TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. **WA-RD**	2. GOVERNMENT ACCESSION NO.	3. RECIPIENTS CATALOG NO
4. TITLE AND SUBTILLE Identifying I-90 Wildlife Corridors Using GIS & GPS: Spatial-Temporal Model of Landscape Use by GPS Marked Cougars		5. REPORT DATE 30 June 2005 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) BENJAMIN T. MALETZKE GARY M. KOEHLER PhD WILLIAM R. MEYER		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Washington Department of Fish and Wildlife 600 Capitol Way N Olympia, WA 98501-1091		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. 04-2014
12. CPONSORING AGENCY NAME AND ADDRESS Washington State Department of Transportation Transportation Building PO Box 47300 Olympia, WA 98504-7300		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.		

16. ABSTRACT

As the residential and recreational development in western Kittitas County increases, as well as interstate travel and commerce, the need arises to expand the interstate highway system to accommodate the increase in traffic volume. This increased traffic and expansion of transportation routes may potentially affect wildlife movements and traffic safety. To identify areas for potential wildlife corridors along Interstate-90 (I-90) and state highways (SR), we analyzed cougar movements and 95% fixed kernel home range estimates from Global Positioning System (GPS) collar locations of collared cougars on a 3,657km^2 area of western Kittitas County, Washington from 2001-2004. A logistic regression model for both winter and summer was developed to determine relative probability of use by cougars for topographic and land cover characteristics. We found cougars (n=11) used a mean elevation of 786 ± 166 m in winter and 971 ± 256 m in summer. We used t-tests and selection ratios (*S*) to compare differences in cougar use locations versus random locations from Geographic Information Systems (GIS). In winter, cougars selected for lower elevations (*S*=0.71), milder slopes (*S*=0.82), open (*S*=1.34) or closed (*S*=1.08) canopy forest types, and south facing slopes (*S*=1.19). They selected against agricultural (*S*=0.43), rangeland (*S*=0.16), cities/roads (*S*=0.93), water (*S*=0.17), rock (*S*= 0.26), north (*S*=0.81), and west (*S*=0.87) slopes. During summer, cougars selected for steeper slopes (*S*=1.05), open (*S*=1.12) and closed (*S*=1.27) canopy forest types on north (*S*=1.15), west

(*S*=1.06) or east (*S*=1.06) facing slopes. They selected against agriculture (*S*=0.43), rangeland (*S*=0.07), cities/roads (*S*=0.46), water (*S*=0.25) and rock (*S*=0.37). From these results, we determined significant variables ($P<0.05$) for inclusion in a logistic regression model of vegetation and physiographic variables associated with cougar GPS locations. Logistic regression indicated cougars selected for open and closed canopy forest and selected against agriculture, rangeland, water, and cities/roads during winter. They selected for lower elevations with south facing slopes and selected against north, west and east facing slopes or flat terrain. During the summer cougars were not as selective, but preferred open and closed canopy forest on north, west or east facing slopes. We found resident females (n=3) occupied home ranges adjacent to I-90, however they did not to cross the interstate. One resident male established a home range encompassing I-90. Sub-adult females (n=2) and sub-adult males (n=2) were documented crossing I-90 and dispersing from the study area. The two lane state route (SR) highways 903, 970, 97, and 10 appeared permeable to cougar movements as male and female cougars established home ranges encompassing these SR's. Crossings along I-90 and SR's tended to occur in areas forested to the highway edge on both sides and along ridgelines or riparian areas.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Cougar, *Puma concolor*, I-90, Interstate, wildlife crossings, GIS, GPS	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 Washington State Department of Transportation. This report does not constitute a standard, specification, or regulation.

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None	42	

IDENTIFYING I-90 WILDLIFE CORRIDORS USING GIS & GPS: SPATIAL TEMPORAL MODEL OF LANDSCAPE USE BY GPS MARKED COUGARS

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Abstract: As the residential and recreational development in western Kittitas County increases, as well as interstate travel and commerce, the need arises to expand the interstate highway system to accommodate the increase in traffic volume. This increased traffic and expansion of transportation routes may potentially affect wildlife movements and traffic safety. To identify areas for potential wildlife corridors along Interstate-90 (I-90) and state highways (SR), we analyzed cougar movements and 95% fixed kernel home range estimates from Global Positioning System (GPS) collar locations of collared cougars on a 3,657km^2 area of western Kittitas County, Washington from 2001-2004. A logistic regression model for both winter and summer was developed to determine relative probability of use by cougars for topographic and land cover characteristics. We found cougars (n=11) used a mean elevation of 786 ± 166 m in winter and 971 ± 256 m in summer. We used t-tests and selection ratios (*S*) to compare differences in cougar use locations versus random locations from Geographic Information Systems (GIS). In winter, cougars selected for lower elevations (*S*=0.71), milder slopes (*S*=0.82), open (*S*=1.34) or closed (*S*=1.08) canopy forest types, and south facing slopes (*S*=1.19). They selected against agricultural (*S*=0.43), rangeland (*S*=0.16), cities/roads (*S*=0.93), water (S=0.17), rock (S= 0.26), north (S=0.81), and west (S=0.87) slopes. During summer, cougars selected for steeper slopes (S=1.05), open (S=1.12) and closed (S=1.27) canopy forest types on north (S=1.15), west (S=1.06) or east (S=1.06) facing slopes. They selected against agriculture (S=0.43), rangeland (S=0.07), cities/roads (S=0.46), water (S=0.25) and rock (S=0.37). From these results, we determined significant variables ($P<0.05$) for inclusion in a logistic regression model of vegetation and physiographic variables associated with cougar GPS locations. Logistic regression indicated cougars selected for open and closed canopy forest and selected against agriculture, rangeland, water, and cities/roads during winter. They selected for lower elevations with south facing slopes and selected against north, west and east facing slopes or flat terrain. During the summer cougars were not as selective, but preferred open and closed canopy forest on north, west or east facing slopes. We found resident females (n=3) occupied home ranges adjacent to I-90, however they did not to cross the interstate. One resident male established a home range encompassing I-90. Sub-adult females (n=2) and sub-adult males (n=2) were documented crossing I-90 and dispersing from the study area. The two lane state route (SR) highways 903, 970, 97, and 10 appeared permeable to cougar movements as male and female cougars established home ranges encompassing these SR's. Crossings along I-90 and SR's tended to occur in areas forested to the highway edge on both sides and along ridgelines or riparian areas.

Key words: Cougar, *Puma concolor*, I-90, Interstate, wildlife crossings, GIS, GPS

INTRODUCTION

As the residential and recreational development in western Kittitas County increases, as well as interstate travel and commerce, the need arises to expand the interstate highway system to accommodate the increase in traffic volume. With average traffic volume increasing by 3% per year, there are plans to expand Interstate 90 (I-90) from 4 lanes to 6 lanes from Hyak east to Easton (I-90 Snoqualmie Pass East Report, Washington State Department of Transportation 2004). Currently, I-90 is thought to be an ecological barrier for some terrestrial species (I-90 Snoqualmie Pass East Report, Washington State Department of Transportation, 2004), which may prevent or inhibit movement and genetic exchange across the corridor (Singleton and Lehmkuhl, 2000). For more mobile species such as elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*) and large carnivores such as black bears (*Ursus americanus*) and cougars (*Puma concolor*), there is also the concern of public safety from vehicle collisions with these animals (I-90 Snoqualmie Pass East Report, Washington State Department of Transportation 2004).

An increase in traffic volume as well as expanded width of the transportation route with added lanes may increase the potential of vehicle collisions and may further create a barrier to wildlife movement. To decrease the affect of I-90 as a barrier to ecological connectivity, wildlife corridors are being considered in the I-90 expansion plan. Identifying and locating these wildlife corridors to facilitate animal movements is currently in question. Our objective was to use existing Global Positioning System (GPS) locations for collared cougars to identify Geographic Information System (GIS) attributes that are correlated to cougar crossings sites and travel corridors used by cougars along I-90 and state highways in western Kittitas County. Funding for this effort was provided by Washington State Department of Transportation (WSDOT) and Washington Department of Fish and Wildlife (WDFW).

STUDY AREA

The study was conducted on an approximately 3,657km^2 portion of western Kittitas County in Washington state from December 13, 2001 through December 26, 2004(47^{o}N, 121°W). Interstate 90 (I-90) and four State Route (SR) highways, SR 10, 903, 970, and 97 intersect the study area. Annual average traffic volume for I-90 ranged from 23,000-28,000 vehicles per day. The SR traffic volume ranged from 1,200 – 5,600 cars per day depending on the highway and location within the study area. (Washington State Department of Transportation Annual Report, 2003)

The elevation on the study area ranges from 462 – 2,279 m with the vegetation ranging from shrub steppe, ponderosa pine (*Pinus ponderosa*) and Douglas fir (*Psuedotsuga menziesii*) at lower elevations to western hemlock (*Tsuga heterophylla*), grand fir (*Abies grandis*), Douglas fir at mid elevations and Pacific silver fir (*Abies amabilis*), noble fir (*Abies procera*) , sub-alpine fir (*Abies lasiocarpa*), Englemann spruce (*Picea engelmannii*) and lodgepole pine (*Pinus contorta*) at higher elevations. The majority of the study area is a patchwork of U.S. Forest Service and privately owned timber lands with the valley bottom primarily private residential or agriculture.

METHODS

Cougars were captured using large box traps or bayed with the aid of hounds. We immobilized cougars with a combination of Ketamine hydrochloride and Xylazine hydrochloride and fitted them with Simplex or Posrec Global Positioning System (GPS) collars (Televilt International, Lindesberg, Sweden). We programmed the collars to attempt to acquire a GPS location at 4 to 6 hour intervals throughout the year. Animals were recaptured and collars retrieved annually to download data directly from the collars to ensure a complete dataset. Collars were also programmed to transmit GPS data remotely to a receiver at 4 or 6 week intervals and to transmit VHF radio signals for estimating telemetry locations. Recaptured animals were fitted with a new collar and physical measurements were recorded.

Geographic Information Systems

We compiled the data collected from GPS collars and edited and revised location data for accuracy of the dates, times deployed, and spatial accuracy. The data was then imported into GIS software, ArcGIS 8.3 (Environmental Systems Research Institute). We edited the data sets and removed any spurious location coordinates or times based on PDOP values and number of satellite acquisitions. Errors comprised less than 0.01% of the total locations collected.

We used a 10-meter resolution Digital Elevation Model (DEM) to develop a GIS layer for slope in degrees and aspect in degrees. For the analysis we separated aspect in to five categories; north, south, east, west, and flat. We determined elevation for each of the locations from the DEM.

Randal Thorp, student researcher, Department of Geography and Land Studies, Central Washington University, assisted in developing a land cover classification GIS layer for western Kittitas County. We used a supervised classification of an August 2000 Land-Sat image to delineate boundaries of land cover classifications. The resulting layer was then ground-truthed with Ortho and aerial photos for accuracy. The land cover classes included agriculture, open forest, closed forest, rangeland, cities/roads, water, and rock. Agriculture was defined as pastures, fallow fields, and active farming. We characterized open forest as selective harvest units, thinned forest stands or sparse Ponderosa pine/Douglas fir forest types. A forest canopy with moderate to dense canopy cover characterized the closed forest. Shrub-step comprised mainly of bitterbrush (*Purshia sp*.) and sage (*Artemisia sp*.) characterized rangeland. Cities and roads defined the urban/rural development of roads and building structures. The water class was comprised of rivers, irrigation canals, lakes, and ponds. Rock was characterized by rock bluffs and cliffs.

Statistical Analysis

We identified annual home ranges for cougars to determine their juxtaposition to major highways (I-90 and SR's) and home range size, location, and juxtaposition to neighboring marked cougars. We used ArcView 3.2a (ESRI, 380 New York St, Redland, CA 92373) and the Animal Movement Analysis ArcView Extension (P. N. Hooge and B. Eichenlaub, 1997) to calculate 95% fixed kernel annual home range estimates for each of the collared cougars.

Preliminary analyses indicated differences in elevation use by cougars between December-April (winter) and May-November (summer). Based on these location differences, we analyzed winter and summer location data separately. We used separate variance t-tests to compare cougar use locations with random locations to determine which variables should potentially be included in a multivariate model. Only those variables that yielded statistically significant ($P<0.05$) differences between used and random locations were considered for inclusion in logistic regression models (Manely et al. 2002). We calculated the selection ratio (S) by dividing the mean of use locations by the mean of availability locations for physiographic and vegetative conditions (Manly et al. 2002).

We used logistic regression for modeling relative probability of presence for cougars on a landscape scale in western Kittitas County (Manly et al. 2002). To select variables for inclusion in the model, we compared the means of vegetative and physiographic conditions for GPS coordinates for cougar locations to those associated with randomly placed locations using t-tests and cumulative percent curves in SPSS 10 (SPSS Inc, 233 S. Wacker Drive, Chicago, IL 60606). We considered variables correlated if Spearman's rank correlation coefficient was >0.50. We selected the collinear variable that showed significant ($P<0.05$) differences, and those we presumed to be biologically meaningful for cougars. Using the uncorrelated variable set, we used a forward stepwise logistic regression for all possible combinations of main effects. Inclusion of variables was based on the χ^2 improvement statistics, and the model that yielded the largest log likelihood χ^2 was selected as best (Manly et al. 2002). Equation [1] defines the relative probability equation for the logistic regression model.

$$[1] \qquad \boldsymbol{P} = \frac{\exp(Bo + B1a + B2b + B3c...)}{1 + \exp(Bo + B1a + B2b + B3c)}$$

Where *P* is the probability of cougar use, *Bo* is a constant, and *B1a - B3c* are parameter coefficients.

Using ArcMap 8.3 (ESRI Inc. 380 New York St. Redlands, CA 92373), we connected the consecutive locations of marked cougars with line segments to analyze travel paths. For each of the line segments that intersected the roads, we identified the time and date of the crossing from the location before it crossed to the locations after it crossed a highway to interpret temporal or seasonal patterns.

