Propositions

1. Implementation of an ecological network in an urban context requires the development of a multiple-scale, long-range plan. One of the most important aspects of this approach allows for incremental implementation as opportunities arise in the process of urban land transformation.
   This thesis

2. Landscape structure indicators are useful tools for assay of an ecological network in an urban area. They are useful as bench marks for longitudinal studies or as measures to compare alternative plans.
   This thesis

3. The differences between North American and European approaches to planning ecological networks are significant. However, similarities do exist and much can be learned by sharing information and by examining the underlying political, social, economic and physical factors that affect the process.
   This thesis

4. A systems approach to planning ecological networks provides a way to address specific management agency concerns while accommodating the requirements for multifunctional plans.
   This thesis

5. The concepts of naturalness and ecological integrity provide important standards by which we can attempt to measure the health of an ecosystem or landscape.
   This thesis

6. Availability of data for key wildlife species is often lacking in urban areas. The use of vegetation communities as a surrogate data source gives some indication of potential habitat value.
This thesis

7. The matrix utility index is a measure that can be an important tool in the urban planning process that can help preserve the integrity of important patches and corridors within the urban matrix.
This thesis

8. Sustainability requires the realization that three principal factors are addressed in equivalent proportion; environment, social equity and economics.

9. As an emerging science, landscape ecology is making important contributions to how we analyze and plan for the future use of landscapes. However, until the fields of economics, politics and other social sciences are more fully integrated, much of the work of landscape ecologists will be frustrated.

10. The study of landscape change and ecological history is critical to the process of landscape restoration and the establishment of effective plans.

11. It is only through the process of sharing knowledge that it acquires value.

12. As familiarity with nature and natural process increases, appreciation of the value of nature also increases. Therefore, adequate opportunity for interaction with nature is important for all people, in all geographic locations.

13. The effort required to achieve an objective is what yields satisfaction, not the act of attainment.

Edward A. Cook
Ecological Networks in Urban Landscapes
September 22nd 2000

Ecological Networks
in
Urban Landscapes

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Ecological Networks
in
Urban Landscapes

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Abstract

Analysis and planning of ecological networks is a relatively new phenomenon and is a response to fragmentation and deterioration of quality of natural systems. In agricultural areas and with existing nature preserves this work has been advancing. In urban areas, however, the problems of land use intransigence, political and jurisdictional issues create a difficult environment for implementing ecological networks.

The specific questions addressed in this research program revolve around the viability of planning an ecological network in an urban landscape. Can such a concept withstand the tests it will be given in a political and economic context of an urban planning process? To address this question, two principal research objectives were established. First, the development and articulation of a planning method will demonstrate that ecological concepts, and in particular the concept of ecological networks, can be integrated into the urban planning process. Second, the establishment of an ecological network will improve the viability of ecological systems in an urban context. This research provides a theoretical framework and a model to test this proposition. A planning method is articulated and a series of assays of landscape structure are used to examine the viability of an ecological network in the Phoenix, Arizona urban area. It is intended that the establishment of a planning method and a structure for assay will make this concept applicable in various urban situations.

The planning method is most appropriately characterized as a hierarchical systems approach. Analysis and planning occur at three scales: 1) landscape (regional); 2) community (municipal); and 3) site (local). At landscape scale, the Phoenix, Arizona urban area (7,300 sq. km.) is studied. At the community level, the city of Scottsdale, Arizona (480 sq. km.) is examined. And, at site scale, a number of patches and corridors ranging from 15 to 75,000 hectares are studied. The systems studied include hydrological, habitat and cultural. These are examined independently to ensure integrity from each specific perspective and then integrated to establish a multiple use perspective in the ecological network.

Following this planning method, an optimal plan was developed for the Phoenix urban area, the municipality of Scottsdale and six prototypical network sites. An assessment of the optimal plan was undertaken using landscape structure indicators. Three principal analyses were utilized: 1) patch content analysis; 2) corridor content analysis; and 3) network structure analysis. Patch and corridor content analyses examined the internal characteristic and immediate context for each of the 89 ecological network elements. The network structure analysis incorporates a process for aggregating results of patch and corridor analyses and incorporates indicators that describe interrelationships between landscape elements. For each of these analyses the existing condition was compared to the optimal plan to demonstrate the level of change that can be expected.

The most notable results of this assessment indicate the following. The patch content analysis reveals 1) an increase in mean native vegetation coverage of 10%, 2) an increase in matrix utility value of 14%, and 3) an increase in naturalness of 15%. The corridor content analysis reveals 1) an increase in mean corridor filter width of 19%, 2) an increase in mean vegetation coverage of 9%, 3) an increase in matrix utility values of 15%, 4) elimination of 59 gaps or barriers in existing corridors, and 5) an increase in naturalness of 17%. The network structure analysis reveals 1) an increase in overall matrix utility index of 3%, 2) the degree of network circuitry increased by 20% and 3) the gamma index of connectivity increased by 12%.

The conclusions of this research are that an ecological network plan provides modest but important improvement in ecological systems in the Phoenix urban area. It is apparent that implementation of an ecological network in an urban area utilizing existing open space elements is feasible and the investment required is modest. Although this method, as outlined in this study, is geared to a specific planning context, it may have applications in other similarly expanding communities in North America or elsewhere. The principal benefit of this approach is that it can be developed incrementally and without initial commitment of extensive resources. Finally, the use of landscape structure indicators provides another useful tool for assessing viability of ecological networks. As these indicators are used more extensively thresholds can be recognized that will help understand the health of these systems.

Preface and Acknowledgments

Since my early years as a young boy growing up in Edmonton, Canada, I have had wonderful experiences interacting with nature. Near my childhood home is the verdant valley of the North Saskatchewan River. The natural power of the river and the foresight of planners have protected this urban river corridor from development and misuse. I was fortunate enough to have this place as my playground and spent many hours there as an unwitting student of natural process. In some ways, I think this childhood experience influenced my interests and ultimately my career choice and this research topic. This small contribution is an effort to try to protect or restore places like the North Saskatchewan River Greenway. Cultivated parks and other types of urban open spaces are useful and important, but the experiences offered and the resources required to sustain them are different. This work is about helping nature find its way back into our cities in ways that are meaningful and sustainable.

This work began with in earnest during a sabbatical leave that allowed me and my family to spend 6 months in The Netherlands, during which time I was welcomed into the community of what is now known as Laboratory for Spatial Analysis and Planning and Wageningen University. Professor Hubert van Lier, my promotor, has given constant support and guidance and shared his home and family. I wish to thank him for his insightful remarks, keen analytical mind and diligence in reviewing evolving drafts of this manuscript. I would also like to thank Professor John Brock, my co-promotor, for his comments and guidance, particularly on ecological issues. Thanks are also due to Professor Frederick Steiner for his support in providing the flexibility in my position at Arizona State University and for his encouragement throughout this process. There are many others who have enriched this process for me with stimulating discussion about the topic of ecological networks.

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Last but not least, I would like to thank my wife, Sheree, and my family. Sheree has been patient, supportive and always encouraging as this and many other adventures in our lives have unfolded. Our children, Jesse, Aimee and Reese, left friends and a familiar environment to live abroad. I would also like to thank my parents for their support and encouragement throughout my life. My mother has instilled in me her optimism, without which I would have never embarked on this path. Although my father has now passed on, he has been my inspiration. I only wish he were here now to talk about some of these ideas. Thanks are also due to Sheree's parents for their enthusiasm, constant interest and for being a fine example of good and genuine people.

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Chapter One

Ecological and Urban Theory

1.1 Introduction

The problems associated with maintaining viable ecosystems in urban landscapes are significant. Urban landscapes are a finely structured mosaic of property owners and uses where competing interests for undeveloped land are intense. This study examines how an ecological perspective on multiple-use can provide the basis for establishing an urban ecological network as a primary means to maintain or re-establish the viability of ecosystems. The planning concept of ecological networks (sometimes described as greenways, habitat networks, ecological structure, etc.) can be described as a system of interconnected or related patches and corridors that provide and sustain ecological values within a human-dominated landscape matrix.

As humans engage in landscape planning and design to restore previously altered ecosystems or protect existing fragments of natural systems, they must recognize that the most effective way to re-establish or maintain the viability of these systems is to ensure they exist as a part of a larger functioning system. Urban landscapes are generally deficient of areas with significant environmental values. This is a result of the anthropocentric orientation of the urban development process. As a consequence, nature (or nature-like) areas are relegated to remnant patches and corridors, severed from their supporting structure. Normally, constraints to urban development such as extreme slope, flooding, poor soils, etc. exclude them. Although these remnants may have deteriorated environmental value, it is fortuitous that in many cases the areas with the most significant constraints for urban development are often the richest (Spirn 1986). Consequently, many urban areas have an existing framework upon which a more comprehensive network can be established.

1.2 Problem Statement

The goal of this planning concept is to preserve or restore the ecological integrity of critical natural systems while allowing for compatible human activities within the network and continued productive (economic) use of adjacent lands. Some modification to adjacent land would, in most cases, enhance the viability of the network. However, the focus is primarily on the integrity of the network and will only indirectly address adjacent land uses to examine appropriate fit in their co-existence.

The primary functions that may be accommodated as a part of an ecological perspective on multiple-use fall into three main categories: hydrology, wildlife habitat, and cultural opportunities. These three perspectives provide a framework for structuring the network as described later. Some of the functions or uses that can be accommodated within these categories are obvious, while others are more obscure. The intent is to accommodate these functions or uses in varied amounts and at varied locations within the ecological carrying capacity (Catton 1983). A description of these functions or uses follows.

Hydrology - Surface drainage corridors serve as filters and transformers for contaminated runoff helping to purify it before it returns to the ground water supply. These areas also serve as sinks facilitating ground water recharge. Flood containment is particularly important in developed areas such as urban landscapes. Sufficiently vegetated drainage corridors also protect against soil erosion and subsequent turbidity in streams and rivers. Additional benefits of providing habitat are also significant.

Habitat - Suitability as wildlife habitat is largely dependent on the type and extent of vegetation that can be used as cover and forage. Consequently, vegetative cover and wildlife habitat are interrelated elements. In an urban context, many areas may not be suitable as primary habitat for some species requiring greater isolation. However, many species may rely on these areas for migration and as islands for refuge or forage. They may also be utilized as secondary habitats. Because both plants and animals disperse through these areas, they are important conduits for nutrient, energy and gene flow.

Cultural Opportunities - The range of compatible cultural opportunities includes certain types (predominantly passive) recreation, environmental education, aesthetics and scenic quality, historical significance, land use buffers or markers and cultural continuity. Recreational activities in the form of hiking, cycling, horseback riding, nature observation, picnicking, and light camping may be the most commonly recognized suitable activities. Environmental education can be reinforced by providing nature areas within the city. Many people in urban situations are losing touch with nature leading to discomfort with wildness in the landscape. Reconnection allows urban-dwellers to learn first-hand about natural process and provides opportunities for sanctuary from the strains of urban life. In the long term this may help promote a stronger environmental ethic in society. An increasingly important issue in many urban contexts is that of cultural continuity. As cities change rapidly, residents often seek some elements of stability that symbolize continued well being. In this way, significant open spaces (such as mountain or river preserves) are often valued by the public.

1.2.1 Research Objectives

The fundamental question revolves around the viability of planning an ecological network in an urban landscape. Can such a scheme withstand the tests it will be given in a political and economic context of an urban planning process? To address this question, two principal research objectives are established. First, the development and articulation of a planning method will demonstrate that ecological concepts, in particular the concept of ecological networks, can be integrated into the urban planning process. Secondly, the establishment of an ecological network will improve the viability of ecological systems in an urban context. This study provides a theoretical framework and a model to test this proposition. A planning method is articulated and a series of assays of landscape structure are used to examine the viability of an ecological network in the Phoenix, Arizona urban area. It is intended that the establishment of a planning method and a procedure for assay will make this concept applicable in other contexts.

1.3 Existing Theory

A review of current literature forms the foundation of knowledge upon which this question can be addressed. A particularly intriguing (and complicating) characteristic of this research problem is that it touches on several distinct disciplinary fields. Consequently, the literature review is broad, yet specific to this problem. The theoretical foundation comes primarily from ecological planning (McHarg 1969 and Steiner 1991) and incorporates theories and methods from landscape ecology (Forman 1995, Hersperger 1994, Forman and Godron 1986, Naveh and Lieberman 1984, and Vink 1982). Specific theoretical perspectives are provided from the work of landscape planners (Kerkstra and Vrijlandt 1990, Hough 1989, Spirn 1984 and 1986) who have begun to address the incorporation of ecological systems into urbanized or industrialized (agriculture) landscapes.

Conservation biology and applied landscape ecology bring a wealth of knowledge on planning for biodiversity (Falk et al. 1996, Noss and Cooperrider 1994, Hanson and Angelstam 1993, Hudson 1991, Soule 1991, Noss 1991, Noss and Harris 1986, Opdam 1988) and habitat networks (Beatley 1994, Rodiek and Bolen 1991, Kleyer 1994). Concepts such as metapopulations (Hanski 1991), island biogeography (McArthur and Wilson 1961) and gap analysis (McKendry 1993, Scott et al. 1992) have been developed and provide additional substantiation to theory and methods for habitat network planning. Eco-hydrology (van Buuren 1991 and 1993) and landscape planning incorporating hydrologic structure (Toth 1991 and Ferguson 1991) are emerging areas in which the literature is thin, but portend to be critical to the future development of fully articulated methods for planning ecological networks.

1.3.1 Ecological Theories

Systems Theory - Systems theory (Naveh and Lieberman 1984, Jones and Street 1990) provides a holistic philosophy by which the order of nature or other systems can be understood. Systems theory aggregates to understand in contrast to traditional scientific techniques that isolate to understand. As such, it is an integral concept to landscape ecology and provides a beneficial link to planning, which also tends to be holistic. The importance in most landscape planning or management contexts is that it is impossible to isolate and collect all necessary data to understand ecosystem functions or to try to discern relative ecosystem health. Within systems theory one can study the hierarchical order and complexities of nature without all data present. The strength of this approach is gained through analysis of the essential functional interrelationships of the system.

Systems are often characterized as open or closed. Closed system's functions are intrinsic and are often theoretical systems or systems of human conception. Chaos theory (Cartwright 1991) has emerged to provide some explanation to system's behavior that do not follow predictable patterns. In landscape ecology the fundamental principle of change embodies this theory. It is no longer assumed that "equilibrium" will be attained in the larger scheme of system's functions. Chaos theory allow that systems evolve in sometimes unpredictable ways, but still describable within a certain order. The discussion of chaos theory continues, but it is clear that predictability may not be a characteristic that scientists expect to be present. The analysis of patches and corridors .of a landscape must then be described as unpredictable and concepts such as flickering or winking patches in metapopulation studies (Verboom et al. 1992) become part of the planning vernacular. This is often disconcerting to those engaged in urban planning because one of the fundamental tenets of planning is to provide some level of predictability. It may be necessary to further examine patch and corridor dynamics (Wu and Loucks 1995) as a part of any planning process that purports to aspire to some level of sustainability.

Hierarchy Theory - Hierarchy theory (Pattee 1973, O'Neil et al. 1986, O'Neil et al. 1989, Haber 1990) relates to the functions of systems or units between scales. Any landscape system is a nested hierarchy. Systems may function predominantly at one scale, but they are linked by containing the levels below and by being contained by the levels above. Forman (1995) notes "a minimum of three linkages must be known. The element is linked to the: (1) encompassing element at the next higher level; (2) nearby elements at the same scale; and (3) component elements at the next lower level." (p.9). Hierarchy theory addresses both spatial and temporal scales (Urban et al. 1987).

In any situation, the scale is responsive to the element or elements of analysis. Consequently, there are no "standard" scales that are universally appropriate for investigation. A specific problem may warrant analysis at multiple levels to adequately understand interactions. Within an urban area, components may be represented by an individual park site, a municipality with an array of park and open space elements or the metropolitan region which is comprised of numerous municipalities and unincorporated land.

Two important elements of scale become relevant in spatial or temporal studies. The grain (Weins 1989), or the smallest unit of analysis, changes with the scale of analysis. It may be most suitable to analyze an urban park site using 0.10 ha. as the unit of analysis. A parks and open space system of a municipality may be studied at 1.0 ha. and at a metropolitan level, 10.0 ha. may be suitable. The extent of analysis may be strongly related to the grain. Extent refers to the breadth of the study area. At site scale, the extent of a single park may be less than 50 ha. and at landscape scale a metropolitan area study may encompass 5,000 square kilometers.

Ecological Integrity - Ecological integrity is a concept that refers to the health of and ecosystem or a landscape (Westra and Lemons 1995, Karr 1995). It can be considered to be the level at which the system is functionally viable. Forman (1995) notes that to achieve ecological integrity near natural levels of production, biodiversity, soil and water characteristics must be present. He also notes "ecological integrity could be measured as the single most important or sensitive attribute of an ecological system." (p. 499). As a measure for sustainable development the challenge becomes quantification of near natural. It is quite simple to assess many areas and determine that they are not near natural because of the evidence of excessive deterioration. But, because there are too many attributes that are often difficult to quantify determining that areas are near natural may be more problematic. Forman (1995) provides the following model (Figure 1.1) and illustrates how the four attributes can be used to establish a framework for assessing ecological integrity.

