CHAPTER 2.0

METHODS

2.0 METHODS

2.1 Introduction

A connected landscape is one that allows animals, plants and ecological processes to persist on a landscape scale by facilitating critical processes such as nutrient dispersal, genetic exchange and daily and seasonal movement to access required resources. Nutrients are distributed over a landscape by animals, water and wind. Plants move through a landscape in the form of pollen and seed that is dispersed by animals, water and wind. Animals must move through the landscape in order for individuals to survive, find mates, and ultimately, sustain populations within the local and regional area. Our analysis of connectivity in Edmonton focused on animal movements and, by doing so, simultaneously encompassed plant and nutrient dispersal by animals. We assumed that wind-dispersed seeds and nutrients would face similar challenges to those of animals trying to cross gaps between Habitat Patches, in that increasing distance would pose an increasing risk of failure to cross the gap. The connectivity models also considered the role of aquatic features in landscape connectivity but from the perspective of terrestrial and semi-aquatic animals. Aquatic connectivity *per se* was addressed separately by mapping Edmonton's network of aquatic resources and discussing it from two perspectives: aquatic organism movement and water as a dispersal vector for seeds, nutrients, sediments and pollutants.

To assess landscape connectivity, we used GIS models to describe the City's landscape and the relative contribution of various landscape elements to impede (and facilitate) animal movement. Our study area included the City lands and an adjacent area approximating the Intermunicipal Planning Fringe - a 1.5 to 2 mile buffer surrounding the entire City. Inclusion of these adjacent lands enabled us to identify critical regional linkages beyond the City limits. Because connectivity from the perspective of animals is species-specific, examination of landscape linkages and connectivity for ecological network planning should ideally consider several different species that move through the landscape at different scales. Accordingly, for this assessment, we assessed connectivity using indicator species. We chose deer and coyote, large, highly-mobile but non-migratory, mammalian species as our reference animals. These species were assumed to be indicative of connectivity for a wide variety of smaller, less-mobile animals, including birds to some degree.

The models identified Habitat Patches, Linkages, Barriers and the Matrices in which these features occur and ranked them in terms of their resistance (positive or negative) to movement from the perspective of our indicator species. From the mapped results, we identified the spatial distribution of areas/features where resistance to movement is high and areas/features offering little resistance (i.e., those facilitating movement). This initial map was then refined according to several parameters and a series of maps produced, culminating in a map illustrating Edmonton's Ecological Network - the spatial distribution of features that facilitate movement through Edmonton, and a slight modified network map showing contiguous Patches and Linkages. We then analyzed those data from the perspective of how selected indicator species might perceive that network (functional connectivity) and mapped the results.

2.2 Analyses Overview

Most animals perceive the landscape within which they live in terms of suitable or unsuitable habitat. Habitat suitability (quality) is judged by the number of resources present, and the number of needs that those resources can meet at any given time. Animals must access various resources over the course of their lifetime, and those resources may be found nearby or in distant areas. In this sense, animals seek resources within both spatial and temporal contexts. Animals may seek out different habitat on a seasonal basis (e.g., a frog migrating between winter and breeding habitat), or daily basis (e.g., a foraging falcon). The resources they seek may be for breeding, daily feeding or shelter. They also travel to seek mates. They may range over a territory of a few square meters (e.g., insects) or many square kilometers (e.g., deer, fox), depending on the mobility and needs of the species. Regardless of these differences in timing, purpose and scale, in all cases the animal must move through the landscape, seeking suitable habitat containing the resources of interest within a matrix of less suitable habitat. Animals do not move randomly, particularly through the less suitable parts of the landscape; instead, they choose the route that is the quickest and poses the least cost to them, in terms of energy expenditures. The routes that they choose have been variously labeled by the scientific community and include the terms travel corridors, travel routes and movement habitats. If suitable travel routes between Habitat Patches are available, a landscape is said to be connected.