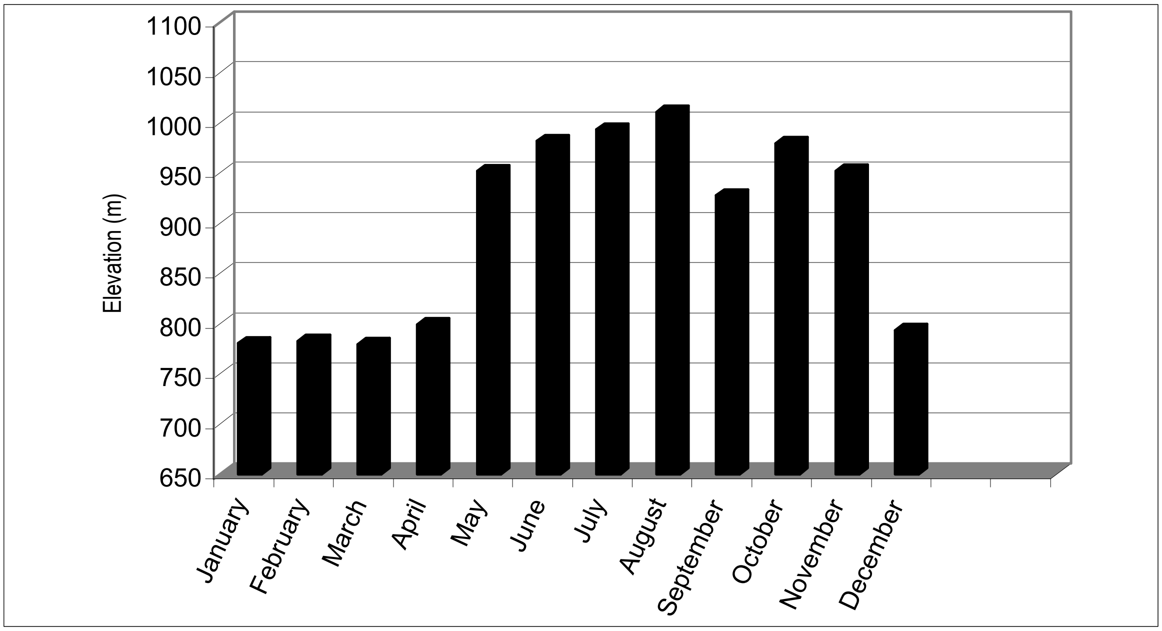
RESULTS

We analyzed movements from 13,074 GPS locations from 11 GPS collared cougars during December 13, 2001 through December 26, 2004. This analysis included 3 adult females, 6 adult males, 1 sub-adult (<3 years of age) female and 1 sub-adult male.

Annual fixed kernel home ranges for male cougars were 2.5 times larger than female cougars. Female cougar annual home ranges (Fig. 2) were on average 139 km^2 (n = 11) and male cougars (Fig. 3-5) averaged 352 km^2 (n = 15) (Appendix A).

Deer and elk migrate to lower elevations near the valley bottoms during the winters where snow depth is less and forage is available. During the summer months they occupy both lower and higher elevations. Cougar movements generally reflected the migratory patterns of ungulates (Fig. 1) occupying higher elevations during the summer months (May-November) and lower elevations on average during the winter (December-April). We found cougars used a mean elevation of 786 ± 166 in winter and 971 ± 256 in summer.

Figure 1. Average (monthly) elevation use by collared cougars in western Kittitas County, Washington, 2001-2004.



Univariate Analysis

We used t-test to compare 6,295 winter and 6,779 summer GPS locations for cougars with 52,125 random locations to examine use of vegetative or physiographic variables (Table 2). Cougars showed greater selectivity for habitat types, land cover classifications, and physiographic features during the winter when they tended to be restricted to lower elevations. Cougars selected against high elevations (T=123.7, df=13,950, $P<0.05$, $S = 0.88$) and steep slopes (T=20.7, df =8,201, $P<0.05$, $S=0.82$) during the winter. Cougars selected for open forest (T=-16.4, df=7,706, $P<0.05$, $S=1.34$) and closed forest (T=-5.1, df=7,872, $P<0.05$, $S=1.08$), but avoided agriculture (T=16.9, df=9,980, $P<0.05$, $S=0.43$), rangeland (T=27.0, df=17,687, $P<0.05$, $S=0.16$), water (T=14.3, df=18,549, $P<0.05$, $S=0.17$), and rock (T=24.3, df=12,695, $P<0.05$,

$S=0.26$) land cover classes. Cities/roads occupied a small portion of the study area and cougar use of these types was not different from that available (T=1.2, df=8,032,$P=0.220$, $S=0.93$). In winter, cougars selected for south facing slopes (T=-8.3, df=7,740, $P<0.05$, $S=1.19$) and flat areas (T=-3.5, df=7,631, $P<0.05$, $S=1.20$). They avoided north (T=8.2, df=8,202, $P<0.05$, $S=0.81$) and west slopes (T=5.2, df=8,081, $P<0.05$, $S=0.87$) and were neutral for east slopes (T=-0.7, df=7,872, $P=0.456$, $S=1.02$).

Cougars showed different selection patterns during summer than in winter. In summer cougars selected for steeper slopes (T=-6.4, df=8,919, $P<0.05$, $S = 1.05$) and selected for lower elevations (T=39.1, df=10,243, $P<0.05$, $S=0.88$) as they did in winter, but the average elevation use was higher in summer with a mean of 971 ± 256 m than in winter 786 ± 166 m. Cougars selected for open forest (T=-6.3, df=8,530, $P<0.05$, $S=1.12$) and closed forest (T=-18.4, df=8,634, $P<0.05$, $S=1.27$), but selected against agriculture (T=17.1, df=11,012, $P<0.05$, $S=0.43$), rangeland (T=38.4, df=41,466, $P<0.05$, $S=0.07$), water (T=11.2, df=15,064, $P<0.05$, $S=0.25$) cities/roads (T=11.6, df=10,836, $P<0.05$, $S=0.46$), and rock (T=19.1, df=11,969, $P<0.05$, $S=0.37$). During the summer, cougar use of aspect shifted to prefer north (T=-5.8, df=8,451, $P<0.05$, $S=1.15$), east (T=-2.6, df=8,562, $P<0.05$, $S=1.06$) and west (T=-2.4, df=8,552, $P<0.05$, $S=1.06$) slopes and selected against south slopes (T=4.6, df=8,760, $P<0.05$, $S=0.91$) and flat terrain (T=15.3, df=11,133, $P<0.05$, $S=0.44$).

In summary, during winter cougars prefer lower elevation, forested habitat with mild slopes with a south facing aspect. In contrast, during the summer, they preferred forested habitat with steeper slopes on north, east, and west aspects. Cougars still preferred lower elevations during summer relative to what is available in western Kittitas County.

Table 1. Winter locations of cougar use (n=6,295) compared to available random points (n=52,125) in western Kittitas County, Washington, 2001 – 2004 with separate variance t-test and selection ratios. Elevations are in meters. Selection ratio by Manley et al. 2002.

		Cougar Use Locations		Availability Random Locations					
Variable		**Mean**	**SD**	**Mean**	**SD**	**t-test**	**df**	***P-value***	***S*-ratio**
Elevation		786	167	1106	343	123.7	13950	0.000	0.71
Slope		14.4	11.1	17.5	12.0	20.7	8201	0.000	0.82
Land Cover									
	Agriculture	0.033	0.179	0.076	0.265	16.9	9980	0.000	0.43
	Open Forest	0.428	0.495	0.320	0.467	-16.4	7706	0.000	1.34
	Closed Forest	0.475	0.499	0.441	0.496	-5.1	7872	0.000	1.08
	Rangeland	0.007	0.084	0.045	0.207	27.0	17687	0.000	0.16
	Cities/Roads	0.038	0.192	0.041	0.199	1.2	8032	0.220	0.93
	Water	0.002	0.044	0.012	0.111	14.3	18549	0.000	0.17
	Rock	0.017	0.129	0.065	0.246	24.3	12695	0.000	0.26
Aspect									
	North	0.168	0.374	0.207	0.407	8.2	8202	0.000	0.81
	East	0.251	0.434	0.247	0.431	-0.7	7872	0.456	1.02
	South	0.332	0.471	0.280	0.449	-8.3	7740	0.000	1.19
	West	0.178	0.383	0.205	0.404	5.2	8081	0.000	0.87
	Flat	0.071	0.257	0.059	0.236	-3.5	7631	0.000	1.20

Table 2. Summer locations of cougar (use, (n=6,779)) compared to available random points (n=52,125) in western Kittitas County, Washington, 2001 – 2004 with separate variance t-test and selection ratios. Elevations are in meters. Selection ratio by Manley et al. 2002.

		Cougar Use Locations		Availability Random Locations					
Variable		**Mean**	**SD**	**Mean**	**SD**	**t-test**	**df**	***P-value***	***S*-ratio***
Elevation		971	256	1106	343	39.1	10243	0.000	0.88
Slope		18.4	11.3	17.5	12.0	-6.4	8918	0.000	1.05
Land Cover									
	Agriculture	0.033	0.180	0.076	0.265	17.1	11012	0.000	0.43
	Open Forest	0.359	0.480	0.320	0.467	-6.3	8530	0.000	1.12
	Closed Forest	0.558	0.497	0.441	0.496	-18.4	8634	0.000	1.27
	Rangeland	0.003	0.051	0.045	0.207	38.4	41466	0.000	0.07
	Cities/Roads	0.019	0.138	0.041	0.199	11.6	10836	0.000	0.46
	Water	0.003	0.056	0.012	0.111	11.2	15064	0.000	0.25
	Rock	0.024	0.152	0.065	0.246	19.1	11969	0.000	0.37
Aspect									
	North	0.241	0.428	0.209	0.407	-5.8	8451	0.000	1.15
	East	0.262	0.440	0.247	0.431	-2.6	8562	0.009	1.06
	South	0.254	0.435	0.280	0.449	4.6	8760	0.000	0.91
	West	0.218	0.413	0.205	0.404	-2.4	8552	0.017	1.06
	Flat	0.026	0.158	0.059	0.236	15.3	11133	0.000	0.44

Logistic Regression Analyses

We selected 4 variables (elevation, slope, aspect, land cover classes) for inclusion in the logistic regression analyses for winter (Table 3) and summer (Table 5). Aspect was separated into 5 classes and land cover classifications were separated into 7 classes. Each class was dummy coded with a “0” for reference and “1” for response. Due to multicollinearity we were only able to determine parameter estimates and odds ratios for 4 classes of aspect and 6 classes of land cover. All 4 variables were included in the best-fit model (Table 4 for winter, Table 6 for summer). Because the analysis required that classes of aspect and land cover classifications be dummy coded, if one class within each category was significant in the model the other classes must be included even if they are not significant. The final model of habitat selection for winter (Equation [2]) is:

$$P = \frac{\exp(2.589 - 0.006(Elev) + 0.026(slope) - 0.448(North) + 0.243(South) - 0.083(West) - 0.677(Flat) - 1.601(Ag) - 1.899(RngLd - 0.979(CtyRds) + 0.834(OpnFor) + 0.915(CldFor) - 1.678(Water))}{(1 + \exp(2.589 - 0.006(Elev) + 0.026(slope) - 0.448(North) + 0.243(South) - 0.083(West) - 0.677(Flat) - 1.601(Ag) - 1.899(RngLd) - 0.979(CtyRds) + 0.834(OpnFor) + 0.915(CldFor - 1.678(Water)))}$$

Selection for open forest, closed forest and south slopes during the winter was reflected in the positive parameter coefficients (Table 4). Avoidance of higher elevations, north slopes, agriculture, rangeland, cities/roads, and water was reflected in the negative parameter coefficients. The odds for relative use by cougars was 2.3 times greater for open forest than any other land cover classes. The odds for relative use were 2.5 times greater for closed forest than other land cover classes. In addition the odds of relative use of cougars was 1.3 times greater for south aspect than for other aspects. According to Steinberg and Colla (2000) and Hensher and Johnson (1981), this model of cougar winter habitat use shows a good fit to the data (Likelihood ratio χ^2 = 9,854.664, df=14, P<0.05, McFadden’s Rho-squared = 0.247)

Table 3. Forward stepwise model selection process for winter habitat selection of cougars in western Kittitas County, Washington, 2001-2004.

Model Variables	Likelihood Ratio X^2	Df	*P*-value	Improvement X^2	df	*P*-value	* Rho_sq
Elevation	5870.899	1	0.000				0.15
Elevation, Aspect	6505.366	6	0.000	634.467	5	0.000	0.16
Elevation, Land Cover, Aspect	9597.252	13	0.000	3091.886	7	0.000	0.24
Elevation, Slope, Aspect, Land Cover	9854.664	14	0.000	257.412	1	0.000	0.25

*McFadden's Rho-Square

Table 4. Logistic regression model distinguishing cougar use locations (response = 1) from availability points (response = 0) in western Kittitas County, Washington, during winters 2001-2004. The Wald statistic for all but West was significant at $P<0.05$, -2 log likelihood = 30,086, model χ^2 = 9,854.664, df=14, $P<0.05$.

Variable	Estimate	S.E.	T-ratio	*P-value*	Odds Ratio[a]
Constant	2.589	0.655	3.951	0.000	
Elevation	-0.006	0.000	-67.533	0.000	0.994
Slope	0.026	0.002	16.112	0.000	1.026
Aspect					
North	-0.448	0.046	-9.710	0.000	0.639
South	0.243	0.040	6.113	0.000	1.276
West	-0.083	0.046	-1.796	0.072	0.921
Flat	-0.677	0.067	-10.139	0.000	0.508
East	0.000	0.000			
Land Cover					
Agriculture	-1.601	0.131	-12.210	0.000	0.202
Rangeland	-1.899	0.187	-10.159	0.000	0.150
Cities/Roads	-0.979	0.130	-7.540	0.000	0.376
Open Forest	0.834	0.111	7.516	0.000	2.302
Closed Forest	0.915	0.111	8.267	0.000	2.497
Water	-1.678	0.315	-5.329	0.000	0.187
Rock	0.000	0.000			

[a]Odds ratio = Exp (β); the factor by which the odds that an area will be used by cougars change for every unit increase in the independent variable.

