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Roadside Laboratories and the Road Effect Zone

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I Executive Summary

Roads and road networks have environmental impacts that vary in type and degree based on the physical properties of the roadway, the activities associated with the road, and the sensitivity of the local environment. The local environment affected by the road surface and traffic has been termed the "road effect zone". Although there is a rapidly growing literature on specific environmental impacts within this zone (stormwater runoff effects, biological invasions, noise, wildlife barriers), there have been few tests of the extent of the road effect zone, how various impacts are interrelated, and how these impacts could be minimized through pavement and roadside management activities. The objectives of the proposal are: 1) To develop a long-term integrated experimental site at the newly-established UC Davis Advanced Transportation Infrastructure Research Center, and 2) To establish a modeling framework for future research on the road effect zone, with special emphasis on defining parameters of relevance for California road systems, but with methodologically broader applicability.

Transportation System Management Relevance

At present, researchers and practitioners lack a methodology for assessing the whole range of impacts of road improvements and for balancing the different mitigation and management methods possible at the corridor–level. This research would provide the methodology for transportation, environmental and resources practitioners to protect and enhance the road side environment in planning and project delivery of transportation infrastructure.

II Background

California's road networks create multi-functional local environments that can be proactively managed for air and water quality, the most effective use of plantings, habitat management, soil types and stabilization, maintenance, fire management and vehicle safety considerations. Roadsides can provide safety shoulders for motorists, roadside plantings that filter toxic pollutants from stormwater run-off and protect our water quality, safe crossings for wildlife, plantings that prevent the spread of invasive species, and wetlands restoration that provides waterfowl and native plant habitat. Achieving such complex, multi-functional, roadside environments will require collaborative research on pavement properties, hydrologic and microclimatic interactions, soils, plant and animal community dynamics, and optimal maintenance technologies.

A Road Ecology

There are many and varied effects of roads and road systems on the natural and human environment; road ecology is the investigation of these effects. Because of the range of effects, road ecology intersects many scientific disciplines and planning arenas and is primarily an applied science or mixture of sciences. The scientific and technical literature, and more recently a book called "Road Ecology" (Forman et al., 2003), have provided definition to this growing field. The complete and geographically extensive set of road effects can be conceptually modeled for a generic road segment or road system, providing a mechanism for both anticipating and retroactively examining the affected area. The part of this affected area that is most likely to be affected by roads and their use is the immediate road-side environment. Transportation agencies often focus on this area because it is within their right-of-way and under their immediate management control. An important scientific and management question is how the ecological effects roads scale up from the square meter-scale of the road-side to the thousands of square kilometers of landscape affected by statewide transportation systems.

The extent, intensity, and types of road effects vary with road/highway type, traffic use, and ecosystem context. Road effects on aquatic ecosystems can consist of chemical inputs to waterways (Gjessing et al., 1984; Hoffman 1981; Bell and Ashenden 1997; Ziegler and Giambelluca 1997), alteration of aquatic community processes (Wilcox 1986; Maltby et al., 1995), impacts upon the physical characteristics (e.g., channelization) and processes of stream systems, and their ability to recover from land-use impacts (Meyers and Swanson 1995). Riparian roads can cause reduced riparian bird species richness and density (Rottenborn 1999) and overall species richness in wetlands (Findlay and Houlahan 1997). Roads can also affect terrestrial biodiversity directly through loss of habitat and increased mortality, as well as indirectly by causing ecological changes in the "road-effect zone," hindering habitat connectivity and fragmenting habitat patches (Jonsen and Fahrig 1997, Chapin et al., 1998, Rosenberg et al., 1999, Baker and Knight 2000). Road and land development can cause fragmentation with varying impacts (Yahner 1988, Theobald et al., 1997, Lidicker 1999). Fragmentation and disturbance impacts from roads may exacerbate threats of extinction from other factors through impacts on migration and habitat quality (Fahrig 2001). Not only do roads create artificial habitat edges, but they also pose a barrier to species dispersal and migration through aversion effects ("habitat alienation", e.g., Mac et al., 1996), direct mortality from traffic (Madsen 1996, Putman 1997, Rubin et al., 1998), and traffic noise-induced effects (Reijnen et al., 1997, Gill et al., 1996). The combination of edge and barrier can reduce the effective area for species that depend on intact habitat in the interior of patches.

What we describe here are two applications of road ecology: 1) a conceptual model describing the “road effect zone” and 2) the development of a road-side zone laboratory adjacent to a pavement-testing facility.

A.1 Road Effects Zone

The "road effect zone" (Forman et al. 2003) provides an efficient way to delineate, describe, and communicate about the interactions between roadways and natural systems and processes. This zone extends from the immediate road-side environment out to the extent of effects from individual roadways and road ssytems. Partial delineation and use of this zone concept has been used for tortoises (Boarman and Sazaki, 2006) and frogs (Lesbarreres et al., 2003). However, there is very little development of the zone concept in the literature, despite the fact that it is robust and measurable and that it would be very useful to guide road ecology research and management strategies.

A.2 Roadsides

The newly-established Advanced Transportation Infrastructure Research Center (ATIRC) at UC Davis offers a remarkable opportunity to develop a long-term experimental site for research on the roadside environment that can integrate ecological studies with pavement research and maintenance technology development. As presently planned, ATIRC is a joint effort of the Pavement Research Center (PRC, John Harvey, director) and the Advanced Highway Maintenance and Construction Technology Research Center (AHMCT, Steven Velinsky, director). ATIRC recently completed pavement construction creating a timely opportunity for REC to work with PRC and AHMCT to design experimental components during 2007-2008 that will address these integrated topics. There will be opportunities for common instrumentation, collaborative experimental planning, and interactive solutions.

III Road Effects Zone

The effects of road can be measured at definable distances from roads and highways, the distance depending on the degree and type of effect. The area affected by roads and their use is called the "road effect zone" (REZ, Forman and Deblinger, 2000; Forman et al., 2002). This concept includes the natural and human processes affected by roads and their use and can theoretically be expressed spatially.

We developed conceptual models for the road effect zone, while considering possible differences among California's 5 eco-regions: the forested North Coast, the South-Central Coast, the Sierra Nevada, the Central Valley, and the Mojave desert. These models were constructed around a generic paradigm of types of effects, modified to reflect the literature on specific effects found in certain eco-regions, and linked to the literature. This means that the model reflects what is known and does not necessarily expose gaps in our knowledge about potential road effects. This report describes the conceptual model for the Sierra Nevada bioregion. The component effects included are intended to reflect the impacts of roads and highways that one would generally find in other bioregions as well as those unique to the bioregions.

The conceptual models will be used for several purposes. One is to develop a geographic information system (GIS) model characterizing the potential effects of roads in a real landscape. The distances of various effects of roads will be used to characterize both the effects on and the collective effects of roads, in the context of each eco-region.