Forman (1995) indicates that plant productivity would be at a level not far from the condition of the native ecosystem. The standard for biodiversity would be that relatively few species have been expirated. "Thus a landscape that has lost certain habitat types or has natural habitats so fragmented and isolated so that their species number progressively drops, is not sustainable." (Forman 1995, p. 500). Lack of erosion or soil compaction is the best measure of sustainability for soils. Any area with substantial erosion due to wind or water or any area that is paved or has compacted soils is unsustainable. Water is best measured by both quantity and quality. Quantity is assessed using attributes such as flooding, minimum flows, evapotranspiration, water table and aquifer recharge. Water quality attributes include turbidity, nutrient status and fish population (Forman 1995).

Possible overall Measures	Components of Ecological integrity	Primary linkages with basic human needs					
		food	water	health	housing	energy	culture
Average of all spatial element types, corrected for area of each	Productivity	⤴	↵	⤴	⤴	↕	↵
Total species richness in landscape	Biodiversity		↵	⤴	↵	↵	↕
Amount of eroded area or average rate of wind and water erosion	Soil	⤴	↕			↵	↕
Average variation in stream/river flows and fish community index	Water	⤴	↕	⤴		⤴	↕

Figure 1.1 *Four attributes of ecological integrity (after Forman 1995).*

Extensive data collection and quantitative analysis is required to verify ecological integrity, however, preliminary assessments can be made to eliminate areas that clearly do not meet a standard. Remaining areas could then be studied in more detail using the best available data for initial planning and management purposes. Subsequently, more detailed data collection and analysis would be necessary.

Landscape Morphology - An historical analysis of landscape attributes provides useful information concerning past structure, function and agents of landscape change. Understanding of the previous state sometimes provides a baseline from which the current status can be measured. Haber (1990) uses two categories, Bio-ecosystem and Techno-ecosystem (Figure 1.2) to separate human dominated or created and various levels of naturalness. Forman and Godron's (1986) modification gradient is a similar concept but uses a five level gradient to characterize level of modification (Figure 1.3).

A.	Bio-ecosystems	Dominance of natural components and biological processes.
A.1	Natural ecosystems	Without direct human influence. Capable of self regulation.
A.2	Near-Natural ecosystems	Influenced by humans but similar to A.1. Little changed after human abandonment. Capable of self regulation.
A.3	Anthropogenic (biotic) ecosystems	Intentionally created by humans. Fully dependent On human control and management.
B.	Techno-Ecosystems Examples: settlements (villages, cities), traffic systems, industrial areas	Anthropogenic (technical) systems. Dominance of technical structures (artifacts) and processes. Intentionally created by humans for industrial, economic, or cultural activities. Dependent on human control and on the surrounding and interspersed bio-ecosystems.

Figure 1.2 *Ecosystem naturalness (after Haber 1990).*

Landscape Modification Gradient

Natural Landscape	without significant human impact
Managed Landscape	for example, pastureland or forest where native species are managed
Cultivated Landscape	with villages and patches of natural or managed ecosystems scattered within predominant cultivation
Suburban Landscape	a town or country area with a heterogeneous patchy mixture of residential areas, commercial centers, cropland, managed vegetation and natural areas
Urban Landscape	with remnant managed park areas scattered in a densely built up matrix several kilometers across

Figure 1.3 *Landscape modification gradient (after Forman and Godron 1986).*

1.3.2 Urban Theories

Extensive bodies of literature exist in subject areas relating to integration of cultural opportunities through urban planning. Most theories and methods have been developed for application in other situations; however, adaptation to the concept of ecological networks is possible. Recreation literature is extensive, but specific literature focusing on planning for passive linear recreational activities (Airola 1982, Furuseth and Altman 1991) is not as common. Environmental education and urban nature centers are topics that are receiving increased attention. In the broad field of environmental education topics such as environmental advocacy, societal environmental ethics and specific educational techniques may be relevant. Environmental psychologists have also written about "urban nature" (Witter and Sherriff 1983) and documented its therapeutic value. Existing visual assessment literature (Whitmore et al. 1995, Zube et al. 1988) is extensive and theories and methods of visual assessment are well documented. Other literature focusing on cultural and historical meaning of landscapes and landscape elements exists (Lynch 1966 and Aggar and Brandt 1988), but has varying degrees of suitability for direct application here. Other qualitative evaluations of open space have also been conducted that address quality of life issues more explicitly (Zacker 1987). Sustainability literature incorporates examples of both qualitative and quantitative studies (Van Lier 1996, F.A.O. 1993, Van der Ryn and Calthorpe 1986, Van Lier et al. 1994). This field is extremely broad, however, some useful indicators or "measures" can be extracted.

Specific examples of planning approaches for ecological networks include ecological infrastructure and the framework or "casco" landscape in The Netherlands (Lammers 1989, Kerkstra and Vrijlandt 1990, and Van Buuren and Kerkstra 1993), recreation and dispersal corridors in Copenhagen (Hansen Møller 1994, Asbirk 1984), habitat networks in Stuttgart (Kleyer 1994) and urban biotope assessment in Berlin (Sukkop and Weiler 1988). Recent publications include numerous case studies describing methods for planning ecological networks (Fabos and Ahern 1995, Arts et al. 1995, Cook and Van Lier 1994, Cook and Hirschman 1991). From these case studies, principles have been drawn to formalize a planning method for establishing an urban ecological network.

1.4 Ecological Network Plan Development

The proposition is established that an ecological network, incorporating multiple-use, is a viable alternative to existing uncoordinated open space planning in an urban context (the Phoenix, Arizona metropolitan area is used as an example). An ecological network plan is developed, based on theories and methods that are utilized in different contexts, utilizing current data and ecological planning methods. A systems approach incorporates hydrology, habitat and cultural opportunities as distinct but integrated systems. The primary purpose is to ensure the integrity of the functions embodied within these types of systems that are often evaluated, planned and managed separately by different agencies. Determination of the nature of the types of systems utilized is relative to the planning context.

Hydrology - The detailed hydrologic structure plan is based on initial characterization of hydrologic elements as largely synthetic (human-created) or natural. Using principles from eco-hydrology (Van Buuren 1997), assessment of the range of functions accommodated by hydrologic elements will form the basis for noting existing deficiencies in the system. Synthetic and natural elements are assessed separately, recognizing that ultimately they may be woven together into a comprehensive system. Historical patterns of hydrologic structure are examined initially to determine the viability of re-establishing connections that have been severed as a result of urban development. Synthetic connections (often following alternative patterns) provide connections where use of natural elements or re-established "historical" connections are not feasible. System hierarchy and the relevance of hydrologic functions are used to assess validity of the network from an ecological perspective.

Habitat - Habitat network planning utilizes a modified gap analysis (McKendry 1993, Scott et al. 1992), analyzing existing species distribution. Habitats are classified by characteristics and habitat affinity (extent of relationships between habitat types) is determined. Opportunities for techniques such as perimeter planting (Baines and Jones 1994), urban de-intensification (a variation on the concept of extensification sometimes used in agriculture) (Kleyer 1994), buffering and clustering of nodes (Noss 1986, Forman 1995) are examined. In many cases, because data is limited concerning specific needs of individual species, habitat value or suitability is evaluated using plant communities as surrogate for wildlife species.

Cultural Opportunities - A system of environmentally oriented sites for human activity, organized in clusters, linear features, or as nodes form the basis for a system of elements with cultural significance. Three primary sub-systems, utilizing different methods for inventory and analysis are integrated to form a comprehensive system of cultural elements with existing or potential ecological value. The first sub-system, recreational opportunities, is an aggregation of existing municipal recreation system plans, supplemented with other sites to link and complement. Second, elements of the city are analyzed using the method developed by Lynch (1966) to provide a descriptive analysis of images (predominantly natural/open space elements of cultural significance) formed through cognitive processes. The third sub-system includes areas of significant visual quality that are identified with expert and/or public valuation methods of visual assessment (Whitmore et al. 1995). In addition, clusters and nodes of other ecologically significant cultural or historical sites complement the sub-systems previously described. These sub-systems are analyzed to assess relative affinity of functions or activities and compiled as a cultural systems plan. Hierarchy within this system is based largely on utilization and exposure or awareness of the public, size and significance of features. Assessment of inherent value of systems elements is a combination of these factors and other environmental factors.

Systems Plan Integration - The three independently developed system plans are intended to demonstrate the integrity of system for specific purposes and to establish an internal hierarchy from each system's perspective. Determining compatibility and establishing system priorities or rankings is the purpose of plan integration. In areas where two or more of the systems overlap, degree of compatibility must be assessed, priorities for use must be determined using criteria from the independent system development phase. In some cases, secondary systems (or alternates) are employed to eliminate incompatible relationships between systems or system elements (such as certain types of recreational activity and sensitive habitat). The resulting integrated plan determines relative priority or degree of utilization of network components for specific purposes.

The method for generating the hypothetical plan follows these steps:

1. Definition of the study area by integrating political and natural boundaries.
2. Examination of the regional context.
3. Documentation of landscape change, within the study area, by examining historical aerial photographs and other records.
4. Assessment of natural and cultural resources at regional level and determination of existing and potential value as network components.
5. Formulation of an independent regional (landscape scale) system plans for habitat, hydrology and cultural opportunities.
6. Formulation of a multiple-use network at the regional scale, establishing priorities for ranking of integrated uses and identification of sites for restoration or improvement.

7. Development of community-level (substructure) system plans for habitat, hydrology and cultural opportunities. These are prepared at the scale of individual municipalities or parts of municipalities (for large cities with extensive planning areas within their jurisdiction).
8. Development of a multiple-use network expanding on the regional-scale plan with localized sub-systems with rankings for integrated uses and identification of sites for restoration or improvement.
9. Development of localized plans for network elements in neighborhoods or prototypical sites that have been identified as needing restoration, improvement or management.
10. Monitoring and feedback.

1.4.1 Landscape Scale (Main Structure) Ecological Network

The network plan prepared at this scale focuses on the Phoenix urban area and the surrounding valley floor (as defined in planning step 1). The study area occupies approximately 7,300 square kilometers and mapping is undertaken at 1:50,000. Consequently, the grain of the data is somewhat coarse (minimum 15 hectares) and the extent is broad. The intent is to understand interrelationships of elements within and outside of the study area of "regional" or "landscape-scale" significance. The network formed at this scale becomes the main, and more stable, structure. Other network elements at finer scales may be more transient in nature, varying in ecological value over time.

1.4.2 Community-level (Sub-structure) Network

The community-level (sub-structure) is prepared at the municipal level (or portions if too large) to correspond with municipal-level planning and management hierarchy. In this case, the City of Scottsdale, Arizona is used as an example of municipal-level planning. The City of Scottsdale occupies approximately 485 square kilometers with mapping at a scale of 1:10,000. The grain of data is less coarse at 1 hectare. At this scale, planning can be undertaken for interrelated network elements. Scenarios for change of landscape structure of network components can be analyzed to determine how potential network element quality can affect the function of the total system.

1.4.3 Local Area (Site-Scale) Planning and Management

Local area planning and management includes specific plans for changes in elements or management plans to preclude deterioration of quality. Individual studies are undertaken that respond to specific site needs and to reinforce the objectives of sub-structure (municipal or community level) plans or landscape scale plans. The scale at which these plans are undertaken varies with the nature of the network element. They are all subject to management by one entity, however, whether public or private. At this level implementation occurs on an incremental basis, consistent with urban planning development processes. Corresponding management units may be such individuals or groups as park managers, neighborhood associations, utility companies or private development companies.

1.4.4 Monitoring and Evaluation

Monitoring and evaluation are important to the long term success of an ecological network. Through this process weaknesses are found and adjustments are made. If the outcome were certain and predictable, evaluation and monitoring would not be required. Noss and Cooperrider (1994) use the term adaptive management for the process of continual re-examination of the effectiveness of an ecological network. They describe a six step process in a monitoring program.

1. Scoping. Scoping refers to problem definition. Through this process problems and issues are identified and refined, data needs are assessed and priorities are established.
2. Inventory. This stage involves gathering information identified in step 1.
3. Experimental design and indicator selection. Based on goals indicators of ecological health are determined. Experimental design involves preparing suitable controls and establishing parameters for data collection. Understanding of thresholds is important in this step to properly detect ecosystem reactions to human influences.
4. Sampling. Sampling is the process of collecting data.
5. Validation of models. Validation occurs to determine how well indicators reflect actual phenomena.
6. Data analysis/management adjustment. Based on knowledge gained from results, adjustments in management are implemented and monitoring continues.

1.5 Summary

While it is clear that a need exists for maintaining the viability of critical ecological systems in urban contexts, it is not certain that this can be achieved over the long term. Ecological and urban theories have evolved in different dimensions and are only now meeting at a point in time when many urban areas have deteriorated value beyond any prospect for revitalization in the near future.

Numerous perspectives exist on how we should conserve existing viable systems and restore those with degraded quality. The concept of ecological networks shows promise in less populated areas and indications are that in proper conditions, urban landscapes will also benefit. The method outlined here is geared toward integration of urban and ecological processes in a way that allows both to continue to function effectively.

Chapter Two

The Status of Planning Ecological Networks

2.1 Introduction

The concept of ecological networks has evolved through the integration of principles of landscape ecology in planning and through the development of local initiatives for planning greenways. Though the origins of ecological networks can be traced back to the early years of this century, it is only in recent years that the concept has been more fully developed and found its way into nature conservation and planning policy. North American and European approaches have differed, principally as a result of different emphasis in the planning process. There is now, however, substantial exchange of ideas and collaboration between North American and European planners working on this concept. The future portends further collaboration and perhaps more similarities in how ecological networks are integrated into the planning process.

2.2 European Ecological Network Planning

With recent impetus resulting from European Union environmental policy, planning for ecological networks at many scales and in many forms has been significant. Although ideas for ecological networks started in individual countries, often at local or regional levels, the concept has been adopted as a principle tool for nature conservation throughout Europe and has become a significant planning tool at the local level. This section characterizes the current status of planning ecological networks in Europe and provides a number of examples that illustrate the range of schemes that exist or are now being developed.

2.2.1 European Ecological Network

Jongman (1995) describes three initiatives that are now underway at the European level; Diploma Sites, Biogenetic Reserves and the European Ecological Network (EECONET). Each of these represents an important component in the net of policies and plans used for nature conservation in Europe. Although they are not specifically comprehensive ecological network plans or policies, they contribute to this goal. Planners, however, at the European Center for Natural Conservation (ECNC) work directly with the concept of "a European Ecological Network" and are utilizing their initiatives as tools.

The European Diploma sites program dates to 1965 and was formulated by the Council of Europe (1991a and 1991b). This program selects a limited number of sites that are examples of European natural heritage. Specific criteria for selection include a) representativeness, b) historic, aesthetic, scientific or recreational value, c) particular characteristics of fauna, flora, geology, climate and geography and d) protection status. Diploma sites are granted this status for five-year period after which they are reevaluated and may be continued or not (Jongman 1995).

Biogenetic Reserves have been established by the Council of Europe (1993) and provide a structure for participating countries to create a network of protected areas. The criteria for selection of Biogenetic Reserves includes: a) value for nature conservation (unique, typical, rare and endangered) and b) protection status. Biogenetic Reserves are selected by experts based on adherence to the previously noted criteria. In 1995 there were 247 Biogenetic Reserves in 16 European countries (Jongman 1995). Perhaps the most comprehensive program for ecological networks in Europe is EECONET (Bennet 1991, Bischoff and Jongman 1993). EECONET includes a spatial component and its principle objective is "enforcement of nature conservation by developing a physically coherent structure of nature and to stop species decline by facilitating migration . . . the network consists of core areas, corridor zones and nature expansion areas; buffer zones can be part of the network." (Jongman 1995 p. 177). Data are collated and stored in GIS and include CORINE (Coordination of Information on the Environment) data for biotypes (Moss et al. 1991), list of important Bird Areas of the International Council on Bird Protection (Grimmet and Jones, 1989; Longeveld and Grimmet, 1990) and natural vegetation maps of Europe (Noirfalise 1987). Jongman (1995) notes there are three criteria to select nature expansion areas; diversity, rarity and location. Diversity aims to include "European diversity in habitats" throughout the ecological network. Rarity assures inclusion of rare and threatened habitats; and, location refers to the physical arrangement of habitats to prevent fragmentation of nature. Nature development areas and corridor zones are the remaining elements of the network. (Jongman 1995). Figure 2.1 illustrates EECONET as mapped in 1993.