The model for summer habitat selection was not as robust as the model developed for winter due to greater availability of habitat types and more generalized use patterns by cougars.

During summer deer and elk were not restricted by forage and snow depth and they tended to migrate to higher elevations away from lower elevation winter ranges. Equation [3] shows the final model of habitat selection for summer:

$$P = \frac{\exp(-0.255 - 0.002(Elev) + 0.018(slope) + 0.037(North) + 0.086(East) + 0.061(West) - 0.954(Flat) - 0.862(Ag) - 2.697(RngLd - 0.878(CtyRds) + 0.586(OpnFor) + 0.753(CldFor) - 0.472(Water))}{(1 + \exp(-0.255 - 0.002(Elev) + 0.018(slope) + 0.037(North) + 0.086(East) + 0.061(West) - 0.954(Flat) - 0.862(Ag) - 2.697(RngLd) - 0.878(CtyRds) + 0.586(OpnFor) + 0.753 CldFor - 0.472(Water)))}$$

Selection for open forest, closed forest, north, east, west aspects, and steeper slopes during the summer was reflected in the positive parameter coefficients (Table 6). Avoidance of higher elevations, south slopes, flat terrain, agriculture, rangeland, cities/roads, and water was reflected in the negative parameter coefficients and constant. The odds for relative use by cougars was 1.8 times greater for open forest than other land covertypes, and for closed forest types was 2.2 times greater. In addition the odds of relative use of cougars was 1.1 times greater for an aspect of north, east or west than for any other aspect. According to Steinberg and Colla (2000) and Hensher and Johnson (1981), the model of cougar summer habitat use shows a relatively poor fit to the data (Likelihood ratio χ^2 = 3,527.615, df=14, P<0.05, McFadden's Rho-squared = 0.08). The result of a poor model fit during the summer is expected since cougars are relatively unconstrained during the summer months. Deer and elk, the primary prey species of cougars (WDFW, unpublished data), are present from low to high elevations and virtually all habitat types during summer.

Table 5. Forward Stepwise Model selection process for summer habitat selection of cougars in western Kittitas County, Washington, 2001-2004.

Model Variables	Likelihood Ratio X^2	df	*P*-value	Improvement X^2	df	*P*-value	* Rho_sq
Land Cover	1184.493	7	0.000				0.03
Elevation, Land Cover	3086.08	8	0.000	1901.587	1	0.000	0.07
Elevation, Slope, Land Cover	3366.943	9	0.000	280.863	1	0.000	0.08
Elevation, Slope, Aspect, Land Cover	3527.615	14	0.000	160.672	5	0.000	0.08

*McFadden's Rho-Square

Table 6. Logistic Regression model distinguishing cougar summer use locations (response = 1) from availability points (response = 0) in western Kittitas County, Washington, 2001-2004. The -2 log likelihood = 38,538, model χ^2 = 3527.615, df=14, $P<0.05$.

Variable	Estimate	S.E.	T-ratio	*P-value*	Odds Ratio[a]
Constant	-0.255	0.105	-2.422	0.015	
Elevation	-0.002	0	-44.057	0.000	0.998
Slope	0.018	0.001	13.484	0.000	1.018
Aspect					
North	0.037	0.038	0.965	0.334	1.038
East	0.086	0.037	2.317	0.021	1.09
West	0.061	0.039	1.559	0.119	1.063
Flat	-0.954	0.091	-10.456	0.000	0.385
South	0	0			
Land Cover					
Agriculture	-0.892	0.111	-8.062	0.000	0.41
Rangeland	-2.697	0.252	-10.717	0.000	0.067
Cities/Roads	-0.878	0.125	-7.012	0.000	0.415
Open Forest	0.586	0.086	6.798	0.000	1.797
Closed Forest	0.753	0.085	8.879	0.000	2.214
Water	-0.472	0.25	-1.892	0.058	0.624
Rock	0	0			

[a]Odds ratio = Exp (β); the factor by which the odds that an area will be used by cougars change for every unit increase in the independent variable.

We analyzed data from GPS collars programmed to collect locations 4 to 6 times per day to determine movements across the interstate (I-90) and state highways (SR 10, 970, 97, 907). Intercepts, illustrated in figures 8-18 and tallied in Table 7, were determined by consecutive GPS locations on both sides of the roadway.

Table 7. Movement intercepts of GPS collared cougars along major interstates and state highways in western Kittitas County, Washington, 2001 - 2004.

Cougar ID	**I-90**	**Hwy 10**	**Hwy 970**	**Hwy 903**	**Hwy 97**
Females					
158158	0	0	0	0	0
156156	0	37	3	0	10
160160	0	0	0	0	84
152153	23	0	0	1	0
Female Totals	*23*	*37*	*3*	*1*	*94*
Cougar ID	**I-90**	**Hwy 10**	**Hwy970**	**Hwy 903**	**Hwy 97**
Males					
151151	0	0	0	1	44
154154	25	7	1	28	0
190190	0	0	0	0	0
159159	1	0	0	0	0
155155	0	0	0	0	4
191191	0	0	9	0	33
130111	2	0	0	0	0
Male Totals	*28*	*7*	*10*	*29*	*81*
Overall Totals	51	44	13	30	175

DISCUSSION

From analysis of home ranges and highway intercepts we observed that intensity of traffic on the highways might inhibit movements of cougars and that such structures may create boundaries for female cougars, but may not for resident male cougars. We observed that most resident female cougars with established home ranges did not cross I-90. Female cougar home ranges overlapped state highways (SR 10, 903, 907, 97) and county roads and females readily crossed these structures. However, I-90 appeared to present an obstacle for movement for all 3 GPS marked female cougars with home ranges adjacent to the interstate. Female cougar 152153 did cross I-90 on 23 occasions. However, these crossing may have been related to social interactions with the adjacent female cougar 158158 and perhaps the young age, social status and dispersal behavior of this individual. After April 25th, 2003, cougar 152153 no longer crossed I-90, but was located within 150 meters from it on several occasions.

A single resident adult male cougar crossed I-90 and established a home range that encompassed I-90. Figure 6 illustrates 2 female cougars (red "156156" and green "152153"), which established home ranges adjacent to I-90 and appear to use the interstate as a home range boundary, while the home range for male cougar 154154 (blue) overlapped I-90. This male cougar crossed I-90 on 25 occasions since 2002 and was killed in an auto collision on I-90. Two of the 7 male cougars have crossed I-90. One of these males that crossed I-90 was a sub-adult and crossed during dispersal movements.

We analyzed cougar crossings along the I-90 corridor and SR's and local highways to determine seasonal and temporal differences of crossings. We observed that adult and sub-adult male cougars crossed (n = 38) I-90 year round with a fairly even distribution between months. We observed only one sub-adult female cougar (152153) cross I-90. She crossed (n = 23) only during the winter months of December, February, and April. After April she established a home range south of I-90, had kittens, and no longer crossed I-90.

SR 97, 970, 10, and 903 are two-lane highways with a lower traffic volume than I-90. Analyzing the cougar crossings along these SR highways, we found an even number of crossing between males and females. We documented 252 crossings with 126 crossings for each sex. For female cougars, there appeared to be no difference for number of crossings between seasons when all highways are considered together. However, when we examined crossings for SR 97 alone, we observed females crossed more frequently in the summer. This is likely due to the higher elevations this SR intercepts and that deer and elk occupied higher elevations during summer whereas during winter deer and elk occupy lower elevations where cougars also concentrate their activities. Males appeared to cross SR 97 more frequently during the winter. Male home ranges are somewhat more restricted to lower elevations in the winter, but they occupy a much larger home range than females. Males generally travel farther per day (minimum mean annual distance = 1,639 ± 61 km) than females (821 ± 200 km). During the summer male and female home ranges expand to higher elevations along with the deer and elk (WDFW unpublished data). As a result, during summer probabilities for cougars to cross the highways in valley bottoms is less. Clevenger (2002) found that cougars in Banff, Alberta consistently used the wildlife crossing structures more than expected during winter months and less than expected during the summer. Although female cougars with established home ranges tended not to cross I-90, SR highways appeared to not inhibit movements of females. Young dispersal aged animals, including females, crossed I-90 on several occasions, as did a dominant male.

We were not able to compare hourly or daily differences for movements of cougars because we were not able to obtain location acquisitions for similar time periods. This was because individual GPS collars did not perform consistently and were not able to acquire satellite coordinates at all programmed times. Satellite acquisition varied from 100-0% of scheduled programmed acquisitions times for individual collars.

We conducted a preliminary analysis to examine the possibility that residential development may restrict or influence movements of cougars. Based on location and movement data of the cougars (Fig. 7), it appears that residential development at higher densities, such as sub-divisions, may restrict or alter cougar movements. In the Santa Ana Mountain Range of southern California, cougars traveled fastest through human-dominated areas and slowest through riparian habitats (Dickson et al. 2005). Development of land near any proposed highway crossing structures may adversely affect cougar use of wildlife crossing structures. Human activity on wildlife crossing structures has been shown to decrease performance of the crossing structures for large carnivores in Alberta (Clevenger and Waltho, 2000).

Figures 8-12 illustrate the cougar highway intercepts, with the deer and elk collision density data from WSDOT, in western Kittitas County. Figures 13-18 illustrate the cougar highway intercepts with the WSDOT milepost numbers for reference. As depicted in the model, the majority of cougar highway intercepts occur in forested areas and tend to occur along ridgelines. Cougar crossing locations along I-90 and SR's appeared correlated with ridgelines at a landscape level where cougars may use these features as travel corridors where they may funnel animal movements across the flat valley bottoms (highlighted in red in Fig. 19).

Management Implications

Based on the results of the univariate analysis and logistic regression modeling, we observed that cougars were more selective of habitats and physiographic features during winter than during summer. Cougars used lower elevations during the winter. This may result in higher probabilities of encounters and crossing of highways located in valley bottoms.

The model we developed can help to predict the relative probability of areas where cougars may cross highway structures. This model could be used to develop a 'cost grid' of land cover-types and physiographic variables identified in the model. This may be used to predict the relative probability of an area for highway crossings for cougars and their ungulate prey using a least cost method in GIS or other similar approaches for Western Kittitas County. It is important to recognize, however, that this model should only be used to rank each habitat type relative to one another. Such a model cannot guarantee actual probability of use, but offers a relative probability comparing each topographic or habitat characteristic against the others in the model (Keating and Cherry, 2004). To validate such a model, future investigation may employ remote cameras to document the probability and intensity of use by cougars and their ungulate prey, and a variety of other wildlife species. Improvements in current generation GPS collars will provide an ability to remotely modify location acquisition schedules on GPS collared animals to test hypotheses developed from observed data. With increased sample size of location data with further research we may be better able to identify a finer temporal and spatial scale where the cougar highway intercepts occur.

ACKNOWLEDGEMENTS

Funding and support for this project came from Washington State Department of Transportation and Washington Department of Fish and Wildlife. Thanks to Cle Elum/Roslyn School District for providing use of their facility. Thanks to Randal Thorp and Robert Hickey at Central Washington University for their work in developing the land classification map for the analysis and for sharing their GIS data. Thanks to Kristen Ryding (WDFW) and Robert Weilgus (WSU) for statistical guidance.

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Figure 2. Female cougar annual 95% fixed kernel home range estimates in western Kittitas County, Washington, 2004.

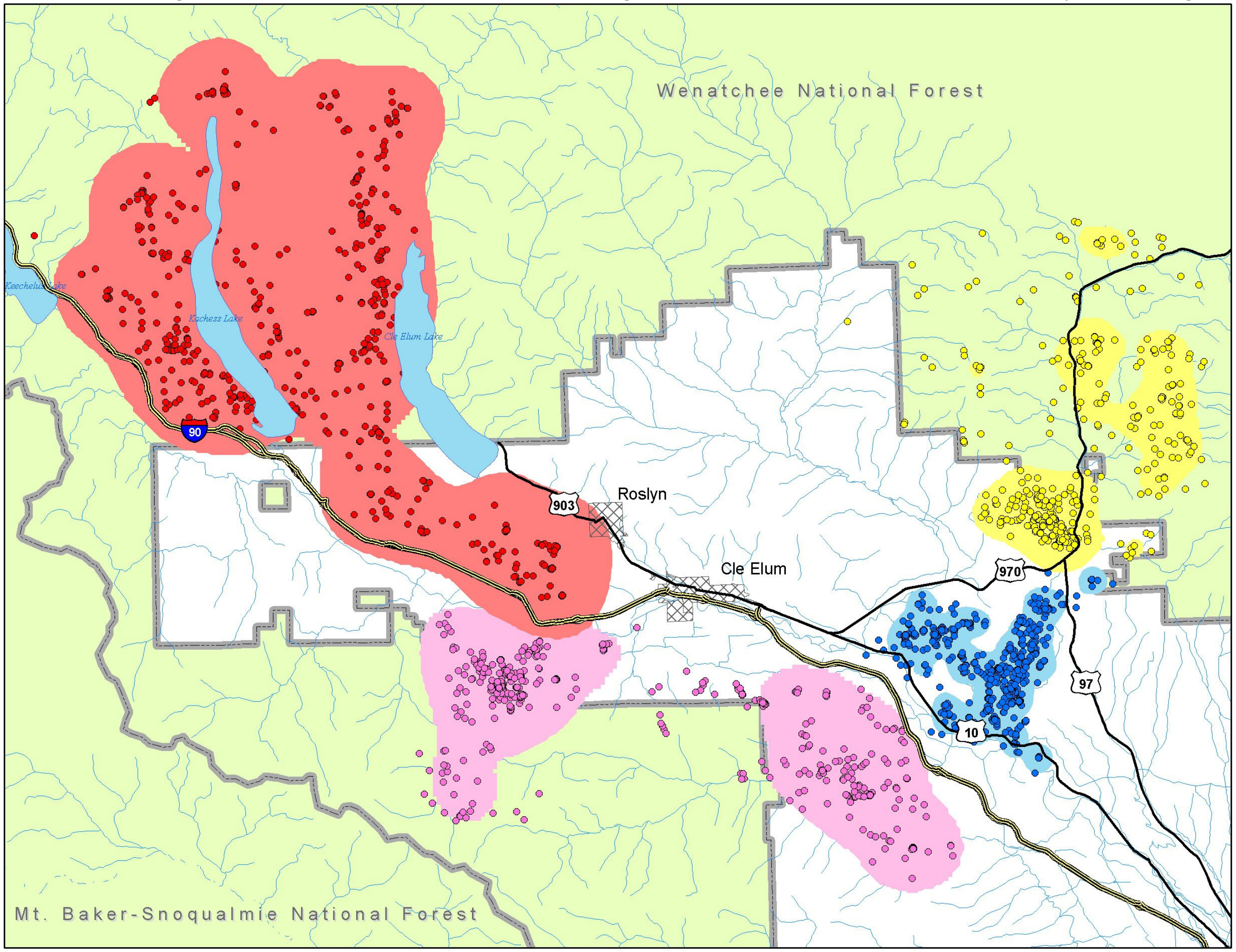


Figure 3. Male cougar annual 95% fixed kernel home range estimates in western Kittitas County, Washington, 2002.