A Conceptual Modeling

Conceptual models are a diagrammatic way to represent systems or ideas. The road effect zone is composed of a variety of road-related outputs (e.g., heat, noise, pollutants) that may affect nearby human and natural systems. Conceptual models are an appropriate way to show these types of effects and systems. The generic REZ conceptual model is shown in Figure 1.

The method used for developing the conceptual models here began with a literature review for possible effects of roads on different ecosystem attributes and processes. We discriminated among and

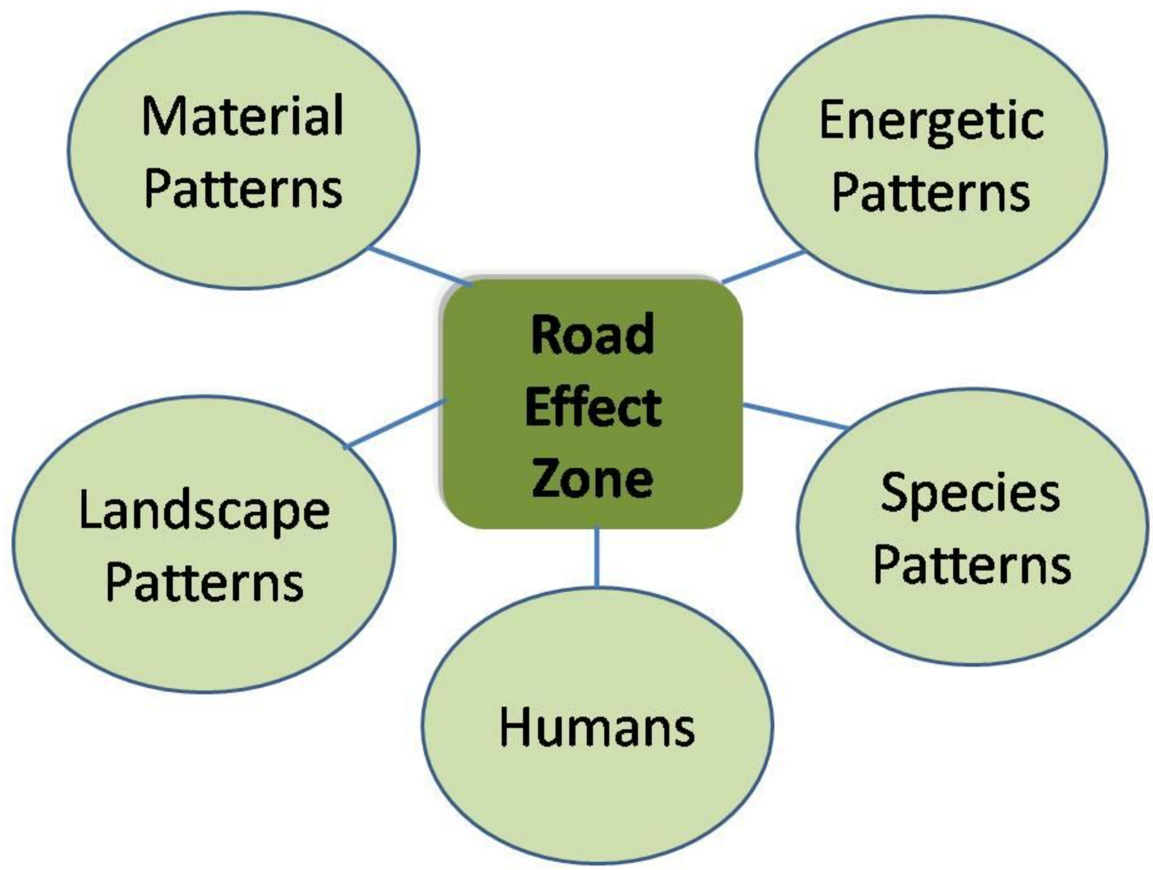


Figure 1. Road Effect Zone core conceptual model. The main categories of effects are shown in the ring of circles (e.g., “energetic patterns”) and each denotes a set of effects that make up part of the overall road effect zone.

classified several main types of impacts: material, energetic, landscape, and species. These impact categories were dissolved into component impacts until an impact could be described which isolated a single species, process, or other attribute of the surrounding systems. Where possible, we noted the effects distances in order to measure the cumulative road effect zone.

Not all road types will exert the influences shown at all times and in all places; nor are all the issues shown relevant in all ecosystems and human communities. To deal with this complexity, the generic model can be modified to show potential impacts from different road types and to show how these impacts will be felt by natural and human systems in different regions.

We developed conceptual models while considering 4 of the eco-regions in California. The models captures issues relevant in the eco-regions, though not necessarily all possible effects of individual roads in each eco-region. No attempt was to identify the relative importance of each of the component effects, meaning that all appear to be relatively similar in terms of their potential impact. Implementing these conceptual models in a particular eco-region (e.g., as a geographic information systems model) would require that these relative contributions of different possible effects be considered.

B Bio-regional Conceptual Modeling

It is likely that types and severities of road effects on natural and human systems will vary with road type, road use, ecosystem context, and community context. Certain ecosystem and human processes may benefit from the presence and use of roads (e.g., economic activities and exotic species invasion). For the most part, road effects are considered to be negative impacts on particular structural or functional attributes of affected systems. The eco-regional descriptions below provide the general backdrop against which specific road effects can be viewed.

Sierra Nevada

The Sierra Nevada is characterized by montane conifer forests, alpine areas, mesic oak woodlands, mixed hardwood/conifer forests, diffuse rural residential, urban areas, and pockets of agriculture. Roads vary from skid trails to multi-lane highways with highly variable rates and types of use. Three classes of roads are forest and ranch unpaved roads, small paved roads, and multi-lane highways. Unpaved roads are far more extensive that the other two classes and have localized and sometimes far-reaching geomorphic effects. Small and large paved roads have local geomorphic effects and wildlife disturbance effects that depend on the size of the road and traffic use. Road development has allowed the continuing transformation of landscapes to serve human economic and settlement desires. They have both facilitated this growing development legacy as well as serving as a legacy land-use in their own right. Although measurement of road linear extent and effects on specific natural processes have been measured and modeled in the Sierra Nevada region, there have been no studies of the likely or actual area affected by roads.

The climate of the Sierra Nevada is Mediterranean, with dry summers and wet winters. The majority of precipitation falls as winter snows at higher elevations and winter rains at lower elevations. Rain on snow events can result in sudden releases of surface waters across roaded and un-roaded surfaces, increasing the potential for rill and gully erosion and failure of road-beds. The range has a steep East to West elevational gradient, with correspondingly narrow plant community distributions in long narrow bands running North to South. In contrast, highway development and modern human development patterns in general have tended to follow a West to East invasion pathway. The vast majority of road development occurred during mining, logging, and early settlement phases. In the last 20 years there have been lower rates of road and highway development. However, the legacy of roads and highways has considerable effects that remain to be remediated or mitigated.