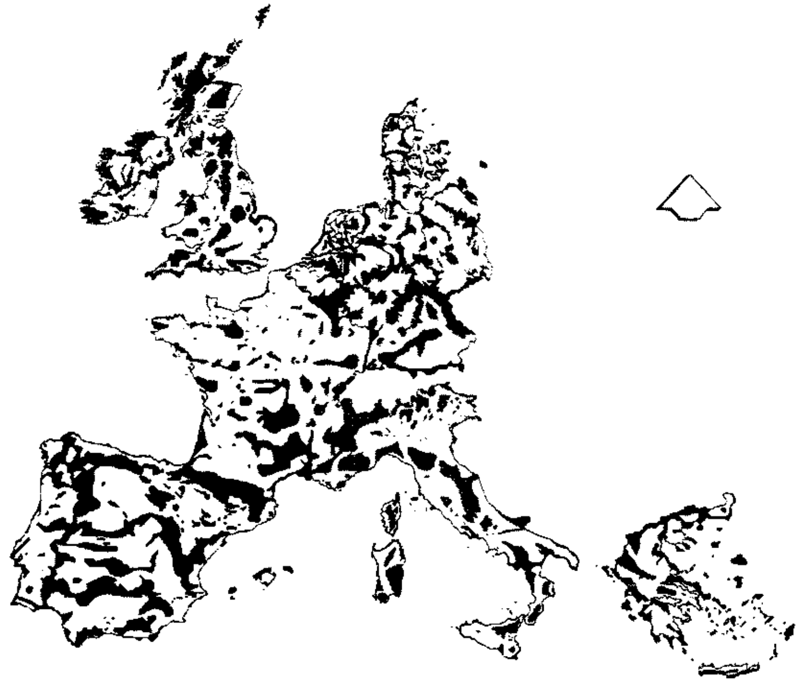

Figure 2.1 *EECONET Map (after Jongman 1994, Bischoff and Jongman 1992)*

2.2.2 Ecological Networks in Greece

The planning process for ecological networks in Greece is still in its formative stage. As such, it represents more of an advocacy plan than an actual plan with support policies that will establish ecological network at the national level. The principle motive for advocating the concept of an ecological network in Greece is the significance of the diverse landscape in the country and large number of endangered, vulnerable or rare species (Troumbis 1995; IUCN 1982). Troumbis (1995) notes that 47% of all plant species within Europe are found within Greece, occupying 1.26% of Europe's land surface (800 species are endemic to Greece). However, rare and threatened plants species make up about 18.5% of total flora. Fauna are also experiencing decline with birds (54%), fishes (5.5%), mammals (25%), reptiles (23.5%) and amphibians (13.5%) listed as rare, endangered or vulnerable by IUCN.

The need for conservation is clear and various authors have suggested that between 22% (Hadjibiros, 1991) and 45% (Bischoff & Jongman 1995) of the land is in need of conservation. Troumbis (1995) notes that the Ministry of Agriculture and Ministry of the Environment have adopted a strategy of designating "protected areas," but experts express concerns over the process by which 'protected areas' are designated and the low compatibility with an ecological network. As a consequence, Dr. Andreas Troumbis and his colleagues at the Biodiversity Conservation Laboratory, Department of Environmental Studies, University of the Aegean, have been working on a scientific methodology for locational analysis for natural areas to form ecological networks at national and regional levels. The methodology follows a three-stage process; 1) definition of available land (suitable) for conservation , 2) location of core areas, and 3) design of the conservation suitability map. Dr. Troumbis hopes that a scientific protocol will allow for politicians, scientists, social scientist, physical planners and developers to communicate and work toward realizing national and ecological networks in Greece.

2.2.3 Dutch Ecological Network

The Dutch Ecological Network planning process is sophisticated and supported by the Nature Policy Plan of 1990. Because of deterioration of natural values in the Dutch landscape over time, environmental issues emerged at the end of the 1980's as a priority for the government, nongovermental organizations and individuals. In 1990 a set of environmental plans were passed by the Dutch Parliament; the National Environmental Policy Plan, the Third National Policy Document on water management and the Nature Policy Plan (Lammers 1994, van Zadelhoff & Lammers 1995). The overall goal of these plans is to offset the deterioration of nature through a more comprehensive approach to nature conservation.

An important strategy incorporated within these initiatives was the National Ecological Network (NEN). Several principles were established to guide the NEN. First, a representative set of ecosystems of national and international importance were to be included. Second, the enlargement and connection of natural and semi-natural ecosystems is to be accomplished. Third, landscape-ecological relations are to be taken into account. This process yielded several scenarios for an ecological network plan that was finalized in the form of a physical plan (Figure 2.2) consisting of core areas, nature development areas, ecological corridors and buffer zones.

Core areas are those greater than 500 ha. with ecological value of national or international significance. In addition, large lakes and Dutch territorial waters of the North Sea are included. Nature development areas are those that offer realistic prospects for the development of nature of national or international importance. These typically include areas suitable for development of wet grasslands, marshland, marshy woodland in both low-lying areas of the Netherlands and in the sandy regions.

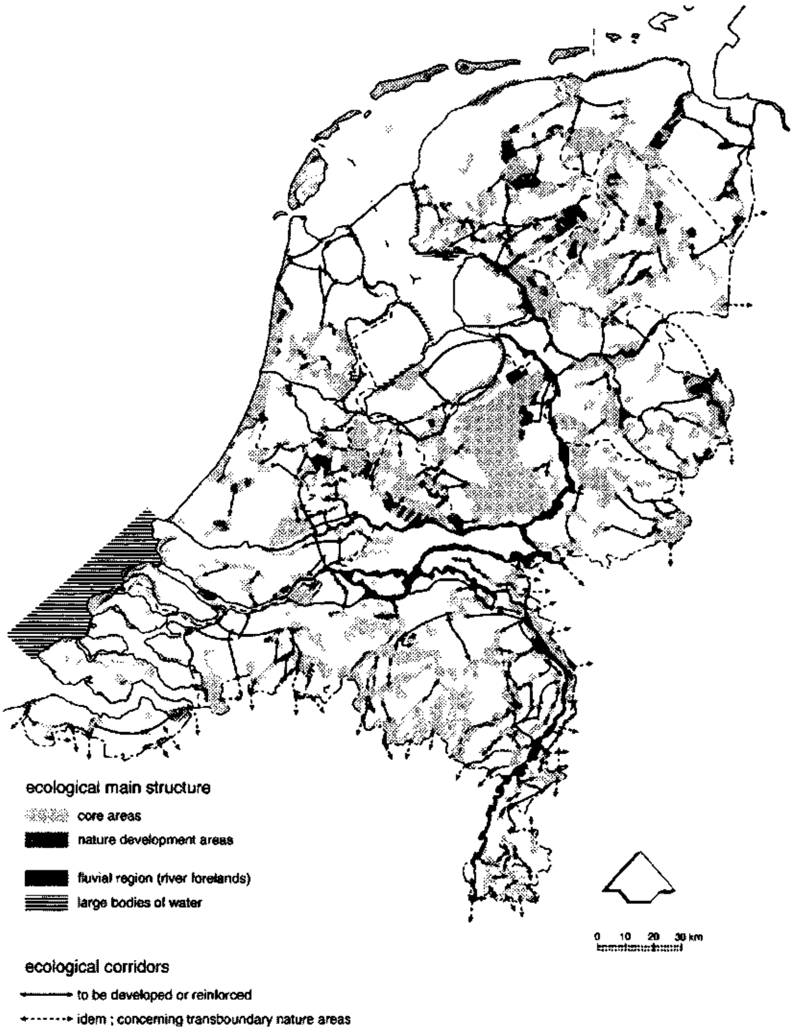

Figure 2.2 *Dutch ecological network plan (after Lammers 1994)*

Ecological corridors are landscape structures and artificial provisions that contribute to migration between other elements of the ecological network. The purpose is to reduce the isolation effect and facilitate migration over land or through water. Buffer zones were added to the plan to protect the network against dilatory impacts, such as flow of polluted ground and surface water, incompatible land uses and other human impacts.

This plan is now in place and provides the basic structure and framework upon which regional and provincial plans for ecological networks are being developed. It is also an important component of the European Ecological Network plan. It includes both policy and physical planning components.

2.2.4 Habitat Networks in Stuttgart

Habitat networks are one of a set of strategies for nature conservation being explored in Germany. Others include preservation and conservation of largely undisturbed landscapes, establishment of biosphere reserve sites where appropriate, integrated systems of nature reserves with regeneration area on previously altered sites and nature development. Kleyer (1994) describes the planning process as one that would stimulate joint conservation actions among communities of the Stuttgart region that share common habitats along their borders. As such, a general planning scheme was established for the entire Stuttgart Metropolitan Area, but individual habitat network schemes were to be worked out at the local level.

At the regional level the process started with an inventory of individual habitats greater than one hectare, mapped at 1:25,000 using aerial photographs and field investigation. At regional scale, analysis was limited to assessment of the habitat types and spatial distribution. In addition, the landscape analysis included a broader assessment of the overall physical environment (soils, climate,nutrient and water supply, etc.) to understand interrelationships between habitats and other elements. Classification of naturalness was also undertaken using three main groups; near natural, semi-natural and artificial. Threshold values for distance between habitats were established using historical patterns to help identify habitats experiencing some degree of isolation. Landscape analysis, historical analysis and habitat similarity analysis were used as tools to assess the overall distribution of habitat patches. The ranking system described as follows was employed to describe the results of the overall assessment (Kleyer 1994, p 261).

> "Rare habitats - This statement was assigned to habitats with a high value of naturalness that occur because of singular environmental conditions. Such patches should be conserved but not considered as elements of a possible network.
>
> Areas with high density of habitat and existing networks (value I) - These areas are assemblages of similar near-natural or semi-natural habitats that are situated closely together or share common borders. The overall area should be greater than 10 hectares.
>
> Areas where habitat density and/or networks are insufficient (value II) - In these areas typical habitat patches of the given regional natural unit are well represented but are either:
> -situated apart from each other, or
> -share only common borders with similar habitats, or
> -consist of habitats with low value of naturalness.
>
> Areas with low habitat density and missing networks (value III) - These are areas where typical habitats of the given natural unit are not well represented or are missing. Habitats with a low value of naturalness predominate. Single isolated habitats may serve as cornerstones for a future habitat network."

Planning recommendations included protection of rare habitats and areas of value I. Existing habitats in value II areas were recommended to be restored, improved or extended. In areas of value III areas for new habitats were to be created. Since this level of investigation was regional in scale, recommendations were given as general guidelines for habitats

On the local planning level, a similar process was followed except more detail was incorporated into the study. Individual cities initiated local habitat network schemes. The inventory was conducted primarily through field investigation and habitat complexes were mapped at 1:5,000 scale and 1:2,500 with individual patches of 200 m^2 or greater included. The analysis at local scale assessed conservation value of patches and spatial distribution and connectedness. Conservation value for a habitat patch was based primarily on rarity and restitution probability. Rarity took into consideration the current frequency and area distribution in the current situation and the historical context. Restitution probability considered the possibility of self-establishment within short time periods based on the criteria of physical condition, age of development and abundance of species with low dispersal capability. Assessment of connectedness values was undertaken only for habitats with high or medium values in the conservation assessment. Connectedness was assessed between habitats of similar type comparing distance and minimum area between patches. Planning recommendations on the local scale included the same three categories as on the regional scale, protection, restoration and creation of new habitats.

2.3 North American Greenway Planning

Planning open space networks in North America has taken a different path than that of Europe. Commonly referred to as greenways, connected systems of open space have largely been initiated through grass roots support and local level initiatives. The North American approach is generally to plan for individual greenways and then over time work on establishing connections. Efforts that are focused on landscape scale greenway planning tend to be scientific studies that are frequently not followed up with policy or plans to implement. A range of examples of planning for ecological networks or greenways in North America follows.

2.3.1 GAP Analysis

The GAP analysis concept, as described by Scott et al. (1992), provides a quick overview of the distribution and conservation status of several components of biodiversity. The GAP analysis process utilizes satellite imagery as digital map overlays in GIS to identify individual species, species rich areas and vegetation types that are unrepresented or underrepresented in specific management areas. It is part of a biodiversity inventory process that was developed in the 1980's to complement other strategies for managing and protecting species. It has been developed and used by the U.S. Fish and Wildlife Service, Forest Service and various state-level departments responsible for wildlife management. In the U.S. it is one of the few broad-based programs to identify gaps in protection of habitats.

The GAP analysis process includes fifteen steps (Scott et al. 1992) that begins with preparation of a vegetation map and ends with design of a reserve network. The fifteen steps are described below. It is characterized as a coarse filter approach that is not a substitute for detailed analysis

1) Draft and digitize vegetation map.

2) Ground truth vegetation map.

3) Prepare maps of predicted species' distribution based on known range limits and association with vegetation types.

4) Ground truth species distribution.

5) Digitize protected areas.

6) Digitize land ownership.

7) Input point data for rare, threatened and endangered species' locations and point or line data for high interest habitats.

8) Map species richness.

9) Generate maps for special interest species and habitats.

10) Delineate centers of species richness.

11) Rank centers of species richness by contribution to state, regional and continental diversity.

12) Determine current percentage of each vegetation type and area of species richness in protected areas by land ownership.

13) Identify minimum areas required for 75% (and 90%, 95%) of species and vegetation types.

14) Identify landscape corridors connecting vegetation types and centers of species richness.

15) Design reserve network.

The GAP analysis process is now being applied at state, regional and national levels and has potential to be applied internationally. As a coarse filter approach, it is a good process to initiate conservation planning activities at a broad scale. It will help to identify opportunities and constraints to conservation management and then help establish priorities for more detailed studies. Applications of GAP analysis can also be extended to include large scale geographic studies, land use planning studies and other types of environmental studies (McKendry and Machlis (1993).

2.3.2 Comprehensive Greenway Planning in Georgia

Greenway planning in Georgia was started in 1976 when the State of Georgia published the Environmental Corridor Study (Dawson et al. 1976), a survey of greenway potential and a statewide interconnected system (Dawson 1995). Dawson describes the study process as combining intrinsic values (natural resources, environmental quality and aesthetics) with extrinsic values (human use, accessibility, market demand and land use). This study formed the basis for establishing priorities for land to be acquired through the Heritage Trust and for other options such as conservation easements and zoning. As the process evolved the methodology for greenway planning in Georgia also evolved. The State of Georgia provided a definition for their Greenway system as: 'a connected integrated system of mostly linear, near-natural and cultural areas which, for various reasons, have remained as almost undeveloped corridors passing through human-altered landscape, and which have prime value to society and/or nature by remaining in there nearest to natural state.' (Dawson 1995, p. 32).

The Environmental Corridor Study included four main parts, 1) resource analysis, 2) final corridor selection and priorities, 3) corridor planning and management options and 4) summary and conclusions. The purpose of the resource analysis was to make an initial selection of greenway corridors for more detailed assessment relating to their overall suitability as potential greenway corridors. Six key resource indicators were used in this assessment: 1) slope, 2) vegetation, 3) geology, 4) soil, 5) wildlife and 6) hydrology. Both environmental and human use criteria were used in the interpretation of the six indicators. The corridor selection process involved assessing corridors using two key indicators, environmental areas and scenic rivers. These were ranked as high medium and low intensity in terms of presence of the two indicators. Planning and management actions involved establishing priorities for timely conservation action. The 26 major greenways identified in the study were classified by intrinsic value, extrinsic value and endangeredness. Intrinsic value refers to the inherent qualities of the greenways, exclusive of the potential impact on the corridors. Extrinsic value refers to the quality and potential that is dependent upon or derived from human activity. Endangeredness expresses the level of potential problems that threaten the existence of the greenway. A composite index is then derived from this classification and priorities for conservation action is established. This process was intended as a 20-year plan for the State of Georgia. New initiatives have been carried forward and further acquisition and conservation activity continues to occur.

2.3.3 Greenbelts to Greenways in Three Canadian Cities

Taylor et al. (1995) note that greenways have played and important role in urban development in Canadian cites for 40 years. Three specific cases were examined by Taylor et al. (1995) and provide and overview of the historical and current status of greenway planning in Canadian cities. The scope and planning method for each of these studies was different but the profiles presented include discussion of development plans, administrative framework, land use control mechanisms and a review of the outcomes. Each resulted in implementation and embodied characteristics of linearity, open space conservation, and connectivity. The three projects are located in the Canadian cities of Ottawa, Ontario; Calgary, Alberta; and Saskatoon, Saskatchewan.

The National Capital Greenbelt in Ottawa, Ontario was initially incorporated into a comprehensive plan for the city in 1950. The greenbelt proposal embodied in this plan was to establish a green zone around the National Capital Region (NCR) that would occupy about 20,000 hectares, averaging 4 kilometers in width. The form and intent was patterned loosely after Ebenezer Howard's greenbelt concept. It was intended to prevent further sprawl and protect adjacent agricultural land, provide a reserve of building sites for future government use and to provide a practical and economic limit an the growth of the Capital by confining development.

The greenbelt at its conception was intended to incorporate a variety of land uses including federal facilities, natural areas, recreation facilities, farmland and land held in reserve for future Capital development. Currently land is allocated as 25% farmland, 15% sensitive natural areas, 30% government research centers and airport, and 30% developed open space, schools and hospitals. This multiple use greenbelt is administered by the federal government and is intended to be controlled by zoning. However, local municipalities opposed this approach and eventually it was expropriated for the purposes of establishing the greenbelt.