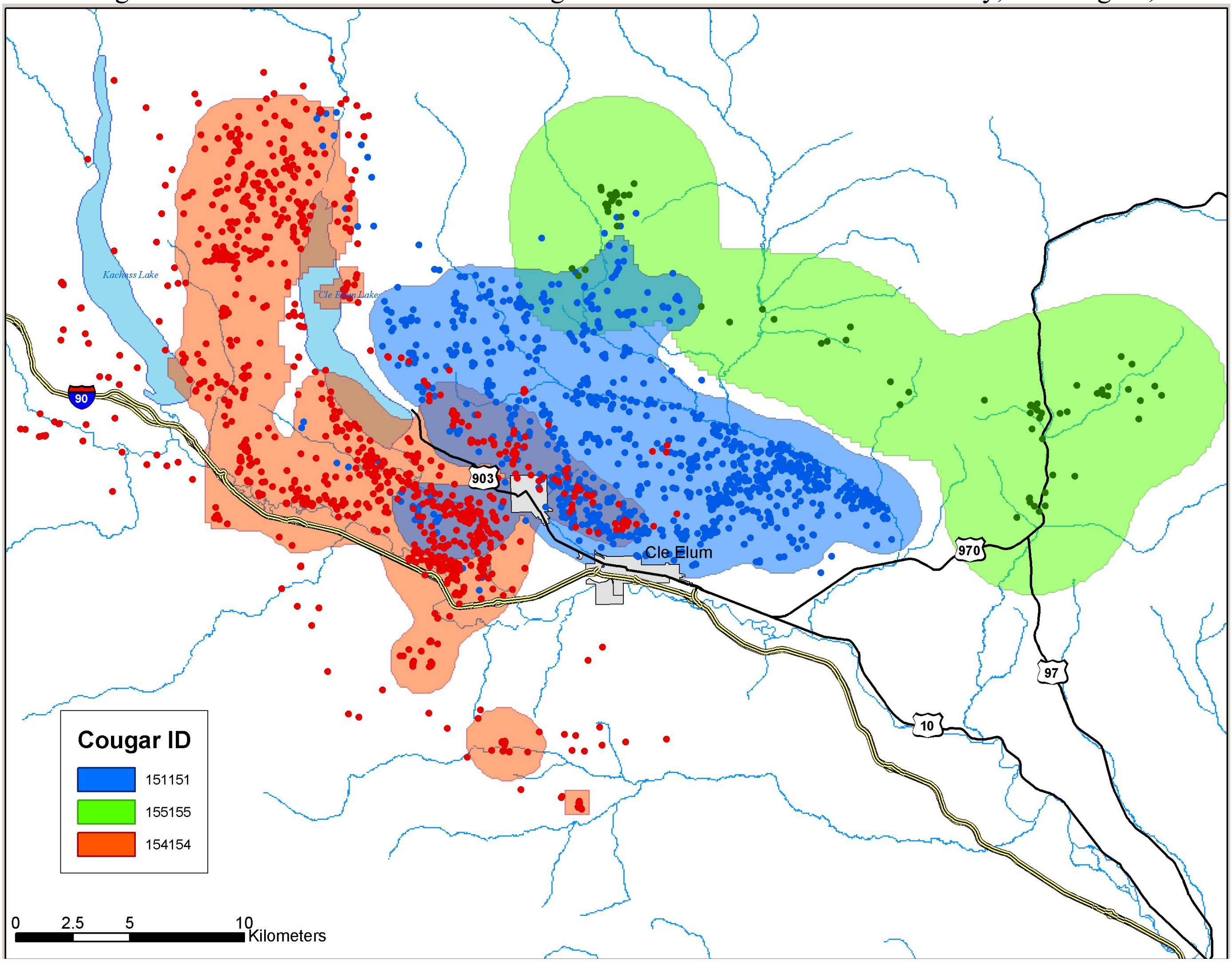


Figure 4. Male cougar annual 95% fixed kernel home range estimates in western Kittitas County, Washington, 2003. Sub-adult cougar 159159 dispersed in April 2003. Cougar 157157 died from a non-human related cause in May 2003.

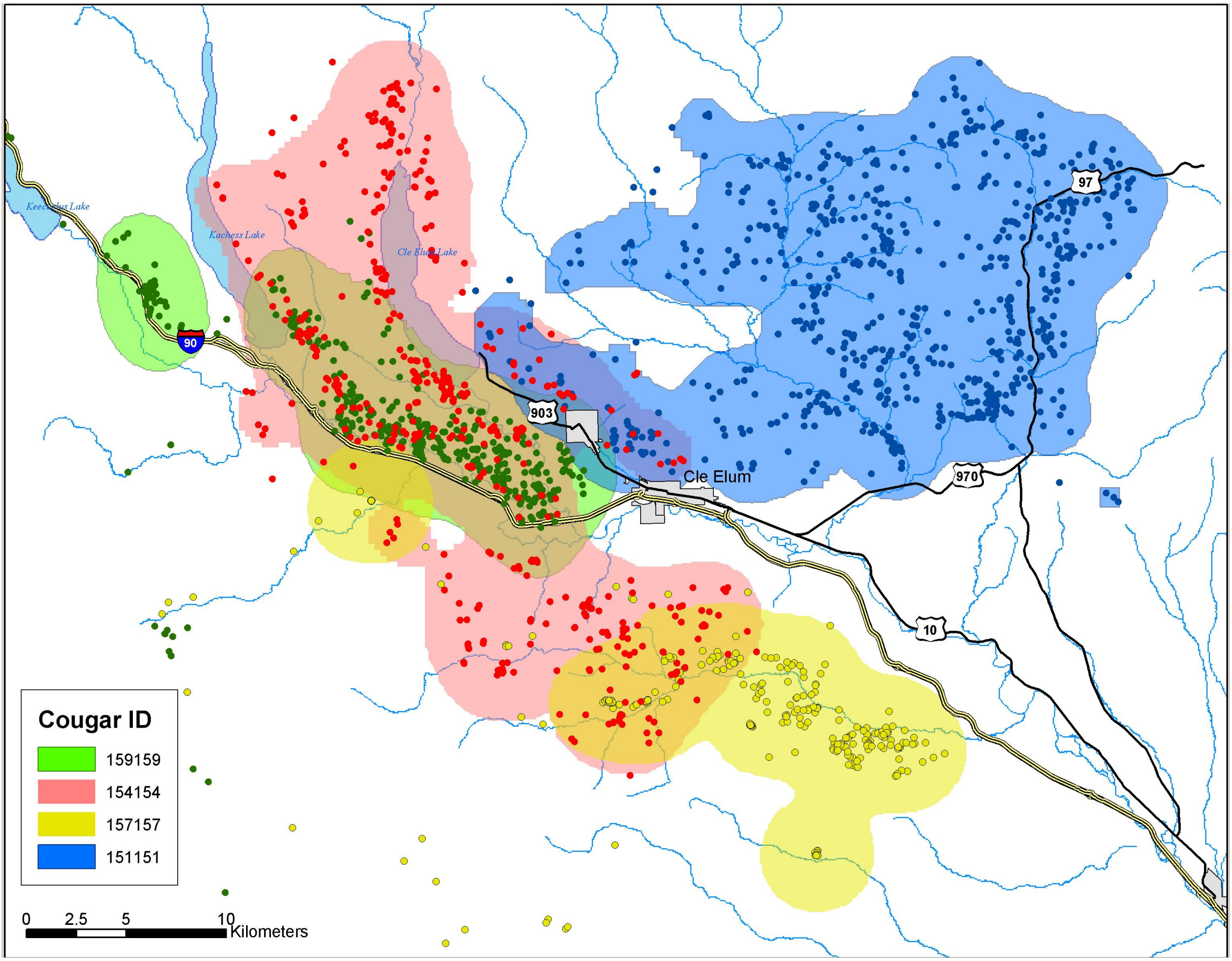


Figure 5. Male cougar annual 95% fixed kernel home range estimates in western Kittitas County, Washington, 2004. Cougar 154154 died from a vehicle collision along I-90 in April 2004.

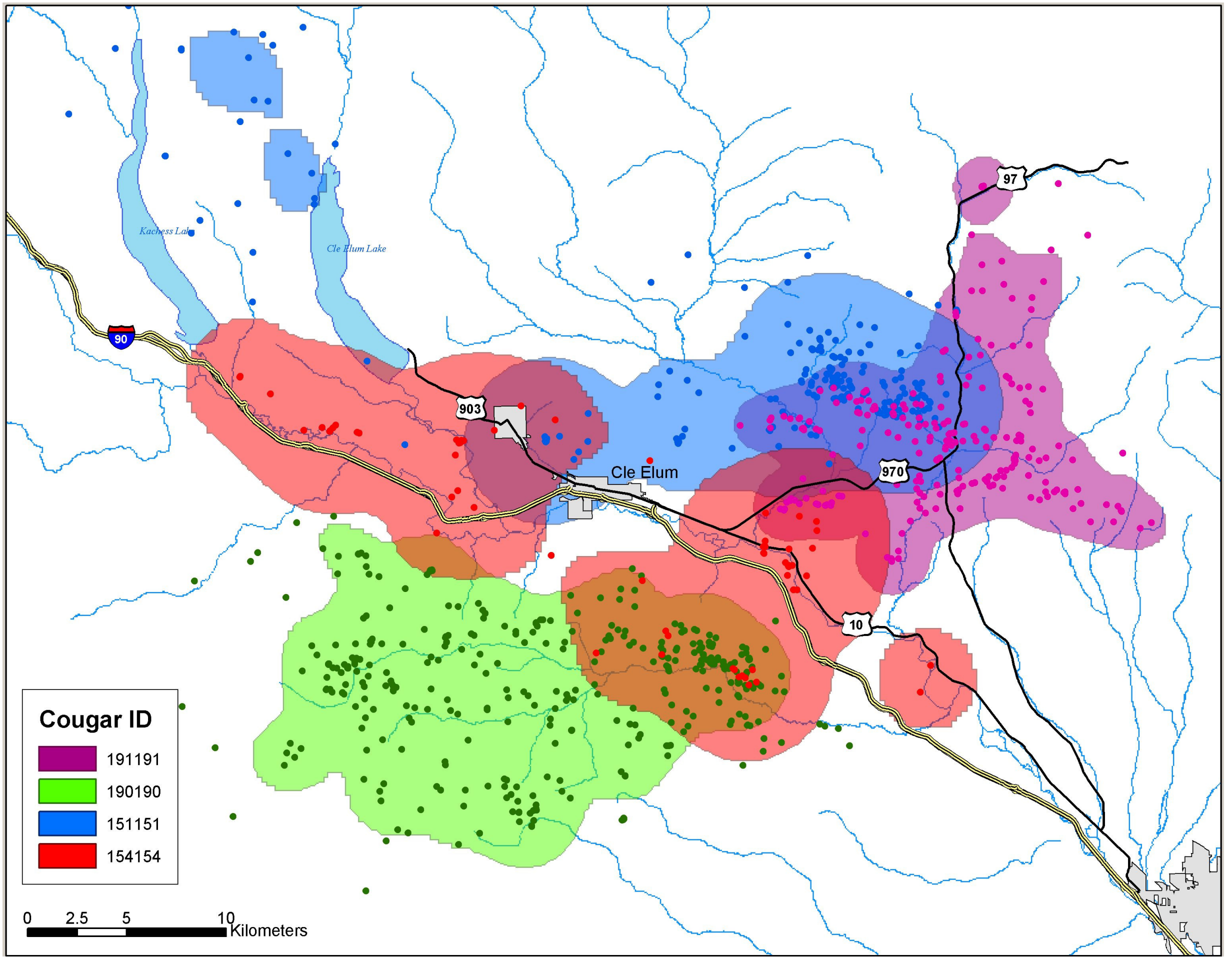


Figure 6. Cougar highway corridor intercepts for a male cougar (blue) and locations of two female cougars (red and green) adjacent to the I-90 corridor.