North Coast

The North Coast is characterized by coastal temperate rainforests, coastal plains, montane conifer forests, urban areas, mesic hardwood forests, and pockets of agriculture. Roads vary from skid trails to multi-lane highways with highly variable rates and types of use. Three classes of roads are forest and ranch unpaved roads, small paved roads, and multi-lane highways. Unpaved roads are far more extensive that the other two classes and have localized and sometimes far-reaching geomorphic effects. Small and large paved roads have local geomorphic effects and wildlife disturbance effects that depend on the size of the road and traffic use. Road development has allowed the continuing transformation of landscapes to serve human economic and settlement desires. They have both facilitated this growing development legacy as well as serving as a legacy land-use in their own right. Although measurement of road linear extent and effects on specific natural processes have been measured and modeled in the North Coast region, there have been no studies of the likely or actual area affected by roads.

The climate of the North Coast ranges from dry inland to extremely wet on the coastal side. The majority of precipitation falls as winter rain, with rain and fog drip providing the balance of water in the other seasons. Heavy winter rains can saturate soils in areas with reduced vegetation (e.g., logged areas and heavily-grazed areas), increasing the potential for rill and gully erosion and failure of road-beds. The range has a moderately steep East to West elevational gradient, but has spatially wider plant community distributions running North to South. Highway development is not as extensive as other coastal and inland areas and modern human development patterns are more diffusely spread across the range than in the Sierra Nevada. The vast majority of road development occurred during logging, and settlement phases. In the last 20 years there have been high rates of road development associated with logging on private lands and exurban development. The contemporary road base and the legacy of roads and highways have considerable effects many of which remain to be remediated or mitigated.

Central Valley

The Central Valley is characterized by mesic oak woodlands/savannahs, fragmented riparian woodlands, grasslands, ephemeral and permanent wetlands, diffuse rural residential, urban areas, and agriculture. Land-use in the Central Valley is primarily agricultural, with corresponding moderate densities of dirt roads. However rural residential and urban development is leading to improvement/paving of these roads and increases in the extent and density of road networks. Roads vary from ranch and farm roads to multi-lane highways with highly variable rates and types of use. Three classes of roads are farm and ranch unpaved roads, small paved roads, and multi-lane highways. Unpaved roads are far more extensive that the other two classes and have localized and sometimes far-reaching geomorphic effects. Small and large paved roads have local geomorphic effects and wildlife disturbance effects that depend on the size of the road and traffic use.

Road development has allowed the continuing transformation of landscapes to serve human economic and settlement desires. They have both facilitated this growing development legacy as well as serving as a legacy land-use in their own right. Although measurement of road linear extent and effects on specific natural processes have been measured and modeled in the Central Valley region, there have been no studies of the likely or actual area affected by roads.

C Landscape Patterns

Road and highway development across California has fragmented landscapes and habitats. This fragmentation has limited movement of wildlife species, affected ecological flows, increased edges, reduced core habitat area, and impeded ecosystem and wildlife recovery from land-use related impacted. Road construction can lead to impacts to wetlands and associated vegetation (Forman and Deblinger, 2000; Findlay and Houlahan, 1997). Increased road density results in increase in the number and isolation of habitat patches (Crist et al., 2005; Lin, 2006; Tinker et al., 1998), and loss of genetic diversity (Mader, 1984; Lesbarreres et al., 2003; Mills and Conrey, 2003). Effects on landscape patterns and fragmentation also depend on the size of roads and highways and traffic volumes (Cypher et al., 2005, Develey and Stouffer, 2001). For species dependent upon dispersal at juvenile or adult stages, fragmentation of habitat and disconnecting habitat areas can have critical consequences. In many rural landscapes in Califonrnia, rural residential development ("exurbanization") is invading previously forest and agriculture areas. This sprawling diffuse development will require either the maintenance and persistence of road networks and/or the development of more extensive networks to provide access to many small to moderately-sized (5-40 acres) parcels. As road systems grow more extensive, they increase the edge of habitat and as edges increase on a landscape, there may be interactions among the edge effects that increase the overall effect of the edges. These effects of roads are dependent on the size, traffic use, relative position, and environmental context of the roads and are shown in Appendix A.1.

D Species Patterns

Various mammal, bird, herpetofaunal, and invertebrate species are affected in various ways by roads and traffic. The extent of road-side vegetative cover is an important determinant of forest mammal and bird movement across and near large and small roads (Oxley et al., 1974; Swihart and Slade, 1984; Develey and Stouffer, 2001). For example, elk (which are a restorable wildlife species in the Central Valley) will avoid roads with high traffic volumes, but will cross these roads if foraging is better on the other side (Gagnon et al., 2007). Animals (such as raptors, salamanders, and elk) often avoid roads, because of traffic noise and/or aversion to the road surface, which increases the effective size of roads on the landscape (Bautista et al., 2004; Jaeger et al., 2005; Storlie, 2006; Semlitsch et al., 2007). In contrast, roadways and roadsides may also serve as pathways for exotic and pioneer plant and animal species invasion (Brown et al., 2006; Spooner, 2005; Stiles and Jones, 1998). These species may stay along the roadside, or venture in adjacent natural habitats. Because individual species may be affected by roads in many or all life-stages and for many habitat requirements, individual seemingly moderate impacts may in combination affect viability of populations or even the whole species. These effects of roads are dependent on the size, traffic use, relative position, and environmental context of the roads and are shown in Appendix A.2.

Species-Specific Effects

Not all species will react in the same ways or to the same degree to roads and traffic. For example, scavenging birds that take advantage of road-kill as forage may benefit from roads and highways. On the other hand, song-birds whose reproductive success relies on sound and song may have their mating calls and other communications affected by traffic noise.

Movement of animals relative to roads is an important type of effect. For example, animals approaching a road may cross what otherwise appears to be a bare open space, disregarding traffic (e.g., amphibian), because of some biological imperative. Others may avoid roads (e.g., grizzly bear and elk) because of an aversion to the smell, sound, and sight of them, or because of prior experience. Vagility of different species is one of the most important determinants of the effects of roads on specific species. Organisms with greater vagility may tend to encounter more roads in a landscape and may have greater ability to avoid conflict (if fast-moving).

For species that tend to occur near roads and highways, there may be significant impacts at the population level of wildlife-traffic conflict, or inability to cross roads and highways. These impacts may be on sheer numbers of individuals, migration for daily or seasonal needs, dispersal of juveniles, the creation and loss of sub-populations, or disconnecting essential habitats. Impact at the population level is one of the most critical types of impacts as it may result in loss of entire populations or even species.

