places along wildlife exclusion fences. These wildlife guards / double cattle guards should have a more rounded or pointed top surface to help reduce wildlife with hooves from using the bars to walk across and accessing the roadway than flat bars, which can promote foot placement and movement. The guards should have continuous bars, with no concrete support between the two, since mule deer photographed in studies in Utah, Montana, Colorado, and Arizona have demonstrated an ability to use that middle strip as a launch point.

Grate style wildlife guards have been successfully used to limit mule deer and white-tailed deer access to roads in Montana (Allen et al. 2013), Utah (Flower 2016), and Florida (Peterson et al. 2003). The sides of all guard types typically have concrete supports for the vault below. Those concrete side supports need to be fenced over and not available to mule deer and other wildlife to walk on to enter the road right of way. The aprons that attach to the posts and cover the concrete lips also need fence placed under them so animals do not use the area beneath the aprons to access the road. Or, the fence can be placed directly to the guard edge, and the aprons placed on either side. The best in road wildlife deterrents are not 100 percent effective and some animals move over the guards and onto the road. However, Cramer and Flower (2017) found double cattle guards to be 85 to 90 percent successful in deterring mule deer efforts to breach them, which was better than any other guard tested.

At every guard location there needs to be escape ramps within several hundred feet (dozens of meters) of the guard, to allow animals that have breached them who become caught in the right-of-way a nearby escape mechanism. In projects in Utah (Cramer and Hamlin 2019 a, b, c) and Colorado (Kintsch et al. 2021, Cramer and Hamlin 2021), all roads, driveways, and vehicle entrance and exit ramp entrances have at least one escape ramp placed nearby. **Figures D-40** through **D-45** demonstrate various types of guards.

Figure D-40. Left, Utah's double cattle guards with appropriate side fences and aprons, no mid-guard support, and rounded top bars of a guard. Photo Credit: P. Cramer. Mule deer ponders a flat bar Utah double cattle guard on US 89 and was deterred. Photo Credit: P. Cramer, Utah Department of Transportation, and Utah Division of Wildlife Resources.

Figure D-41. Elk breached double cattle guard in Arizona. Photo Credit: Arizona Game and Fish Department and Arizona DOT.

Figure D-42. Left, a wildlife guard in Utah, on US 91. Mule deer breached the guard by walking on the outer lip of the vault. Photo Credits: P. Cramer, Utah Division of Wildlife Resources.

Figure D-43. Left, desert bighorn sheep breach a single cattle guard by using support lip in Arizona. Right, the guard was adapted to a double cattle guard and the vault lip was covered with fence. Monitoring found no bighorn breaches after retrofit. Photo Credit: Arizona Game and Fish Department, Arizona DOT.

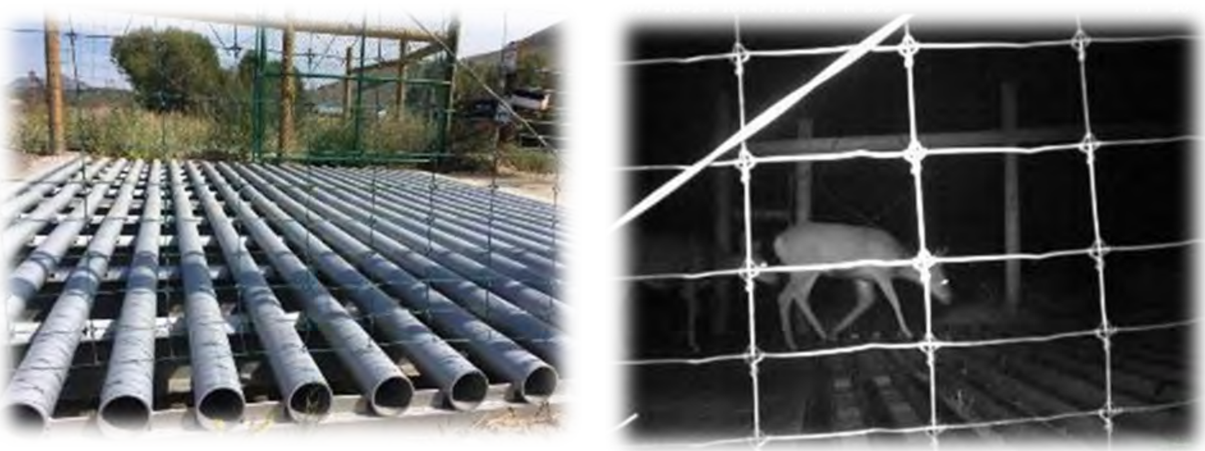

Figure D-44. Left, Colorado SH 9 round bar double cattle guard. Photo Credit: P. Cramer. Photo on right demonstrates how mule deer can use the support beams to breach the guard. Photo Credit: Colorado Department of Transportation, Colorado Department of Parks and Wildlife, and ECO-resolutions.

 

Figure D-45. In New Mexico, along US 550 near Cuba, a double-width cattle guard, (game guard) with perpendicular fence and beveled vault edges to prevent wildlife from walking on them to access fenced right-of-way was placed. Photo Credit: Arizona Game and Fish Department.

Cattle guards can be altered for smaller animals. They can be placed in areas fenced to deter turtles, snakes, frogs, and other animals. A narrow guard with round rails and an open pit below rather than a vault allows animals that attempt to breach it to fall into a sand pit below, and walk out the sides back to the fenced area. **Figure D-46** demonstrates how this was used in Valentine National Wildlife Refuge for painted and bog turtles.

Figure D-46. A small animal guard along a turtle fence on Valentine National Refuge in Nebraska allowed turtles and others to fall back to ground level and to try to move along the fence rather than cross over the road. Note painted turtle along the fence. Photo Credit: P. Cramer.

Electrified barriers along with wildlife guards at the road surface hold promise as a potential to provide vehicular access while excluding wildlife from the right-of-way. They function by providing a shock to the animal when they attempt to walk on the alternating charged and grounded sections. A powerful enough energizer must be used to deliver a shock to hooved animals when standing on asphalt. Electrified guard or barriers are particularly effective on padded feet animals such as bears. Electrified components should be Underwriter Laboratory approved to ensure they will provide a shock but are not unsafe to humans or animals.

Appropriately designed electrified barriers should be at least 12 feet (4 meters) wide (as the animal traverses them to access areas) and use sturdy and proven designs that not only are effective on wildlife but hold up to extreme environmental and traffic conditions (Cramer and Flower 2017, Gagnon et al. 2020b). Use of experimental untested designs along roads can increase the risk of failure and need for replacement over a relatively short time period. Personnel trained in the maintenance of electrified components (e.g. signs and lights) should be used for repairs and maintenance. Fault switches that relay loss of power to maintenance personnel can be included in the design. Although the electrified barriers/guards are safe for those with shoes on, temporary push button shut offs can allow pets and horses across them. Gates can also be used to allow pedestrians with small children or strollers, their pets, and equestrians passage. However, there is a risk of gates being left open unless there is a spring mechanism to automatically close them.

Gagnon et al. (2020b) recommend that in areas where electrified guards are preferred over standard double cattle guards, consider either a wide stand-alone electrified guard or a combination of electrified and non-electrified guards, such as one panel of electric placed with an adjacent game guard.

Early research of these electrified barriers or guards revealed shortcomings in the designs and components (Cramer and Flower 2017, Cramer and Hamlin 2017), which in turn helped to improve later designs. Arizona DOT installed electrified barriers along SR 260 after evaluation of these structures in a controlled test site demonstrated effectiveness in deterring elk and withstanding extreme heat and freezing conditions. The electrified barrier was installed to keep elk and deer from entering the fenced right of way as they cross at the end of the fence where an animal detection system warns motorists of their presence. Traffic volume on Arizona's SR 260 ranged from approximately 4,000 to 20,000 vehicles daily, including heavy semi-truck traffic. In spite of these volumes and heavy truck weights, the electric pavement remained intact after three years. Similar electrified barriers were installed in New Mexico along US 550 with the same goal as the guard in Arizona; to act as a fence end treatment. See **Figure D-47.**

Continued research on the effectiveness of electrified guards will help determine if these are a viable option and in what circumstances.

Figure D-47. Electrified barriers installed along SR 260 in Arizona (left), and in New Mexico (right) along US 550 to keep elk and deer out of the fenced right-of-way. Photo Credit: Arizona Game and Fish Department.

Place Escape Mechanisms for Smaller Animals

Smaller animals can be trapped in roadways or fall into gutters along curbs. Minnesota (Leete 2014) instructs designers and construction crews of curbed roads to make the slope of the curb gentle to allow turtles, young ducklings, and other small animals an escape from the paved traffic area (**Figure D-48**). Traditional curb and gutter designs have large openings at the curb and gutter joint that these animals fall into and then die inside the sewer if not rescued. These designs should be replaced with those that keep a full grate over the entire gutter opening, thus keeping animals from falling in.

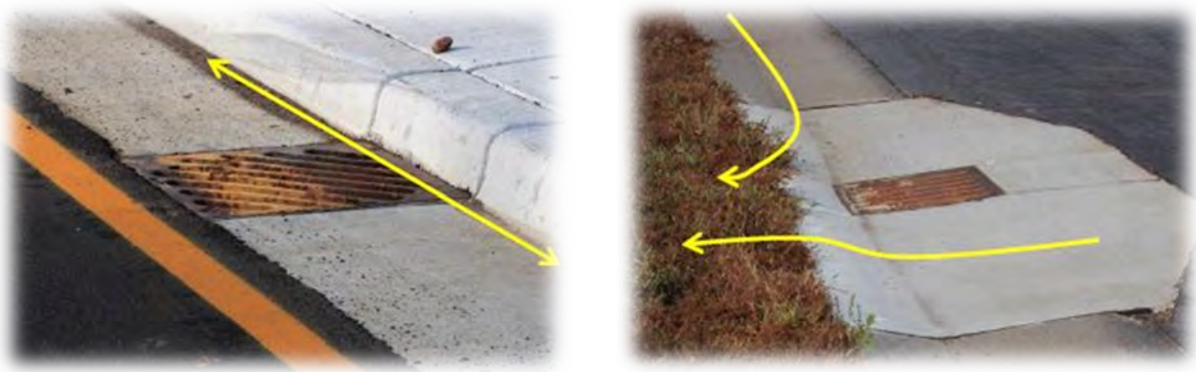

Figure D-48. A curb and gutter designs that allow small animals to pass above the grate without falling in (left) and a sloped curb allows animals to leave the road at any point, not just at gutters. Photo Credits: P. Leete, Minnesota Department of Natural Resources.

Prevent Wildlife Entrapment in Erosion Control Blankets

Smaller animals are also at risk for becoming entangled in erosion control blankets. Plastic netting is a hazard to them long after the need for erosion control, as it remains for years. Reptiles and amphibians, ducklings, small mammals and fish have become entangled in these types of blanket/netting and often die. The solutions are to use biodegradable netting from natural fibers that do not need ultra violet light to degrade, as these blankets/nets are often placed under bridges. See the Minnesota best practices guide book (Leete 2014).

Reduce Deer Populations

Objective

Reduce deer population sizes in areas near roads with high incidence of wildlife-vehicle collisions to reduce the likelihood of deer-vehicle collisions.

Options

This approach engages sharpshooters to cull deer populations in suburban areas, or increase hunter tags in hunting units with high wildlife populations near roads. Hunting is recognized as an effective means of reducing a deer population; however, the subsequent impacts on wildlife-vehicle collisions is uncertain, particularly in rural areas, although at least one study documented a decrease in deer-vehicle collisions following deer population culling, targeting reproductive-age females (Muller et al. 2014). Kilgo et al. (2020) documented as high as a 50.8 percent reduction in deer-vehicle collisions utilizing sharpshooters at select times during the year. The impacts of culling on population size are temporary and increased harvesting must be implemented annually for long-term impacts to population size. Targeted harvesting to control population size is best done in conjunction with public education and outreach, particularly where population management is being conducted near suburban areas. It is the responsibility of the state wildlife agency to create and oversee these programs.

Experimental, Ineffective, and Inconclusive Methods Targeting Wildlife

The following types of measures have either been tried and proven to be less than fully effective at reducing wildlife-vehicle collisions, or are ideas that have not been tried. All these are not necessarily recommended at this time, but are for reference in the case of questions concerning them.

Vegetation Management

The objective of vegetation management is to make the roadside vegetation less attractive to wildlife. Vegetation management can be used to reduce the presence of highly palatable grasses and plants in the right of way. Low nutritional species of plants can be planted in the right of way to prevent attracting ungulates that come to graze on the plants. Cutting vegetation to keep it short for lines of sight of drivers can also make the plants less attractive for wild animals. This also applies to small mammals. In dry and desert like ecosystems, the small amount of precipitation that falls on the road drains off to supply the right-of-way with greater amounts of moisture than nearby landscapes, thus providing opportunity for vegetative growth that attracts not only ungulates, but small mammals that are then hunted at night by terrestrial wildlife and owls. Vegetation management can be an important part of mitigating roads for wildlife.