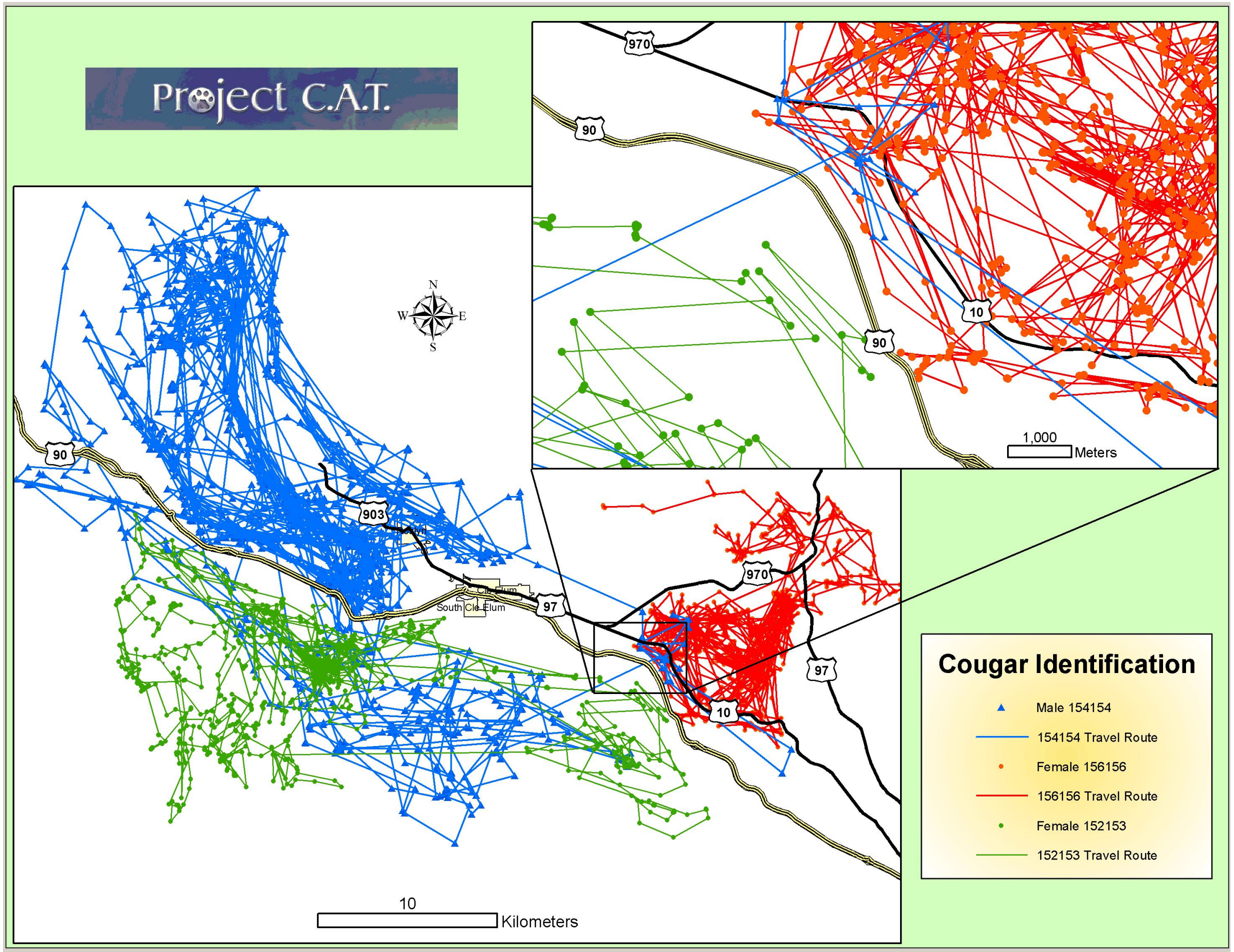


Figure 7. Movements of female cougar 152153 among parcels of land developed with at least one structure in western Kittitas County, Washington, 2001 - 2004.

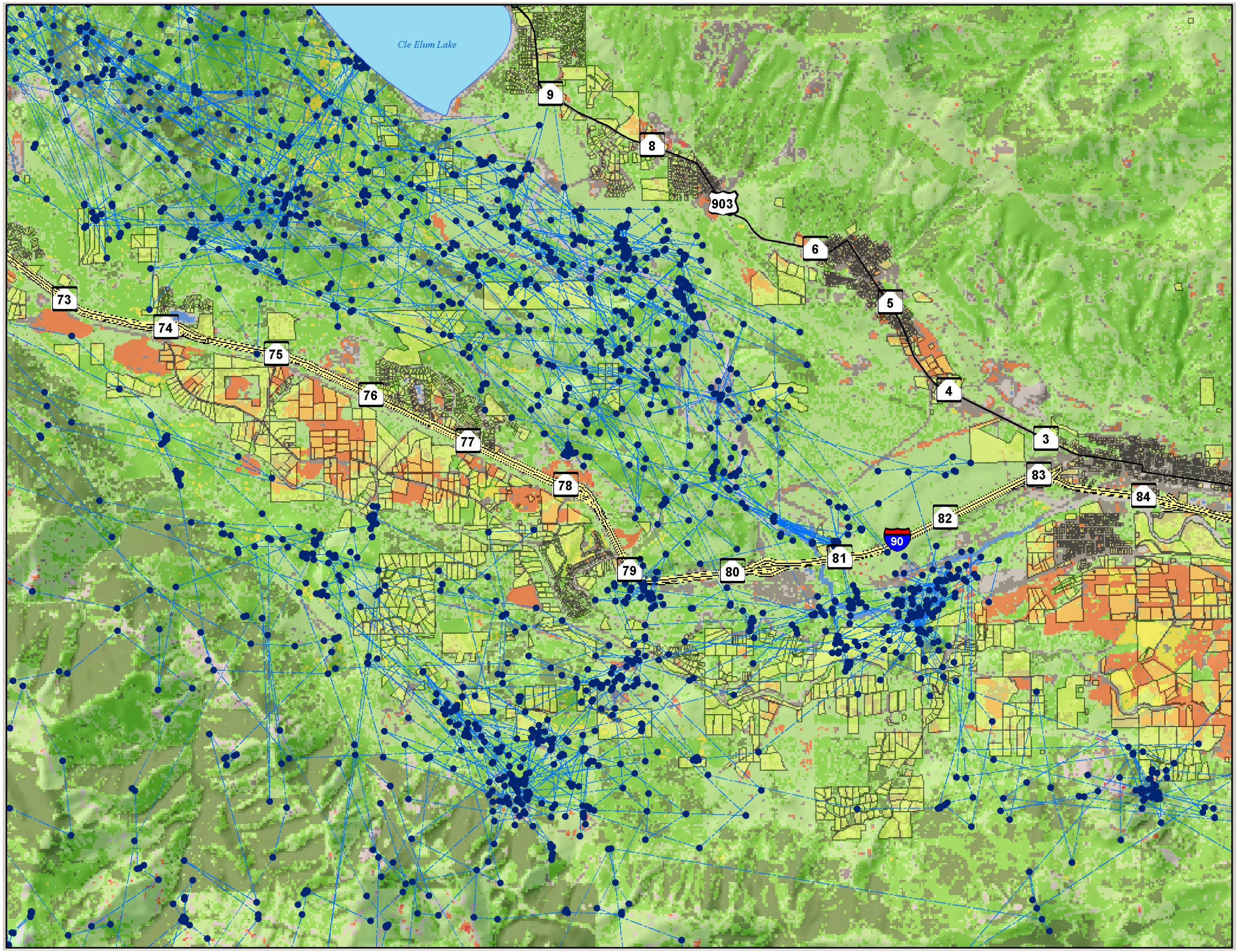


Figure 8. Segments connecting locations where cougars were crossing Interstate 90 between Easton and Cle Elum Exits in western Kittitas County, Washington, 2001-2004.

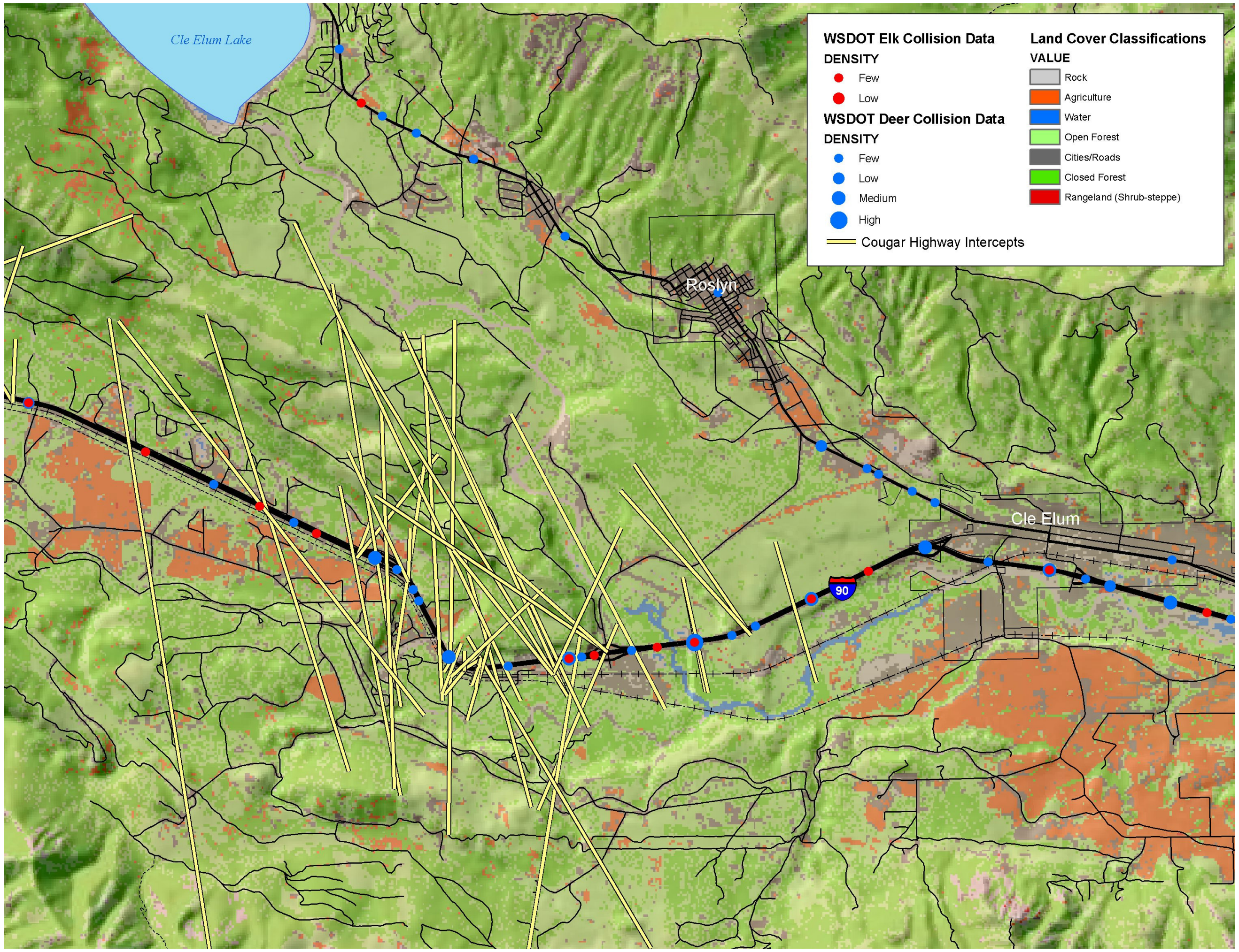


Figure 9. Segments connecting locations where cougars were crossing Interstate 90 between Cabin Creek and Easton Exits in western Kittitas County, Washington, 2001-2004.

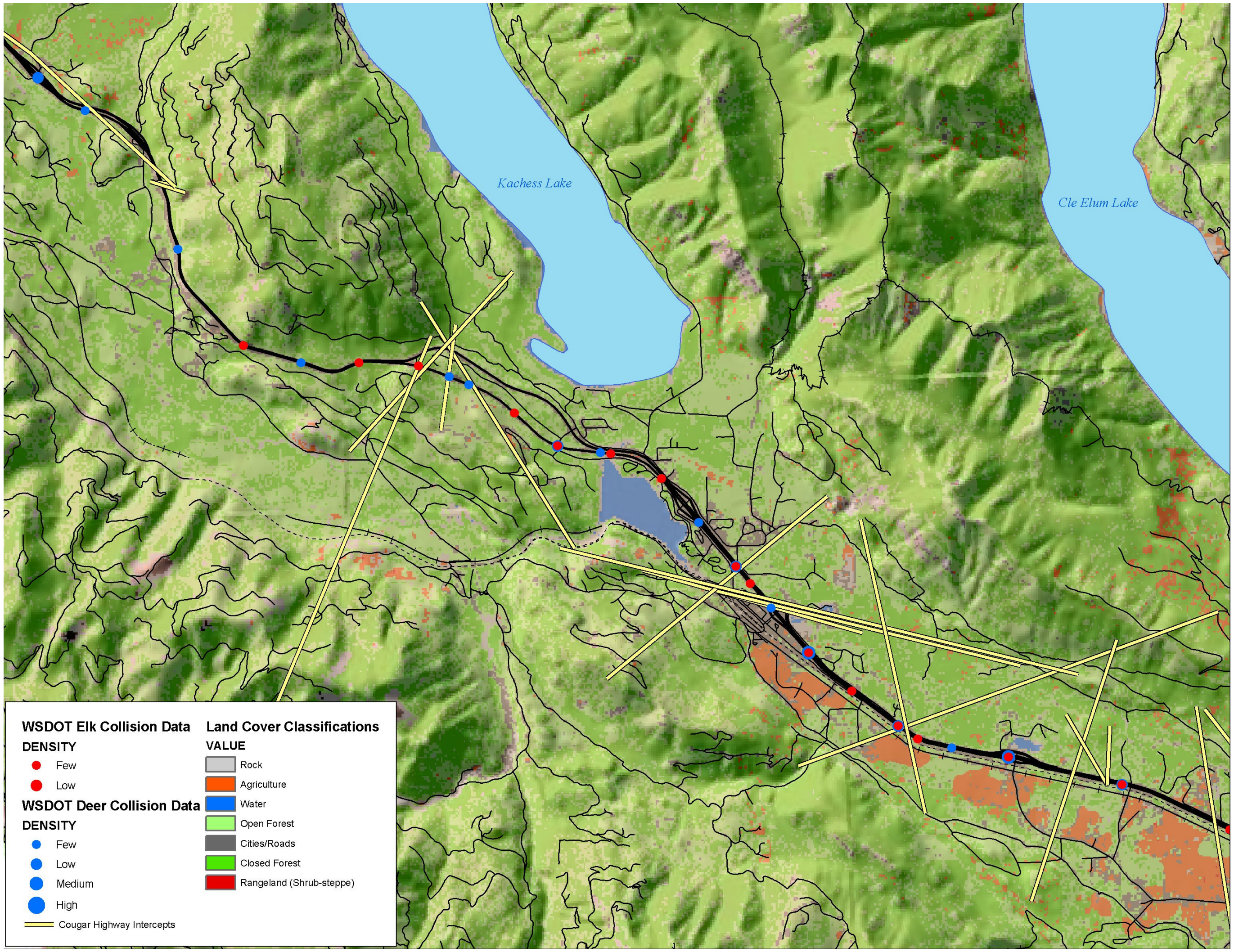


Figure 10. Segments connecting locations where cougars were crossing Interstate 90, SR 10, 970, and 97 between Cle Elum and Elk Heights Exits in western Kittitas County, Washington, 2001-2004.