Discussions of suitable movement habitat (habitat connectivity) from the wildlife perspective are ultimately based on animal behavior, and the animal's perceptions of risk and effort required. Animals face several risks in their search for suitable habitat. To avoid predation and accidents, most species use security cover (vegetation and/or terrain) to hide from potential threats. For this reason, most animals tend to travel in vegetated or structurally variable terrain rather than open space. The search for resources also requires energy and that cost also factors into decisions on travel routes. Terrestrial animals typically avoid steep slopes, cliffs and wide rivers that would be difficult to negotiate and instead choose terrain offering fewer obstacles. The perception of what is suitable and what is not is central to discussions of structural and functional connectivity, and, as said above, varies with the species.

To describe the Edmonton study area, we characterized the landscape in terms of elements facilitating or impeding movement from the perspective of deer and coyote, our indicator species:

- Habitat Patches – contiguous units of native habitat (aquatic or terrestrial) (in our case greater than or equal to 1.0 ha) that have experienced little to no fragmentation relative to our scale of analysis (e.g., small trails of 5 m width would not be considered as fragmentation) that would be of interest to a given

- species. In this case, Habitat Patches are synonymous with the City's identified Natural Areas.[1]

- Linkages (Linkage Habitat) – contiguous units of manicured and naturalized vegetation that promote movement (e.g., vegetated rights-of-ways other green space such as parks and golf courses, and stormwater management facilities).
- Matrix – land use in the areas surrounding/adjacent to Habitat Patches and Linkages, including agricultural lands.
- Barriers – an element that wildlife would consider a deterrent to movement, and thus would generally avoid crossing (e.g., roads).[2]

Referencing the behavioral requirements of deer and coyote, we then assessed given landscape features within these categories according to the level of resistance they presented to movement (Vuilleumier and Prélaz-Droux 2002). Deer and coyote are both highly-mobile species that require natural Habitat Patches for daily needs, security cover for movement, and typically avoid using open areas with high human activity. They share these characteristics with other species that are less urban-adapted but exist within Edmonton, and thus were considered representative of many species.

Working towards identification of an ecological network, we then produced a series of increasingly simplified maps. First, we mapped all landscape elements according to the relative level of resistance they offered (the Landscape Connectivity map). Next, we mapped only those elements that scored positively with respect to resistance, resulting in a map of features and matrices that facilitate movement. In the next map, we included all facilitating linkage and habitat patches but excluded all matrices to focus only on the discrete features that facilitate wildlife movement (Edmonton's Structural Connectivity) Based on analysis of various patch metrics to identify specific types of Habitat Patches and Linkages, we then produced two additional maps: Edmonton's Ecological Network (showing Core Areas, other smaller Habitat Patches and Two kinds of Linkages), and, Key Segments of that network.

Lastly, using the Habitat Patches and Linkages as a foundation, we assessed functional connectivity. We investigated the degree to which Habitat Patches or Linkages could be accessed across an open gap at four different scales, using gap tolerances of three different animal indicator species. The indicator species were selected to represent a suite of plants and animals with similar habitat requirements, whose movements, including gap crossings, are typically restricted to a certain scale. The resulting

[1] In this analysis, we have not considered the quality of habitat contained within a given patch. This is in part because consistent data across the area were not available, but is mainly related to the objective of this analysis. The goal of this assessment was to identify the naturally vegetated or aquatic patches that would connect to form a network in the City of Edmonton. Habitat quality and relative value of each path within that network is a more detailed assessment that was beyond the scope of this project. Other vegetated areas, such as manicured parks, while having some habitat value, were considered as linkages in recognition of the fact that Natural Areas will be the focal landscape features of Edmonton's conservation plan. It is Natural Areas that the City will wish to ensure are connected. Other, less suitable habitat, such as parks, was considered to be linkages that aid in connectivity.

[2] Broader, scientific definitions of these terms are provided in the glossary.

functional connectivity mapping highlighted areas in which land use was amenable to movement, and so allowed animal access to otherwise separate habitat. It also highlighted opportunities where restoration could reduce gaps and improve network function.