However, the U.S. FHWA study on mowing practices related to deer vehicle collisions (Normandeau and Associates 2012) found inconsistent results with changes in vegetation practices and reduction of deer-vehicle collisions.

Devices Intended to Elicit Behavioral Response Through Wildlife Senses

Several studies have attempted to measure if different devices can elicit a behavior from wildlife, primarily deer, through visual, auditory, and olfactory senses that would cause them to avoid roads. To date many of these studies have shown mixed results, generally ineffective or inconclusive but in some instances warrant further investigation.

Reflectors and Noise

To utilize vision as a warning cue to deer of oncoming vehicles, standalone wildlife warning reflectors that cause a beam or reflection directed toward animals when cars pass have been tested on several occasions. Results have been largely ineffective or inconclusive (Brieger 2016, Rytwinski et al. 2016). D'Angelo et al. (2006), and Jared et al. (2017) found wildlife warning reflectors completely ineffective and not even visible to the deer eye. This method is not a viable measure to deter deer from the road.

Fence tags are small, playing card sized reflectors that fasten onto wire fences and are meant to elicit a vigilant response behavior from ungulates as they reflect light and flutter in the wind. Fence tags can gather sunlight during the day and re-emit absorbed light overnight. This "glow-in-the-dark" function does not require passing cars for activation, continuously alerting animals to the presence of the fence and associated roadway reducing their desire to cross the right-of-way fence, thus reducing ungulate-vehicle collisions. Fence tags have been used to effectively reduce sage grouse collisions with fences but are considered untested along roads. Arizona Game and Fish was testing fence tags along roads in Arizona at the time of this writing, and results should be available in 2022.

To stimulate auditory response of deer as vehicles approach, several methods have been attempted including "deer whistles" which contrary to popular belief, are not effective in reducing deer-vehicle collisions even at varying decibel levels (Romin and Dalton 1992, Valitski et al. 2009). Acoustic road markings have been tested to determine deer response to vehicles passing by and deer showed relatively quick habituation (Ujvári et al. 2004). This measure is considered ineffective.

The combination of auditory and visual stimulus may have potential for deterring road crossings by wildlife. Optical and acoustic sensors, attached to posts by the roadside, pick up the sudden increase in light from a car headlight, trigger an alarm, which then emits a strobe light emitting diode (LED) light towards where the deer are coming from, and a high-pitched sonar signal between 4kHz and 8kHz. A grey literature study found that these devices reduce accidents with red and roe deer in Italy by 62-70 percent. Utah DOT conducted a study on these devices and found results were inconclusive. Like other devices, animals can habituate to them. Additional research on these devices may be warranted. At this time, they are not recommended.

Olfactory

Predator urine is produce by companies that sell urine or urine-like compounds of wolves, coyotes, and bobcat as a purported deterrent for prey species. These products are not proven to work along roadsides to deter deer and other animals. Andreassen et al. (2010) observed “questionable” beneficial results on the use of scent to reduce moose-train collisions. If they had some efficacy, the urine would have to be sprayed every week to keep the scent present. Urine products are not recommended and are currently considered inconclusive.

Painted White Lines

Some U.S. state DOTs paint parallel white lines on the road surface to mimic cattle guards as a low cost alternative to deter cattle guards, with the intention of repelling animals from walking over the surface to access highways. Cramer (2012, 2014a), and Gagnon (2020b) found these painted lines do not deter wild animals. In Utah, Cramer (2014a) documented elk, moose, and mule deer walking over painted white lines to access and escape I-80 over 200 times (**Figure D-49**). In Arizona Gagnon et al. (2020b) tested painted stripes against various wildlife crossing guard options and painted stripes repelled only 9 percent of the 647 attempted breaches over the lines by elk, which was only slightly better than a control of asphalt that repelled only 4 percent of the 862 attempted breaches by elk. Although the painted stripes appeared to mildly confuse elk on the first day, over a several days the painted stripes became even less effective. Painted white lines are not recommended as a deterrent for wildlife.

Figure D-49. Elk move over painted lines mimicking cattle guard in Utah along Interstate 80. Photo Credit: P. Cramer, Utah Department of Transportation, Utah Division of Wildlife Resources.

Actions that Target Drivers

The following approaches target slowing down drivers and making them more aware of the potential for wildlife-vehicle collisions.

Public Education and Awareness Campaigns

Objective

Public education and awareness campaigns are used to alert the public and, in particular, the driving public, about the potential hazard of wildlife-vehicle collisions and, in some cases the countermeasures being implemented to reduce the likelihood of wildlife-vehicle collisions.

Options

Public education and awareness campaigns typically communicate the scope of the wildlife-vehicle collisions problem and the impacts to wildlife and ecosystems and may provide driver safety tips. These types of public outreach efforts have been conducted across the country and may target a particular timeframe (rut or migration) or species, or may provide more general awareness.

Colorado DOT has a seasonal campaign to watch for wildlife, (Colorado Department of Transportation 2016).

British Columbia Ministry of Transportation (British Columbia Ministry of Transportation 2020) continually keeps motorists abreast of seasonal warnings on various social media platforms, (https://twitter.com/TranBC/status/1270121868226371585) and different aspects of wildlife collisions (https://www2.gov.bc.ca/gov/content/transportation/driving-and-cycling/traveller-information/routes-and-driving-conditions/wildlife).

Signage

Objective

Driver warnings and caution signs are used to alert drivers to the potential for wildlife on the road in areas with high wildlife-vehicle collision rates. Signage includes static signs, seasonal or temporary signs, and variable message boards.

Options

Static Signs and Signs with Lights

Typical, non-location-specific warning signs, usually with words or a silhouette of an animal such as a deer, have been widely (over-) used across the county and although may help in the very short term (Found and Boyce 2011), are generally recognized as having no long term impact on driver speeds and their ability to respond to an animal in the roadway. Features that add to a signs distinctiveness (e.g., flashing lights, flagging, animation, unique graphics, **Figure D-50**) attract more attention from drivers and may perform better at reducing vehicle speeds and motorist awareness, however their effect on reducing wildlife-vehicle collisions remains moderate to ineffective (Pojar et al. 1975, Sullivan et al. 2004). Similarly, signage that is posted only seasonally when wildlife is most active or that indicate caution over a limited distance elicit a moderately increased response from drivers and influence vehicle speed more than signs that are posted year-round (Sullivan et al. 2004).

Figure D-50. Warning sign with flashing yellow lights in Chama, New Mexico. Photo Credit: P. Cramer.

Sielecki (2017b) proposed and tested a Wildlife Hazard Rating System that provides drivers with a more consistent and comprehensive warning about deer hazards. The sign changes the color and flashing pattern of deer silhouette signs depending on daily or seasonal crash likelihood in certain geographic areas that could potentially provide speed reductions during high risk periods (**Figure D-51**). These enhanced signs could cause motorists to increase vigilance during high risk wildlife-vehicle collision periods.

Figure D-51. Variations of deer-vehicle collision warning signs with flashing border intended to alert motorists during peak potential crash periods. Color and flash pattern can be changed as needed. From Sielecki (2017b).

Variable Message Boards

The electronic variable message board or variable message sign (VMS) can be used in specific areas where a problem of wildlife on the road is short in duration and predictable (**Figure D-52**). The wording on the sign can be changed to suit the situation, and can be programmed daily, sometimes from remote locations. The signs can be programmed to be general or very specific to detail the problem. However, DOTs and the U.S. FHWA have specific criteria for the number of lines displayed in a message, display interval and other factors that must be followed. Hardy et al. (2006) found that portable message signs were more effective than permanent signs in eliciting a driver response. Recent research by Donaldson and Kweon (2018) indicated deer carcass removals were significantly lower and motorist speeds were reduced when variable message boards were present. Variable message signs provide a temporary option to potentially reduce collisions. Additional research to corroborate their effectiveness is warranted.

Figure D-52. M. Watson of New Mexico Department of Game and Fish installed driver warning variable message board with New Mexico Department of Transportation maintenance personnel. Photo Credit: New Mexico Department of Game and Fish.

Speed Reduction Zones

Wildlife Crossing Zones

Objective

Speed reduction zones are road segments with reduced speed limits to both reduce wildlife-vehicle collisions and protect wildlife.

Options

Speed reduction zones are based on seasonal or night-time reductions, or with physical traffic calming measures such as more narrow lane widths or mimics of narrower lanes with white stripes that come inward to reduce vehicle speeds in areas with high wildlife-vehicle collision rates.

On low speed, low volume and more suburban/urban roads temporary speed bumps, bulb-outs, or roundabouts can be implemented.

Figure D-53. Wildlife Sign. Photo Credit: Colorado DOT.

Seasonal sign can be folded up and down by maintenance workers in accordance with the specified speed limit seasons (**Figure D-53**). In Colorado research was inconclusive on the effectiveness of speed reduction zones in reducing wildlife-vehicle collisions, although no concurrent population studies were conducted. Although it is generally recognized that drivers are better able to avoid wildlife-vehicle collisions at slower vehicle speeds, speeds would have to be reduced to 45 mph or less to achieve a notable reduction in wildlife-vehicle collisions (Nichols et al. 2014). Roadway design may have a greater influence on vehicle operating speed than the posted speed limits.

Animal Detection Driver Warning Systems

Objective

Driver warning systems alert drivers that animals are nearby and may be in the road, and thus help prevent collisions. Animal detection systems consist of sensors along both sides of a road segment that detect wildlife movement and send a signal to flashing warning signs alerting drivers that an animal is currently present within the right-of way and possibly entering the road.

Options

These systems may use: full light spectrum cameras, infrared light beams, laser, radar, LiDAR, thermographic cameras, vibration, or electromagnetic/buried cable fields to sense wildlife activity (**Figure D-54**). Radio-collared animals have also been used to activate warning signs. In-vehicle sensors and warning systems are also being developed and may ultimately provide a reliable, targeted driver warning system as their development continues; however, widespread deployment and use may take several generations.

Figure D-54. The British Columbia Ministry of Transportation and Infrastructure used thermal, video, and radar animal detection systems to identify animals of a minimal size and then set off the driver warning systems. Figure Credit: L. Sielecki and British Columbia Ministry of Transportation and Infrastructure.

Animal Activated Detection Systems (AADS)

Until relatively recently, various technologies used to detect wildlife for purposes of activating roadside warning systems have shown mixed or inconclusive results. Early tests of animal detection technology held up fairly well in controlled test sites but did not meet expectations when implemented in a field setting. Huijser et al. (2009) evaluated nine detection technologies and five of those technologies met recommended performance requirements yet even those systems lacked suitable robustness for field settings. Historically, many detection systems evaluated in field settings rarely met desired outcomes due to the maintenance needs and the lack of robustness of the systems or high levels of false positives or negatives (Huijser and McGown 2003).

More recently, advances in radar, LiDAR, electromagnetic, and thermal technology and research have provided promising results even in field settings. However, in many instances these should still be considered experimental until additional systems have been successfully deployed. Radar based systems showed promising results in Idaho (Huijser et al. 2017) and British Columbia (See **Figure D-55**, Sielecki 2017a, Sielecki 2016 for videos on how these systems work) and additional research and deployments are warranted. Ontario has used a laser based system to detect animals and warn drivers (Rotalec 2022).

Figure D-55. British Columbia Ministry of Transportation and Infrastructure installed a radar based animal detection driver warning system on Highway 3. Photo Credit, British Columbia Ministry of Transportation and Infrastructure.

Chen et al. (2019) successfully utilized LiDAR technology to detect animals in Nevada in field settings. Overall, electromagnetic technology has not met expectations, and has been discontinued in Colorado (Huijser et al. 2012). However recent research in Virginia by Druta and Alden (2019) identified the advances of this technology in the animal detection realm with successful field deployments. Arizona successfully implemented thermal imaging technology along SR 260 beginning in 2007 and upgraded to more advanced thermal imaging technology in 2020 to increase accuracy and robustness (Gagnon et al. 2019).

Motorist response to signs activated by animal detection systems is a crucial component to their success. The signs must be properly located, spaced, and draw enough attention to the signs to elicit a response from motorists to give them the opportunity to reduce reaction time and either avoid a collision altogether or hit the animal at a slower speed reducing the potential for injury (Huijser et al. 2009). The effectiveness of the signs overall is dependent on the accuracy of the detection technology to activate them. If signs are constantly activated, drivers eventually become complacent. When signs are not activated drivers will be inattentive, in both cases increasing potential for collisions. Assuming the signs are activated properly then their ability to get the drivers' attention is important and can include flashing lights, LED's, or variable message signs. Grace et al. (2015) used driving simulators to find that drivers responded more to picture based animal detection system signs than word based signs, although both significantly reduced the probability of a crash.