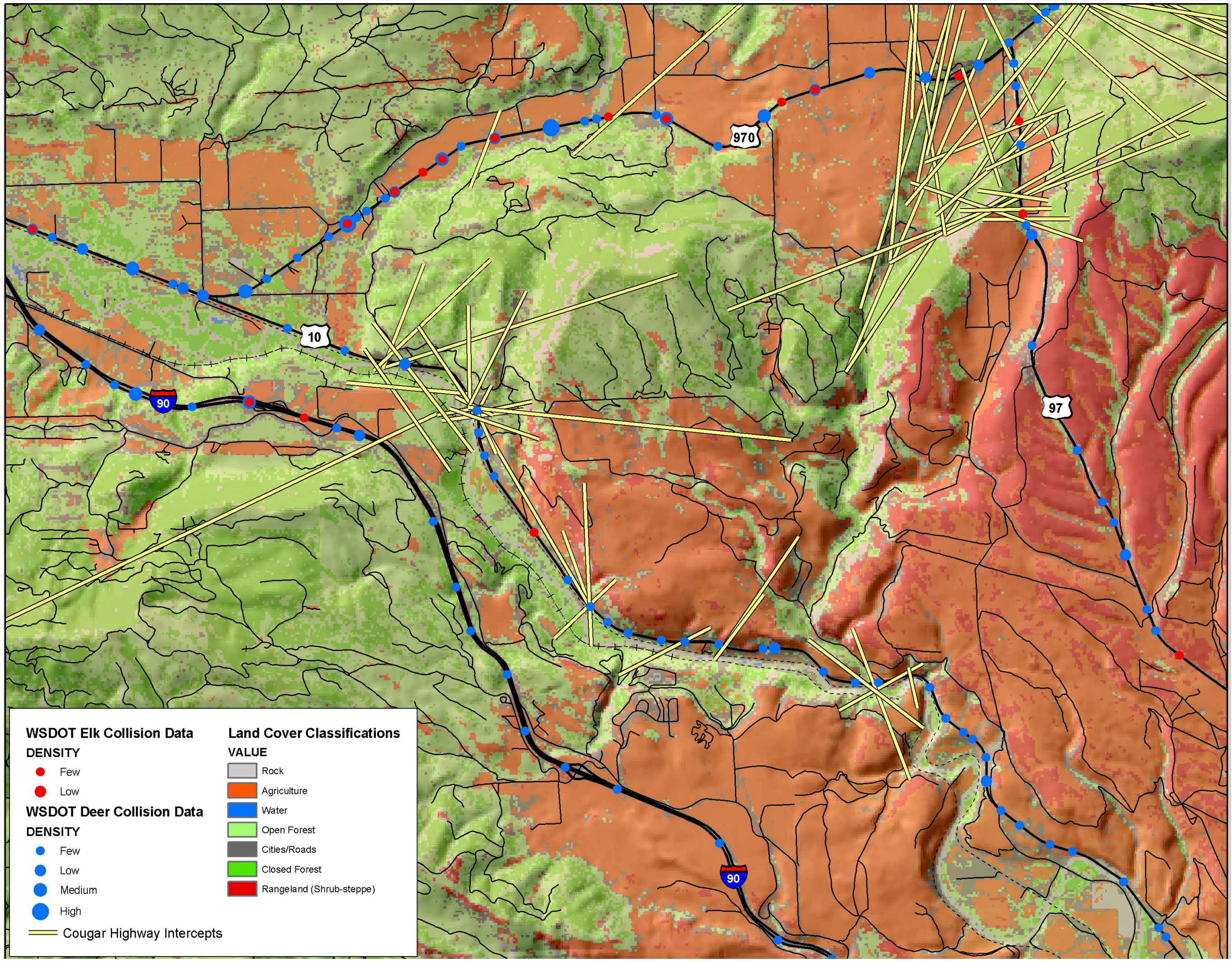


Figure 11. Segments connecting locations where cougars were crossing Interstate 90, SR 10, 970, and 97 in western Kittitas County, Washington, 2001-2004.

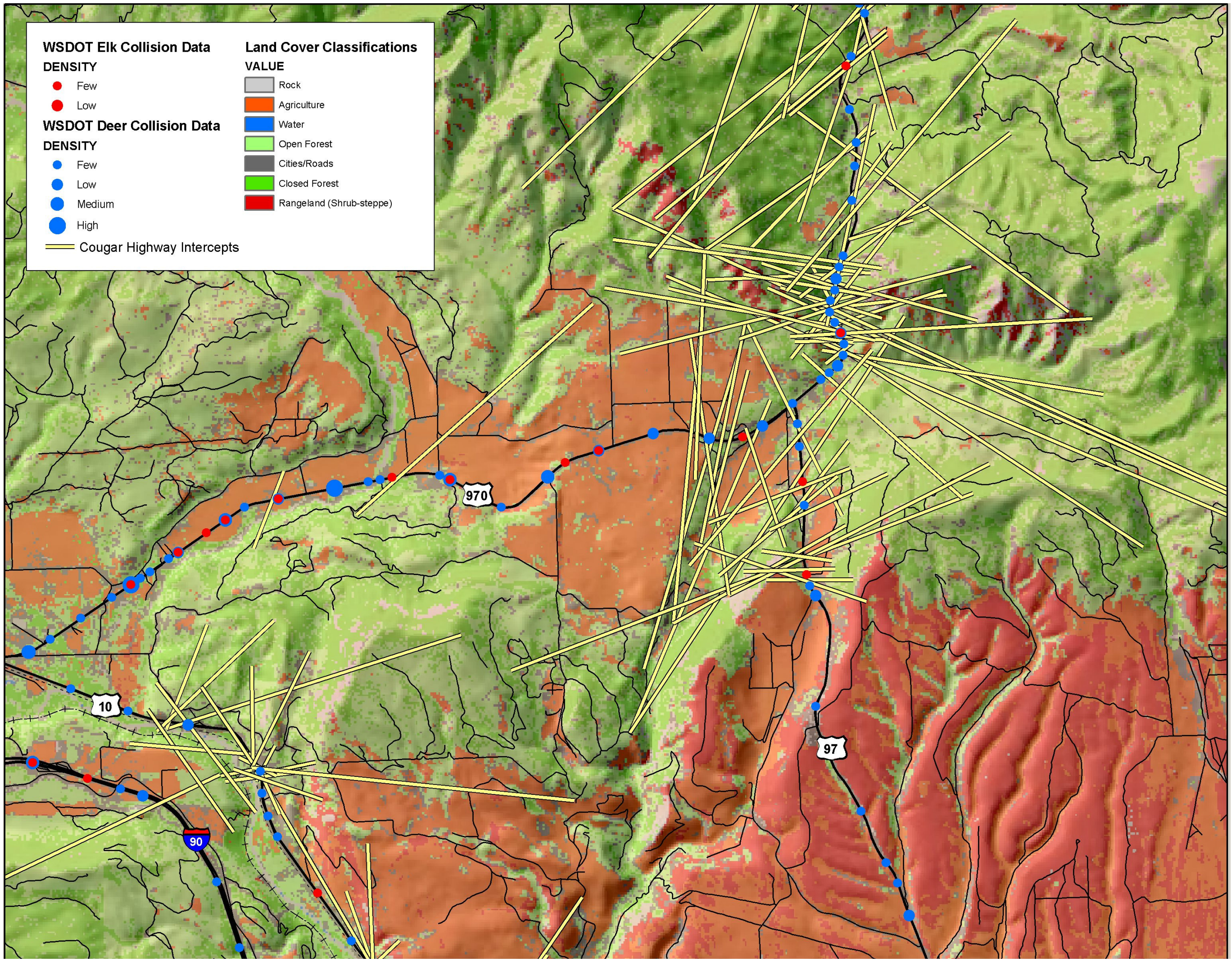


Figure 12. Segments connecting locations where cougars were crossing SR 970 and 97 near Blewett Pass in western Kittitas County, Washington, 2001-2004.

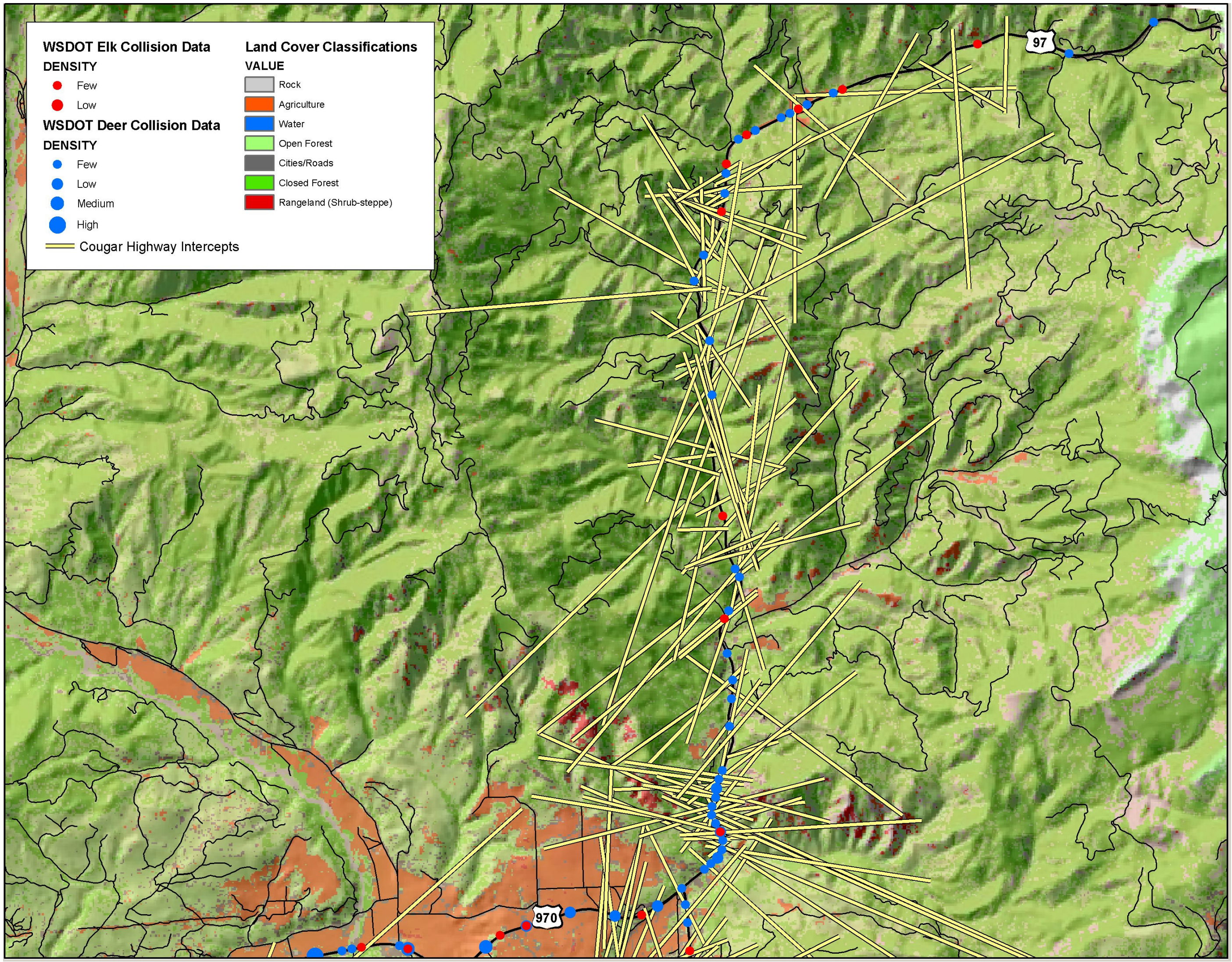


Figure 13. Segments connecting locations where cougars were crossing I-90 near Lake Kachess in western Kittitas County, Washington, 2001-2004.