E Material Patterns

During and after construction, roads and highways can influence the distribution of water, sediment, and other natural materials across the landscape and into waterways. Similarly, roads and traffic can be sources of chemicals, dust, and gases that are exported beyond the road surface by rain and wind. Roads, highways, and their attendant urban development are a source of initial, potentially-mitigated impacts and long-term un-mitigated impacts to aquatic ecosystems (Wheeler et al., 2005). Roads may initiate channels or contribute to their initiation on slopes, connect drainages, and otherwise exacerbate natural geomorphic and hydrologic processes (Montgomery, 1994). Physical wearing, as well as de-icing salts and precipitation contribute to the wearing and movement of chemicals from the road surface to adjacent landscapes (Backstrom et al., 2004). In the rural mountainous areas, dirt logging and ranch roads may contribute fine sediments to waterways through surface runoff and all-sized sediments through road collapse or near-road slope collapse into streams. These roads may also constrain channels passing through culverts and re-route sub-surface and surface water more rapidly to waterways, causing both downstream and upstream geomorphic effects. The combination of roads and road-facilitated land development can be the predominant cause of erosion, channel geomorphic change, and radical changes in local and watershed hydrology (Sidle et al., 1985; Reid, 1993; Reid and Dunne, 1996).

F Energetic Patterns

Excess energy is produced by roads and traffic as sound, light, heat, and seismic vibration. Roads are sources of heat, due to absorption and reflection of sunlight. Even individual logging roads can cause large temperature changes in creeks, depending on the flow, ambient temperature, and ground-water recharge rates (Story et al., 2003). Traffic-induced noise and light can result in aversion to roads and changes in nearby bird and mammal populations (Clair, 2003; Clevenger et al., 2001; Forman and Deblinger, 2000; Forman et al., 2002; Jaeger et al., 2002; Pocock and Lawrence, 2006). These noise impacts could have long-lasting effects on fitness and there is little evidence of habituation or adaptation in certain species (Quinn et al., 2006). Although the amplitude of traffic noise is an important factor in deterring animals, the frequency of road-surface and engine noise is also a factor in determining bird susceptibility to traffic effects (Rheindt, 2003). By changing the routing and timing of water entry into watershed channel networks, roads can also change the intensity of localized and watershed flooding. This intensity is a reflection of the release of potential energy in upslope and upper watershed precipitation as the kinetic energy of surface water flows. This accelerated release of energy can have severe impacts on downstream human and aquatic habitats in the winter and result in a depletion of water that could be slowly-released through the summer.

G Cumulative Road Effect Zone

Although many road effects are independently generated, they may have synergistic effects on the surrounding environment, may interact with each other, and will pose both individual and collective policy and management problems. The idea of cumulative effects is firmly entrenched in the California Environmental Quality Act and the National Environmental Protection Act (among others). Quite often, environmental effects of facilities or activities are considered individually and reported collectively without addressing additive, multiplicative, or other synergistic effects. One way to begin understanding and dealing with the multiple effects of roads and road systems is to include the effects into a single decision space. The geographically explicit nature of the road effect zone makes it a useful tool in road and highway planning as well as land-use planning.

As our knowledge of road effects grow, so will the potential for developing evaluative tools that effectively describe the cumulative road effect zone, as well as its component parts. There are important guidelines to consider as this idea evolves. These include the fact that the road effect zone is not a simple 2-dimensional shape surrounding a given roadway, but rather a 3-dimensional envelope with diffuse boundaries (Figure 2). In addition, the effects may or may not interact, they may co-exist, interact, and/or negate each other. The effects will be felt by different systems in different ways and across varying scales (extents and granularities). Similarly, responsible planning and regulatory bodies may intersect with parts or all of the zone, with different statutes coming into play at different times and places.

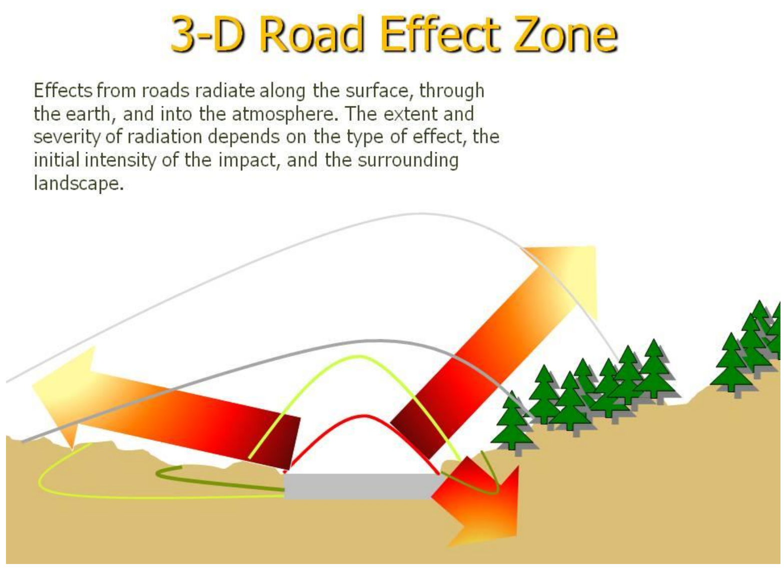


Figure 2 Three-dimensional road effect zone

I Developing GIS Tools

We have developed the basis for a GIS tool to understand road effects on a local or regional scale. We are beginning to pilot this approach as a tool for a particular stretch of highway 49. The tool runs on grid representations of landscape attributes and has as outputs the effect on specific landscape processes and the sum effect distance and intensity from the right-of-way. Examples of data input types and effect distances are show in Figure 3.

Figure 3 Natural system attributes and road effect distances for select processes.

IV Road-side Laboratory

We have planned for a long-term series of experimental investigations of road effects and roadside management at the ATIRC site (Fig. 4). This plan will form the operational foundation for the "Integrated Roadside Management Experimentation Facility" (IRMEF) and will explicitly describe the integration between fine-scale investigations of roadway engineering and road-side systems. For example, the PRC will test different road surface preparations for 1) modifying storm-water permeation and runoff, 2) tire-noise abatement, and 3) local heat generation. For these 3 areas, we will develop and encourage corresponding investigations of: 1) roadside fate and treatment of storm-water runoff, 2) roadside noise-abatement structures, such as vegetated berms, that can serve ecological functions, 3) managed systems of native and non-native plants, and 3) ecological effects of road-