In Arizona a combination of static, variable message signs, and flashing lights on a static elk silhouette sign were used to help reduce accidents with elk and consistently reduce motorist speeds and braking behavior for nine years (**Figure D-56**, Gagnon et al. 2019).

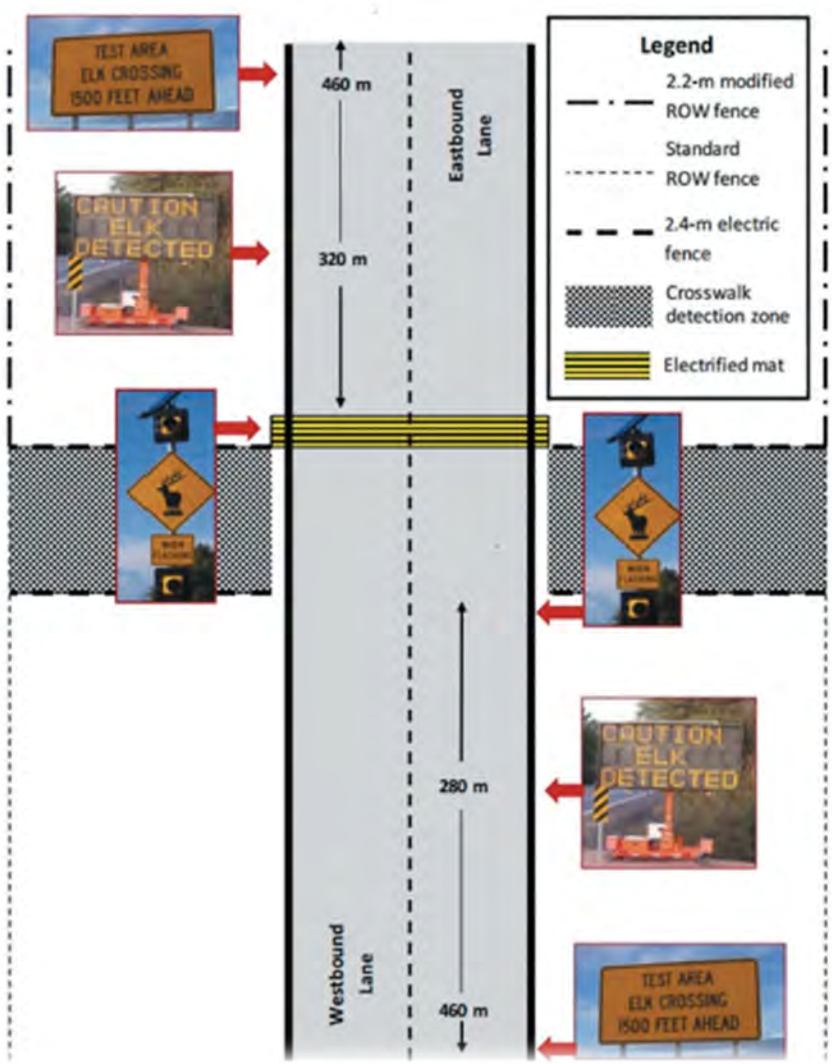

Figure D-56. Combination of signage used to successfully reduce speed and increase braking response of motorists along SR 260 in Arizona (from Gagnon et al. 2019).

There are three kinds of situations where animal detection driver warning systems are placed: 1. Along stretches of road where there are no wildlife exclusion fences; 2. At wildlife-exclusion fence ends; and 3. Where the wildlife-exclusion fence funnels wildlife to a specific crosswalk area over the road. Below we present the first two of the three placement types. The placement of driver warning systems at animal crosswalks has not had across the board success, and this third method is presented in the next section, “Ineffective, Inconclusive, or Experimental Approaches to Target Driver Response.”

Animal Detection Systems No Wildlife Exclusion Fence

The use of standalone animal detection systems that cover long stretches of road are an important option under some circumstances. This option may be desired: in areas with multiple lateral access roads that would require multiple wildlife guards if there were fences; or where eight-feet (2.4 meter) high fence is not desirable, such as along adjacent private land; or where the terrain does not allow for fence construction. Implementing detection technologies over long stretches of road without fences is one of the most complex situations to overcome as the capabilities of the detection technology is pushed to its limits. Depending on the technology, several detectors may need to be linked together to cover the needed distance which can lead to a higher risk of equipment failure. Additionally, the potential for false positives or negatives increases as distance covered increases. Last, being able to properly locate and design the signs in a manner that gets the attention of drivers at the appropriate time increases in difficulty or expense as distance increases.

In some instances, areas of a mile or more may need to be covered, in these instances a radar based system may be the best option because it utilizes the least number of components versus linking together shorter distance technologies to achieve the same result. A radar based system was successfully implemented at two locations in British Columbia (**Figure D-57**, Sielecki 2017a). These systems can provide a potential option under the appropriate circumstances.

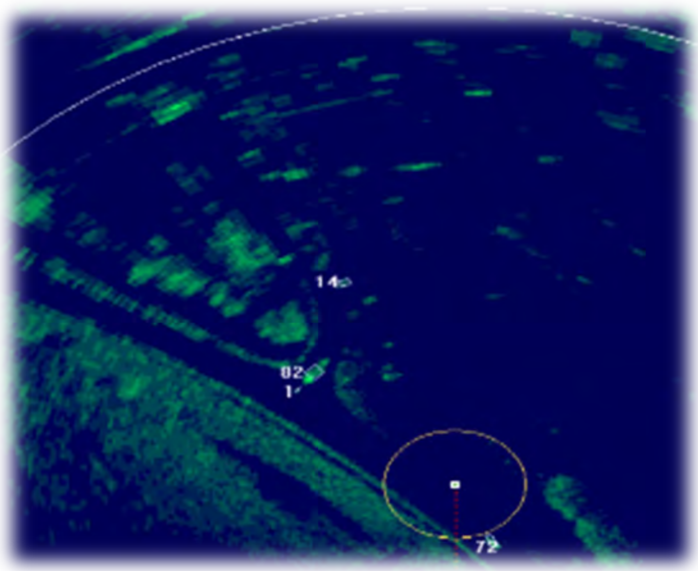

Figure D-57. Radar scatter plot detection of wildlife in depicted in Figure D-53. Photo Credit: CrossTek, LLC, and British Columbia Ministry of Transportation and Infrastructure.

Animal Detection Systems with Wildlife Exclusion Fence

Fences are a time proven method for keeping many wildlife species off roads and when combined with appropriately designed and located wildlife crossing structures provide a successful system for mitigation of roads on wildlife. At some point fences used to exclude animals and guide them to wildlife crossings needs to end, and can lead to animal end-run events, or concentrated wildlife crossings at the ends of fences. In these instances, animal detection systems can be used to alert motorists of wildlife presence as they cross at these fence termini. A working example of a detection system that addresses an end run situation was implemented in Arizona along SR 260 in 2007. The SR 260 system utilized thermal imaging technology (**Figure D-58**) to detect wildlife approaching the road at the end of the fence. This system combined with the exclusionary fences reduced accidents with elk by 97 percent and continually reduced motorist speeds for nine years. In 2019-2020 this system was upgraded to a more robust and accurate FLIR based thermal system (Gagnon et al. 2019).

Figure D-58. Left, screen capture of thermal camera image of elk cow and calf and motorist warning sign on Arizona State Route 260. Photo Credit: Arizona Game and Fish Department and CrossTek, LLC.

New Mexico DOT collaborated with Arizona Game and Fish Department and placed a similar wildlife activated FLIR based thermal sensor system with motorist warning signs along US 550 south of Cuba, New Mexico (**Figures D-59, 60**). These systems were part of a retrofit of existing bridges to guide wildlife under the road. The project was completed in 2019 and both driver behavior and wildlife use of the structures and fence ends were being monitored by Arizona Game and Fish Department and New Mexico DOT at the time of this writing.

Figure D-59. Wildlife activated driver warning system on US 550, New Mexico. Photo Credit: Arizona Game and Fish Department.

Figure D-60. Driver warning signs and electrified barrier at fence end on US 550, New Mexico. Photo Credit: Arizona Game and Fish Department.

Ineffective, Inconclusive, or Experimental Methods to Target Driver Response

There are methods to improve driver awareness of roadway hazards including the presence of wildlife. Some of these have proven to work in more human dominated settings, such as traffic calming actions. Other methods have little to no research to back their use for reducing wildlife-vehicle collisions. New technologies are also a way to help affect drivers to slow in caution in areas where wildlife-vehicle collisions are more likely. These approaches are presented below.

Objective

The goal of these treatments is to help keep drivers more alert to the dangers of wildlife-vehicle collisions. This can be done with illumination, traffic calming methods, opening lines of sight with a reduction of vegetation, telling drivers exactly where wildlife will be, and leaving it all to the smart car.

Traffic Calming

There are methods to reduce driver speeds. These include:

- Installation of a median with vegetation in two lane roads;
- Traffic calming striping to reduce the driver’s perceived width of the roadway, which is done by bringing the painted white line on the right edge of the road inward several inches or feet (Kahn and Kahn Goedecke 2011);

- Road speed tables, including temporary speed tables that could be placed during specific wildlife-vehicle collision periods; and
- Speed bumps or rumble strips.

Reduce Roadside Vegetation

Roadside vegetation can be trimmed or eliminated in areas where wildlife is known to cross the road and become involved in vehicle collisions. This would be especially important in areas where the road has abundant vertical and horizontal curves, or vegetation that grows adjacent to the driving lanes. In this type of roadway condition, motorists have a difficult time responding to hazards including wildlife hazards. It is also important to mow vegetation within the right-of-way, to help keep a visual landscape where drivers can see wildlife moving into the roadway. The effectiveness of road treatments to improve sight-distances for drivers with a resulting decrease in wildlife-vehicle collisions are difficult to quantify and inconclusive. A recently mowed right-of-way may be more appealing to deer, resulting in the unintended consequence of attracting deer to the roadside – fall regrowth may be less palatable than spring regrowth, and mowing can be timed accordingly. In addition, vegetation clearing may increase the barrier effect of the roadway for some species. Meisingset et al. (2014) recommend targeting vegetation clearing to short wildlife-vehicle collision hotspot segments in the late fall when vegetation regrowth has ceased; they found a 53 percent decrease of deer-vehicle collisions in winter in areas where road edges were cleared in fall. Targeted clearings may be most effective when used in conjunction with seasonal speed limit reductions through these hotspot segments.

Wildlife Crosswalks and Animal Activated Crosswalks

Wildlife crosswalks are an area where animals are allowed to cross roads at a discrete location that is defined by an area that warns drivers of the potential for wildlife presence as they approach that location. This method was used in Utah along US 40 south of Park City. Although animals were able to cross at this location there was no significant reduction in accidents, in part due to vehicle speeds over 50 miles per hour (80 kilometers/hour), and the size of the four lane, divided highway the animals had to cross (Lehnert and Bissonette 1997). These inconclusive results were primarily due to the lack of motorist response to the static warning signs. This method should be considered ineffective until further research is conducted

Crosswalks would be an unfair location for wildlife to become involved in motor vehicle collisions. For the best possible conductions for considering crosswalks, there needs to be: only two lanes of traffic; the speeds are below 55 miles per hour (88 kilometers/hour); the area is rural; and AADT is 2,000 vehicles per day or less for diurnal periods, and less than 8,000 vehicles per day for species that are nocturnal/crepuscular. Otherwise motorists cannot stop in time for an animal, and animals cannot find a break in the traffic to cross safely.

This method should be considered untested. Additional research is needed.

Roadside Lighting

In theory, street lighting may help drivers and wildlife to see one another in semi-developed rural areas. However, Reed and Woodward (1981) found highway lighting was not effective at reducing deer-vehicle collisions. This method should be considered ineffective until further research is conducted.

In Road Lighting with Solar Pucks

Raised Pavement Markers (RPM), can be adapted to provide lighting at the road level, and are known as solar pucks or Internally-Illuminated Raised Pavement Marks. These markers "enhance delineation and driver awareness, especially in low light conditions" (**Figure D-61**, Federal Highway Administration 2009). Their added purpose on rural roads would be to provide lights along the white line on the right side of the lane, and in the center strip that would illuminate if a large animal such as an elk, were positioned across one of these lines of light, thus a driver would be better able to evaluate the animal's presence. This potential use is not tested and further research is needed.

Figure D-61. Solar pucks installed in pavement of Interstate 70 in the mountains outside of Denver. Photo Credit: Fox Denver, KDVR.com.