Although the map products provide a concise illustration of the degree of connectivity within the City, they do not allow comparative assessment. To provide a quantified description of the network, we conducted a Landscape Metrics analysis. The analysis determined the characteristics of Habitat Patches at the structural and functional level of connection using a suite of standard metrics (e.g., average patch size, patch density). In one component of that analysis, these metrics were related to the area required by indicator species representative of small, medium-sized and large animals to identify the level of biodiversity most likely to be sustained within the network. These metrics will also establish a baseline for future monitoring of the status of Edmonton's Natural Areas and tracking the long-term success of the forthcoming City of Edmonton Conservation Plan.

The section below describes the specific methods for the Landscape Connectivity Model, the Functional Connectivity Analysis and the Landscape Metrics Assessment. Complete documentation for these analyses is provided in Appendix A.

2.3 Landscape Connectivity Model

The Landscape Connectivity Model comprised two geographical modules to recognize the differences in terms of risk and energy costs for animals traveling in the North Saskatchewan River Valley (NSRV) system and on the Tablelands. The river valley slopes present a constraint to deer and coyote movement, our indicator species for the model, a factor not present on the largely flat tablelands. Land use in the river valley is more restricted and, as a result, Barriers associated with land use are fewer. Lastly, the separate models were necessitated by the type of data available. Vegetation data available for the river valley was different than that for the Tablelands, which required a slightly different modeling approach.

For both modules, we first classified the landscape in terms of spatially explicit Habitat Patches, Linkages, Matrix and Barriers (the specific landscape elements and their classification are provided in Appendix A). We then scored each of the landscape elements (e.g., vegetation community, natural areas, parks, roads) comprising a given landscape class in terms of the resistance they would present to the movement of a deer or coyote. Although the two modules used different data and incorporated slightly different variables, the scoring system used to identify the resistance to movement was the same:

Resistance Level	Score
High	-2
Moderately High	-1
Moderate	0
Moderately Low	1
Low	2

The variables and data used in each model, as well as their associated resistance, are described in Table 2.1 for the NSRV and in Table 2.2 for the Tablelands. The scale of the data used in the analysis ranged from 1:20,000 to 1:50,000, and therefore, the resulting scale of the analyses was extrapolated to the higher limit (1:50,000). Where buffers were used to approximate accurate widths of features (i.e., where the GIS data comprised only line features; not having any width) the buffer width is also indicated. The detailed models in Appendix A also list the data sources used in the model, and the rationale for buffer widths.

We modified some datasets to more specifically address animal movements. The pipeline dataset included all low and high pressure lines within the City, however, development is permitted over some of those lines (primarily the low-pressure lines). Only those pipeline rights-of-way that remain undeveloped are useful as wildlife corridors. The pipeline dataset did not provide enough information to allow determination of the presence of a vegetated right-of-way on the ground. Using aerial photograph interpretation we eliminated all pipeline right-of-ways that appeared to be developed, mapping only those that appeared to be suitable for use by as a movement corridor. Powerline data were not available as a comprehensive dataset for the City. We purchased a dataset from Natural Resources Canada (NRCAN), and updated it to include all major powerlines with wide rights-of-way using 1 m resolution digital aerial photography (City of Edmonton 2005 dataset).

We also added to the existing roads digital data to update features not included in those datasets. Southwest Anthony Henday Drive was completed during this present study, and the alignment had not been added to the City's road network data. Southeast Anthony Henday Drive is still under construction, and data was similarly unavailable showing that alignment. We digitized the road alignment for inclusion into the dataset, but could not accurately delineate the interchanges. As a result, those interchanges are not included in the data, and the resulting mapping include in this report. The nearly-completed section of Northeast Anthony Henday is also not represented here.

Although the two modules used different data and incorporated slightly different variables, the use of the same scoring system produced similar outputs. Because of the similarities, it was possible to combine the two module outputs into a single map representative of the resistance to wildlife movement across Edmonton's landscape, effectively illustrating landscape connectivity.