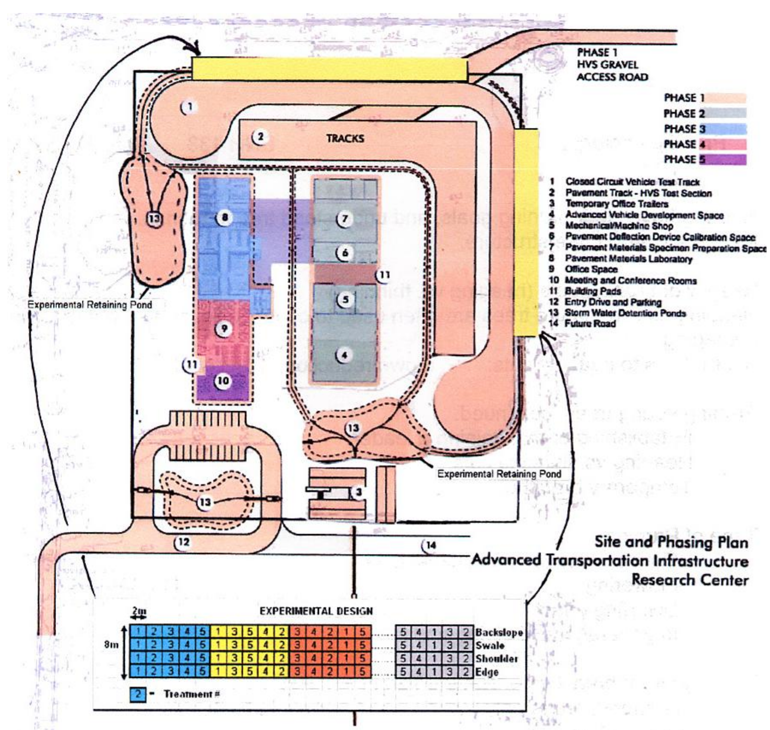


Figure 4 Site plan for the ATIRC/IMREF

ways as heat islands. The AHMCT investigators are interested in developing new roadside maintenance technologies that can improve vegetation management, especially for reducing invasive weeds and promoting native plant communities. The IRMEF will provide a site for systematic testing of management of roadside communities of native and non-native plants.

A. Site Design

The UC Davis Advanced Transportation Infrastructure Research Center (ATIRC) project site is a unique opportunity for collaboration between three research facilities: the Pavement Research Center (PRC), the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center and the Road Ecology Center (REC). Through this collaboration, we have begun to explore the relationships between the pavement, the machinery and activities used for roadway maintenance, and the ecological processes that occur around roadways.

The experimental site is built upon approximately four acres of undeveloped agricultural land. It is comprised of two L-shaped test tracks (1 and 2 in Fig. 4), an outer test track 30 feet by 1000 feet and an inner test track 30 feet by 300 feet. Both test track systems will be utilized by the PRC and the REC, while the AHMCT Research Center will conduct their research on the outer test track. Each road has bordering road-side verges and swales, with three water drainage retention basins to catch storm water runoff (13 in Fig. 4). With the use of a Heavy Vehicle Simulator (HVS), continuous traffic from oversized tractor-trailer transport trucks will be replicated. In only a period of 2 to 3 months of this high-traffic simulation, the HVS has the capability of duplicating highway wear-and-tear representative of a 20-year period. Once experimental specifications are set in place, simulation vehicles with known pavement loads will be applied. The questions and objectives of each research group will guide the direction of the experiments, from which collaboration will arise. The following describes each research groups' objectives.

Pavement Research Center

The PRC will utilize both test tracks to administer pavement research. The PRC will utilize the ATIRC facility to develop the pavement field in a variety of areas including the following:

- Geotechnical Engineering
- Construction Engineering and Management

• Traffic Engineering Materials
• Mechanics
• Statistical Performance Modeling
• Systems Analysis/Economics
• Information Management
• Planning

Advanced Highway Maintenance and Construction Technology Research Center

The outer test track will be used by the AHMCT research center to test prototype road maintenance vehicles for efficiency and reliability (i.e. street sweepers, striper trucks for pavement markings, etc.) The AHMCT Research Center has the following objectives:

• Improving the safety of both highway workers and the traveling public.
• Improving the efficiency of highway maintenance and construction activities.
• Improving the reliability of the highway infrastructure.
• Minimizing the congestion delays brought on by highway maintenance and construction activities.
• Minimizing the negative environmental impacts of highway maintenance and construction activities.

Road Ecology Center

The objectives of the Road Ecology Center at the Advanced Transportation Infrastructure Research Center are to (1) develop a long-term integrated experimental site, and 2) to establish a modeling framework for future research on the part of the road effect zone within the right-of-way, with special emphasis on California road systems, but with methodologically broader applicability. Examples of potential experiments that could be established in the ATIRC roadside research plots include the following:

Roadside Vegetation Management

1) Use of microtopography to create invasion-resistant communities and to mitigate storm-water runoff effects.
2) Development and testing of mowing technologies that support native plant communities and reduce weed invasions.
3) Investigation of root growth contributions to soil strength to avoid liquification and slumping.
4) Use of mulch for weed control.
5) Investigate invasivity and natural vegetation establishment controls.

6) Use both natural (competitive) and management (chemical, mowing timing) approaches to managing planted weed plots.

7) Understand the effect of pavement replacement timing (2 years) vs. native growth (3-5 years for successful establishment and 10 years for strong community)

8) Test the plant species complexes that are best suited for roadside establishment and fitness(forbs vs. grasses)

Soil Dynamics

9) Regeneration of soil aggregates on substrates disturbed by construction.

10) Stabilization of organics on mineral surfaces to improve sorption of pollutants from runoff

11) Study of soil depth needed to support adequate (weed excluding) native plant stands

12) Soil structure in first meter – what can and can't grow there, what is the micro-structure

Hydrological Interactions

13*)* Interaction of permeable paving and plant community water relations.

14) Stabilization of organics on mineral surfaces to improve infiltration.

15) Prediction of rainfall events and sequences that trigger overland flow.

16) Establishment and management of stormwater detention pond vegetation zones.

17) Investigate causes of road surfaces and beds sloughing off and storing water in context of wet (ditch irrigation) and dry (natural seasonal dry) roadsides

Micro-climate effects

18) Analysis of local air flow, diffusion, and turbulence associated with road edge that influence tracking of pollutants and nutrient deposition.

19) Study of roadway environments as precursors to global climate change (more extreme temperature, greater variability in moisture, aerosol pollutant production).

Acoustic Environment

20) Interaction between frequency range of acoustic pavements and animal behaviour.

21) Fine-scale and short-distance mitigation of sound amplitude and frequency within the right-of-way.

Whole system management model

21) Inter-institutional process model for paving and management

B. Site Development-

Construction of the ATIRC site began late 2007 and continues today. The series of photographs (Figure 5) depict the building of the first experimental run at the ATIRC site with a specified pavement structure. These photographs specifically illustrate the progression of the outer track, their associated road-side verges and swales as well as the drainage basins.

The Road Ecology Center will initiate experiments late winter of 2008/2009 by planting the roadside verges with native vegetation. The groundwork for the roadside verges is currently completed with a 2% grade with widths varying 5-20 feet. The construction of the inner track is under way. The soil below the tracks was lime-treated and constructed in a way that prevents lime from drifting into the soil that comprises the roadside verges. As an effort to decrease the severity of weed invasion prior to the native planting in 2009, the road-side verges have been planted with a sterile wheat X wheatgrass seed called Regreen.

The detention basins have been designed to contain a 100-year flood for a period of 24 hours. With a storm of this magnitude, 2.2 acre-feet of runoff is estimated to be produced. With the 12" outfall pipes built with in the walls of the detention basins, the basins are designed to empty within a period of 24 hours once the storm has passed.