On-Vehicle Lighting

Vehicle lights can illuminate roads allowing motorists to see wildlife alongside or crossing the roads (Mastro 2010). However, deer and other wildlife are known to “freeze” or act erratically when vehicle lights shine on them and can contribute to collisions. Although sample sizes are relatively low, recent research by DeVault et al. (2020) showed that rear-facing lights mounted to the front of a vehicle and aimed toward the vehicle to illuminate the front of the vehicle versus shining directly outward caused more deer to move out of the way of the vehicle versus animals freezing.

This method should be considered inconclusive but additional research is warranted.

Driver Phone Applications

Smart phone applications, such as WAZE inform drivers of immediate road conditions in real-time. A transportation agency could install driver warning public messages for a specific stretch of road, during specific times of year when wildlife movements make the risk of wildlife-vehicle collisions greatest. In turn, drivers could warn one another of live wildlife and killed wildlife in the road. These applications are more heavily used in the eastern U.S. These methods of warning drivers have not been tested for efficacy at reducing wildlife-vehicle collisions. However, Virginia DOT has experimented with these warnings, and collecting deer carcass data on WAZE (Donaldson 2017). More use and research are warranted.

In Vehicle Warning Systems

Volvo and other vehicle manufacturers are experimenting with infrared cameras on the vehicles feeding images to an on-board computer that then warns drivers of animals in the road and may even brake the car (Volvo’s system is called Pilot Assist II, Adams 2017). The Volvo Pilot Assist II can detect large animals from a distance of 656 feet (200 meters) via radar and camera components and alerts the driver with a loud warning and flashing dashboard lights (Cheng 2017). These in-vehicle systems have not been tested for efficacy in reducing collisions with wildlife. It may take several years for these systems to become used in high enough numbers to test their efficacy and safety.

Self-Driving Vehicles

Driverless vehicles are being developed with the above onboard camera systems that detect wildlife from the approximate size of a raccoon or a human toddler, and automatically brake or avoid hitting the animal or human. The combined work of citizens reporting wildlife on or near the road through smart phone applications, known wildlife-vehicle conflict areas programmed onto vehicle computers, and sensors in high wildlife-vehicle crash areas that could warn the vehicles of animals entering the roadway (another type of animal detection driver warning system) could all be used to create a more wildlife-friendly smart car. These systems are being developed and should become common enough in the near future to measure their efficacy in reducing wildlife-vehicle collisions.

Summary

These mitigation measures are the majority of what are used across the U.S and Canada, but are not inclusive of all types of approaches. This appendix is meant to add clarity to types of mitigation detailed in the manual, and to help agencies and their partners find the best solutions for specific challenges to getting wildlife beneath and above roads. Readers are advised to stay current of developing research and applications, through participation in conferences, checking the Transportation Research Board, TRID website (https://trid.trb.org/), and other avenues for learning.

Appendix E. Monitoring Plan Guide

A Monitoring Plan Structure

A thorough monitoring plan is essential to determine the efficacy of mitigation put in place to reduce wildlife-vehicle conflict and minimize habitat fragmentation. It is recommended that monitoring plans are created with a transportation agency in coordination with wildlife researchers. The partners can develop project-specific plans to conduct pre- and post-mitigation monitoring. Collaboration with experienced wildlife biologists is critical throughout the process.

The four major steps to monitoring and the inputs into a monitoring plan are presented in this appendix and depicted in the flow diagram, **Figure E-1**.

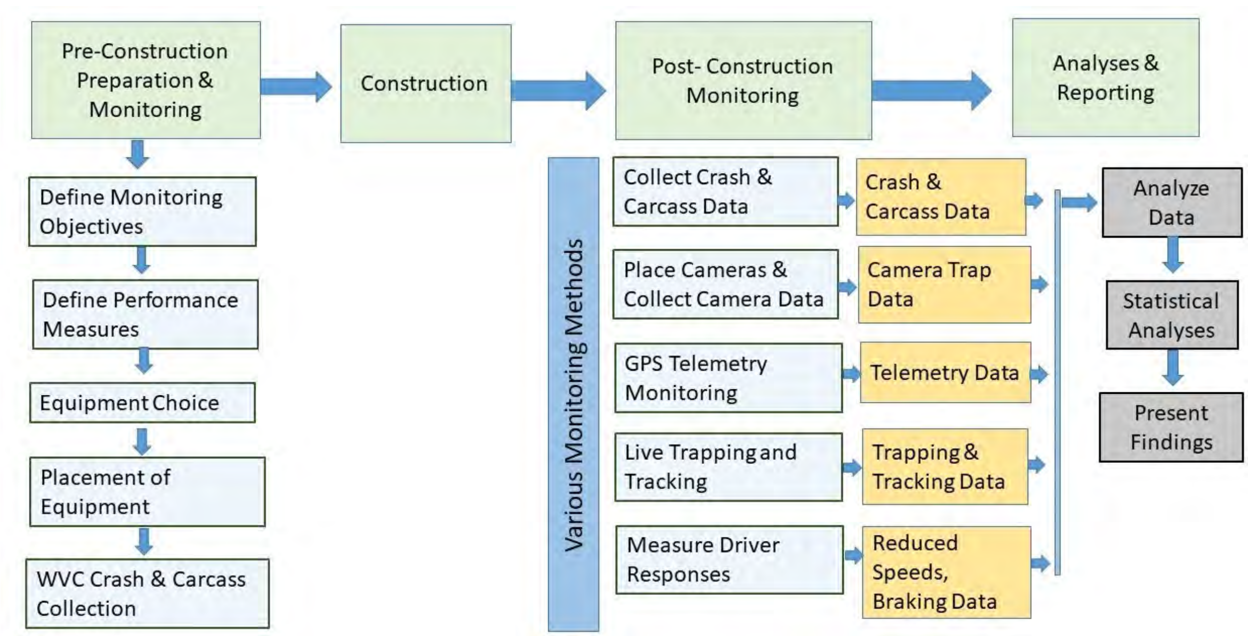

Figure E-1. Flow of steps to a monitoring program for evaluating wildlife movements in relation to transportation-wildlife mitigation.

Pre-Construction Preparation and Monitoring

Define Study Objectives

The goals of the mitigation project are defined as a first step in the process. The objectives can be seen as a series of questions, the first one being “What is the main objective of the study?" There are typically two main objectives in studying transportation-wildlife mitigation:

1. Did the mitigation improve wildlife species' ability to move across the road and landscape?

2. Did the mitigation reduce wildlife-vehicle collisions, making the road safer for motorists?

The following list of defining more specific objectives is provided below. The list is not exhaustive but presents the majority of objectives studied in transportation ecology.

- What is your question?
- What species of animals are expected to use the structures, including primary target species and other species?
- What species of small animals and species of medium to larger animals actually use the structure?
- Are the success rates through the structure for the species of interest high enough?
- What species are nearby but not using the crossing structure?
- What is the timing of species use of the structures and how does that use relate to migration and daily movement needs of those species?
- Determine if there are components of the structures, such as type, height, width, and length that are also being tested as gauged by different species' success and repel rates.
- Determine if the escape ramps are facilitating wildlife escape from the fenced right-of-way.
- Determine if the guards, wildlife and double cattle guards, are deterring animals from entering the fenced right-of-way.
- Determine the data and methods to be used to compare wildlife-vehicle crash and carcass data pre and post construction.
- If studying motorists' responses to animal activated detection system, select the various factors to monitor, such as reduction of wildlife-vehicle collisions, braking responses of drivers, reduced speeds, false positives and negatives (Gagnon et al. 2019).

Define Performance Measures to be Evaluated

The monitoring project is structured to address the various performance measures which are agreed upon prior to beginning monitoring. Performance measures should be specific and measurable; they typically delineate rates and numbers as the targets to reach. This list is not exhaustive but presents the major performance measures that are typically assessed in transportation ecology research. This list may be used as a starting point for developing specific performance measures for a particular monitoring study.

- Set minimal success rates, allowable repel rates, and other rates for various species of animals at the crossing structures that would be met in the final year of monitoring in order to determine the structure was "successful."
- Ask "What is an acceptable average daily number of successful passages of the target species through or over the structure over the course of the final year of monitoring?"
- In pre-construction monitoring, gauge the rate of animals crossing over the existing road without crossing structures. Set a goal for a permeability rate that the crossing structures should meet at minimum that exceeds that rate.
- Set use rates of the structures by all age classes and genders of a species, meaning, the permeability of the road with the structures for entire populations of species of interest. What is the degree of permeability desired for each target species – meaning how many animals of the species of interest use it on average each year, if all genders and age groups used the structure when they needed to move to both sides of the road, and in numbers comparable to the population nearby and moving through the area. Who uses the structure and when?
- Set a degree of permeability for post-construction structures based on telemetry data and maps of collared animals. These telemetry data can demonstrate animals using structures (See Dodd et al. 2007), permeability of the structures for all members of a population(s), and an increase in permeability post construction when compared to pre-construction.
- Set a bar of success for the reduction in wildlife-vehicle crashes, or carcasses or both, in the study area and outside the area.
- If studying deterrents such as cattle guards/wildlife guards, what percentage of deterrence is acceptable?
- If studying escape ramps, the two performance measures rates that would be set to acceptable rates would be: the ramps' rate of interception of animals moving in the

right-of-way near the camera; and rate of escape or jump off of animals photographed at the top of the ramp.

- Determine what the target decrease is in either rates or numbers, of animals moving around the fence end over time
- If monitoring motorists' responses to future driver warning systems and signs, define the goal of the reduction of motorists' speed, in response to sign warnings, percentage of reduced crashes with wildlife, the number of potential successful animal movements over the road, or other objectives of the system, such as rate of false positives and false negatives, days the system is in working order, or reliability of system in different conditions and over time, and time costs to maintenance personnel.

Select Equipment for Monitoring and Equipment Settings Based On Performance Measures

Identify whether the study is sampling animals and their movements, or conducting a census of all animals and movements in an area. This determines the equipment type, such as cameras and camera quality, pitfall traps for smaller animals, telemetry equipment, etc.

Figure E-2. Cameras on the Interstate 90 Snoqualmie Pass overpass recorded success movements by all ages and genders of elk. Photo Credit: Washington DOT.

If using camera monitoring, select the best quality cameras that the budget can afford and according to objectives. Multiple high quality cameras may be necessary for photographing all the animals at the site (**Figure E-2**).

If using cameras, the cameras' method of detection, such as infrared and thermal sensors, number of pictures per trigger, or video footage will need to be determined with respect to the monitoring objectives. If conducting a census of all animal movement, the trigger should have no down time, and pictures per trigger should be 3-10 depending on the number of animals and battery life of the camera.

If the objective is to live-capture smaller animals, selection of pitfall traps and live traps that match the species' sizes and modes of locomotion is critical.

If using Passive Integrated Transponder (PIT) tags, size and type are important for the target species, and using qualified wildlife personnel who can place these on and in the animals is crucial.

If using telemetry equipment, experienced wildlife researchers are necessary to help capture animals and place monitoring collars and other equipment on the animals. Selection of the type of telemetry tracking devices will involve costs, size constraints, and how many times a day the information is recorded.

Figure E-3. A pre-construction right of way camera recorded how often white-tailed deer succeed in crossing US 93 pre-construction in Montana, thus helping to estimate a pre-construction success rate across the road. Photo Credit: P. Cramer and Montana DOT.

Placing Camera Equipment

Placement of camera equipment can mean the difference in detecting wildlife accurately and missing many wildlife movements. It also effects accuracy in movement rates that later are critical to the reporting on how well the mitigation met objectives.

Camera Monitoring at Future Wildlife Crossing Structure Sites

For pre-construction monitoring, place cameras near the location of the future wildlife crossing structure, or the existing structures, or other mitigation, facing in a direction that animal approaches and movements can be captured.

Camera Placement Along the Road Right-of-Way

Pre-construction monitoring of the road and wildlife interface can help determine the successful passage rate over the road prior to the mitigation (**Figure E-3**, Cramer and Hamlin 2017). In turn, this rate can be used as the basis for creating a performance measure for improved successful passage and thus connectivity with crossing structures. Camera placement along roads can be a delicate operation of minimizing photographs of vehicles, protecting possible motorists who crash into the camera mounts, and protecting the cameras from theft.

Continually test the cameras' sensitivity to moving traffic nearby. Set the cameras' angles and sensitivity to avoid capturing vehicles passing nearby, to the greatest extent possible. If the area has less than 2,000 vehicles per day, it is possible to capture passing vehicles and the batteries to last one month until next camera check.

Trim vegetation that may grow and blow within the cameras' trigger range. If monitoring through the growing season, (especially the month of June), be sure to schedule a camera check with vegetation clippers, sling blades, etc. to cut back vegetation.