Table 2.1. North Saskatchewan River Valley Landscape Connectivity Model Module

Landscape Connection Component	Variable	Element	Score [1]	Friction Level	Buffer Width (m)
Patch	*Vegetation*	Natural vegetation in the NSRV	2	Low	
		Tributary ravines	2	Low	
Matrix	*Vegetation*	Developed urban landscape (exposed soils, built up areas, gravel pits)	-2	High	
		Agricultural fields	1	Moderately low	
	Vegetation	Manicured areas	1	Moderately low	
		Road ROW managed as City parkland	0	Moderate	
Linkage	*Rights-of-way (ROWs)*	Pipelines	1	Moderately low	20
		Powerlines	1	Moderately low	
	Transportation and Utilities Corridor (TUC)	TUC (minus any built roads)	1	Moderately low	
Barrier	*Hydrology*	No surface water	2	Low	
		Streams	1	Moderately low	
		River	-2	High	
	Transportation	Highway/Freeway	-2	High	20
		Arterial Road	-1	Moderately high	20
		Ramp	-1	Moderately high	20
		Rapid Transit/Railway	-1	Moderately high	20
		Collector	-1	Moderately high	10
		Local/Street	0	Moderate	5
		Service	0	Moderate	5
	Slope	Steep (>30%)	-1	Moderately high	
		Moderate (<=30% or >20%)	0	Moderate	
		Level to rolling (<=20%	1	Moderately Low	

[1] Scores range from -2 to 2

Table 2.2. Tablelands Landscape Connectivity Model Module

Connection Component Type	Variable	Element	Score [1]	Friction Level	Buffer (m)
Habitat Patch	*Edmonton Natural Areas in 2005*	ESA, SNA and NA	2	Low	
	Regional, Adjacent Natural Areas	Enoch natural areas	2	Low	
		Lois Hole Provincial Park	2	Low	
		Regionally Significant Natural Areas w/in Intermunicipal Planning Zone	2	Low	
		Naturally vegetated areas outside the City of Edmonton	2	Low	
	Hydrology	Lakes, manmade lakes and reservoirs, streams	2	Low	
		Wetlands	2	Low	
Linkage	*Rights-of-way (ROWs)*	Road ROW	0	Moderate	
		Rail ROW	0	Moderate	20
		Powerline ROW	1	Moderately low	
		Pipeline ROW	1	Moderately low	20
	Transportation and Utilities Corridor (TUC)	TUC (minus any built roads)	1	Moderately low	
	Other Green Space	Edmonton cemeteries	1	Moderately low	
		Edmonton school grounds	0	Moderate	
		Edmonton neighborhood parks	1	Moderately low	
		Edmonton golf courses	1	Moderately low	
		Edmonton sports fields	0	Moderate	

Connection Component Type	Variable	Element	Score [1]	Friction Level	Buffer (m)
Linkage	*Edmonton Storm Water Management Facilities (SWMFs)* [3]	SWMF (except dry ponds)	1	Moderately low	
		SWMF (dry ponds)	0	Moderate	
Matrix	*Land Use Zones*	Commercial	-2	High	
		Light Industrial	-2	High	
		Medium to Heavy Industrial	-2	High	
		Residential [2]	-1	Moderately high	
		Agricultural	1	Moderately low	
		Recreational (Parks)	1	Moderately low	
		Recreational (other than Parks)	0	Moderate	
Barriers	*Transportation*	Highway/Freeway	-2	High	20
		Arterial	-1	Moderately high	20
		Ramp	-1	Moderately high	20
		Rapid Transit	-1	Moderately high	20
		Collector	-1	Moderately high	10
		Local/Street	0	Moderate	5
		Service	0	Moderate	5
		Railway	0	Moderate	5

1 Scores range from -2 to 2

2 Data on the Land Use Zones for the City of St. Albert and City of Ft. Saskatchewan were not available for this analysis. The developed areas of both Cities were both scored as -1, reflecting the predominance of residential land use. As such, commercial, industrial and open space areas were scored on par with residential.

3 Storm water management facilities (SWMFs) include both naturalized and non-naturalized ponds. We assumed that from the perspective of wildlife movements, both these pond types would be perceived as 'suitable habitat' and could therefore serve as linkages. Although the length of time spent in such habitat could be different, based on the habitat quality of the site, this level of detailed assessment was outside the scope of this exercise, which focused instead on identification of the existing ecological network within the City.