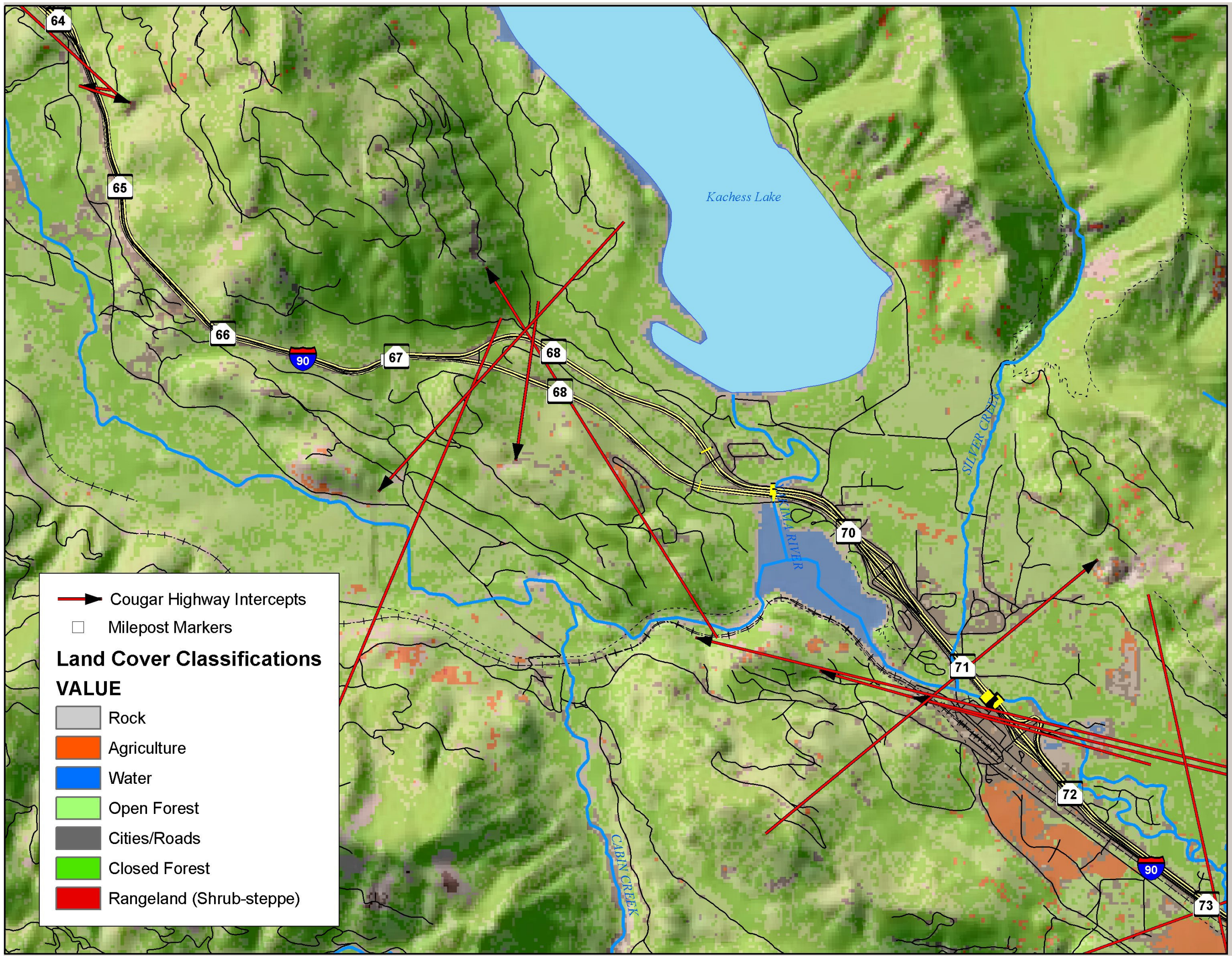


Figure 14. Segments connecting locations where cougars were crossing I-90 near Keechelus Lake in western Kittitas County, Washington, 2001-2004.

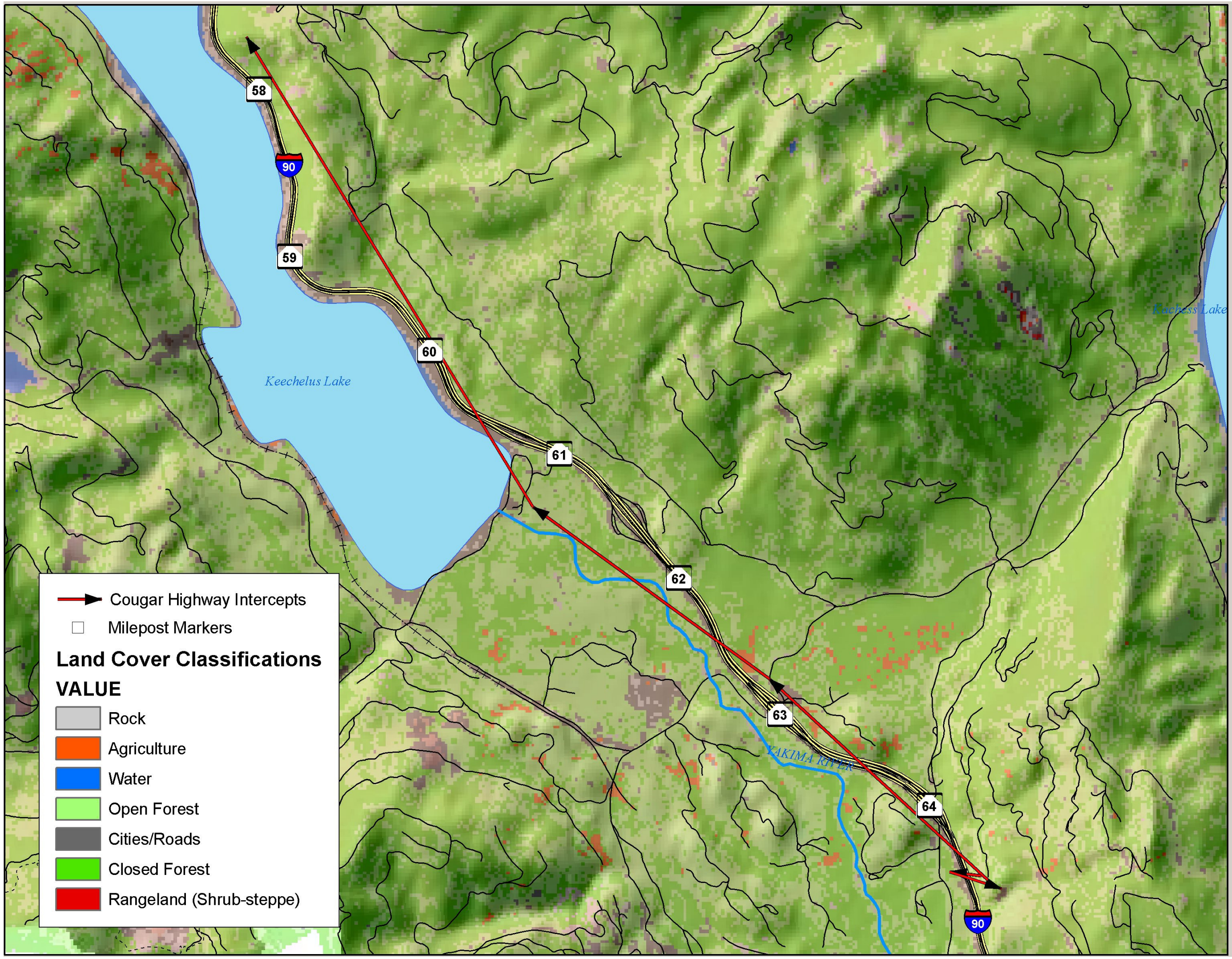


Figure 15. Segments connecting locations where cougars were crossing I-90 near Cle Elum in western Kittitas County, Washington, 2001-2004.

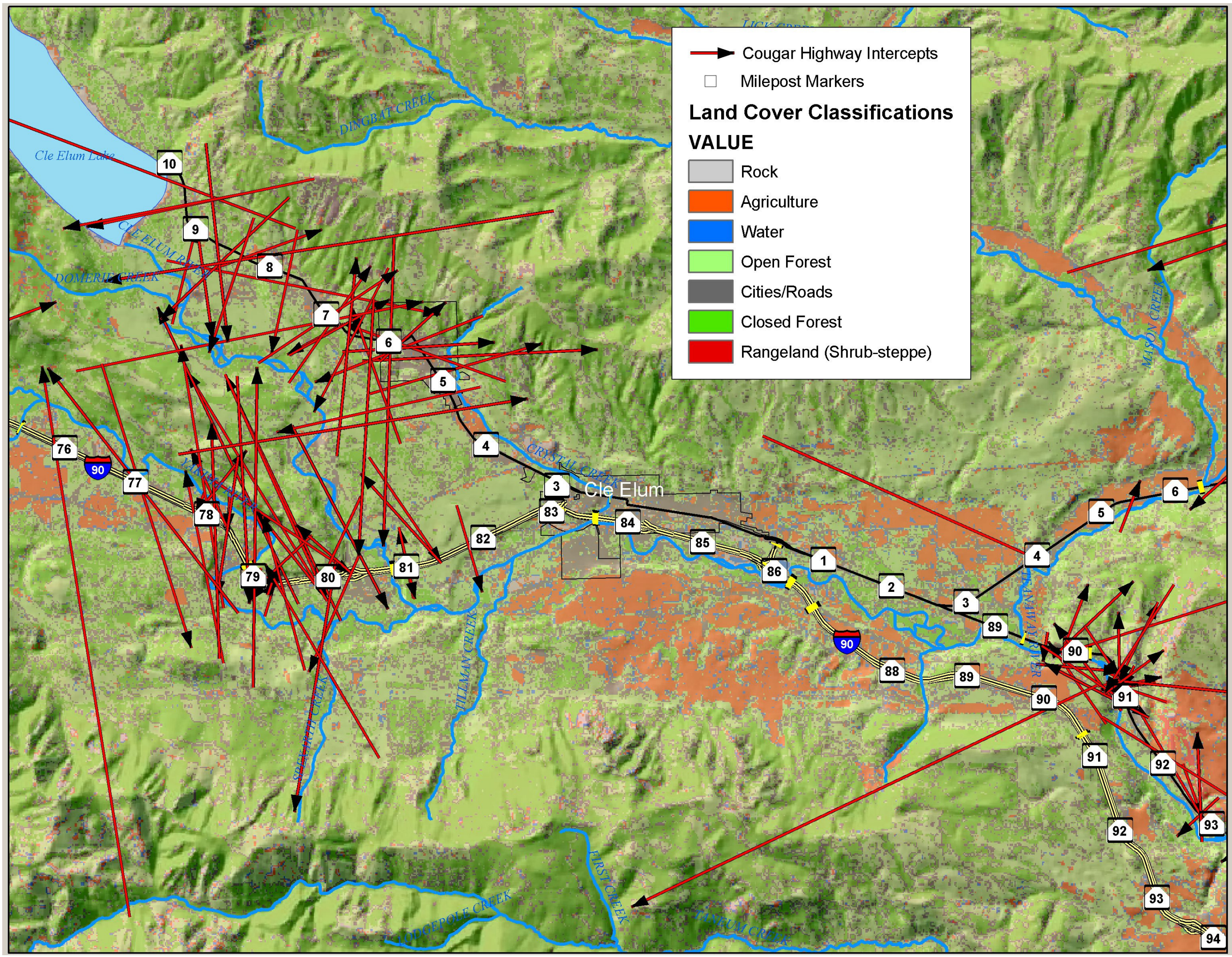


Figure 16. Segments connecting locations where cougars were crossing I-90 and SR10 near Indian John Hill in western Kittitas County, Washington, 2001-2004.

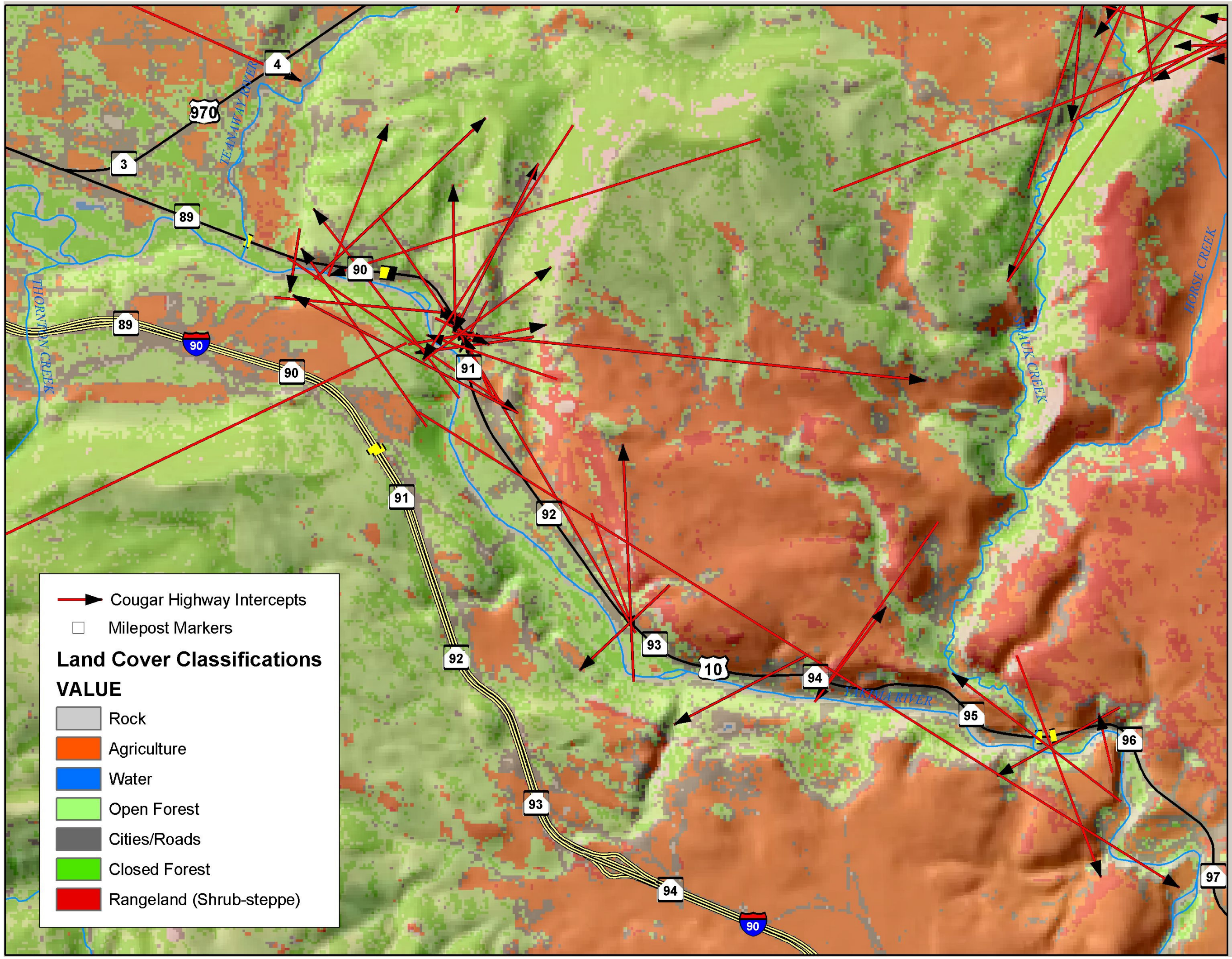


Figure 17. Segments connecting locations where cougars were crossing SR970 and SR10 near Swauk Creek in western Kittitas County, Washington, 2001-2004.