Placement of Live-Traps and Tracking

If using other methods to detect wildlife such as live traps and sand beds or general tracking, it is important to have an understanding of how the animals under consideration move and use the landscape. Place monitoring equipment in areas the animals are likely to use in the same methods described above. It is important to standardize these methods across space and time, for instance, with equal sized grid patterns for live traps, and equal sized track beds.

Determine a Consistent Approach for Wildlife-Vehicle Collision Data Collection

Prior to project implementation select what wildlife-vehicle collision data will be collected, based on the type of the project and species of interest and use the same approach before and after project completion. For example, standard crash data may suffice for large animals like elk but more thorough carcass/roadkill surveys may be required for smaller animals.

Where possible, collect data within the planned mitigated area at a minimum, but preferably beyond the extent of the mitigated area to identify the potential for increased wildlife-vehicle collisions at fence ends. Also collect data in control sections of road for where feasible. These control areas are where there is or will be no construction or changes to the road, and the landscape conditions and wildlife activity are relatively the same as the mitigation portion of the road. A control section of the same or another road area setup helps to discern if the changes between pre and post construction were a result of the mitigation, and not changes in traffic, animal populations, the landscape, or weather patterns.

At least two years of pre-construction wildlife-vehicle collision data collection is recommended to account for variation in seasonality and changes in precipitation that can affect crash rates. It is strongly suggested that crash data be the data of choice for discerning if wildlife-vehicle collisions were reduced although additional evaluations can be made using carcass data or roadkill survey data. The state or province or territory has many decades of data on crashes. Five-year crash analyses prior to construction is the standard used in transportation agencies and in research, and should be the goal of the monitoring study.

Telemetry Monitoring of Wildlife

Telemetry monitoring of wildlife prior to a wildlife mitigation project helps to determine how the animals used the landscape for comparison to how they used it post-construction.

Where possible collect at least two years but preferably up to five years of pre-construction GPS movement data to obtain baseline levels of highway permeability and distribution of locations where wildlife cross or approach the road. This is particularly important for species that show high road avoidance and low wildlife-vehicle collision incidence (see Dodd et al. 2010 for pronghorn movement study).

During Mitigation Construction

Most wildlife monitoring at or near wildlife mitigation does not take place during construction. However, larger transportation projects may be phased over time, and construction takes place in one area of the study while other parts are being monitored pre- and post-construction. (Cramer and Hamlin 2017, Kintsch et al. 2021).

Ensure Infrastructure is Constructed as Planned

This is not typically the role of wildlife researchers, but is important for wildlife professionals involved in the project to be cognizant of the construction activities.

Researchers should regularly consult with experienced biologists and planning and construction engineers to ensure mitigation components are constructed and implemented correctly, such as wildlife crossings, fences, escape ramps, and detection systems. Also, monitoring results from pre-construction can inform the construction phase and adjustments to the plans and designs.

Also coordinate with experienced biologists or monitoring teams so that any integrated monitoring equipment, such as built-in camera boxes and video surveillance systems are properly incorporated during construction.

Construction Phase Data Should Be Considered Separately

Construction activities affect traffic speeds and flow, wildlife movements, and the road bed. This phase should be considered outside of the comparisons of pre- and post-construction of any rates, such as wildlife-vehicle crashes. Camera monitoring and other monitoring methods are typically not initiated until after construction is completed.

Post-Construction Monitoring

Plan for the Five Year Time Line

Conduct long-term post-mitigation monitoring for at least three to four years, preferably five years to account for wildlife adapting to mitigation and seasonal or annual variations. If monitoring can be carried on past the five-year mark, the information could greatly contribute to the scientific literature of transportation ecology, and assist the transportation agency in adaptive management of the infrastructure over time. Another consideration is to re-visit a wildlife mitigation project several years after monitoring has ceased, to evaluate if the structures and other mitigation are working as planned.

Collect Crash and Carcass Data

Collect wildlife-vehicle crash and carcass data at the mitigation site and at areas of control sites using the same methods as for pre-mitigation. As with pre-construction data, five years post construction is preferred for a more robust analysis.

Monitor Wildlife with Cameras

Monitoring with cameras (camera traps) has been the standard method to evaluate wildlife movements by large and medium-sized animals at crossing structures and other mitigation features. Other methods for evaluating smaller wildlife movement are discussed in the Smaller Animals section below. Smaller animals are typically not detected by the motion sensors on cameras that are placed and set to capture large animal movements.

Camera Placement at Structures

Where appropriate collect camera or video data on use of use of mitigation features. Where appropriate collect approach and crossing information to determine success and failure rates. This is also applicable to wildlife escape ramps and deterrents.

Figure E-4. Wildlife researchers place a monitoring camera at the entrance to a wildlife crossing structure in Utah along US 89. Photo Credit: J. Gagnon.

A camera placed at each end of a culvert or on each side of a bridge that monitors wildlife approaches and movements into and out of the structures typically is sufficient to calculate success rates, rates of repellency, and parallel rates (**Figure E-4**). Some structures may be wider than the ability of the cameras to capture animal movement at night, which is typically about 30 feet (9 meters) (**Figure E-5**). If this is the case, additional cameras may be necessary to collect data most accurately. The goal is to have the camera trigger at its maximum range in night conditions, which could be greater lengths, while also allowing photographic analyses to detect animals at the structure that may ultimately repel from the structure.

Figure E-5. Monitoring camera is placed on steel post approximately 30 feet (9 meters) from entrance of structure on US 160 in Colorado. Photo Credit: P. Cramer.

Modern technology is becoming more available with monitoring cameras that can detect wildlife at greater distances than infrared and LED flash cameras currently most used to monitor wildlife. Thermal imaging cameras detect many animals, even medium-sized mammals up to a quarter of a mile (0.4 kilometers) away. These cameras cost several thousand dollars, and have to be highly secured to be in use. Washing DOT is using these thermal imaging video cameras to detect wildlife on an overpass and underpasses along I-90. See Chapter 4. Monitoring for a presentation of these new monitoring technologies.

Camera Placement at Escape Ramps

For escape ramps, place a camera along the ramp base in the right-of-way to detect animal movements and calculate rates of interception (**Figure E-6**), and a camera on the wild side of the fence facing the top of the ramp to evaluate escape rates. (**Figure E-7**, see Kintsch et al. 2021, Cramer and Hamlin 2019b).

Figure E-6. Animal movements near the base of the escape ramp and their movement over the top of the ramps were monitored by right-of-way cameras in Utah. Photo Credit: P. Cramer.

Figure E-7. Cameras on the wild side of the fence capture animal movements at the top of the ramp and wildlife movements inside the fence. These bighorn sheep escaped the road in Arizona. Photo Credit: Arizona Game and Fish.

Camera Placement at In-Road Deterrents

Cameras at in-road deterrents such as double cattle guards or wildlife guards need to be placed to record animals' initial response and final actions. The camera is placed to face the leading edge of the guard on the wild side or side where the animals are coming from to try and enter the road right-of-way. The goal of the camera angle is to capture animal approaches, and repel movements, and potential breaches and how the animals accomplished those breaches (**Figure E-8**).

Figure E-8. Cameras at deterrents are aimed at where animal behaviors are to be evaluated. Mule deer were repelled from this double cattle guard on US 191 in Utah. Photo Credit: P. Cramer and Utah DOT.

Place a Wild Camera to Assess All Wildlife Nearby

Additional cameras placed away from the crossing structures facing out toward the wild area are used to assess what animals are near the road but not approaching the structure. This camera is especially important for discerning if more reluctant species are present that are not using the structure. This camera is placed along the right-of-way fence, facing away from the road, and along the fence line, into the natural area. For instance, if elk are known to be in the area, but are not using the structure, which is a common problem, then the structure did not function as providing connectivity for elk. This is also helpful for detecting carnivores that may be nearby and not using the structure (**Figure E-9**). This has proven helpful in studies in Utah (Cramer and Hamlin 2019a), and Colorado (Cramer and Hamlin 2021, Kintsch et al. 2021).

Figure E-9. Cameras placed away from crossing structures and toward the wild area can reveal the presence of wildlife more reluctant to approach the road and structures, such as this black bear near US 93 in Montana. Photo Credit: P. Cramer and Montana DOT.

Protect cameras from vandals

Fortifications of cameras placed in these studies are needed to deter vandals. The camera will need to be locked to a part of the mount to prevent the camera, and its entire mounting from being stolen. See **Figure E-10** below. This entails locks with clasps protected, steel boxes, mounts on concrete structures, and mounts solidified in concrete in the ground.

Figure E-10. Camera mounting options: top left - on steel posts mounted in concrete; top right - on concrete wing walls of culvert; lower right - on posts of guard rails; and lower left – in a utility box, Photo Credits: top left – P. Cramer, top right J. Gagnon, lower right J. Gagnon, Lower left, P. Cramer.

Monitoring Small Wildlife

Small animal monitoring can entail the use of cameras, live trapping and marking with ear tags or PIT tags or placing telemetry transmitters on animals and releasing for telemetry monitoring, genetic sampling of small samples of the animals, environmental DNA analysis for detection of specific animal presence in aquatic environments, and road surveys for tracking carcasses. Monitoring structures for small animal is given an overview by Smith et al. (2015), Clevenger and Huijser (2011), and McDiarmid et al. (2012). Details of these approaches are presented below.

Overall, the digital cameras used as camera traps are the most commonly used technique to monitor small animals. Monitoring smaller animals with cameras entails special considerations to account for small body size, rapid movements (e.g. mice), or cold blooded body temperatures (amphibians and reptiles) that are not sensed by cameras that rely on thermal detection of the differences between the animal and ambient temperatures, or aquatic species which are also cold blooded and may not be restricted enough in their movements to be photographed.

In wildlife crossing structures and along fence lines, cameras need to be mounted just a few feet from the animals' passage locations. The camera can be programmed to take pictures at specific intervals for set amounts of time (time lapse) during the period the target species are expected. This amounts to approximately 20,000 photos in a two-week period. This is a sampling of the movements of animal, rather than more formal census approaches.

Figure E-11. Vermont Transportation Agency scientist checks monitoring camera at Vermont's Monkton Amphibian Crossing. Photo credit from the video: https://www.youtube.com/watch?v=1Q9U1oKv9

For example, in Vermont's Monkton amphibian crossing, the camera is set to take one photo per minute during the migration period. See **Figure E-11** for a web address link to short video on this set up.

Another camera method is to constrict the passage area to force animals over a trigger device. There are several methods. Hobbs and Brehme (2017) created a system that employs a Hobbs Active Light Trigger (HALT) trigger that is coupled with digital passive infrared (PIR) cameras designed to detect small animals and even insects traversing small tunnels, narrow trails, and areas along drift fences.

Another such camera method is the Adapted-Hunt drift fence technique (AHDriFT) which uses drift fences to channel animals into modified Hunter traps under a passage PIR sensor that can more accurately detect an animal inside the trap than in a natural setting. See Amber et al. (2021) for how these have worked for small mammals and herpetofauna.

Small animal photo booths are also used. The overall concept is to provide an enclosed space in a wildlife crossing structure to monitor structure success (see Colorado example below), or near structures to evaluate species presence on either side of the road.

Kintsch et al. (2022b) adapted these techniques to construct small mammal photo booths along linear cover features designed to promote small fauna passage through large wildlife crossing structures (**Figure E-12**). The photo booths were positioned near the middle of a structure with a camera positioned to look into the photo booth. Wildlife using the cover feature triggered the camera's motion sensor. The cameras took video instead of still photos to assist in the identification of species that may move rapidly across the camera's field of view. The assumption is made that an animal detected in the middle of a cover feature can cross all the way through to habitat on either side of the structure.

Figure E-12. Small mammal photo booth designed to capture small animals using habitat cover features through a large underpass. Photo credit: J. Kintsch.

Bucket photo booths entail placing small containers, such as five-gallon buckets with an entrance and exit hole at the base. Bait is placed in the bottom, and a motion triggered camera is mounted to the ceiling, facing down to the bottom and bait. Small animals (typically mammals) attracted to the bait trigger the camera and are photographed while inside the bucket or "photo booth." This allows for a sampling of species present in an area, and possible inside a crossing structure.

Road Surveys are the most common method to asses where amphibians and reptiles are experiencing road mortality. See Langen et al. (2007) for a description of methods.

Genetic sampling of carcasses of animals along the road or blood or tissue samples from live animals can be taken to determine genetic factors of the population such as genders and age ratios, genetic heterozygosity, and overall genetic distinctness.

Pitfall traps are a series of small buckets buried in the solid with a drift fence along a transect, which can force certain animals traversing the fence to fall within the buckets. The traps must be checked at least once a day. See Pagnucco et al. (2012) for how these were also used at the entrances to crossing structures.