The Landscape Connectivity Model results can be displayed in several ways, each illustrating different aspects of connectivity in Edmonton. We developed a series of maps that describe:

- the level of friction across the entire landscape (Landscape Connectivity Map);
- the level of friction across the entire landscape, excluding the more resistive matrix elements (Landscape Elements Facilitating Movement Map);
- the landscape elements facilitating movement, excluding the Matrix (Structural Connectivity Map);
- the landscape elements reclassified to identify Core Areas[4], other Habitat Patches, Stepping Stones and Linear Corridors (Edmonton's Ecological Network Map); and
- the areas offering the largest and longest contiguous (unfragmented by higher order roads) segments of Habitat Patches and Linkages within Edmonton's Ecological Network (the Key Connected Segments of Edmonton's Ecological Network).

The last of these maps, the Key Connected Segments of Edmonton's Ecological Network, was created by identifying all contiguous Habitat Patches and Linkages as distinct units, sorting these contiguous units into classes based on the distribution of sizes, then identifying the top two classes (i.e., the largest units) as Primary and Secondary Key Segments.

2.4 Functional Connectivity Analysis

Connectivity in an undeveloped area is relatively simple to describe, as the matrix is likely to have a high degree of permeability and barriers will be few. Urban and urban fringe areas, such as on Edmonton's tablelands, are a much more complex landscape, and connectivity is thus more difficult to describe. Here, the Matrix will have varying degrees of resistance to movement (related to land use type), and Linkage Habitat (Stepping Stones and Corridors) will play a critical role in connectivity. Together, the complex spatial distribution of these landscape elements will ideally be one that will allow organisms to negotiate through it.

Edmonton's landscape can be seen as a mosaic of patches of green space of various sizes, configurations and naturalness, embedded in a Matrix of developed and fringe agricultural lands. These patches include Natural Areas (Habitat Patches), the larger of which may be Core Areas and managed-vegetated areas that can provide possible Linkage Habitat (e.g., rights-of-way, neighborhood parks). Non-linear Linkages may act as Stepping Stones, while linear Linkages may act as Corridors. Both can support and attract wildlife but not to the same degree as Habitat Patches owing to lack of native plant communities. Barriers are scattered throughout in varying concentrations.

[4] Definitions of Core Areas, Stepping Stones and Corridors (two forms of Linkage Habitat) are provided in Appendix B

The Matrix can be viewed as gaps of varying permeability (depending on the type of land use) that must be crossed to move between patches and linkages. Where gaps are a tolerable width and strong Barriers do not exist, species will cross the Matrix. Where the distance between patches is too large given the need of the species for security cover, a gap will function as a Barrier. Our Functional Connectivity Analysis assessed the extent to which the gaps associated with Edmonton's Ecological Network are tolerable, or crossable, based on the gap tolerance of three indicator species commonly found in the City of Edmonton: red-backed vole (*Clethrionomys gapperi*), black-capped chickadee (*Poecile atricapillus*) , and deer (*Odocoileus spp*.) (Table 2.3).

Gap tolerance is a relatively new term, but the concept has been applied to the study of large mammal behavior for many years. In the course of daily movements through a home range, an animal will choose to use certain habitats, and avoid others, based on their need for security cover. Deer in particular, have been well assessed in terms of their security or escape cover requirements. Typically, deer tend to venture no further than 100 m from shrubby or forested escape cover or rough terrain (Thomas *et al.* 1979). This is an average distance: as the gap width increases, the number of deer willing to cross it decreases. The 100 m gap distance also relates to other mobile species including weasels and urban deer populations (DeNicola *et al.* 2000, Gehring and Swihart 2002). For our analysis, we assumed that at a gap width of 250 m (2.5 times the average deer gap tolerance) few to no deer would cross. We set this as the limit of functional connectivity. Beyond 250 m there would be *very* limited connectivity, and it would only exist for large highly-mobile species such as deer.

At certain times, large animals like deer and coyote may travel much greater distances (e.g., during the rut, or when young disperse), but this aspect of connectivity was not specifically examined in this analysis, as these movements can take place over a much broader regional scale and are more unpredictable. Dispersal, seasonal migration and other periodic, long-distance movements of smaller species would, however, be accommodated within the 100 m and 250 m gaps (Table 2.3).