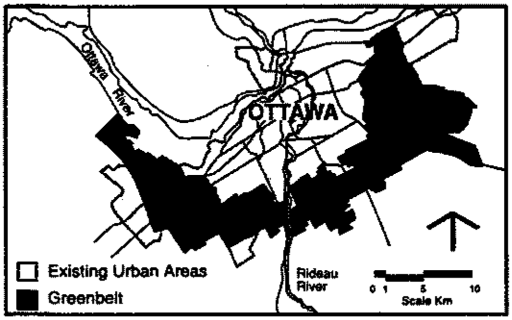

Figure 2.3 *National Capital Greenbelt, Ottawa, Ontario (after Taylor et al. 1995).*

Fish Creek Provincial Park in Calgary, Alberta was initially established in 1972 when the Province of Alberta purchased this corridor to deter development. Under the guidance of a citizens advisory committee the plan was prepared. The goal of the Fish Creek plan was to provide conservation of significant natural and cultural values of the greenway area, while accommodating appropriate levels of use (Taylor et al. 1995). The planning concept included development of links and nodes and to concentrate intensity of use in specific areas with greater carrying capacity. As the plan has been developed approximately 900 ha. of the total 1200 ha. has retained its natural state. Fish Creek was the first urban provincial park in Alberta and was a forerunner of the Urban Parks Program, which promoted urban greenway development in several Alberta communities (Taylor et al. 1995). Land use control was accomplished by acquiring all the land by purchase or expropriation.

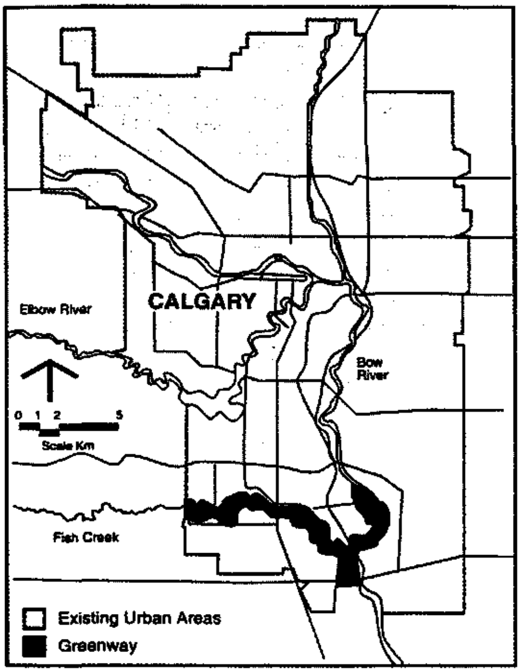

Figure 2.4 *Fish Creek Greenway, Calgary, Alberta (after Taylor et al. 1995)*

The Meewasin Valley greenway on the South Saskatchewan River in the city of Saskatoon, Saskatchewan was developed in the 1970s as a natural amenity for use of the residents of Saskatoon. The planning process included an analysis of natural and human history, identification of site opportunities and constraints, and development and refinement of plan alternatives. Community and university groups, residents and community leaders, elected representatives and other government leaders all participated in the planning process. The plan promoted a concept of balance and distributed uses along the 80-kilometer corridor to avoid over intensifying uses in any one area. A special need for and independent controlling authority was identified early in the planning process and the Meewasin Valley Authority (MVA) was empowered in 1981 to serve as the regulatory, planning and management body. Within the Meewasin greenway two types of zones are the responsibility of the MVA. Control zones are directly affected by the river or directly affect it and include flood plains, wetlands, ravines, creeks, unstable slopes and river terraces. Buffer zones are indirectly affected by the river and include those that may cause aesthetic or physical infringement. The MVA also controls land use changes, building standards and site plans within the greenway (Taylor et al. 1995).

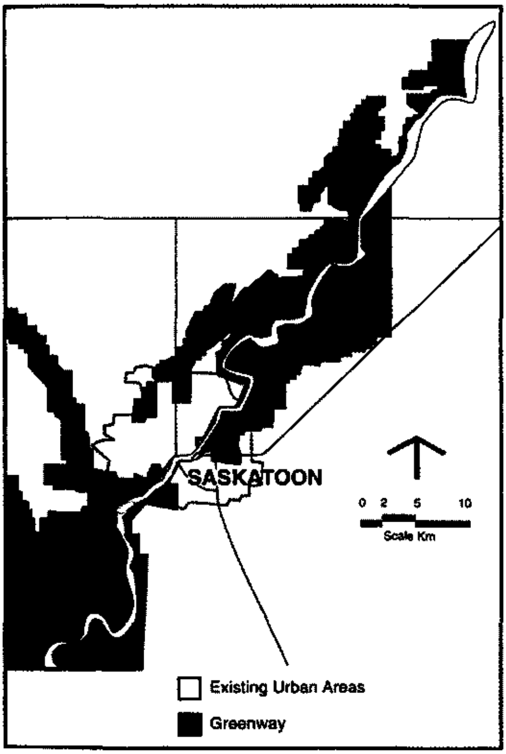

Figure 2.5 *Meewasin Valley, Saskatoon, Saskatchewan (after Taylor et al. 1995)*

2.4 Comparisons between Europe and North America

There are many different approaches based on specific problems or opportunities arising from the unique characteristics of the context. Some apparent differences in planning for ecological networks can be acknowledged between western European initiatives and those in North America. Although not universally true, the largest amount of work in planning ecological networks in Europe concentrates on intensively used landscape and to some extent, the effects of urbanization and intensive agriculture on ecological health. In North America, less work is being done in urban areas, with emphasis on rural landscapes, and in many cases, largely unpopulated preserves and parks. The reason for the difference is obvious when one compares the history and characteristics of Europe and North America.

The European landscape settlement and use pattern is a product of consistent intervention and manipulation by humans that spans millennia. Most European countries (especially those in Northwestern Europe) have well established land use planning instruments with power to act at several levels. National, regional and local physical planning, land reallocation planning and other government initiatives facilitate incorporation of new planning concepts such as ecological networks. A Danish architect, Erik Skoven, once said speaking of his homeland that "in Denmark there is no longer any nature, only culture." With the exception of the northernmost areas of Scandinavia, which still remain unfettered by humans, this is largely true for all of Europe. In North America, there is a common perception that there is an abundance of pristine land and the principle task should be conservation and protection of the most valued of these areas from continued spreading of consumptive land use. While North America has also been inhabited for millennia, it was settlement of transplanted Europeans that resulted in significant manipulation of the native landscape.

Chapter Three

Landscape Scale Main Ecological Structure

3.1 Introduction

The problems associated with maintaining viable ecological systems in urban areas are significant. Decades of overuse and environmental stress has resulted in deterioration and dysfunction to the point that many of the natural systems society depends upon are no longer providing the benefits previously enjoyed. Hydrologic systems, particularly in arid regions, have been manipulated, often diverting perennial flows for human use leaving stream and river corridors barren and spoiled. Human disturbances have resulted in destruction of native vegetation, forcing wildlife to remote remnant patches and ultimately into decline. Introduction of exotic species leads to changes in the ecosystems that reduce their utility for animals and humans alike. Increasing economic pressures squeeze every development opportunity to maximize profits with little regard for the disruption of natural systems. Cities are viewed as human dominated environments in which nature has taken second, third or fourth place.

In many urban situations the result has been a loss of relation with nature by a large percentage of the increased population. Lack of contact engenders lack of understanding and increased fear and hostility toward elements of nature. The logical outcome of this trend is increased disregard for nature's place in society and a degraded environmental ethic among much of the urban population. Those individuals who do make an effort to interact with nature must do so by first traveling by automobile out of the city. This results in increased pollution, reduced efficiency, greater need for roads and additional services and increased stress on nature areas.

In recent years, efforts have been made to preserve remnants for future generations. However, it is increasingly difficult to maintain viable "bits of nature" without the supporting structure and processes upon which it depends. Some efforts are made at reclamation or restoration. These are important steps but often these are compromised by intensified human use in order to justify expenditures. It is apparent, as humans engage in landscape planning and design to restore previously altered ecosystems or protect existing fragments of natural systems, that the most effective way to restore or retain ecological integrity is to ensure that these elements are connected as part of a larger system.

It is also generally true, that only small amounts of money and energy are spent solely to restore disturbed ecosystems. With the exception of the work done by a few non-profit conservation organizations and restoration mandated by law, most other initiatives to restore or preserve areas are linked with some other land use action. Consequently, it is beneficial to recognize that by linking restoration or preservation activity with proposals for other land use actions, the process of re-establishing integrated systems is accelerated. The prospect of establishing an integrated system, or ecological network, within an urban context may help to resolve many of the recurring ecological problems in cities noted previously.

3.2 Planning Justification

A primary issue in achieving an ecological network is providing suitable justification within current land use planning frameworks. To provide a foundation for the planning model that follows the notion of multiple-use is described. Perhaps most importantly, cultivated landscapes and in particular urban landscapes, are generally deficient of areas with significant natural value. This has occurred for several reasons that are related to the fact that the land use planning process is highly anthropocentric in orientation. The result is that any natural (or nature-like) areas that do exist are relegated to remnant patches and corridors. The primary reason is they are less suitable for development than other areas. Factors such as steep slopes, inadequate soils and flood hazard exclude them. The result is a collection of fragments each with depleted natural value and in many cases depleted value for human use.

The most likely way to establish an viable ecological network is to ensure the integrity of the critical systems are retained or re-established while allowing adjacent land uses to continue to function effectively. Clearly, compatibility of adjacent land use is an important issue and where it is possible to modify adjacent lands to make them more ecologically compatible it should be done. Continuous networks can provide greater efficiency for functioning ecosystems, but also in preserving the integrity of adjacent uses. The overall goal is to accommodate the greatest level of biodiversity and ecological processes while accommodating compatible uses. A number of potentially compatible functions or uses are articulated below.

Hydrologic Processes - The functions of hydrologic processes are among the most critical to preserve and restore. These areas are well suited to serve as the foundation of a network since they are often left as undeveloped because of flood danger. They are also, particularly in desert regions, among the most environmentally rich and sensitive. When in a viable state, drainage corridors serve as filters for surface runoff, helping to purify water before it returns to water supply sources. They also serve as sinks for groundwater recharge. Flood containment and protection against soil erosion are also important.

Biological Diversity - Both habitat and conduits for species migration are among the most important ecological functions that can accommodated. Within an urban context, the network may not be entirely suitable as primary habitat for all but a few species, but as islands for refuge or places to forage they may be quite suitable if connected to node or primary source areas. Plants and animals, both are dispersed through corridors and patches of natural systems. These zones serve as conduits for nutrient, energy and gene flow.

Climate Amelioration - Specifically in urbanized areas, climate modification can be achieved by increasing vegetative cover in appropriate locations. In the metropolitan areas of Phoenix, Arizona, an "urban heat island effect" has increased average temperatures as much as 3°C (Balling and Brazel 1987). Negative effects of wind can also be mitigated through increased plantings.

Recreation - The most commonly recognized human activity that may occur in more natural areas is that of recreation. Suitable activities would likely be passive, such as hiking, cycling, horseback riding, nature observation, picnicking and light camping in specific locations.

Aesthetics - Although it is difficult to place specific monetary values on beautiful scenery, it is generally understood that aesthetic qualities are important. Research has shown that properties adjacent to nature areas have increased economic value that may be translated into tax revenues for government. In many cases, the image of an entire district is formed because of the existence, or lack of, natural landscape characteristics. The spiritual or emotional value of beautiful natural areas should also be recognized.

Education and Human Psychology - Education and human psychological ties with nature can be reinforced by having accessible nature areas within cities. As society becomes more urbanized, the danger of losing touch with nature becomes real. Functioning nature areas within an urban setting can provide opportunities for city-dwellers to learn more, first-hand, about natural processes and also provides sanctuary from the strains of urban life. In the long term this may promote a stronger environmental ethic in society.

Cultural and Historical Significance - Often locations of cultural or historical significance are identified and set aside, or should be set aside, to be preserved for use or appreciation by the public and future generations. Trails, monuments, sites of important events and other significant locations are often restored or preserved with the former character of the place as the model. Both ecological and cultural value is often implicit and as a network component its value could be enhanced by its connection to other elements within a system.

Land Use Buffers and Markers - Separation of incompatible land uses is a frequent use of open space patches and corridors. They also help delineate property boundaries, changes in use or other cultural phenomena. This is quite common in agricultural areas and is occasionally found in urban areas.

A number of other functions could be identified, but these are some of the most relevant in Arizona. All of these functions or uses would likely not occur throughout the system. There may be several compatible functions with varying levels of priority in certain segments. However, some places may be critical and single functions may predominate.

3.3 Planning Method

The following planning method is described to illustrate how the concept of ecological networks may be integrated into the urban planning process. An example from the Phoenix, Arizona urban area demonstrates how incorporating ecological determinants meshed with political realities can improved the prospect of maintaining or restoring healthy ecosystems.

3.3.1 Study Area Delineation

Frequently, planning studies commence with no discussion of the extent of the area to be examined beyond the immediate rationale of political jurisdictions. The most difficult problem relating to study area delineation is that natural and political boundaries do not generally coincide. There are many examples of political boundaries having been drawn as a result of natural determinants, but usually these are only partially coincidental with specific objectives of an ecologically oriented planning process. From an ecological perspective issues of extent and grain of study are essential and should be explicit. Numerous ecologists also suggest that ecological problems should be studied at more that one scale, incorporating notions from hierarchy theory (Pattee 1973, O'Neil et al. 1986).

The main objectives of this approach to study area definition are to ensure that the minimum area of study includes the entire political jurisdiction necessary for examination. Study area boundaries are extended sufficiently beyond the political jurisdiction so that supporting natural systems (structure) and external influencing factors are included. The study area must also be large enough to ensure that external influences do not significantly reduce the capability of the network to function. It is also important to recognize that once the boundaries of the study area are determined, that they allow for external connections. Consequently, the boundaries are not hard but permeable.

Employing Forman and Godron's (1986) definition of a landscape as the smallest possible unit of study is the frame upon which the study area delineation is built. They define a landscape as "a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout. Landscapes vary in size down to a few kilometers in diameter." They note that landscapes are formed "from three mechanisms operating within a landscapes boundary: specific geomorphologic processes taking place over a long time, colonization patterns of organisms and local disturbances of individual ecosystems over a shorter time" (page 11).

The Phoenix area is comprised of more than twenty separate municipalities and three Native American reservations, mixed with unincorporated land from Maricopa and Pinal Counties. An examination of the Phoenix area would require inclusion of all these municipalities and some of the surrounding unincorporated areas. (Figures 3.1 and 3.2).

Geomorphologically, there are two distinct formations in the area of Phoenix. The urbanized area largely exists on the lower Sonoran Desert floor. An alluvial basin is surrounded by igneous mountains, with some outcroppings of igneous material occurring within the valley floor. To the north and east the rugged topography of mountains forms a clear boundary between two landscape types. To the south and east, however, definition is less clear. Distinctions can be made through examination of colonization patterns and disturbance regimes. The dominant distinguishing characteristics in this case are the impacts of human colonization and disturbance. Based on Forman and Godron's description of landscapes these areas can be distinguished as agricultural, urbanization and uncultivated desert landscape types (Figure 3.3). Aggregation of the distinguished landscape types to encompass the project or study area can then be accomplished.

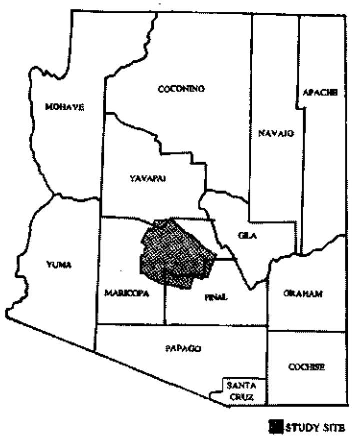

Figure 3.1 *Study area location in Arizona*

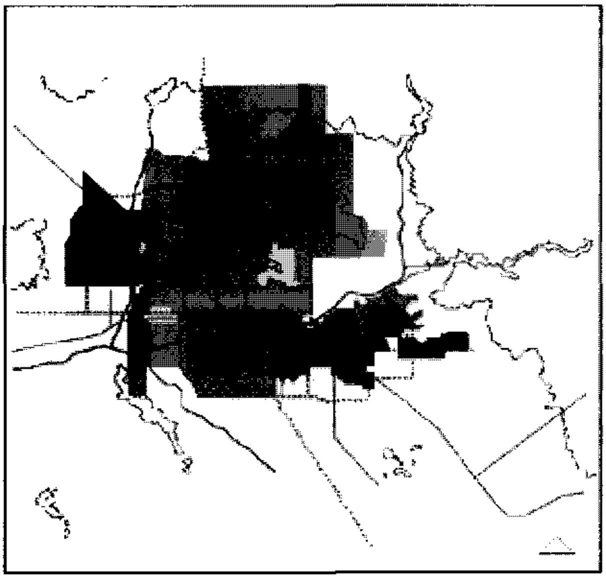

Figure 3.2 Municipal jurisdictions in Phoenix urban area

Additionally, realistic limitations such as availability of data, expertise of staff and resources may also affect the final delineation of a study area, as with any planning project.