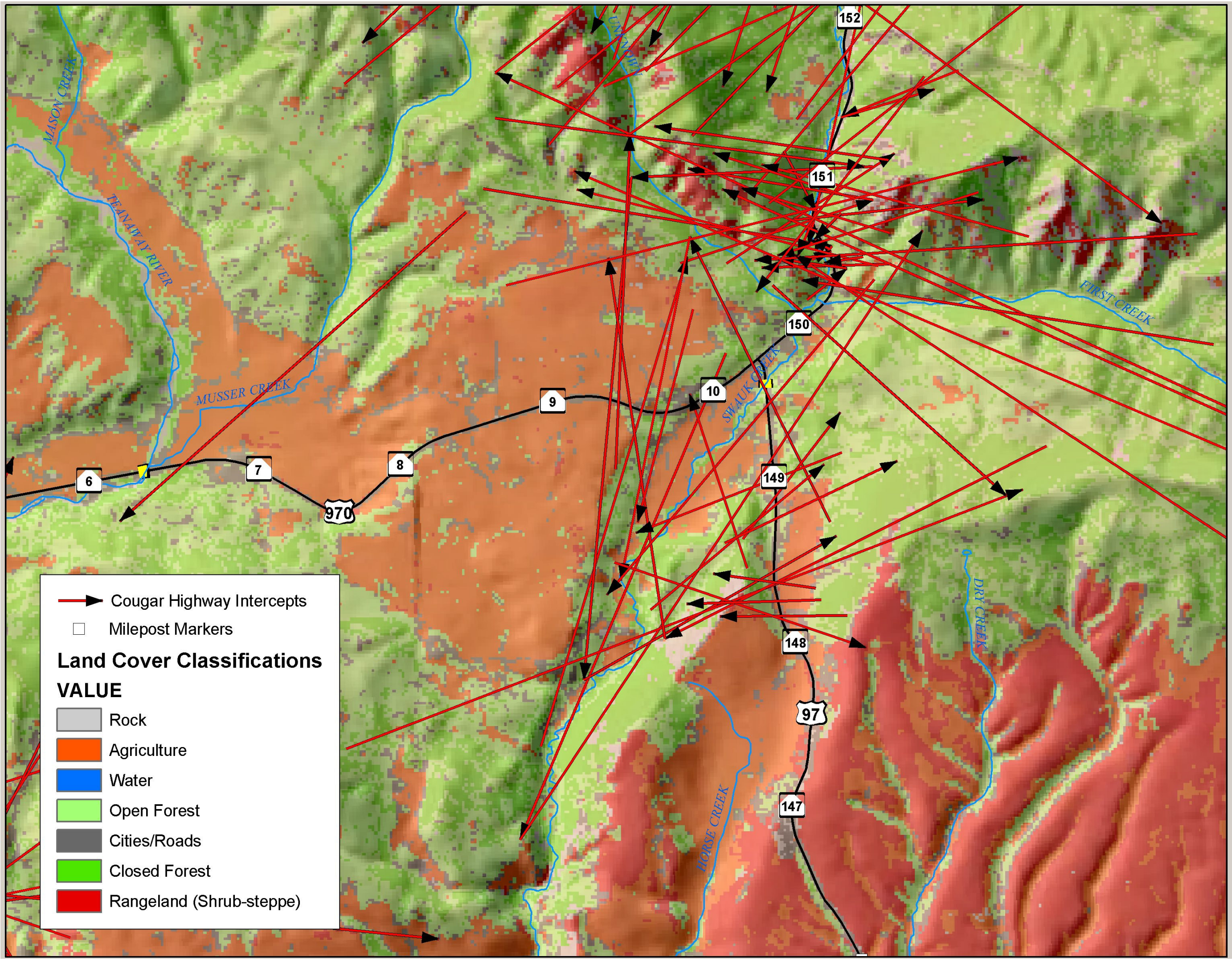


Figure 18. Segments connecting locations where cougars were crossing SR 97 and SR 970 in western Kittitas County, Washington, 2001-2004.

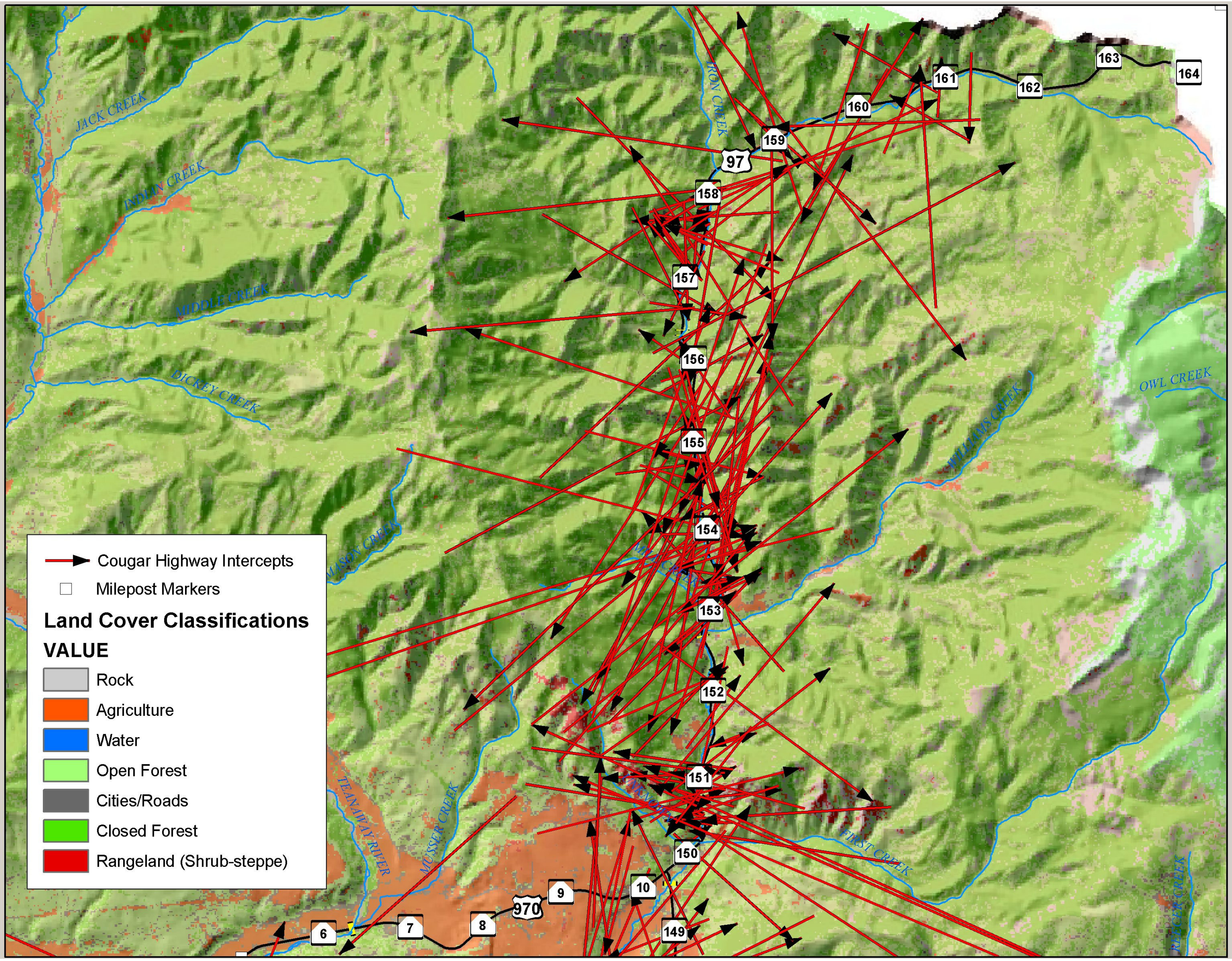
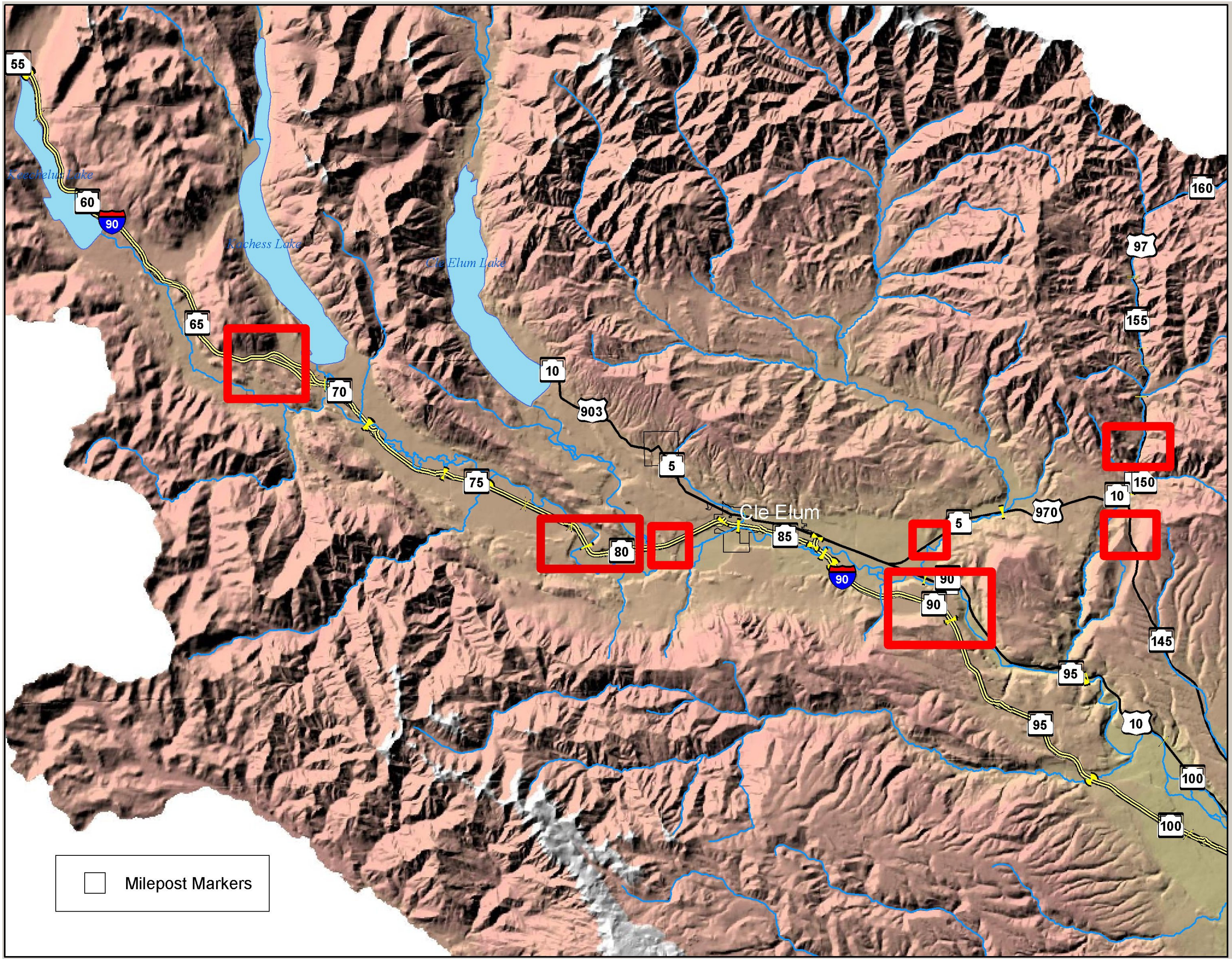


Figure 19. Topographic features (ridgelines), at landscape scale, observed to be important for movements and travel corridors of cougars in western Kittitas County, Washington, 2001-2004.



Appendix A

Table 1. Annual 95% Fixed Kernel and Minimum Convex Polygon home range estimates for cougars in Western Kittitas County, Washington, 2001 - 2004.

2002 Annual Home Range Estimates

Cougar ID	Sex	Locations	Fixed Kernel HR (km^2)	MCP (km^2)
152153	Female	1112	138.8	230.6
154154	Male	1342	223.6	595.3
155155	Male	80	274.5	159.8

2003 Annual Home Range Estimates

Cougar ID	Sex	Locations	Fixed Kernel HR (km^2)	MCP (km^2)
160160	Female	751	127.3	162.9
152153	Female	1170	153.2	246.6
158158	Female	929	164.8	341.5
156156	Female	765	91.5	169.6
130111	Male	586	680	1278.6
157157	Male	358	201.1	568.1
151151	Male	826	480.9	660.3
154154	Male	580	462.4	527.8
131131	Male	326	221.8	356.3
159159	Male	480	350.9	544.9

2004 Annual Home Range Estimates

Cougar ID	Sex	Locations	Fixed Kernel HR (km^2)	MCP (km^2)
162162	Female	42	38.4	35
160160	Female	420	60.1	201.9
248137	Female	395	229	474.9
152153	Female	386	124.4	222.6
158158	Female	530	360.2	347.5
156156	Female	577	40.8	68.5
191191	Male	248	197.9	255.9
130111	Male	47	1007.1	671.3
151151	Male	173	240.5	447.9
154154	Male	71	364.1	245
131131	Male	489	166.5	281.8
190190	Male	233	289.7	350.7
195195	Male	326	123.3	327.8