The tolerance of other wildlife species for crossing open spaces has also recently been examined, mainly in terms of the willingness to 'short-cut' across unsuitable areas to access other patches of suitable habitat. Various small songbird species, including the black-capped chickadee, have been found to avoid open gaps larger than 50 m (St. Clair *et al.* 1998, St. Clair 2003). Amphibians have a similar tolerance limit for crossing unsuitable habitat, mainly dry areas (Roberts and Lewin 1979, Rothermel and Semlitsch 2002).

Landscape level assessments of connectivity for small mammals have also only recently been examined. We selected the red-backed vole (known to reside in Edmonton) as an indicator species that would be representative of species that have small territorial requirements and are thus likely to travel only relatively short distances. Red-backed voles prefer older forested sites and are generally thought to be less tolerant of habitat fragmentation (Pearson 1999, Silva *et al.* 2005). Silva *et al.* (2005) found that canopy forest gaps were important determinants of small mammal diversity within small woodlands, and tree density to be a strong influence on red-backed vole population size in particular. Although the influence of specific gap width was not identified in their study, Slade and Crain (2006) found prairie voles were unwilling to cross a 15 m mowed gap separating more suitable habitat. Hilty *et al.* (2006), in summarizing research by others, note that several species of voles (*Microtus spp.*) are reluctant to cross gaps of mowed grass that are between 4 and 9 m in width and only rarely will they travel across more than 9 m of inhospitable Matrix. We adopted a slightly wider gap of 20 m for red-backed voles to address the uncertainty related to perceptions of 'functional connectivity' for these and other species with similar small scale gap tolerances (see Rudd *et al.* 2002).

The functional connectivity analysis was run four separate times, once each for the different scales at which we wished to assess Edmonton's Ecological Network: 20 m, 50 m, 100 m and 250 m. Respectively, these scales were considered to indicate good, fair, moderate and poor functional connection, supporting movements of progressively fewer species. For each analysis run, we buffered the Habitat Patches and Linkages by widths corresponding to the gap width tolerance of the indicator species being used for a given scale (Table 2.3). The resulting polygons were merged together in areas where they overlapped, forming 'clusters' of functionally linked Habitat Patches and Linkages. The Barriers layer was then placed over the polygons and used to sever otherwise acceptable connections. Areas where the functionally connected polygons lay within a Matrix land use type generally unfavorable for movement (industrial and commercial areas), were similarly erased from the polygon.

Table 2.3. Functional Connectivity Analysis Parameters

Landscape Components	Gap Width (edge to edge)	Indicator Species	Level of Connection	Functions and Species Facilitated [1]		
				Species Group	**Purpose of Movement**	**Frequency of Movement**
Habitat Patches and Linkages	20m	Red-backed vole (small mammals)	Good Functional Connection	∉ Most species	∉ Daily, seasonal, mating and other movements	∉ Frequent use
	50m	Chickadee (songbirds and amphibians)	Fair Functional Connection	∉ Most species	∉ Daily, seasonal, mating and other movements	∉ Frequent use
	100m	Deer (gap tolerance for many medium-sized and larger animals)	Moderate Functional Connection	∉ Mainly medium to large-sized species	∉ Daily, seasonal, mating and other movement	∉ Frequent use
				∉ Smaller species	∉ Seasonal, mating and dispersal movements	∉ Infrequent use
	250m	Deer (limit for daily movement of most animals)	Poor Functional Connection	∉ Medium to larger-sized species	∉ Daily, seasonal, mating, and other movements	∉ Less frequent
				∉ Small to medium-sized species	∉ Seasonal, mating and dispersal movements	∉ Low frequency to rare

1 Functions facilitated by the indicated gap width can be described in terms of the species that would use such gaps, the type of activity the functional connection aids, and the frequency of movement likely to occur at that gap width.

This process produced separate polygons of functionally-linked clusters of Habitat Patches and Linkages for each scale of connection. Displaying all four levels of connection on a single map was not possible at the City level, but the contrast between the Habitat Patches, and the 50 m and 250 m scales of functional connection illustrated well the expanding effect of functional connection on the Ecological Network.