Mark recapture studies involve capturing animals and inserting PIT-tags into the animals, placing ear tags on mammals, or notching scutes on turtles (see Robertson et al. 2013), placing a visible implant elastomer (see MacNeil et al. 2011) in salamanders, and using image-recognition software.

Radio-telemetry and passive data loggers with PIT-tag readers can be used to monitor animals with a hand-held receiver. Passive data loggers and PIT tag readers can be mounted near or at the crossing structure entrance to record wildlife movement into and out of the structures (James et al. 2011).

See the Washington Interstate 90 case study in Appendix A. Case Studies for how many of these methods were used to monitor smaller animals use of wildlife crossing structures.

Gunson et al.'s (2016) manual, "Best Management Practices for Mitigating the Effects of Roads on Amphibian and Reptile Species at Risk in Ontario" is a highly regarded guide and we refer the reader to use it if more interested in smaller animal monitoring (**Figure E-13**). In their monitoring recommendations, they describe the approach for assessing how smaller animal populations are surviving pre- and post-construction mitigation. The goal is to make sure a population is at least stable, or if it is decreasing or increasing as a result of the road mitigation.

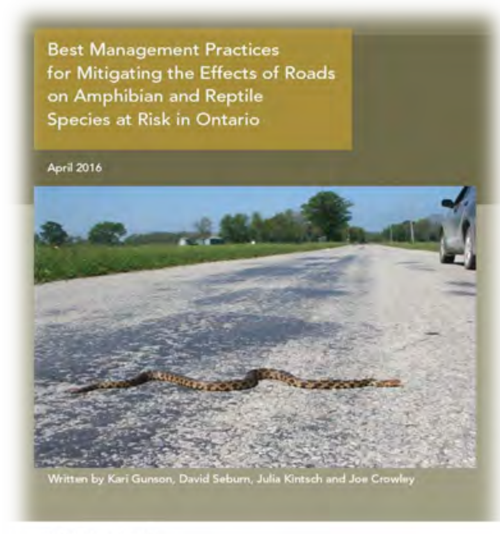

Figure E-13. Ontario's Best Management Practices guide for mitigating for reptiles and amphibians.

The first step is to measure the population size of the various species affected by the road and selected as target species for the mitigation. It is important for assessing the viability of populations affected by the road pre- and post- mitigation. As an example, the authors mention breeding females' ability to access breeding sites, and if they do not use the crossing structure or existing culverts or bridges that new wildlife exclusion fence has been placed to, this could lead to reduced breeding success and population declines.

Measuring the population for an estimate of its size pre and post mitigation can be conducted using one or combination of the above methods.

Mark-recapture studies where an animal is tagged with a marking or device have traditionally been used, but dozens to hundreds of animals need to be marked to create a statistically sound estimate.

Abundance surveys, which provide a count of animals per unit area standardized by the search effort, can be conducted over space and time to allow for pre and post mitigation comparisons. These are conducted using a standardized approach in the landscape and over time, such as visual searches for the species, or cover boards for snake snakes and salamanders.

Call surveys for frogs and toads can be conducted near the road (Eigenbrod et al. 2008).

If it is not possible to measure the change in the population size, the research question should ask, "Is the current rate of mortality on the road sufficiently low, and/or is the rate of use of crossing structures sufficiently high to ensure population viability?" If the population(s) cannot be assured of viability, then researchers and transportation professionals should ask, "What factor of the road, traffic, or mitigation structure and fence should be modified to improve survival and viability to levels that are acceptable?" To answer this question, roadkill/carcass surveys should be conducted pre and post construction to ascertain carcass rates and species and age classes affected and monitoring of the structures with cameras and other methods should be conducted to determine crossing rates and best structure designs.

Gunson et al. (2016) recommend at least a three-year time period for both pre- and post-construction monitoring, but this should be adjusted based on the ecological response and target species characteristics.

For further reference, the book, Roads and Ecological Infrastructure: Concepts and Applications for Small Animals (Andrews et al. 2015) presents many ways to monitor, retrofit, and build crossing structures for smaller animals.

Telemetry Data Collection

Telemetry data collection is another very accurate method to detect how animals move in relation to the road. The way in which researchers capture and track animals is not covered in this manual. However, there are references to several studies, particularly in Arizona, where researchers have placed GPS collars on wildlife to track their movements near roads. Where possible collect additional GPS movement data to assess levels of post-mitigation highway permeability and distribution of crossing locations. If GPS movement data were collected pre-mitigation, then permeability can be compared to determine if any changes occurred in highway. (See Gagnon et al. 2013, 2014, 2017).

Analyses and Reporting

Once the data are collected, the difficult portion of monitoring begins. This includes the tasks of categorizing and analyzing thousands to millions of photos and/or telemetry data points, along with crash or carcass data. How the data are analyzed and presented are important; the results could empower or detract from a wildlife mitigation program. The scientific investigators will need to be completely truthful and present multiple views of looking at the data and results, and what they mean for future wildlife mitigation. In this section we present how photo analyses should be conducted, how telemetry data can be analyzed and presented, how smaller animal studies present data, and how statistical analyses have been used in the past to analyze wildlife and wildlife-vehicle collision data.

Photo Analyses

Rates of Structure Use

Photo analyses have traditionally been conducted by wildlife ecologists parsing through the photographic data. While automated tasks can relieve the burden of initial photo processing, much is to be learned from careful review of the wildlife images. Animal reactions, interactions, and counts of each animal's behaviors, should all be viewed by trained wildlife scientists who are able to interpret these behaviors.

To capture success and failure rates (also called successful passage and repel rates, respectively), one must capture the number of animals that approach a feature and the number that actually use the feature or are repelled by it. Dividing the number of uses by approaches calculates the success rate (successes/approaches = success rate). For example, if 100 deer approach a culvert and 50 deer actually cross through the culvert you have a success rate 0.50, which can also be interpreted as 50 percent. If repelling or deterring animals from entering the road, the failure, or repel rate is essentially success rate and can be more informative with these infrastructure. For example, if you are monitoring deer breaching a cattle guard to access the road right-of-way and 100 deer approach the guard and 10 deer cross the guard, the repel rate is 0.90 (1- 10 crossings/100 approaches), which can also be translated as a 90 percent repel rate.

These rates not only help normalize wildlife response to measures to provide a consistent comparison they also work across different population densities of the same species. For example, if you have an area with a higher density of deer and 1,000 deer approach an underpass and 300 deer cross through the underpass, you have a 30 percent success rate. However, in an area with lower densities you only document 30 deer using a structure and 100 deer approach the structure you have an equally effective structure with a success rate of 30 percent even though one structure has 10x the number of crossings as the other. The conclusion that the structures used by 30 deer and 300 deer were equally effective would have been impossible without collecting rates versus simple counts of the structures' use.

It is important to also consider wildlife responses to the structure that are just parallel movements of animals that did not intend to use the structure. Although these rates are typically somewhat around 10 percent and lower (Cramer and Hamlin 2019a, Kintsch et al. 2021), it is still important to document animals grazing or walking along the fence line and past the structure rather than trying to move through a structure.

Success and failure rates are especially important for smaller structures, novel features, or species where little to no prior research has been conducted on their use of crossing structures. There are instances however when detailed monitoring data may not be cost-effective, such as at large viaducts and bridges spanning the natural area. In these instances, simple documentation of use still provides a relative measure of success that can be compared to nearby structures within the same wildlife population densities.

Also, in many cases with structures like large bridges over streams, there is already enough evidence collected in the field of road ecology that supports their use as passages for most wildlife species and simple use of the structure provides estimates on number and species richness at the structure. Species richness information is useful for comparison to species data collection away from the road to identify species are present but may not be approaching the structures (**Figure E-14**).

Figure E-14. Example from New Mexico monitoring of smaller culvert where capturing both approaches and crossings of deer and other wildlife was beneficial to furthering knowledge of the success of mitigation measures (left); and a larger structure that will generally pass most local species.

Rules for Analysis

Photographic data analyses require decision rules to consistently interpret photo data. Below are rules that have been used to evaluate millions of photos in past studies.

- Define an event from camera trigger to end of the series of photos, or time limit, such as 15 minutes or one hour (see Cramer and Hamlin 2019a, and Kintsch et al. 2021).
- Determine the difference between repel and parallel movements (Cramer and Hamlin 2017, 2019, Dodd et al. 2007; Gagnon et al. 2011).
- Determine how groups of individuals will be recorded, such as how many were successful in the movement through the structure and how many were not; if the genders and ages of the animals will be recorded, if known, and what genders and age classes were successful and what were not. This will be important for more rare species like carnivore mothers with young. (Cramer and Hamlin, 2017, 2019, and Kintsch et al. 2021.)
- Determine whether origin of the direction of travel by individuals is important and record if so.
- Define human events, and how many humans, how long they stayed, and if they had dogs with them in the rules, which will allow for a human influence analysis. (See Gagnon et al. 2011).

Presenting Data

The number of successful passages (success movements) of the target species can be presented with respect to the total movements (total approaches) of the species detected at the entrance on a weekly or monthly basis. This allows the reader of reports to understand the percentage of successful passages, changes over time as animals adapt to the structure, and numbers of successful passages on a weekly or monthly basis, **Figure E-15** below.

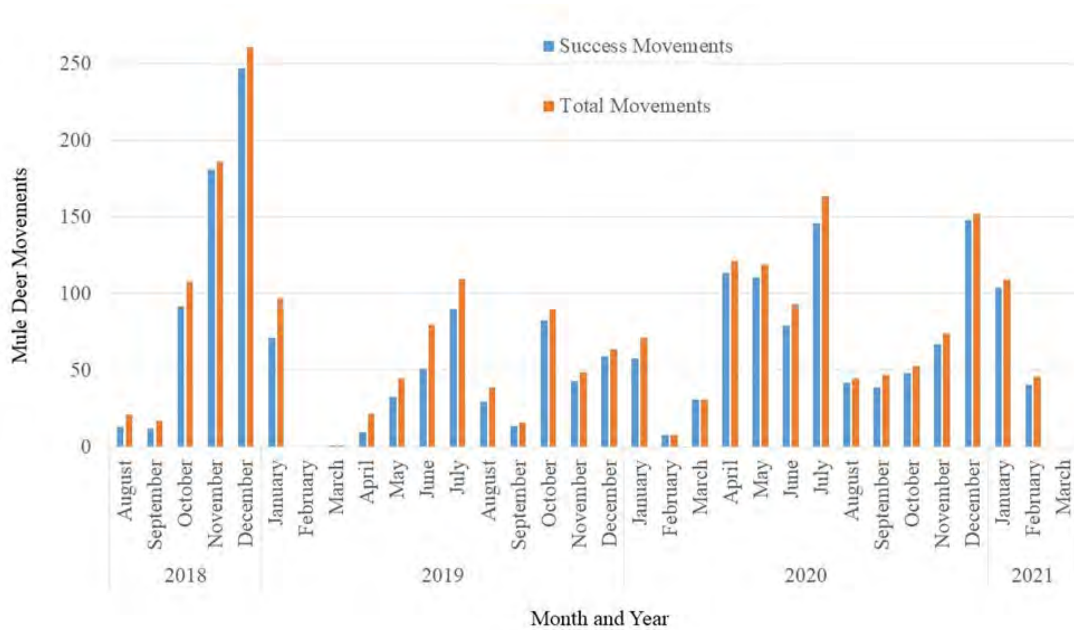

Figure E-15. Figure representing the number of total mule deer movements and success movements each month of a study of a wildlife crossing structure on US 160 in Colorado. Figure Credit: P. Cramer and R. Hamlin, 2021.

Species' use of different crossing structures in a study can be presented in one figure that allows comparisons of how many times the target species used the structure. This display can show what areas of the landscape may have more animals and thus why more were at certain structures, changes in use over time, and a comparison of structure types, such as use of underpasses versus overpasses, see **Figure E-16** below from Kintsch et al. 2021.