Figure 5 Development of different aspects of the ATIRC site during 2008

Outer Test Track

May 19, 2008 - Northern edge; facing west; first layer of earthen material

June 5, 2008 - Northern edge, facing west

June 12, 2008: Northern edge, facing east- Gravel material added to track

June 20, 2008- Northern edge, facing west; Resurfacing and compacting of gravel material on test track

June 30, 2008- Northern edge, facing west; Pavement layer added to gravel material and shaping of road-side verge and swale

July 16, 2008- Northern edge, facing west; Shaping of road-side verge and swale

August 6, 2008- Northern edge, facing west; Regreen added to road-side verge

<u>**Southern Drainage Basin**</u>

June 6, 2008- Southern drainage basin

July 16, 2008- Southern drainage basin inlet

Eastern Drainage Basin

August 8, 2008- After the basin was landscaped and applied with a cover of Regreen seeds which produces sterile plants.

August 8, 2008- Eastern drainage basin after initial landscaping

6.30.08

Bindweed becoming established near the perimeter of the ATIRC site

6.30.08

Mallow becoming established near the perimeter of the ATIRC site

C. Scale

Roads affect ecosystems for up to multiple kilometers from the road's edge. For many of these affects, the roadside verge acts as the gateway into the ecosystems' matrices. If road-side verges are correctly managed for, they have the potential to diminish the magnitude of road effects. The ATIRC project will focus on effects that occur with in the first 10 meters. These effects involve physically moved material through means of water flow, wind and road splash.

We also intend to engage in research at other scales – from highway stretches (km, see section V) to regional landscapes (>100 km2). Vertical integration of studies from the road-side laboratory scale to highways to landscapes is critical to not only understanding how road effects are manifested across these scales, but also how best to manage highway systems to reduce the effects.

D. Material and Energy Outputs from Roadside

Roads physically change watersheds as they meander through the landscape. Pavement increases the impermeable surfaces of watershed, and with traffic emits energetic and material outputs into surrounding ecosystems. Investigations at the IRMEF/ATIRC site will improve understanding of these processes and facilitate the mitigation necessary to adjust for these changes through means of experimental design. The material and energetic outputs that change the roadside verge affect the disturbance regime around roads and are the crux of the questions asked by the Road Ecology Center:

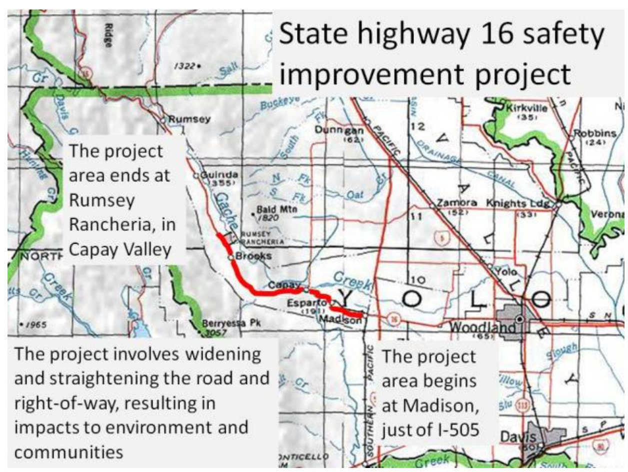
- **Water and Sediment Flows-** altering the surface water flow and groundwater flow causing excessive erosion
- **Chemical Inputs**- from road-related activities are transported through wind and water flows
- **Wind-** transports chemicals and erodes verges that ultimately will carry fine sediments from roadways to the surrounding environment.

V Integration of Roadside Laboratory with Regional Roadsides

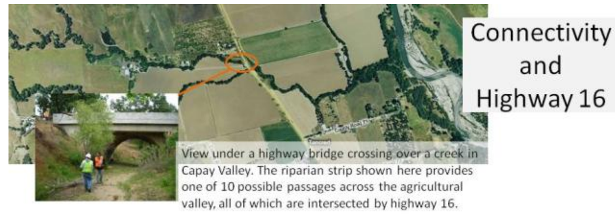
To further understand the ecological processes occurring near road systems we would like to ask the same questions posed at the ATIRC site along an existing roadway. As the ATIRC project is located in the Central Valley, where urbanization and agricultural fields are common fixtures, an existing roadway that is representative of this bioregion would complement this study. The knowledge gained through the roadside laboratory would be put to use to mitigate for roadside effects on regional roadsides in general. We have focused on state highway 16 between Madison/I-505 and Rumsey Rancheria in Capay Valley because there is an extensive, proposed highway project there, which involves a complicated assortment of possible ecosystem and community impacts.

State Highway 16 Case Study

State highway 16 is a meandering state route that provides access from the Central Valley to Capay Valley and the Coast Range beyond. The safety improvement project proposed would involve raising flood-prone sections of the road-bed, re-aligning segments to become straighter, widening the road-way and right-of-way to conform to current standards, with the idea that safety for local and visiting drivers would be improved.



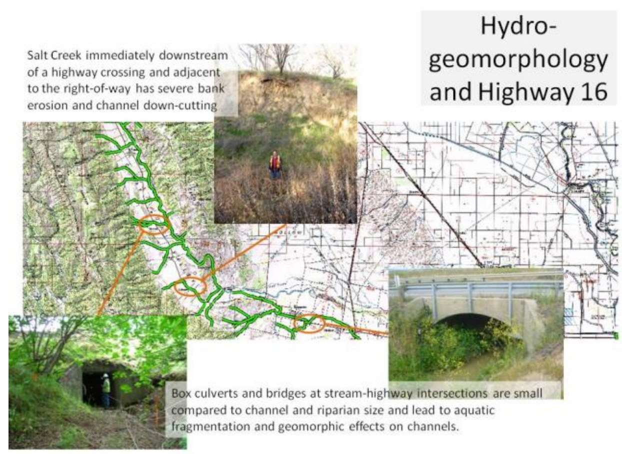
Highway 16 has a variety of existing and potential impacts on the surrounding environment. These include impacts to landscape connectivity, wildlife movement, riparian zones, geomorphic processes in stream channels, remnant wetlands, oak trees, the small towns of Esparto, Brooks, and Capay, and other ecological and human properties. The proposed project would avoid, minimize, or compensate for some of these impacts, but not necessarily all of them. There are potential deficiencies in the project mitigation plan, including availability of pre-project condition information and lack of post-project mitigation effectiveness evaluation. The Road Ecology Center has proposed to Caltrans, District 3, that we are well-positioned to assist with these deficiencies, including bolstering the thoroughness of the environmental condition assessment, improving the process of including and acting in response to community concerns, and monitoring change after the project has occurred.



View under a highway bridge crossing over a creek in Capay Valley. The riparian strip shown here provides one of 10 possible passages across the agricultural valley, all of which are intersected by highway 16.