Within a given scale of functional connection, a cluster of accessible Natural Areas could comprise a viable home range for certain species, expanding the available area beyond that within the Structurally Connected system alone. Comparison of the patch metrics of the Structurally Connected system and the various scales of Functional Connection creates a more complete estimate of the biodiversity potentially sustained within the Ecological Network. The methods used to calculate the area of Natural Areas captured within clusters at each scale of functional connection are outlined in Section 2.6.

2.5 Aquatic Linkages Map

The previous two models addressed both terrestrial and semi-aquatic linkages and considered aquatic resources but only in a limited way. The models considered the connective value of watercourse valleys and riparian corridors, the habitat value of aquatic features for semi-aquatic species, and, the role of the river as a potential barrier. The Aquatic Linkages map sought to address aquatic connectivity more directly by using the hydrology and built infrastructure (primarily roads) data to identify aquatic linkages and gaps within those linkages that have been created by diversion and road crossings. We created the map by overlaying the hydrology and stormwater facility data with the road data and the 2005 Edmonton Natural Areas dataset to illustrate the following:

- Gaps in streams within the City.
- The relationship of the aquatic network (including stormwater facilities) to the network of Natural Areas.
- Potential road crossings, where the quality of the aquatic linkage may have been degraded to some extent.

Road crossings were identified by isolating the points where the hydrology and roads data intersected. Where crossing were known to be bridges this was indicated by showing a continuous watercourse. The City's stormwater facility database did not identify naturalized stormwater facilities, which may provide higher quality habitat than the non-naturalized facilities. Because this map addressed connectivity, and because habitat quality can be quite variable even among naturalized ponds, we did not distinguish between the two facility types in the mapping.

2.6 Landscape Metrics

2.6.1 Patch Characteristics

Patch size and distribution metrics have been well studied over the past decade, as measures of ecological function at the landscape level. Various measures have been introduced to characterize the spatial distribution and function of ecological networks. Mitchell (2006), in his review of 'best' landscape metrics (those with correlation and limited overlap), identified those listed in Table 2.4 below. Nodal weight, the extent to which a patch (and here, also a cluster of patches) would satisfy the territorial requirements of an indicator species has also been used as a descriptor of functional connectivity within an ecological network (Linehan *et al.* 1995, Rudd *et al.* 2002). We used both sets of metrics to describe Edmonton's Ecological Network, calculating metrics for the natural areas within the river valley, on the tablelands and over the entire Edmonton study area. A summary of the metrics, and the formulae used for the calculations follows in the table below.

Table 2.4. Patch Size and Distribution Metrics

All Individual Natural Areas	Formula (after McGarigal and Marks 1995)
Individual Patch Metrics	
Mean patch size	MN=AVERAGE(patch areas)
Median patch size	MED=MEDIAN(patch areas)
Standard Deviation of patch size	SDN=STDEV(patch areas)
Range of patch sizes	
Histogram of patch sizes	
Landscape Metrics	
Proportion of landscape occupied by patches	PLAND=sum(patch areas)/total study area
Average perimeter to area ratio	AVGPAR=AVERAGE(patch perimeters/patch areas)
Patch density	PD=number patches/total study area
Nodal Weight	NW=patch area/minimum patch size [a] x 10
Connected Patch Metrics [b]	
Average area of connected patches (Natural Areas) per cluster	SUM(area of functionally connected patches within cluster)/Number of clusters
Average number of connected patches (Natural Areas) per cluster	COUNT(area of all functionally connected patches within cluster)/Number of clusters
Clustered Nodal Weight	NW= clustered patch area/minimum patch size x 10

[a] Minimum patch size = an arbitrary size of patch selected based on the management objectives of a given ecological network. For example, the patch size could relate to the area requirements of a population of a species of interest.
[b] Calculated for each spatial scale of connectivity: poor, moderate, fair, and good functional connection.
.