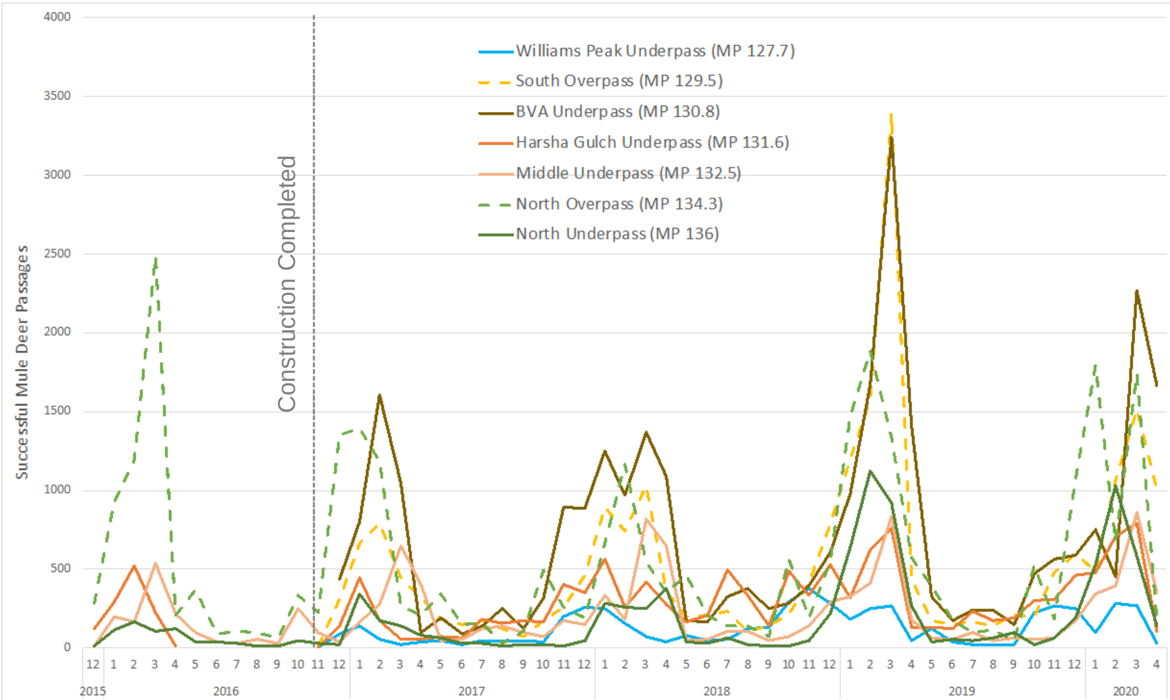

Figure E-16. Successful mule deer passages by month and year at each of the wildlife crossing structures over the five-year study period in the Colorado SH 9 Wildlife Monitoring Study. Figure Credit: Kintsch et al. 2021.

Before and After Comparisons

Several post-construction rates can be compared to pre-construction rates in camera studies. This includes comparing the number of approaches or movements in an area over time of various species, to evaluate if the structure accommodated all species detected pre-construction and how often they moved over the road pre-construction compared with post-construction use of structures. It can entail comparing pre-construction road crossing success with success rates through structures.

Telemetry Data Collection and Presentation for Pre- and Post-Construction Monitoring

GPS telemetry data can help to determine the effectiveness of wildlife-highway measures at the road interface and at the landscape-level. These data may also be used to assess the effects of traffic on wildlife passage rates and the distribution of wildlife adjacent to the highway (e.g. road-effect zone). Where possible, collect GPS movement data to assess levels of mitigation highway permeability and distribution of locations where animals crossed the road pre- and post-construction; permeability can be compared to determine if any changes occurred along the highway. (See Gagnon et al. 2013, 2014, 2017).

Dodd et al. (2007) was one of the first studies to utilize GPS telemetry to determine highway crossing locations of animals which were inferred from lines connecting consecutive GPS fixes taken every two hours. Where those lines crossed the highway in a 0.1 mile (0.16 kilometer) segments were highlighted. Passage rates and metrics of permeability were determined by comparing the number of times the collared animals approached to within 0.15 miles (0.24 kilometers) of the highway to the number of times the animal crossed the highway. Dodd et al. (2012) used a Before After Control Impact (BACI) approach (described in a section below) to evaluate elk adaptation to mitigation along SR 260 in Arizona by comparing passage rates, or proportion of successful crossings to approaches, throughout different phases of construction. This project showed an increase in passage rates as structure density increased. A similar approach was used by Gagnon et al. (2017b) for desert bighorn sheep along US Highway 93 that identified a 1,367 percent increase in passage rates along a newly constructed 4-lane divided highway compared to the previously unmitigated 2-lane road.

At the landscape scale it is important to understand the impacts of roads on migration corridors and the corresponding effectiveness of wildlife crossings. Methods like those used for Migration Mapper (https://migrationinitiative.org/content/migration-mapper) that utilize a Brownian bridge movement analysis of GPS collar data and a prioritization-based on the number of animals migrating through specific areas can help determine mitigation effectiveness by showing impacts or improvements to movement corridors.

Presenting GPS Data

GPS collar data should be presented in a manner that supports the objectives and performance measures of the study. For example, if the study examined the extent the road and traffic caused habitat fragmentation and restrictions of wildlife movements, a map of locational data displaying the lack of movement over the road may help elucidate the road and traffic effect more than the entire report. See the **Figure E-17** below from Dodd et al. (2010) in Arizona.

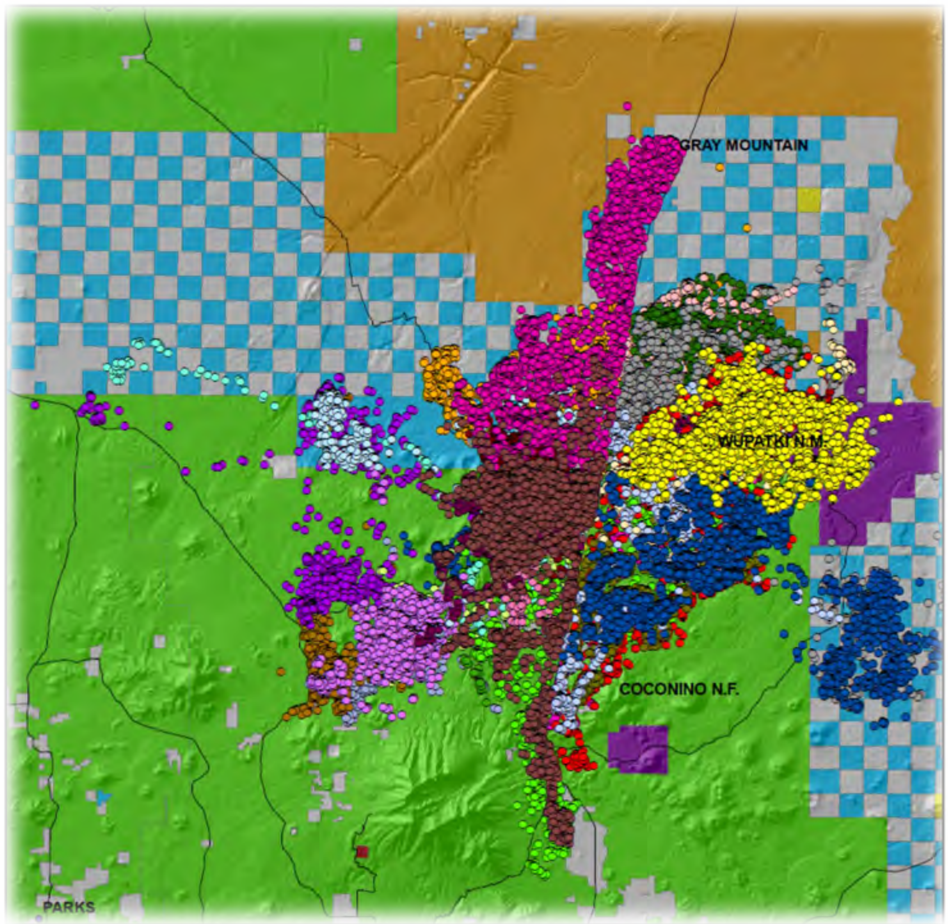

Figure E-17. Distribution of GPS fixes for 37 pronghorn accrued from 2007 to 2008 adjacent to US 89, Arizona. Each color represents an individual collared pronghorn. Figure Credit: Dodd et al. 2010.

GPS locational data of animal approaches to the highway can be displayed on a graph to help elucidate the most important mile post locations for wildlife to be accommodated with wildlife crossings structures. **Figure E-18** below is taken from Gagnon et al. 2013 on collared elk movements near Interstate 17, for both approaches and approaches with a weighted frequency. These types of graphs are instrumental in placing the wildlife mitigation in the best locations for wildlife.

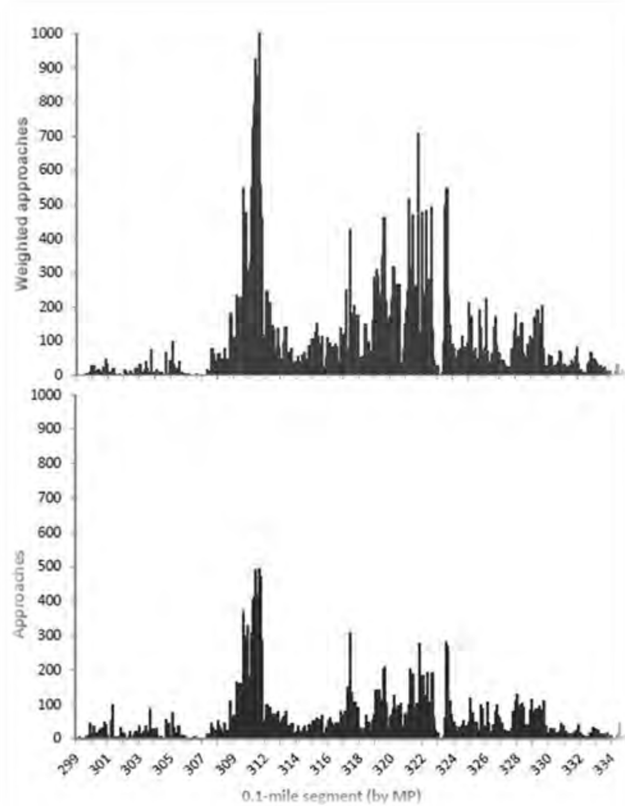

Figure E-18. Approaches made by GPS-collared elk to within 0.15 mile (0.24 kilometer) of Interstate17 (bottom) and SDI weighted approach frequency, (top). MP equals the mile post of Interstate17. Taken from Gagnon et al. 2013.

In the case of traffic-sensitive species such as pronghorn, which were found to seldom cross highways, (and thus seldom involved in wildlife-vehicle collisions), approaches to the highway within a 0.15-mile (0.24 kilometers) distance were calculated. The locations were displayed on a GIS map with bar graph representations at the locations where animals approached the road, which helps the reader of reports see exactly the top areas for wildlife. In **Figure E-19** below, Dodd et al. (2010) placed colored bar graphs along US 89 where collared pronghorn came near the road.

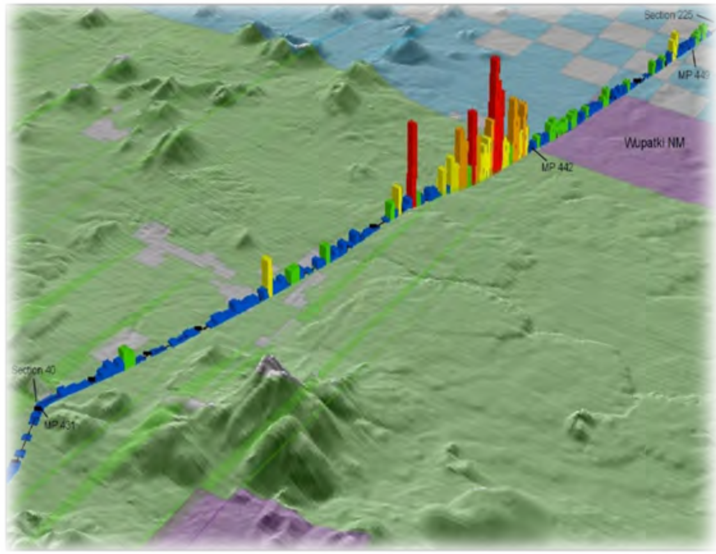

Figure E-19. Combined frequency distribution of 0.1 mile (0.16 kilometer) segments of weighted approaches to US 89 by 31 collared pronghorn on both sides of the highway. Figure Credit: Dodd et al 2010.

Pre-construction monitoring of where wildlife move on the landscape can be used to present where biologists recommend wildlife crossing structures, as Arizona Game and Fish biologists have done over multiple studies, as seen in **Figure E-20**.