3.3.2 Examination of Regional Context

Study area boundaries have been previously described as permeable because it is necessary to understand how supporting external systems are related to elements within the study area. Within hierarchy theory, it is also important to understand the role that elements within the study area may have as stepping stones, connections or linkages for core or source areas beyond. Consequently, an examination of the regional context is important. Young and Steiner (1983) have explored the concept of regional context and provide some direction in understanding the interrelationships. Essentially there are three main ways of examining regional contextual factors; watershed dynamics, species diversity (incorporating metapopulation and community approaches) and political management units. The examination of the regional context can be limited to key relationships that may have some bearing on future planning within the study area.

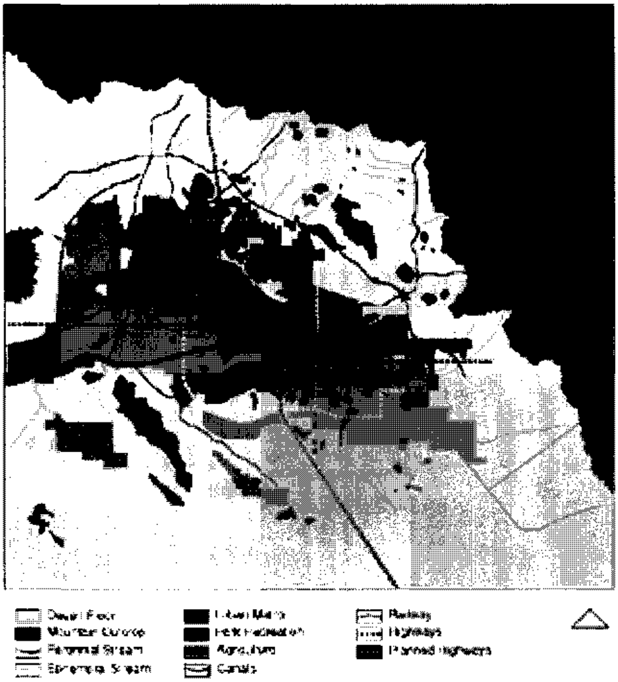

Figure 3.3 *Regional ecology of Phoenix urban area*

A cursory watershed analysis identifies relationships between elements within the study area to the larger system. In addition to the hydrologic dynamics that are important to understand, riparian areas are often the most rich and diverse biologically. Species distribution in the regional context has two important dimensions, species richness and diversity and species of particular interest (either target species or rare or endangered species). Data about fauna is often unavailable, so use of vegetation analysis may be necessary as a indicator of habitat quality and quantity. Metapopulation studies, if available, are useful at this scale as a more definitive indication of the roles of specific patches or corridors in supporting certain species.

3.3.3 Landscape Change and Ecological History

Examination of landscape change and ecological history provides information about previous functioning of ecosystems. Re-establishing previously existing connections or ecosystems (patches and corridors) is a useful way to improve the possible successful rehabilitation of degraded ecosystems. Although it is generally not feasible to attempt to return a degraded ecosystem to some previously existing state at anything other than site-scale, understanding the previous landscape structure and its evolution will be useful in making planning and management decisions and adapting to future landscape dynamics.

Historical maps, aerial photographs and other forms of documentation are necessary to understand the earlier ecosystem structure and function. In the Phoenix area, historical information from two periods was used to document landscape change and ecological history. First, historical settlement and agricultural patterns were mapped throughout the Salt River valley. These show canals and villages of Hohokam Native American settlements to about 1400 a.d. The extensive canal system utilized water from the Salt River for the irrigation of agriculture which is thought to have occupied most of the valley floor. The best documentation of landscape change and more recent ecological history is also in maps from earlier periods of early European settlement in the 1850's. Figure 3.4 illustrates the Hohokam settlements.

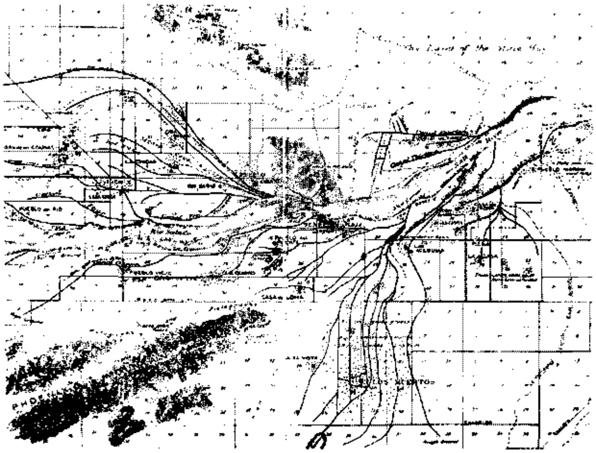

Figure 3.4 *Hohokam Indian settlements and canals (after Fifield et al. 1990)*

Recent history is best documented through aerial photographs which provide a clear image of land cover types. Figures 3.5 - 3.8 illustrate the extent of landscape change using time-series analysis in 20 year increments from 1932-1992. An examination of major elements such as rivers, large outcroppings or other major landforms over time reveals the strongest potential structural elements of a system. In some cases, certain elements have been utilized for various economic purposes and then reverted to a unutilized state. This reoccurring remnants of natural systems can be referred to as the deep structure, meaning that forces of nature acting in these elements or systems are stronger or more persistent over time than human intervention. The prospect is that they will likely continue to revert, so human-dominated activity is expensive to maintain and sometimes hazardous. A logical proposition is to recognize the characteristics of these elements and incorporate them as a part of an ecological network, rather than continuing to battle the forces of nature to dominate.

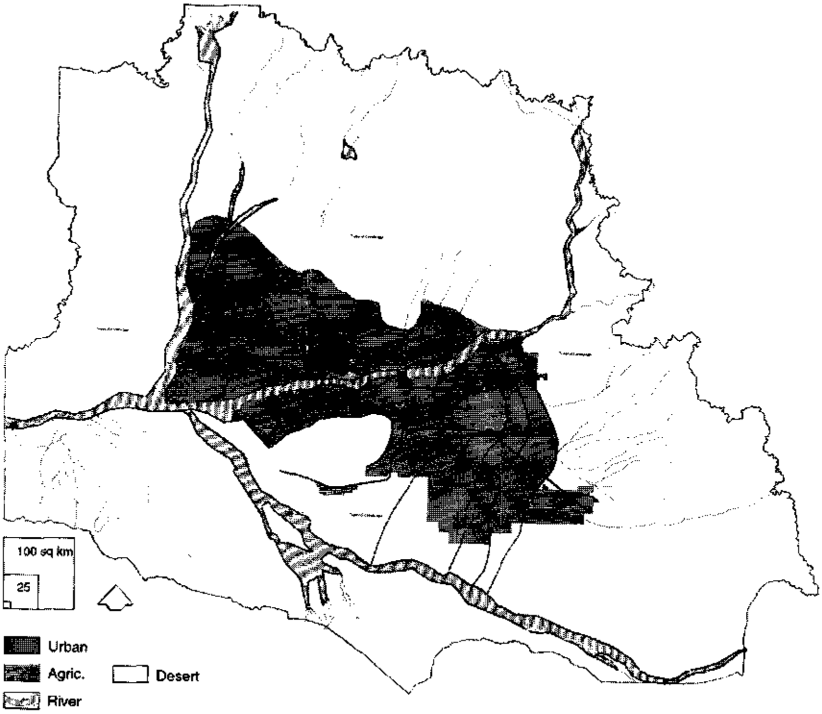

Figure 3.5 *Phoenix area landscape - 1932*

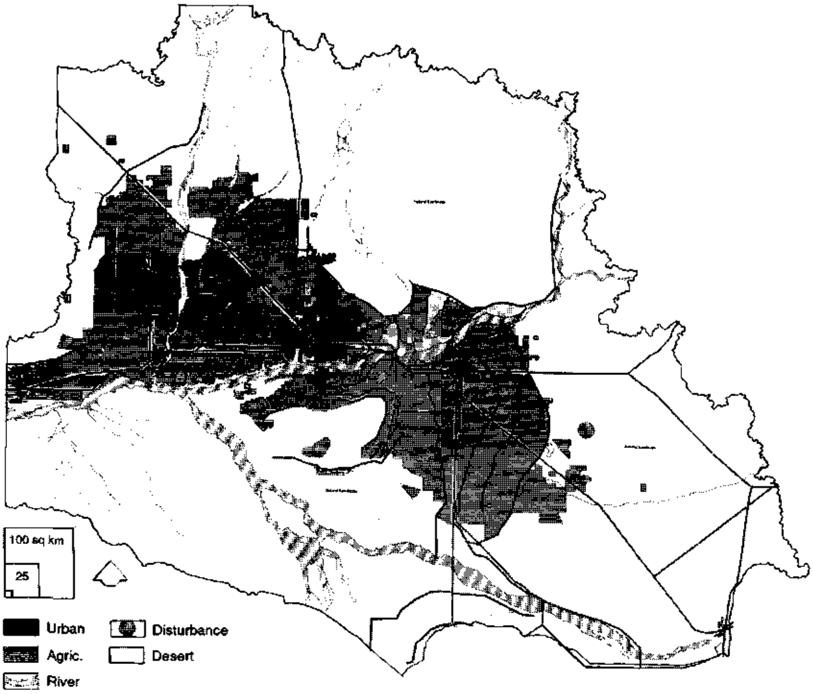

Figure 3.6 *Phoenix area landscape - 1952*

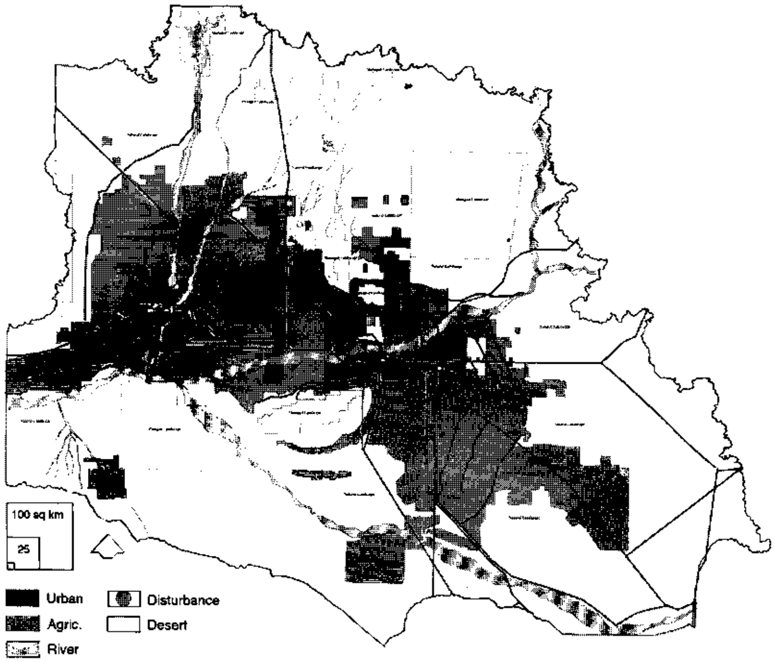

Figure 3.7 *Phoenix area landscape - 1972*

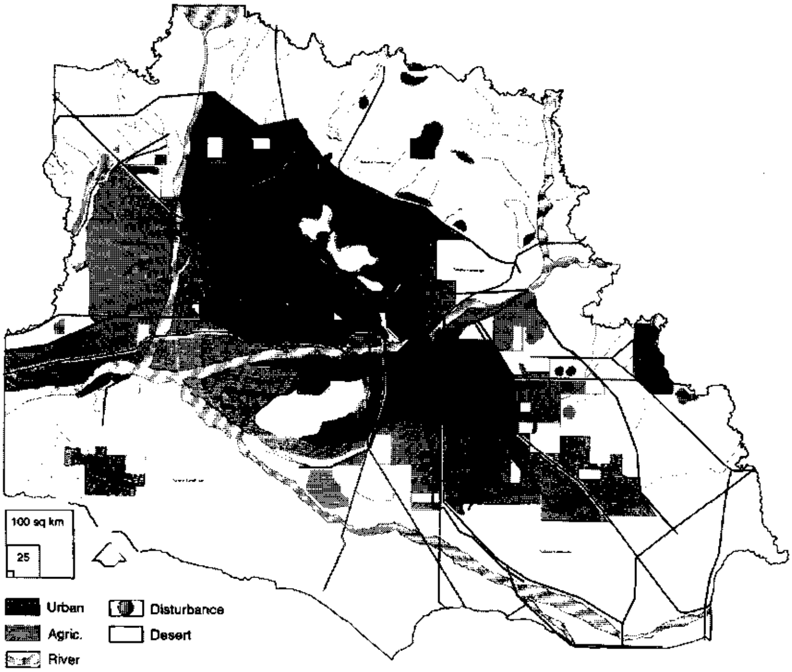

Figure 3.8 *Phoenix area landscape - 1992*

3.3.4 Systems Inventory and Assessment

A systems approach necessitates inventory and classification of landscape elements consistent with the systems being studied. At landscape scale and for the purpose of establishing a planning framework for an ecological network, selective mapping of elements of regional or landscape-scale significance is consistent with the hierarchy in ecological terms, but also when determining relevance within the socio-political context of a metropolitan area. Selective mapping (Sukopp and Weiler 1988) employs a strategy of inventory and classification of elements deemed to have inherent value within the framework of the analysis at hand. At landscape scale, comprehensive mapping (inventory and classification of all landscape elements) would require extensive resources, yielding marginal benefits. The resources required to conduct a comprehensive inventory and classification are best preserved and utilized at the community-level. Therefore, an inventory of patches and corridors that have landscape-level significance provides the basis for a primary structure plan.

In the example using the Phoenix urban area, three main system types are used in this process (hydrology, habitat, cultural) and have different bases from which they are studied and classified. Consequently, they are examined within their own scientific framework and then assessed using criteria that will yield useful results for determining their value as an ecological network component. This ensures that the integrity of the system independently so that individual management priorities are explicit and can be fully integrated into any multiple-use plan. The types of systems utilized in this process may vary according to specific needs and priorities within each planning situation. Effectiveness of the plan will be largely dependent upon proper recognition of specific problems of the study area.

The hydrologic system is examined first since it often provides the basic frame for ecological network planning and also often has value from a habitat and recreational/cultural perspective (Toth 1990, Van Buuren 1991). A range of hydrologic elements exist within the study area and can be broadly organized in to two groups, predominantly natural or cultural. Natural elements include such things as river and stream corridors, lakes, and groundwater recharge or discharge zones. Cultural elements include canals, constructed lakes and reservoirs, significantly reconfigured drainage corridors and others. Figure 3.9 shows the various hydrologic elements in the study area.

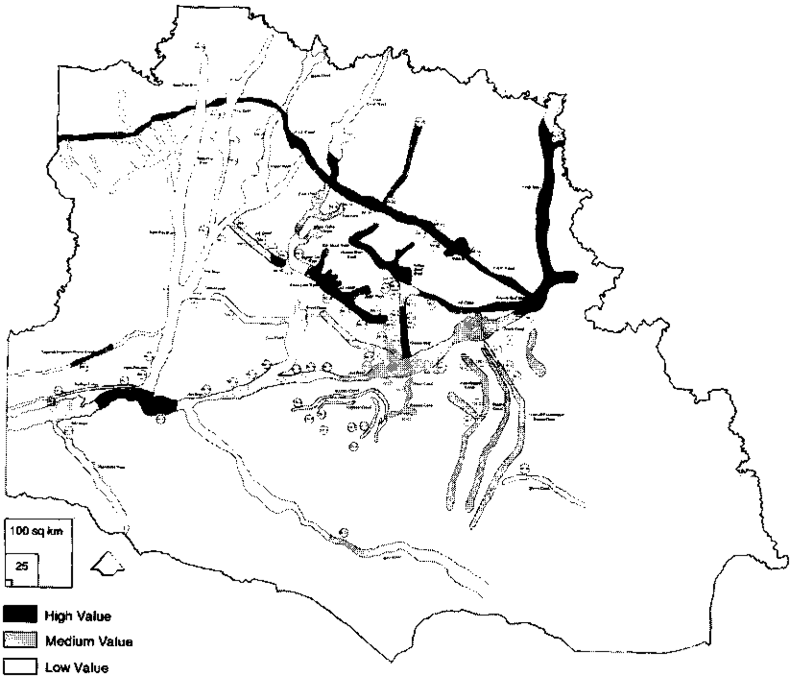

Figure 3.9 *Hydrologic elements of Phoenix urban area*

The process used for inventory and assessment of the habitat system is a modified gap analysis method (Scott et al. 1992) as is now being employed in the U.S. to assess biological diversity in several regions. Elements of the habitat system are grouped into three main classifications; source areas, patches and corridors (or linkages) and data are gathered for each element. Although we know organisms will use the surrounding matrix in varying degrees, the focus on source areas, patches and corridors (selective mapping) is intended to demonstrate the importance of the critical systems that may be threatened or deteriorating. Consequently, the intention, at this scale, is to focus on areas with the greatest existing or potential diversity or on areas that are necessary to maintain the supporting structure within the landscape, so that critical areas are not weakened. External influences (human disturbance or activity levels, ephemeral and longer-term barriers, adjacent filters and buffers) are incorporated in to the assessment as factors that may enhance or hinder the ability of a network component to function as a part of the habitat system.