2.6.2 Nodal Weight Analysis

The nodal weight metric provides an indication of the ability of the ecological network to meet management objectives. In this instance, we used nodal weights for individual Habitat Patches (Natural Areas) and functionally-connected patches (clusters of Natural Areas) to test how well the current Edmonton Ecological Network provides for a diverse and sustainable population of plant and wildlife species. Using a set of indicator species representative of different area requirements, we compared each patch to its species-specific minimum patch size according to the following formula:

Patch area (ha)/Minimum Patch Size (ha) x 10 = Nodal Weight (patch)

The summed area of Natural Areas within the functionally-connected clusters was compared to the species-specific minimum patch area, as follows:

Total patch area within a cluster (ha)/Minimum Patch Size (ha) x 10 = Nodal Weight (cluster)

We assessed the nodal weights for the clusters created at each of the 4 spatial scales of connectivity (poor to good functional connection).

For each of the 5 indicator species used in this analysis (deer, coyote (*Canis latrans*), porcupine (*Erithizon dorsatum*), chickadee, red-backed vole), population size and habitat requirements are relatively well documented. Based on that information, we identified the minimum patch size of each species, based on the number of individuals required to sustain certain proportions of the minimum viable population[5] at the metapopulation[6] level (the selection process is described in more detail in Appendix C). This led to a targeted population of five individuals within a patch or a clustered set of patches. Table 2.5 below outlines the minimum patch size required to support the target populations used in this analysis.

The average nodal weight of all individual patches and of all clusters of Natural Areas was compared to determine several aspects regarding the function of the Ecological Network:

- What level of biodiversity could be sustained within the entire network?
- Does functional connectivity improve the ability of the network to sustain a given indicator species?

If the average nodal weight for individual or clustered patches was above 10, on average, most of the patches (or clusters of patches) in the network should meet the minimum patch area requirement for the indicator species. An average value below 10 indicated that insufficient area was available in the patches or clusters of patches.

[5] For definition, see Appendix B.
[6] For definition, see Appendix B.

Table 2.5. Minimum Patch Size Used in the Nodal Weight Analysis

Species	Territory (ha) [a] or Density (number per ha)	Minimum Patch Size [b] (ha)
Red-backed vole [c]	20 voles/ha	0.25
Black-capped chickadee [d]	0.5 ha	2.5
Porcupine [e]	7 / 100 h	71 ha
Coyote [e]	1.05 / 100 ha	476
Deer [f]	1.5 / 100 ha	333

[a] Territory size was used for the chickadee, a species that does not typically have overlapping territories. Territory size can result in misleading minimum critical area calculation for species with territory overlap or non-adjacent territories (Snaith and Beazley 2002). Density was used for the other species as they can have overlap in home range. Both density and territory size fail to account for variation in natural systems and hence represent an ideal.

[b] Minimum Patch Size = area required to sustain 5 individuals of the indicator species.

[c] Data for local densities of red-backed voles were not available. Westworth et al. (1984) and Boutin et al. (1996) reported density of red-backed vole in aspen forest of Alberta and the Yukon of 20 voles/ha.

[d] Black-capped chickadee territory size

[e] Banfield (1974) reported porcupine densities ranging from 7.7-10.8 animals / 100 ha in Maine and 2.3 – 3.0 animals / 100 ha in New Brunswick. More recent or local data was not available, however because this species is relatively common in the City, and particularly the river valley, and represents a species typically present at a moderate density level, we included it in this assessment, using the lower density reported for Maine (the most similar of the two study areas to ours)..

[f] Pruss (2002) reported coyote densities of between 0.87 and 1.05 coyotes/100 ha in Elk Island National Park (EINP), an average of 0.96 animals / 100 ha, a much more rural context than the Edmonton study area. Atwood *et al.* (2004) found coyote home range sizes along a gradient of suburban to exurban to rural habitat in the Eastern States ranged between 2.97-23.48 animals / 100 ha, with much smaller range sizes in suburban areas than rural areas. Coyote density within Edmonton is not known. Instead we used the lower of Pruss's densities, as this provided a better local estimate.

[g] EINP aerial survey in spring 2006 found deer density of 0.93 deer / km^2. Folinsbee (1993) winter survey of Edmonton found a white-tailed deer density of 1.5 deer / 100 ha. We used Folinsbee's estimate as it best represented local conditions.