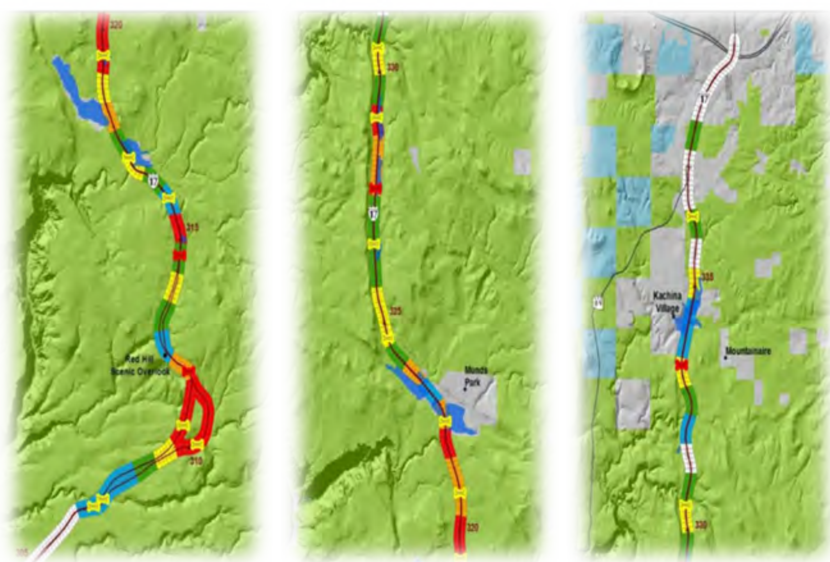

Figure E-20. Interstate 17-recommended wildlife crossing locations based on elk movement data and biologists' expertise. Hotter colors such as red delineate areas where elk most often approached the highway and hourglass shapes denote recommended future wildlife crossing structures. Figure Credit: Gagnon et al. 2013.

Mapped data points of wildlife movement post construction in the mitigation project area can display how successful wildlife crossing structures can be in facilitating animal movement to both sides of a highway. In Arizona's State Road 77 or the Oracle Road mitigation project, Arizona Game and Fish Department's monitoring of mule deer with GPS collars was able to demonstrate how several mule deer were using the new overpass and underpass to cross the highway. The GPS collared animals to the north of the mitigation structures were much less successful in crossing this four-lane highway at grade (**Figure E-21**). The GPS data alone could not confirm use of crossing structures by collared animals; however, the increase in collar data points on both sides of the road near the overpass and underpass, combined with photographic data at the structure cameras, (displayed in black and yellow triangles) did confirm that these animals were using the crossing structures to access habitat on either side of the road.

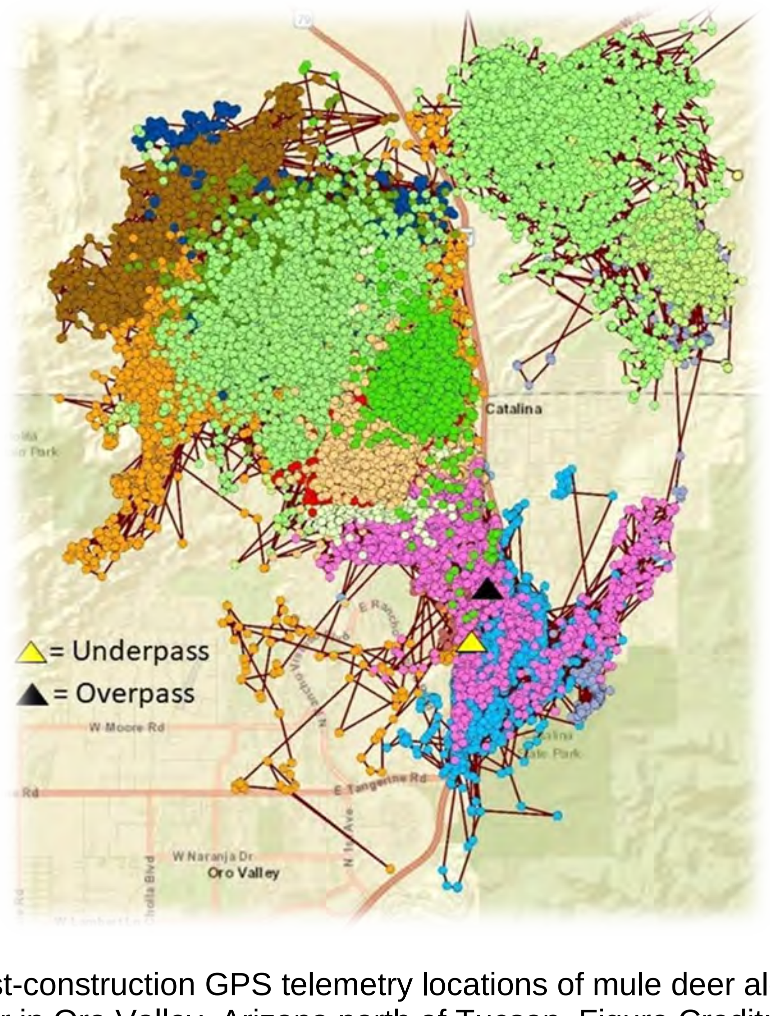

Figure E-21. Post-construction GPS telemetry locations of mule deer along the State Route 77 corridor in Oro Valley, Arizona north of Tucson. Figure Credit: J. Gagnon, Arizona Game and Fish Department.

GPS telemetry also allows for the comparison of wildlife crossing patterns and passage rates before and after wildlife fencing is erected along highways to limit at-grade (across the road) movements and link wildlife crossing structures (Gagnon et al. 2010, **Figure E-22**).

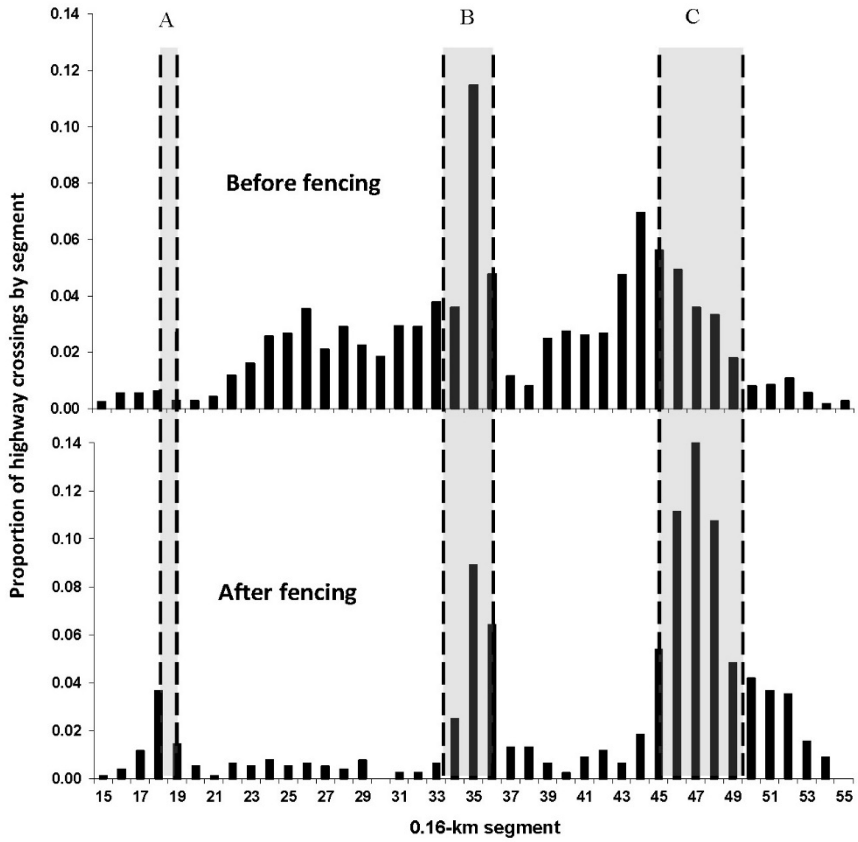

Figure E-22. Distribution of elk highway crossings by 0.1-mile (0.16 kilometer) segment along the State Route 260 before (top; 2002-2005) and after (bottom; 2006-2009) fence was erected to limit elk at-grade crossings. Light gray shading denotes the locations of the wildlife crosswalk.

Statistical Analyses

For large studies with large enough sample sizes, statistical analyses of the data are helpful for providing credence to the results or teasing out the relationships, for example, between crossing structure characteristics and wildlife responses. A knowledgeable statistician in academia, within the agency, or as a consultant should be consulted at the onset of the study to allow for robust statistical analyses.

These statistical analyses rely on how wildlife movement data were categorized, photo analyses of wildlife use of multiple similar structures monitored, and variables measured that may affect effectiveness of the mitigation. For photos, linear regression is often used to assess wildlife use responses to different types of structures (Cramer and Hamlin 2017, Dodd et al. 2012), and generalized mixed models can be used to also discern effects of various factors (Kintsch et al. 2021). Generalized mixed models can also be used as a statistic for analyzing crash data with a BACI analyses (Cramer and Hamlin 2017). Reporting p-values and other indicators of the strength of relationships is important.

Before After Control Impact (BACI) Crash Analysis

BACI analysis may be used to compare changes in crash rate between pre- and post-construction in the control sections, with the same crash rate change between pre- and post-construction in the mitigation section (e.g., Cramer and Hamlin 2017, 2019a, Kintsch et al. 2021). An easy mistake is to place the control section at the fence end. This area is not a control, but rather a place to further examine for increased crashes with wildlife moving around the end of the fence and crossing the road. A control area is some distance down the road from the fenced mitigation area, or a nearby similar road, dependent on the size of the animals and how far they move.

For example, Colorado's US 160 wildlife mitigation project east of Durango was evaluated for changes in wildlife-vehicle crash rates in and outside the mitigated area, with the outside control area 1/10th of a mile (0.16 kilometer) from the fence ends (Cramer and Hamlin 2021). The crashes/mile/year were calculated for each section for the pre-construction period and post-construction period. The changes in rates from pre to post construction were then compared for each control section with respect to the mitigation section, **Table E-1**. Statistical analyses, with either high level statistics such as generalized linear mixed models, or a simple T-test (as was this case) can help determine if the changes in crash rates among the controls and mitigation were significant enough to confidently say the mitigation was the cause of the differences. In this Colorado US 160 example, the pre-construction crash rate was different from the post-construction crash rate in the mitigation section ($p = 0.11$); and the crash rate changes between pre- and post-construction in the west and east control sections were different than the crash rate change between pre- and post-construction in the mitigation section ($p = 0.12$, West; $p = 0.16$, East). There was good evidence that the change, decrease, in wildlife-vehicle crashes in the mitigation section was due to the wildlife crossing structure and fence. These analyses are becoming more common with every wildlife mitigation monitoring project.

Table E-1. Wildlife crashes per mile (1.6 kilometer) per year and changes in wildlife crashes in a section of road mitigated for wildlife. From Cramer and Hamlin 2021.

Time Period	West Control Wildlife Crashes per Mile per Year	Mitigation Wildlife Crashes per Mile per Year	East Control Wildlife Crashes per Mile per Year
Pre-construction	4.4	4.0	4.9
Post-construction	3.2	1.8	3.7
	Change = -1.2	Change = -2.2	Change = -1.2

In some instances, BACI studies can be impractical or unattainable because a project may already be completed or sufficient controls sites are not available. Where possible, at least one of the comparisons of the mitigation site pre- and post-mitigation (Before-After), or to sufficient controls (Control-Impact) is the next best option.

Reporting and Communicating Results

Periodic and final reports for monitoring studies should present various pieces of information important to both ecologists and transportation planners and engineers. The reporting of the reduction (or lack of reduction) of wildlife-vehicle collisions has not always been included in monitoring studies in the past, but is an important part of the evaluation of mitigation projects. The effectiveness of the structures in promoting wildlife passage, and the fence and wildlife deterrents in preventing wildlife access to the fenced mitigation road area are all important to the teams who created and maintain those structures. Monitoring results help in the adaptive management of all components of the mitigation monitored. This can mean changes to the substrate in the wildlife crossings structure, removal of barriers near and in the structures, trimming vegetation, placement of additional fence and wildlife crossing structures, adaptations to the deterrents and escape ramps, changes in the timing of human activities such as hunting nearby to assist wildlife in their migrations and movements, and many other aspects. Monitoring can become a standard part of creating wildlife mitigation. With predetermined performance measures, the monitoring process can help transportation departments meet the letter of a transportation law and thereby help ensure future funding. Lastly, monitoring reports help wildlife ecologists and transportation professionals create the most cost-effective and ecologically effective wildlife crossing structure that help protect wildlife and the traveling public from future wildlife-vehicle collisions.

Monitoring reports may also include an evaluation of the costs and benefits of a mitigation project, which help in demonstrating how upfront mitigation investments can result in an overall cost savings to society over time (see Kintsch et al. 2021).

Communicating results in interactive on-line formats for the public to learn more is also important if there is funding for such endeavors. In British Columbia, the BCMoTI Wildlife Program displayed the results of thousands of camera trap data on mule deer use of structures through a video showing changes over time, (see Sielecki 2020).

Summary

This monitoring plan provides broad overviews on the various types of methods used to monitor wildlife mitigation, data analyses, and presentation of the results. Readers with a need for greater details can consult the authors of the manual or the literature referenced. Multiple guides, manuals, and websites can also help with these efforts.

Nevada Department of Transportation

Kristina L. Swallow, P.E. Director
Ken Chambers, Research Division Chief
(775) 888-7220
kchambers@dot.nv.gov
1263 South Stewart Street
Carson City, Nevada 89712