In the Phoenix study area a habitat system or network relies upon interrelationships between source areas, patches and corridors. Source areas feed the network with diverse plant and animal species. The species migrate through corridors or across the matrix, between source areas and interior patches. Organisms, genes and energy flow in and around this system in many directions and are important to sustain the ecosystems. Source areas are the largest in size and most biologically diverse yielding greater carrying capacities for ecosystem functions. Human disturbance in source areas is generally low, consequently, interference or resistance factors are not as significant and yield fewer negatively acting phenomena such as edge effect. A hierarchy can be established within source areas relating to inherent biological qualities, but also relating to size and proximity to other source areas and/or patches and corridors.

In an urban/suburban landscape matrix corridors are vital components that connect "islands of greater diversity" and facilitate exchange and movement. Isolation has been proven to be a significant factor in extinction of species (Soulé 1991). Many characteristics determine a corridor's effectiveness as a network component and hospitable habitat conditions for one species of organisms may inhospitable for others. We do know, however, that certain characteristics generally improve conditions for many species humans consider desirable. Factors such as corridor width, distance between patches, intensity of activity or use in surrounding matrix, content, absence or presence of barriers, filters or buffers affect the usefulness as a network component. In addition to existing corridors or links that are readily identified, synthetic or restored corridors can supplement. Synthetic corridors (Forman and Godron 1986) are linear elements already existing in the landscape, but have limited current value as habitat. Canals, road rights-of-way, utility corridors, and other elements can provide secondary links if managed sympathetically to habitat values. Restored corridors are those that existed previously and could be reclaimed.

Patches are remnants of open space, some predominantly natural and others predominantly cultivated left within the urban/suburban matrix. They are largely dependent on links to outlying source areas and other patches to function within the habitat system. As with corridors, different types of patches have varying levels of importance for habitat purposes. The highest valued patches are those that are larger in size, retain a significant amount of native vegetation and are well linked to other patches and source areas. It is also possible to establish and utilize synthetic (introduced) or restored patches within the framework of a habitat system.

Diversity between types of source areas, corridors and patches is also important to distinguish. Determination can be made primarily on vegetative consistency. In the case of the Phoenix study area four broad distinctions are made based on field investigation and review of aerial photographs. First, the native Sonoran (including upper and lower) occupies the desert floor (lower) and dry uplands consisting of sandy soils and exposed granite outcroppings. Harsh temperatures, low rainfall and poor soils limit the abundance and diversity of vegetation. However, uniqueness and rarity of species found here is significant (Table 3.1). Second, cultivated areas are those that have been significantly modified to accommodate human interests and are now dominated by exotic species. This may include agriculture, residential and commercial areas, and some parks, golf courses and cemeteries. Soils are varied and rainfall is often supplemented by automated irrigation practices. Domesticated animals and other exotic (sometimes referred to as weedy) animal species that are well adapted tend to dominate (Table 3.2). Third, regenerated areas have been disturbed or cultivated and then have been allowed to return to a more natural state. These are often different in character than the original condition, but generally have more value for native species than cultivated area. Over time they evolve to increasingly complex and diverse communities (Table 3.3). Fourth, riparian and aquatic areas are some of the most important zones within this region. Over 85% of the desert's wildlife species rely upon these areas for some critical function. Few of these areas have permanently flowing water, but the vegetation is significantly more lush and dense (Table 3.4).

Table 3.1 *Sonoran vegetative community*

Upper Sonoran Plants:	
Ambrosia sp.	bursage
Atriplex sp.	saltbush
Carnegea gigantea	saguaro
Cercidium microphyllum	foothills palo verde
Encelia farinosa	brittle bush
Ferrocactus acanthodes	barrel cactus
Fouquieria splendens	ocotillo
Olneya tesota	desert ironwood
Opuntia sp.	prickly pear
Opuntia sp.	buckhorn cholla
Opuntia bigelovii	teddybear cholla

Prosopis sp.	mesquite
Simmondsia chinensis	jojoba

Lower Sonoran Plants:

Ambrosia sp.	bursage
Baccharis sarothriodes	desert broom
Cephalcereus senilis	hedgehog cactus
Cercidium floridum	blue palo verde
Cercidium microphyllum	foothills palo verde
Encelia farinosa	brittle bush
Larrea tridentata	creosote bush
Olneya tesota	desert ironwood

Table 3.2 *Cultivated vegetative community*

Plants:

Bougainvillea sp.	bougainvillea
Brachychiton populneus	bottle tree
Cupressus sempervirens	Italian cypress
Cynodon dactylon	bermuda grass
Hedra canarensis	algerian ivy
Hibiscus sp.	hibiscus
Pinus sp.	allepo pine
Rosa sp.	garden rose
Ulmus parvifolia	Chinese elm
Washingtonia ap.	Fan palm

Table 3.3 *Regenerated vegetative community*

Plants:

Atriplex sp.	saltbush
Baccharis sarothriodes	desert broom
Typhia sp.	cat tails

Table 3.4 *Riparian and aquatic vegetative community*

Plants:

Baccharis glutinosa	seep willow
Hymenoclea monogyra	burro brush
Paspalum distichum	knot grass
Populus fremontii	cottonwood
Prosopis sp.	mesquite
Rorippa nasturtium aquaricum	watercress
Salix gooddinggii	Arizona willow
Tamarix chinensis	salt cedar
Typha sp.	cat tails

In addition to biological characteristics, anthropogenic factors have an impact on source areas, corridors or patches as habitat system components. The urban/suburban context necessitates analysis of several socio-economic factors to determine the viability of any proposal for use of land as habitat. Four factors serve as a final sieve once biological determinants are understood. In the U.S., land ownership represents is an important factor determining how land is utilized and managed. With few exceptions (land purchased by conservation organizations represents the primary exception), management practices on privately held land are less predictable and may be unsympathetic with habitat system objectives. In the same vane, land with high real estate values is vulnerable to intensive uses, also not conducive to habitat system objectives. High land values also make acquisition (an option with private ownership) more difficult. Deteriorated natural values present the third potential factor in the sieve. Often restoring a healthy functioning ecosystem takes long periods of time and major investment. The final factor has to do with the relative importance of a network component to the system. In some cases, certain critical links or patches are required in order to support a viable existing patch so that isolation effect (Soulé 1991) does not cause deterioration over time. Relative importance can be determined by examining scenarios for network formulation using alternative patch and corridor relationship studies (Forman 1995). The result of this analysis yields the primary elements to be included in a habitat network at landscape scale. Figure 3.10 illustrates habitat system elements.

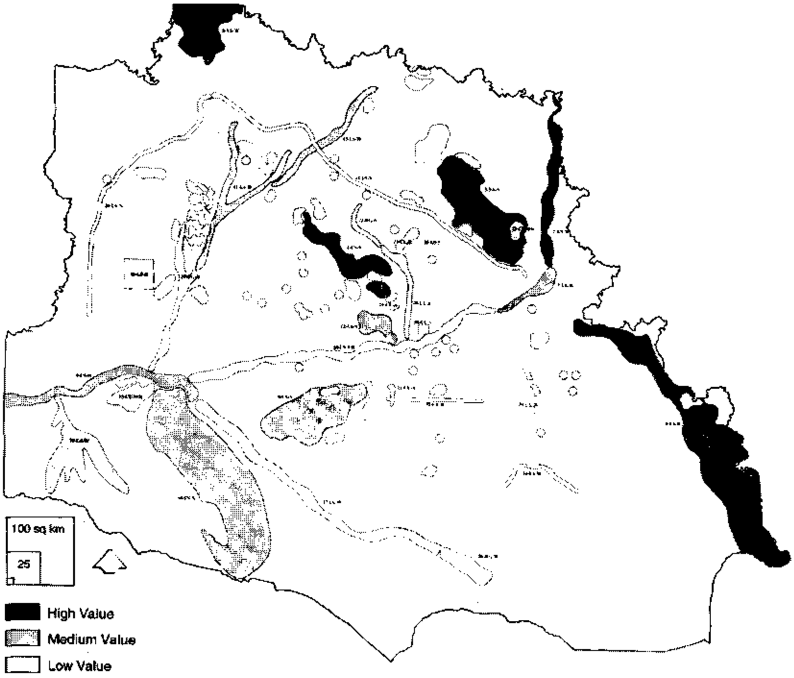

Figure 3.10 *Habitat elements of Phoenix urban area*

Cultural systems are assessed using aspects of several methods of landscape interpretation. The cultural characteristics provide additional economic and social justification for preservation of sites in that they give identity, purpose and value. Dietvorst and van Bolhuis (1994) note that relationships between cultural/recreational activities and ecological values are strong and as such can be planned for in an integrated manner. Lynch (1960) provides a basic theoretical structure for understanding physical characteristics of a city that have meaning to inhabitants. The five elements; landmarks, nodes, paths, edges and districts can be reinterpreted for inclusion in ecological network planning. Landmarks, nodes, paths and edges are often manifested in cities in the form of open spaces, either passed over by development because of physical constraints to development or preserved because of the cultural significance of the element.

Historical values are often imbedded within Lynch's theoretical structure, but historical sites are also assessed explicitly because not all historical sites fit Lynch's framework. Recreational areas (both passive and active) were also assessed as locations of cultural importance that may have potential as network components.

The range of cultural/recreational values assessed are not distinguished by cultural (including historical) and recreational relevance. Some factors are related to both dimensions while others are not. The following factors were assessed to determine relative value of various sites for the cultural/recreational system.

a) time in existence

b) educational and research value

c) spiritual or emotional relevance

d) archeological/historical value

e) landmark, monument or artifact

f) border, edge, boundary or seam

g) scale, size or level of significance

h) recreational activity level or uniqueness of opportunity

The analysis of the cultural elements on the Phoenix study area demonstrated that the range of types of elements is varied and the relationships between certain elements is strong, while others are not. Extraction of the essential functions or meanings enabled the definition of clusters of sites related by proximity or functional affinity, corridors that link various elements, mountains and other landforms that create boundaries and define space and regional links between spatially segregated areas or clusters. As the number of sites increases in a particular cluster, so does the value of the cluster as a system component. The clusters are useful as the primary elements of an interconnected system. Corridors that link various elements are often manifest as drainage corridors or linear parks that have inherent recreational value. Often they function as a boundary or edge that is discernible by area residents and can be an important contributing factor in establishing district or community identity. Mountains and other significant landforms are historical and contemporary landmarks that exude strong characteristics of regional identity. They define spaces and hold significant value in the cultural heritage of this valley. Most are set aside as mountain preserve areas as a result of considerable community expression of interest to save these features. Several regional links exist in the form of major river corridors that exist in varying states of suitability for cultural functions. While all have immense potential to provide significant cultural/recreational benefits, significant improvements are required to turn back decades of mistreatment and neglect. In their current state, even the worst cases are important artifacts and hold significant historical and cultural value. Figure 3.11 illustrates the various components of the cultural system.

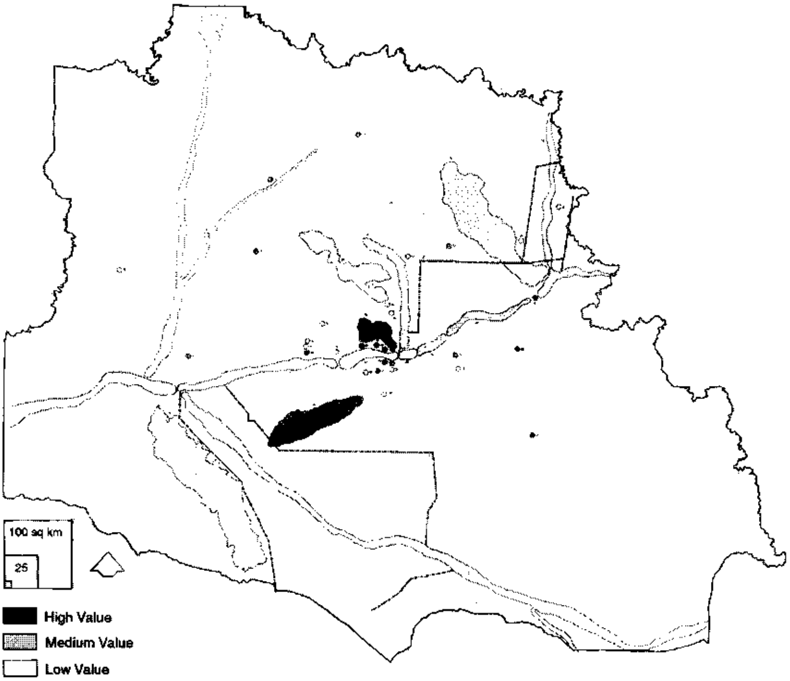

Figure 3.11 *Cultural elements of Phoenix urban area*

3.3.5 Systems Integration and Hierarchy

The three independently developed system plans are intended to demonstrate the integrity of each system for specific purposes and to establish an internal hierarchy from each system's perspective. Determining compatibility and establishing system priorities or rankings is the purpose of plan integration. In areas where two or more of the systems overlap, degree of compatibility must be assessed and priorities for use must be determined using criteria from the independent network development phase. In some cases, secondary systems (or alternates) are employed to eliminate incompatible relationships between systems (such as certain types of recreational activity and sensitive habitat). This process utilizes the information gathered in the independent system inventory phase, but also requires evaluation and judgement as is typically employed in the urban planning process. Therefore, each site or network component (as identified within the three system plans) is evaluated for the alternative system use potential. For example, if a site was identified as part of the hydrologic system plan, but not for habitat or cultural/recreational, it should then be assessed for its value as a component in the other systems. Hence, all sites are now assessed for the degree of utilization of network components for specific purposes.

For the purposes of this study, three teams of landscape architecture students (hydrology, habitat and cultural) conducted the field assessments and mapping of individual system components. Field inventory and evaluation sheets were patterned after Sukkop and Weiler's (1988) selective mapping method, but adapted for the specific needs of this study. The teams compiled and aggregated data and evaluated relative value of each component based on functions or activities articulated by various agencies normally responsible for management of these individual systems (i.e. hydrology - Maricopa County Flood Control, habitat - Arizona Department of Fish and Game, Cultural - City Parks, Recreation and Library Departments). The aggregation of scores for individual sites yielded an overall preliminary total value as a network component. The aggregation process is patterned after McHarg's (1969) ecological planning overlay method, sometimes referred to as multiple criteria analysis.

Table 3.5 lists all sites and indicates a preliminary assessed value by system type and also provides an overall preliminary score for aggregate value for all systems. Figure 3.12 shows the aggregation of the systems mapped as a comprehensive network.