Capay Valley and state highway 16 separate two large wildland areas in the Coast Range (light green), home to elk, deer, black bear, and other wildlife. The light blue swaths indicate paths of least resistance between these areas. The circle indicates the junction of a large concrete canal and highway 16 (see picture), effectively constraining this wildlife connection

This section of highway and its associated Caltrans project provides an opportunity to both evaluate ecological and human community impacts at the scale of a highway project and to provide the information to the project decision-makers and local communities. The intersection of this proposed project and the ATIRC site is at the road-side, where certain road-way impacts begin. By using both environments and scales, we will be able to more effectively test weed management scenarios, study immediate road-side effects (e.g., water runoff and heat production), and model improved ways to manage the road-side environment in the highly-controlled ATIRC site and the real-world highway 16 site.



Salt Creek immediately downstream of a highway crossing and adjacent to the right-of-way has severe bank erosion and channel down-cutting

Box culverts and bridges at stream-highway intersections are small compared to channel and riparian size and lead to aquatic fragmentation and geomorphic effects on channels.

VI Integration of Roadside Laboratory with Road Effects Zone

The immediate road-side is usually the zone where road effects are the most severe. Although the road effect zone is likely to extend hundreds or even thousands of meters, the road-side environment is a critical component and may be the easiest to physically manage. The ATIRC site will provide a laboratory to both test native and non-native plant cover scenarios and to understand the flow of materials and energy from the road-way into this environment. It is thus an ideal setting to test those aspects of the road-effect zone that that are within 10 meters of the road-way.

VII Literature

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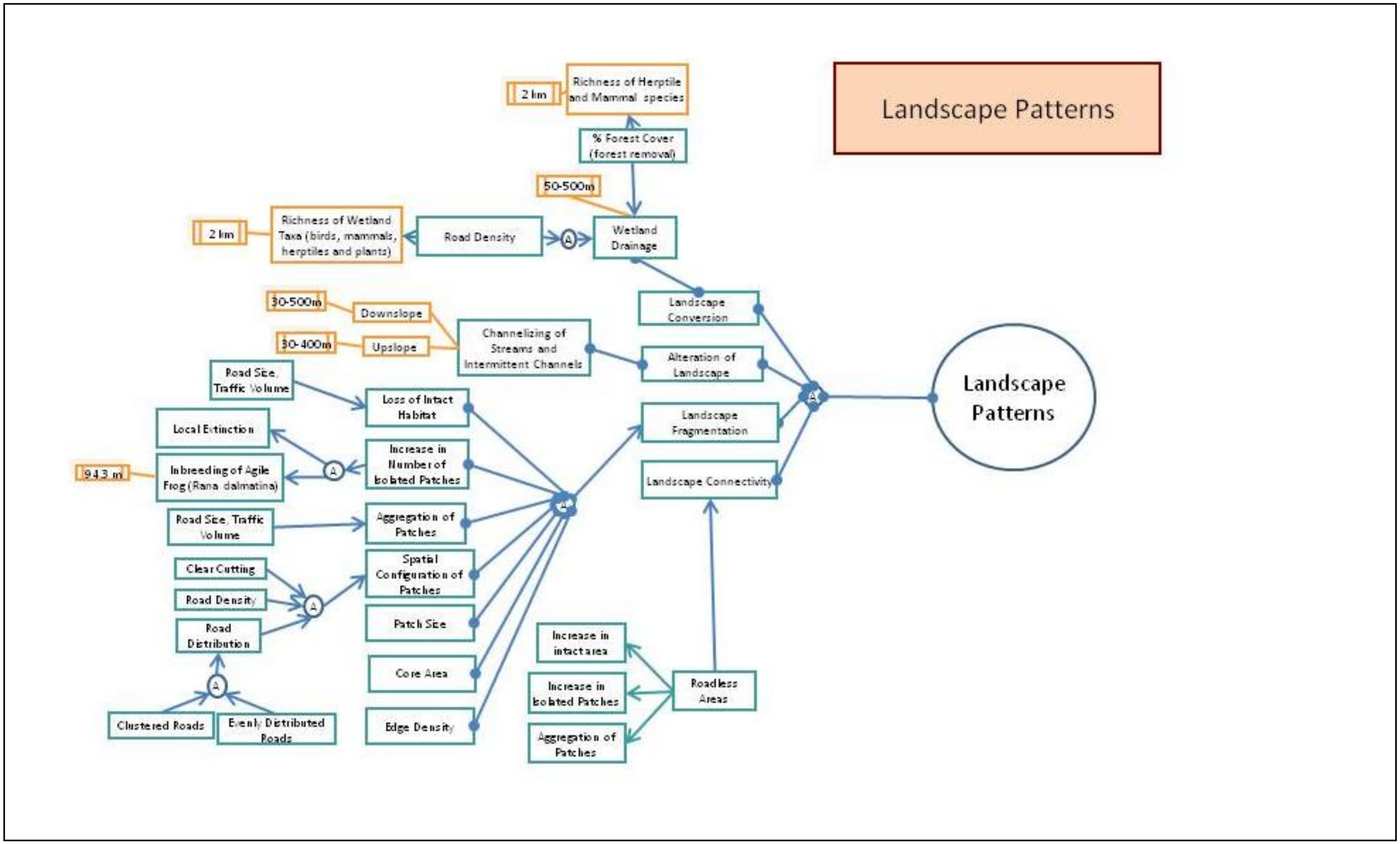
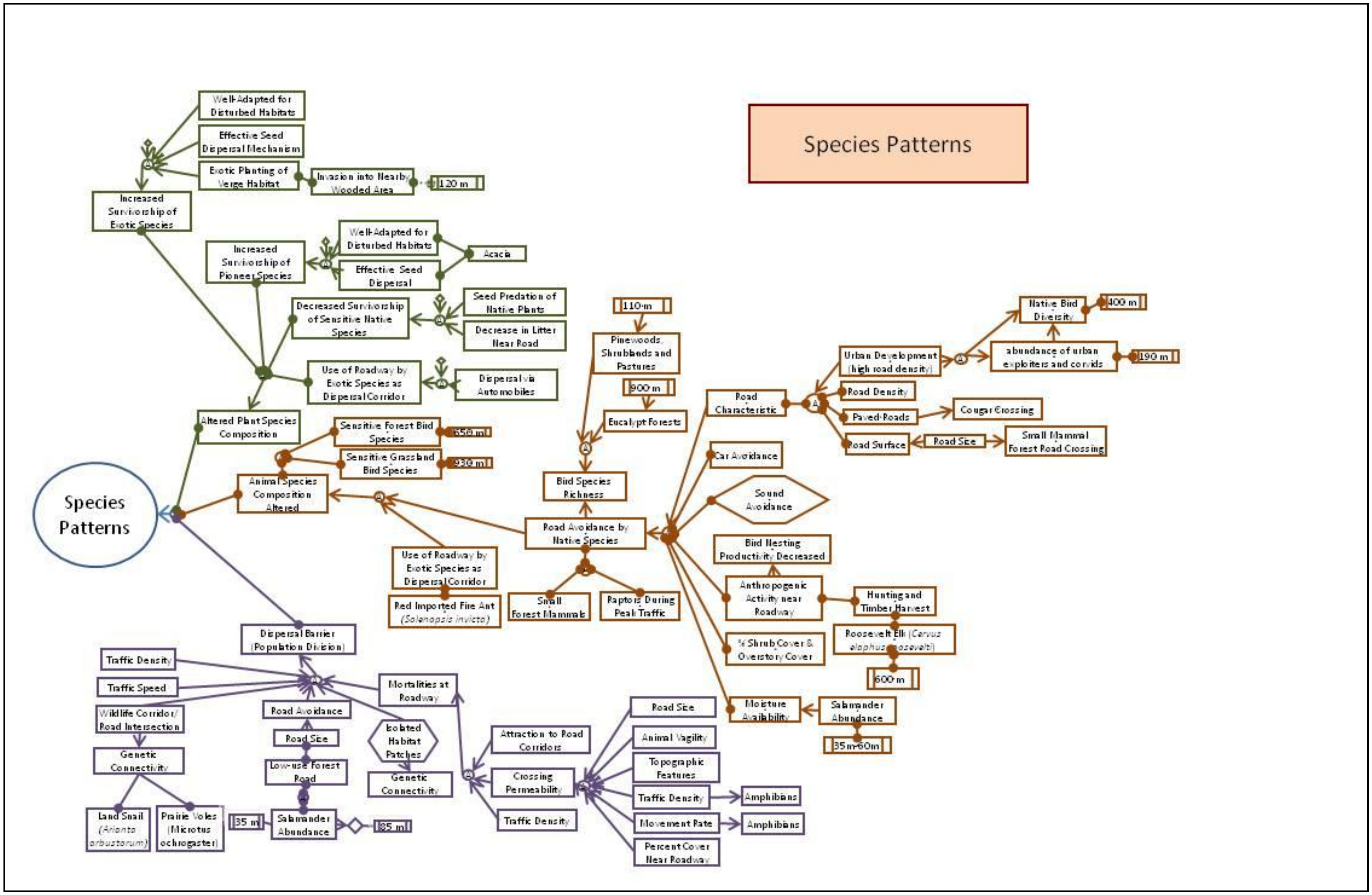
Appendix A