Table 3.5 *Aggregate Site Elements - Patches*

No./Name	Area (ha.)	Hyd. Value	Habitat Value	Cult. Value	Agg. Value
PN1- A Mtn	52	5	3.3	2.7	11.5
PN2-Camelbk	369	4.1	1.7	1.9	7.7
PN3-EstrMP	11468	5	2.3	2.2	9.5
PN4-FtMcDIR	9830	5	5	4	14
PN5-GilaIR	75336	2.1	1.8	2.7	6.6
PN6-Hedgpth	698	3.7	2.2	2.5	8.4
PN7-Hedgpth2	752	3.7	2.2	2.5	8.4
PN8-LkPlsnt	6420	1.5	1.5	1.5	4.5
PN9-McDPk	15155	3.4	1.5	2.2	7.1
PN10-PapPk	947	2.8	3.3	1.3	7.4
PN11-PhxMt	3146	3.9	1.7	1.6	7.3
PN12-SRIR	17674	3	5	4	12
PN13-SanTan	3809	3.7	1.8	2.2	6.7
PN14-SthMtn	9093	4.2	1.7	1.1	7
PN15-McDPr	3537	3.4	1.5	1.5	4.4
PN16-Usery	2816	4	1.6	1.9	7.5
PN17-Wstcrt	35	4.8	3.3	3.9	12
PC1-ASUCamp	93	5	2.8	2.8	10.6
PC2-ASUWest	128	5	3.8	4.1	12.9
PC3-BosnPk	58	3.7	3.4	3.5	13.6
PC4-CircKPk	15	5	3.3	4	12.3
PC5-EncanPk	83	3.2	2.8	3	9
PC6-EstrGC	43	4.4	2.5	4	10.9
PC7-SanMaGC	74	4.1	5	4	13.1
PC8-FreesPk	26	4.9	3.3	4	12.2
PC9-GaineyRc	158	4.2	4.5	4.1	12.8
PC10-HohokP	53	3.9	3.3	3.1	10.3
PC11-KiwanP	48	5	2.4	2.6	10
PC12-PionPk	18	4.1	4.5	4.5	13.1
PC13-PlazPk	45	4.1	4.5	4.5	13.1
PC14-Pueblo	59	5	3.3	4	12.3
PC15-RiverP	83	4.1	5	4.1	13.2
PC16-Tovrea	19	4.3	3	3.7	12
PC18-AdobeD	629	1.5	2	2	5.5

Table 3.6 *Aggregate Site Elements - Corridors*

No./Name	Length (m)	Ave. Width(m)	Hyd. Value	Hab. Value	Cult. Value	Agg. Value
CN1-AguaFria	57,950.00	790	3.4	3.3	2.7	9.4
CN2-CaveCrk	37,100.00	200	2.6	1.9	4.3	8.8
CN3-GilaRivr	90,146.00	1500	2.1	1.8	2.6	6.5
CN4-GranRf	9,500.00	800	1	2.5	4	7.5
CN5-NewRiv	45,100.00	680	2.7	2.3	4.5	9.5
CN6-QueenCr	35,400.00	75	4	1.9	4	9.9
CN7-SaltRivr	52,300.00	400	2.7	3.5	3.1	9.3
CN8-VerdeRv	27,000.00	1500	1	1	2.5	4.5
CN9-WtrmnW	17,700.00	75	3	2.3	4	9.3
CN10-Shea1	12,800.00	60	1	2.3	3.3	6.6
CN11-Shea2	8,000.00	60	1	2.3	3.3	6.6
CN12-Shea3	6,500.00	60	1	2.3	3.3	6.6
CN13-Shea4	6,000.00	60	1	2.3	3.3	6.6
CN14-SkunkC	48,300.00	200	3.1	2.3	3.3	8.7
CN15-IdBndN	14,500.00	80	1.2	2.5	2.6	6.3
CC1-AzCanal	51,500.00	50	2.3	4.7	3.8	10.8
CC2-AzCrCut	5,800.00	50	3.5	4.7	4.2	12.4
CC3-BckeyeC	22,500.00	50	2.8	4.6	4	11.4
CC4-CAPCan	85,500.00	50	1	5	4.8	10.8
CC5-ConsCan	37,000.00	50	2.8	4.7	4.6	12.1
CC6-CrCtCan	3,850.00	50	2.5	4.8	4.5	11.8
CC7-EMarFl	35,400.00	50	3	3.3	4.5	10.8
CC8-EastCan	32,400.00	50	1.7	4.5	4.8	11
CC9-GrndCan	35,800.00	50	2.5	4.6	4.6	11.7
CC10-IndBdS	20,000.00	500	3.1	2.9	2.5	8.5
CC11-KyrCan	22,500.00	50	1.9	4.6	4.5	11
CC12-OldVrd	19,300.00	50	4.8	3.5	3.7	12
CC13-RsvltCa	25,700.00	50	1.9	4.6	4.6	11.1
CC14-SBrHig	16,100.00	50	3	5	4.6	12.6
CC15-TmpCa	15,200.00	50	2	4.5	4.6	11.1
CC16-WstrnC	15,000.00	50	2.5	4.3	4.5	11.3
CC17-ThnPas	9,500.00	65	4	2.3	2.5	9.6

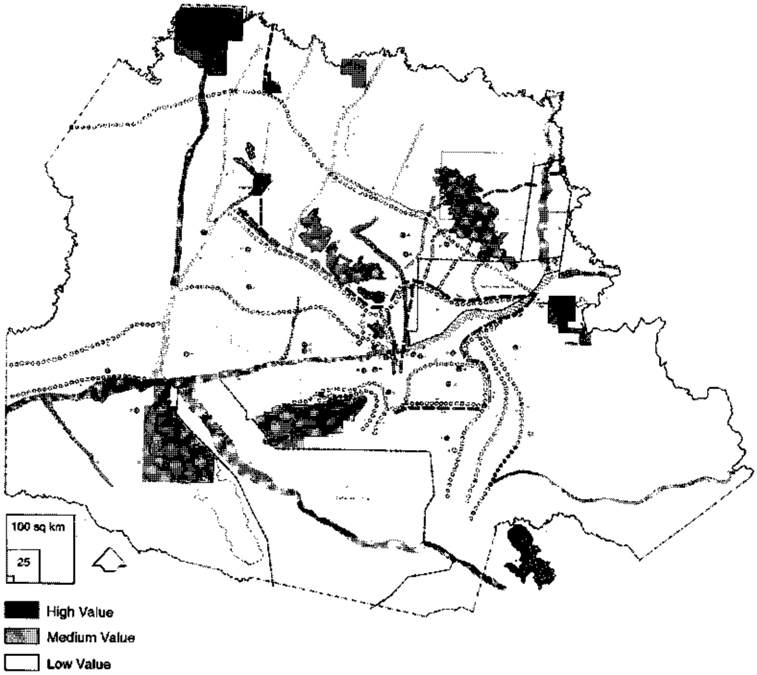

Figure 3.12 *Aggregated site elements map*

3.4 Discussion

The objective in formulating the spatial structure of an ecological network is to develop a comprehensive system of patches and corridors with proposed functions identified and prioritized for each of the network components. This requires working at several scales, starting with landscape scale to establish the primary structure. Although there are gaps in the system and gaps in knowledge and data, the primary structure represents a stable foundation upon which more detailed and perhaps ephemeral elements could be added.

The next detailed level addresses developing "sub-structure plans that are developed and managed on a community level. At this scale, elements that are included are often more heavily dominated by human functions. The core of the sub-structure may be a cluster of important patches and corridors. Elements such as boulevards, path systems, cultivated parks, etc. supplement the primary structure. Throughout, but particularly at the sub-structure level, network-to-context relationships influence the configuration and character of the network. Incompatible adjacent land uses may require additional buffers or filters. Elements of the substructure may also be ephemeral and dependent upon variable management strategies and budgets.

Planning and managing network components is the level of detail in which specific plans are made on a project basis to support the overall goals and functions of the ecological network. These pieces are transformed or preserved so that they may be useful parts of the network. Components that are significantly degraded may require restoration or even more aggressive redesign to accommodate other functions that may be incorporated to provide additional justification for budgetary purposes.

3.4 Summary

This chapter outlines a rationale and process for planning for urban ecological networks at landscape scale. The systems approach, by planning for the integrity of independent systems helps place these distinct perspectives on equal footing in the planning process and helps address specific management agency concerns. The aggregation of systems into a comprehensive network, yields combined benefits and increases the viability of all systems. The hierarchy also allows for planning and implementation to occur at all levels, engaging site management teams like individual park managers and municipal, county and even state level governments.

Over the long-term, urban ecological network plans require monitoring and re-evaluation. Since these are dynamic systems that are experiencing continual urban pressures, change must be built into the system. It is also not possible to create fool proof models that will predict how ecosystems will react to varying conditions. With continual monitoring it is possible to learn more about what has been successful and future plans can incorporate this new knowledge.

Chapter Four

Implementation at the Community Level

4.1 Introduction

Cities are often deficient in natural open spaces due to intense development pressures and heavy use patterns. The open spaces that do exist often consist of cultivated and/or exotic vegetation that offers limited natural values. Remnant natural areas that exist are often located at the perimeter of the city with impending development prospects. Or, if located within the urban landscape matrix they are overused and severed from supporting ecological structure that will facilitate regeneration. The result is a fragmented, ecologically dysfunctional system of open spaces that satisfy only a narrow range of human-oriented functions.

Hough (1995) provides a description of a spectrum of open spaces (Figure 4.1) most often found in cities and illustrates the relative ecological values associated with each. If a worthwhile goal is to establish increased levels of sustainability in our cities, then it follows that, where possible, open spaces should provide an ecological frame or network. This type of system can provide the supporting structure to keep open spaces ecologically viable. Using Hough's framework, it is possible to link different types of open spaces, with existing or potential ecological values to form an integrated network. Some open spaces, like natural parks, have existing ecological values and need mostly to be managed so that critical resources and functions are preserved and tied in to a larger system to facilitate exchange and regeneration opportunities. Other less natural open spaces, such as cultivated parks, provide greater ecological benefits by pursuing alternative management strategies like organic pest control, less frequent mowing of grassy areas and replacement of some exotic vegetation (in areas not requiring it for critical park functions) with native species.

Downtown Paved Spaces

⇩

Hard-surfaced Sports Facilities

⇩

Turf Sports Facilities

⇩

High Maintenance Parkland

⇩

Low Maintenance Parkland

⇩

Naturalizing Areas

⇩

Remnant Natural Areas

Figure 4.1 *Spectrum of urban open spaces (after Hough 1995)*

An ecological network, to be effective, needs to function at several levels or scales. The primary structure occurs at landscape (regional) scale and establishes a network of regionally significant source areas, patches and corridors that have long-term protection and provide the prospect of continued renewal and exchange (see Chapter 3). At the community-level (the focus of this chapter) smaller scale elements are incorporated in to the network consistent with the needs of municipal government planning and nature conservation strategies. Specific site-level (see Chapter 5) planning and management is the third level at which ecological networks are relevant. Individual sites are preserved, restored or transformed on an incremental basis to realize the potential of a comprehensive ecological network plan, the overall goal being to achieve some degree of ecological integrity throughout the network (Karr 1990).

Special problems exist with the implementation of ecological networks in urban landscapes. Some of the most significant can be explained by studying the concepts of content, context, connectivity and structure. Each of these deals with a different aspect of the consistency of and ecological network and must be satisfied for network effectiveness over time.

Content refers to the internal characteristics of the integral parts or components of an ecological network. Specifically, landscape attributes including vegetation, soils, hydrology and others are necessary for species to be supported and ecological processes to function. Although this occurs in varying degrees, the objective of supporting modest levels and reaching for maximum potential is important.

Context refers to the relationship of an ecological network with the surrounding matrix. Compatibility between land uses in the surrounding matrix and the network components allows ecological processes to function unimpeded. Organisms can also utilize a compatible surrounding matrix, essentially extending the effective size of the network. Incompatibility can be mitigated with buffer zones or filters, insulating the network from the full effect of negative impacts.

Connectivity is a function of physical connection (spatially) and suitability of content for organisms to utilize the landscape and facilitate migration. Relationships between content suitability and spatial connections are inversely correlated to a certain degree. Lower content value can be accommodated (to varied levels for different species) if the extent of connections is greater. The reciprocal is also true within bounds. Of course, the presence or absence of barriers is a significant and related factor.

Structure relates to the arrangement, size and shape of patches and corridors imbedded within the matrix. Although needs vary with species, there are accepted parameters (Forman 1995) for many species that guide decisions about arrangement and size of patches and corridors. However, since in the urban matrix patches and corridors are most often relegated to be remnants, it is difficult to exercise much flexibility dealing with the concept of structure. Often the best solutions available are extensivication of existing elements such as road rights-of-way, utility corridors, parks, and similar sites.

An exploration of the concepts of content, context, connectivity and structure is provided using a planning study for a community-scale ecological network for the city of Scottsdale, Arizona. Scottsdale represents a suitable case to study for several reasons. First, it is a low density city overall, but has variable densities throughout allowing for the study of different context relationships. Second, there are numerous potential ecological network components with diverse content, from cultivated and highly maintained to naturally regenerating following disturbance to predominantly natural. Third, a number of different types of linear elements exist (canals, linear parks, abandoned railway lines, etc.) that can be used to examine connectivity issues. Fourth, Scottsdale is a developing city and still has the potential to plan for and ecological framework in some areas using optimal configurations of patches and corridors. Fifth, a primary structure plan at the landscape-scale, encompassing Scottsdale, has been prepared providing the nesting frame for more detailed analysis in this study.

4.2 Scottsdale, Arizona

Scottsdale is one of approximately twenty cities that constitute the Phoenix metropolitan area. It has a population of over 170,000 which is about 7.5% of the Phoenix area's total population of 2.3 million. Land area in the city of Scottsdale is 480 square kilometers or 7% or the 7,300 square kilometers in the Phoenix area. Scottsdale is known for its tourism and actively promotes and image of a beautiful environment, warm climate and hospitable people. City officials and residents have made serious efforts to preserve distinctive natural features, such as the McDowell Mountains, and to manage open space within the city boundaries.

The physiographic region in which Scottsdale is situated is the basin and range province common to much of the southwestern United States. Scottsdale lies within a basin and the north end of the city extends in to foothills known as the McDowell Mountains. This area is part of the Sonoran desert which extends south in to Mexico and west across Arizona. Average rainfall is 180mm and average annual temperature is 23°C (minimum 14°C, maximum 29°C) with extremes as high as 49°C and as low as -4°C.

The predominate native vegetation is desert shrub with areas of upland Sonoran desert (bursage, saguaro, creosote, bush mesquite, palo verde). Within the city there is an array of exotic ornamental species. Riparian corridors (predominately xeric riparian) are also found in this area. Deep alluvium deposits are characteristic of the southern part of the city, while igneous outcroppings and more shallow soils are found in the north.

4.3 Landscape Analysis

The landscape analysis was based upon a comprehensive inventory and mapping approach (Sukkop and Weiler 1988). Data were collected and mapped relating to the following topics (Anderson et al. 1994).

a) land use

b) land ownership

c) transportation

d) urbanization

e) physiography

f) geology and soils

g) hydrology

h) landscape character/vegetation

i) special problem sites (i.e. groundwater contamination)

j) open space patches and corridors

These data provide a basis for understanding landscape relationships and is the foundation for further analysis for more detailed analysis of patches and corridors. Table 4.1 and Figure 4.2 provide additional information about patches and corridors by type in Scottsdale.

Table 4.1 *Patches and corridors in Scottsdale*

Type	Area (Sq. Km.)	Percent of Total Open Space	Percent of Total City Area
Canals	3.20	2	0.6
Cultivated Parks and Golf Courses	16.20	11	3.5
Linear Parks	1.58	1	0.3
Natural Preserve	104.67	66	21.1
Natural Parks	1.58	1	0.3
Vacant Lots	4.75	3	0.96
Washes	25.38	16	5.14

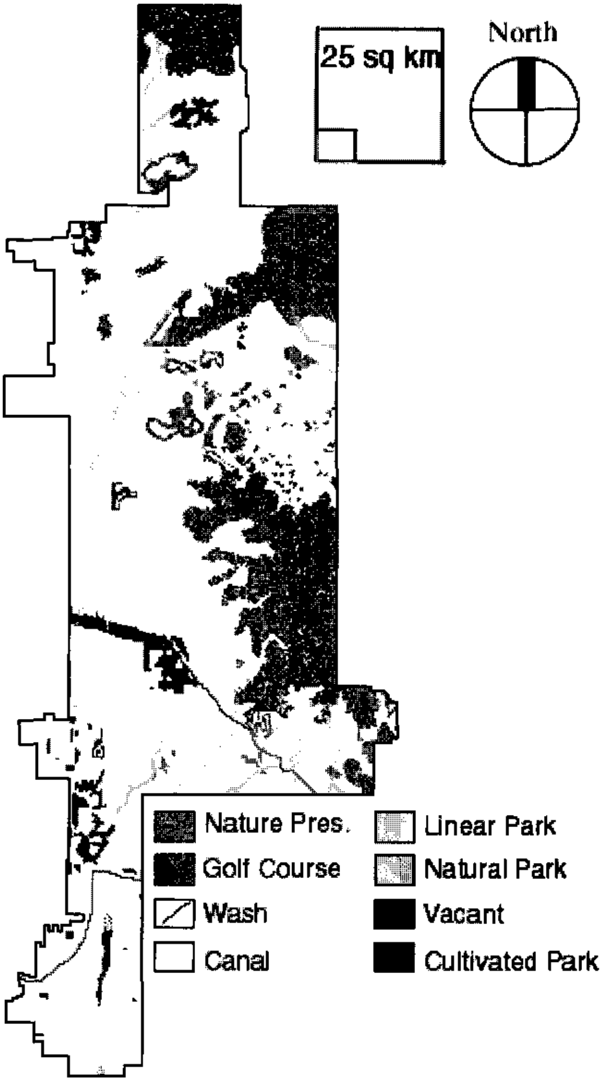

Figure 4.2 *Map of patches and corridors in Scottsdale*

Each of the patches and corridors were analyzed for its inherent characteristics against the eight variables that are described in the following text. The variables contribute to describe aspects of content, context, connectivity and structure. Components with better aggregate scores are deemed to make stronger contributions to ecological network functions individually and collectively.

Physical Diversity - Physical diversity is present with greater topographic variation, geologic structure and soils diversity, or the presence of other physical elements that bring variety. In an urban context human-created elements may also create diversity and are viewed positively.

Biological Diversity - Biological diversity refers to the actual numbers of living organisms in and area, but also to the richness and diversity of species. Greater diversity is considered positive. No qualitative assessment is given in this case (i.e. weighting native species higher than others), although that is often an important factor in wildlife management decisions.

Degree of Naturalness - This factor reflects the extent to which a site is undisturbed or has regenerated following disturbance. This favors native species providing a counter balance to high biological diversity resulting from exotic species.

Uniqueness or Rarity - Areas with uncommon biological or physical characteristics are regarded as important because of the value placed on rare, threatened, endangered or unique organisms or artifacts.

Connectivity - Connectivity simply related the degree to which a patch or corridor has contiguous links with other patches and corridors. Size of the component and number of links are considered.

Existence of Barriers - The presence of obstacles or other factors that impede movement of an organism is considered a barrier. Generally, barriers are considered undesirable, so their presence yields negative scores.

Remoteness or Isolation - This refers to separation from humans or human-induced activity. Areas that are more remote or isolated experience fewer human disturbances and are more conducive to the sustenance of ecological processes. Isolation as referred to in "isolation effect" (Soulé 1991) is addressed in the assessment for connectivity.