In each of these conceptual model diagrams, each rectangular box represents a road effect on a specific aspect of ecosystem structure and/or function. The direction of the arrows indicate influence direction (the box at the beginning of the arrow causes the effect at the end of the arrow), or factors contributing to a conceptually larger effect. The “A” in a circle indicates the linguistic operation “and”, where two or more concepts have additive or multiplicative effects. Rectangles with distances (e.g., 2 km) indicate the distance that a particular effect has been found, as reported in the literature. Not all species and ecosystem contexts have been evaluated for road effects, so the attributes and processes indicated here are examples that may be useful in studying road effects.

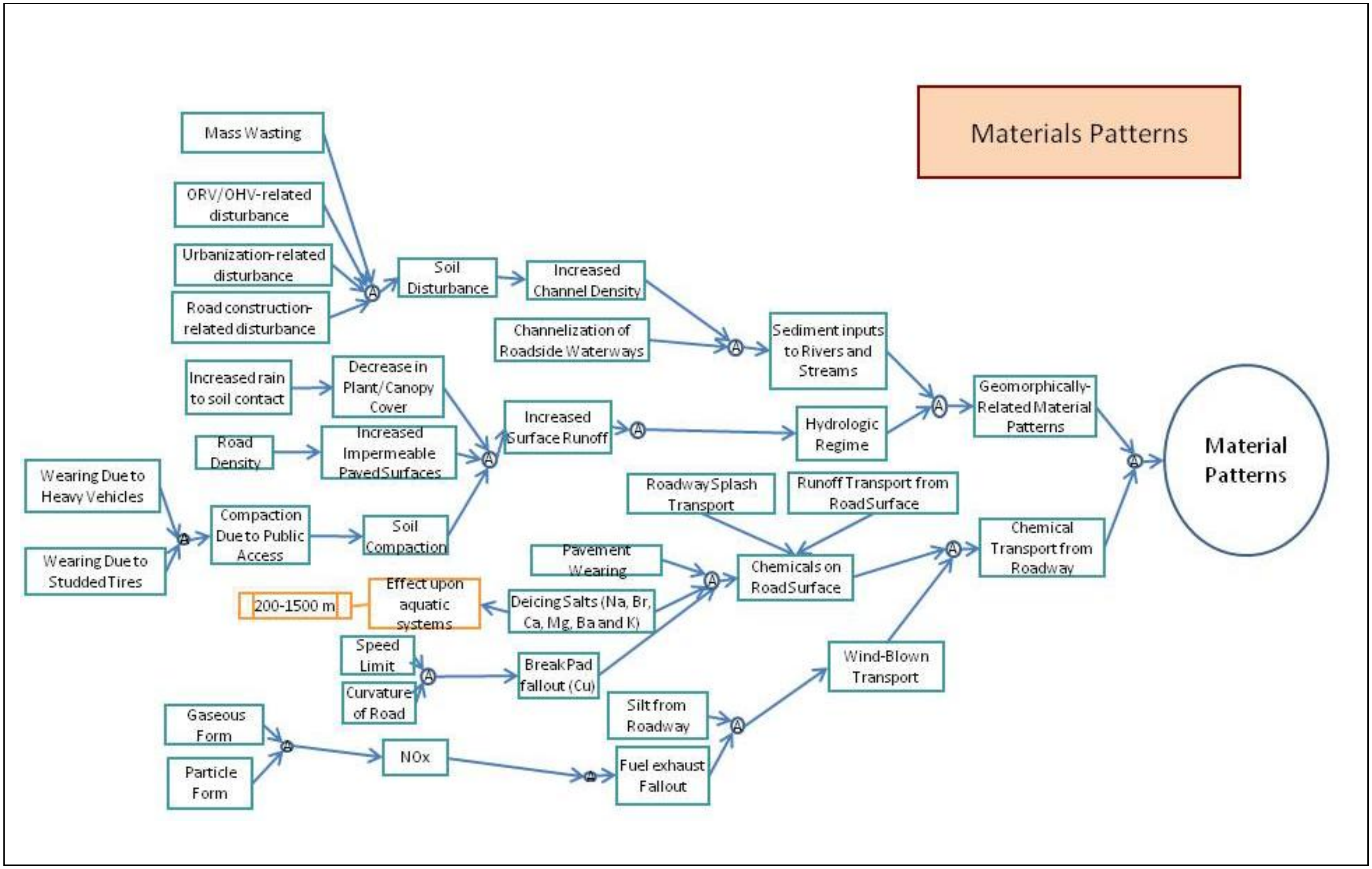
A.1 Landscape pattern component of the road effect zone.



Appendix A.2 Species pattern components of the road-effect zone.



Appendix A.3 Material pattern components of the road-effect zone.



Appendix A.4 Energetic patterns component of road-effect zone.