Modification Gradient - The modification gradient (Forman and Godron 1986) describes the surrounding matrix not the actual patch or corridor. Forman and Godron developed this concept to describe the level of modification of a landscape and as applied here the surrounding matrix. The five categories ranging from most to least modified are 1) urban, 2) suburban, 3) cultivated, 4) managed and 5) natural. In this case, the factor is used to assess the level of potential impact experienced as a result of compatibility level with adjacent land uses. Maps illustrating assessment of patches and corridors in relation to the eight variables are included in the appendix.

4.5 Composite Mapping Systems Analysis

The eight variables are also analyzed consistent with a systems approach to planning for ecological networks. The analysis examines scenarios for hydrologic, habitat and cultural systems. The variables are factors that indicate the value of individual components as a part of a distinct system. Some are not relevant and are excluded from the analysis. Table 4.2 illustrates how variables are weighted to adapt to specific functions of distinct systems. The column labeled composite value is used with all variables having equal value.

Table 4.2 *Weighting of map variables*

Variable	Hydrology	Habitat	Cultural	Composite
Barriers	3	3	1	1
Biodiversity	2	3	2	1
Connectivity	3	3	2	1
Remoteness	1	3	2	1
Modification Gradient	2	1	1	1
Naturalness	2	2	2	1
Physical Diversity	1	3	2	1
Rarity/Uniqueness	NA	NA	3	1

Figures 4.3 - 4.6 illustrate the results of these analyses. Variability of scenario results was very minor, indicating that the differences between system requirements using this planning approach are not significant. The conclusion that can be drawn from this is that the multiple purposes of hydrology, habitat and cultural/recreational systems can be well-served with a common network approach at the community level.

4.6 Scottsdale Ecological Network

With a base set of elements derived through the composite mapping process, a hierarchy is established based on attributes of system components. The hierarchy is composed of three levels; primary, secondary and tertiary, indicating relative importance to this community-level ecological network. Figure 4.7 illustrates the hierarchy in an ecological network for Scottsdale.

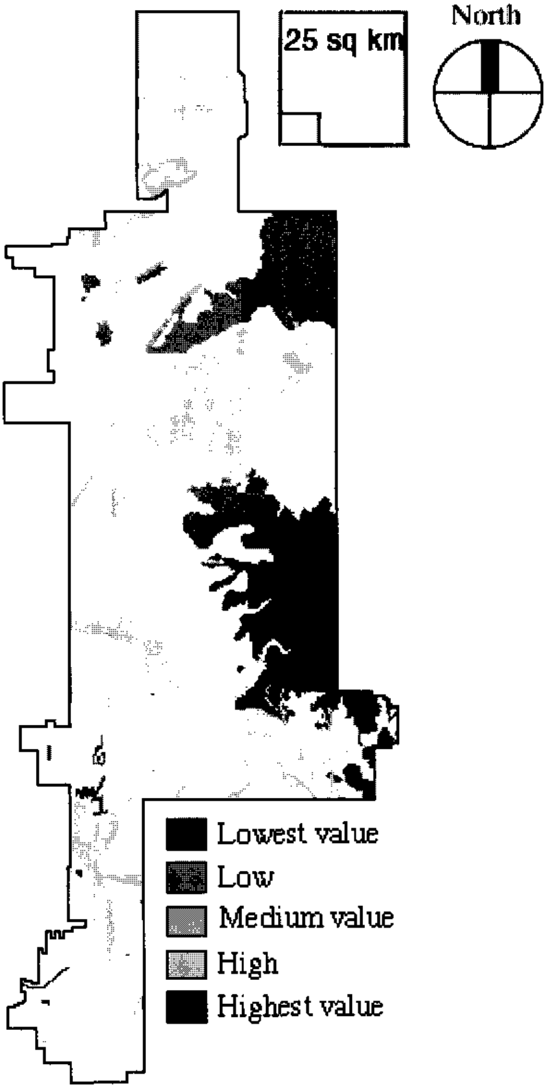

Figure 4.3 *Hydrologic Systems Map*

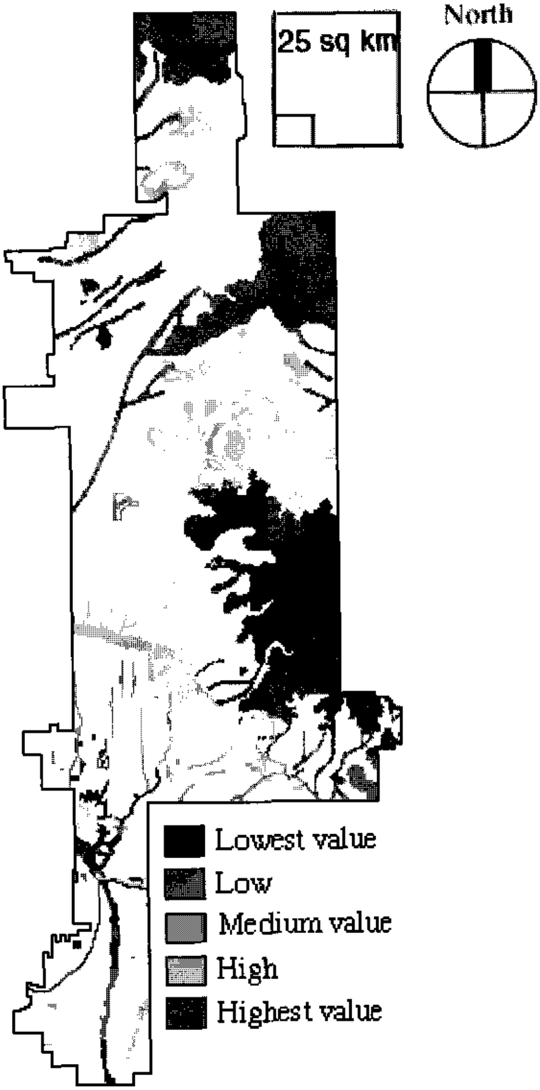

Figure 4.4 *Habitat Systems Map*

Figure 4.5 *Cultural Systems Map*

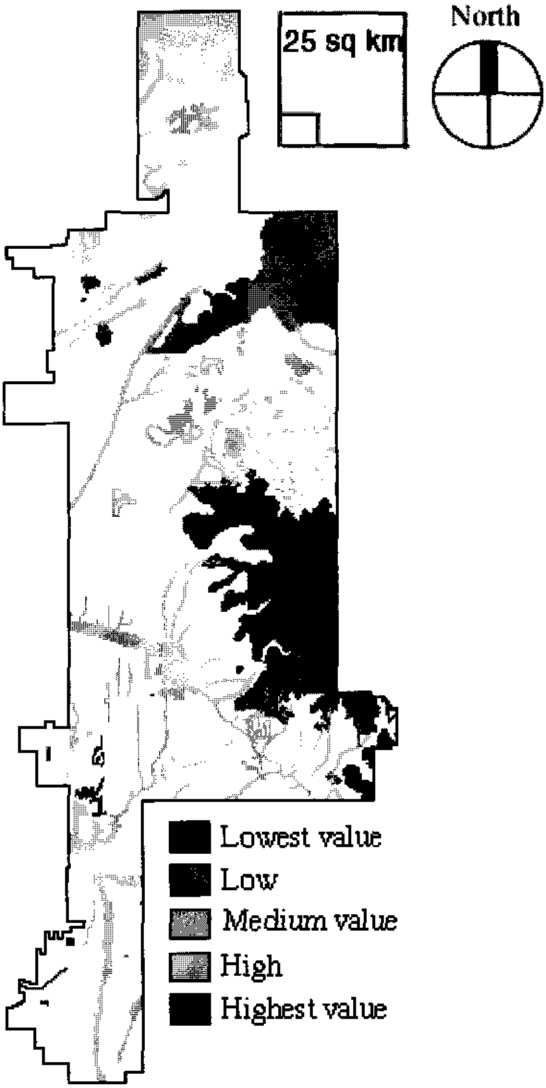

Figure 4.6 *Composite Map*

Primary Structure - The primary elements are most important and are of regional or landscape significance. They are the cornerstones derived from the primary structure of the landscape scale ecological network . They are larger and generally more biologically and physically diverse. An example of a primary element is the McDowell Mountain Preserve.

Secondary Structure - The secondary structure is comprised of elements significant at the community level. As such, components are smaller and less diverse. Higher levels of modification as a result of human intervention also affect the character of the elements. They may also be inconsistent with the native bio-physical characteristics, but do provide certain dimensions of ecological processes that are important. An example of a secondary element may be a modified drainage corridor or golf course.

Tertiary Structure - The tertiary structure consists of elements that are ecologically viable or site-specific basis and may be temporal in nature. Tertiary elements are often more heavily constrained because of some other primary use or sporadic change in function. Examples of tertiary elements are vacant lots, road rights-of-way, or utility corridors.

4.7 Summary

This analysis demonstrates that it is possible to improve the quality of nature at a community level by developing mechanisms to reinforce the variables of content, context, connectivity and structure. It has been shown that with modest, incremental improvement or constant preservation, ecological processes can be sustained. There are other variables that can be studied and a wide range of management options that can be explored to sustain and improved the characteristics that make ecological networks function.

Figure 4.7 *Hierarchy in Ecological Network*

Chapter Five

Urban Patches and Corridors

5.1 Introduction

Urban open space systems contribute to the quality of the urban environment in many ways. The range of open space types includes urban plazas to remnant natural open space or natural parks (Hough 1990). Each of these plays an important role in the dynamics of a urban landscape. However, urban open spaces which are valued for their natural qualities are in a precarious position. Research has demonstrated that over time the qualities that are so valued in these "natural" places will deteriorate because of fragmentation from the supporting structure resulting in isolation (Soulé 1991, Lord and Norton 1990, Opdam 1989). Thus, it is important to establish methods for preserving and re-establishing natural qualities in functioning, self-sustaining ecosystems.

The concept of the urban ecological networks addresses the ecological functioning of urban, patches and corridors. The best way to ensure the integrity of these systems is to establish the viability of critical ecological systems within the urban landscape context. This requires planning and management at multiple scales (see Chapters Three and Four). Although the actual scales will vary with the context and the planning problems to be addressed, three levels are generally necessary the properly understand the context (landscape), employ the planning authority (community) and address specific management needs or implementation schemes (local). The focus of this chapter is at the local scale.

At the landscape scale, analysis of the Phoenix urban area and surrounding valley floor, constituting approximately 6,500 square kilometers, the grain of the data is coarse (minimum five hectares) and the extent is broad. However, the objective is to understand interrelationships of elements with regional or landscape-scale significance. The landscape scale network becomes the main, and more stable, structure.

At the community-scale, the level of detail is more refined. The grain of data is less coarse at about one hectare. Planning is undertaken for interrelated network elements. Approximately 480 square kilometers were studied and plans with primary, secondary and tertiary elements of a network formulated. An example of the City of Scottsdale (Chapter 4) demonstrates how ecological network plans can be developed to correspond with the municipal planning process.

To preserve, rehabilitate or restore the various components of an ecological network, management strategies must be developed for individual sites on the local level. This will include various types of patches and corridors and the landscape matrix. The viability of any ecological network or system of interconnected patches and corridors, is made possible at the local scale. The types of elements that need to be addressed may include pieces of the main ecological structure of an area (i.e. large remnant patches or corridors) or sites of a more ephemeral nature (i.e. vacant lots). The future value or potential may also need to be addressed with sites in need of regeneration or restoration.

5.2 U.S. Planning

In the U.S. context and particularly in the Phoenix, Arizona urban area, the predominance of land use planning authority lies at the municipal (community) level. In large urbanized or urbanizing regions there is sometimes a county planning authority or an association of municipal governments with strong planning authority that acts to coordinate activity of municipalities. But, most often the municipal government is empowered to plan within its jurisdiction and employs that power within the frame of its planning context. It is also evident that issues of private land ownership and management entity prerogative are given extraordinary weight by municipalities and other levels of government in the land use decision making process. Hence, it is essential to address these issues when planning for the viability of urban open space systems. Without this recognition, implementation becomes very improbable. Chapter Four addressed planning at a municipal level. This chapter addresses planning and management of patches, corridors and some aspects of the landscape matrix at the local or site level.

5.3 Management Options and Plans

There are two dimensions of management that are particularly important. Actions required at site scale, range from conservation of remnant patches and corridors to restoration of degraded landscape elements. First and most importantly, conservation of existing resources is essential. The creed of the medical professions to first do no harm is also relevant here. Preservation of intact native or highly valued landscape elements ensures optimal utilization of any resources. Second, many landscape elements of degraded quality may benefit from restoration activities. At the very least, allowing areas to regenerate naturally is usually beneficial but natural regeneration may take a long time in desert ecosystems. In all cases, effective long term management strategies and monitoring will facilitate these processes. Linkage to landscape scale functions is critical.

Addressing both conservation principles and conservation planning strategies is necessary to respond to the biological needs and the land use planning process that is driven by political and socioeconomic considerations. Duerksen et al. (1997) have articulated a series of principles (Table 5.1) and strategies or management tools (Table 5.2) that are relevant at site scale.

Table 5.1 *Conservation Principles at Site Scale*

1. Maintain buffers.
2. Facilitate wildlife movement.
3. Mimic natural features.
4. Minimize contact with predators (including pets).

Table 5.2 *Management Tools at Site Scale*

1. Regulatory	zoning ordinances
	special overlay districts
	performance zoning
	development phasing
	subdivision review standards
2. Incentives	density bonus
	clustering
3. Acquisition	fee simple purchase
	sell backs or lease backs
	options/first rights of refusal
	easements
	purchase of development rights
	land dedication and impact fees
4. Development agreements	
5. Control public improvements	
6. Taxing/assessment districts	
7. Private sector initiatives	land trusts
	limited conservation development
	restoration showcase projects
8. Education citizen involvement	
9. Technical Assistance	

Restoration projects can be classified into four categories (Bradshaw 1984). *Laissez faire*, Bradshaw notes, allows nature to take its own course and regenerate itself with no positive or negative impact by humans. Sites that have a natural propensity toward regeneration may best left to this process. Flood plains provide the best example. Frequent flooding generally brings fertile soil and an infusion of new life with ideal conditions for fertilization, seed germination and growth. On the other hand, many sites may be seriously polluted or severely disrupted without recurring natural processes in existence that are capable of cleansing and regenerating. In this case, other more proactive approaches are required. Positive construction is the next least intrusive approach. This approach provides for an initial inoculation to introduce plant and animal species and then nature is allowed to take its course. The third approach is restoration. Restoration uses the original landscape structure as a model for re-establishment of a site. This process is most appropriate if the site retains integrity and could support similar populations again. Bradshaw's fourth method is manipulation of development which can include all of some of the previously noted approaches in combination.

Other strategies are also relevant in this context. Forman (1995) defines three additional management strategies. Adaptive management stresses the need to adjust as new information is provided through monitoring. Management to minimize cumulative impacts is particularly relevant in an urban landscape context. Impacts may result from synergistic effects and in multiple locations or over time. And, ecosystem management focuses on natural process as the preeminent management objective. Therefore, the use of models, knowledge of context, ecosystem function and the study of population dynamics, nutrient and gene flow and biodiversity become important variables.

5.4 Site Studies

A selection of sites are used to demonstrate how they contribute or may contribute to the vital functions of an urban ecological network. The patches and corridors represent only four of ninety for which data were collected and analyzed at landscape scale. The one matrix segment represents 700 hectares. Table 5.3 illustrates the type of elements examined in further detail. The selection of these elements provides a cross section of landscape elements that are represented throughout the study area. Hence, the examples may be useful models for other landscape elements with similar characteristics. Each landscape element warrants individual analysis to determine the most appropriate strategy, but, the solicitation of explicit studies for each patch and corridor and multiple segments of the landscape matrix seems unlikely. The importance is however, that as opportunities arise, individual studies can be undertaken on an incremental basis.

Table 5.3 *Patch, Corridor and Matrix Segment Characteristics*

Landscape Element	Ecol. Desc.	Size	Owner/Mgmt.
1. South Mountain Park	Remnant Patch	5,500 ha.	City
2. Indian Bend Wash/Park	Introduced Corridor	700 ha.	City
3. Verde River	Stream Corridor	2,500 ha.	Govt. Agency
4. Salt River	Stream Corridor	10,000 ha.	Govt. Agency
5. Phoenix Canals	Line Corridor	10,000 ha.	SRP
6. Dobson Ranch	Suburban Matrix	700 ha.	Private H.O.A.

5.4.1 South Mountain Regional Park

South Mountain Park is a remnant patch of regional significance on the southeastern edge of the urban matrix. It is bounded by the Gila River Indian Reservation on the southwest side and by encroaching urban development on all other sides. The park is owned and managed by the City of Phoenix Parks, Recreation and Library department. The actual park boundaries include about 5,500 ha. of a rugged mountainous area that is dominated by native plant species and an exotic annual grass (red brome). It is used heavily for recreational activities such as hiking, bicycling, horseback riding. A summary of the current hydrologic habitat and recreation conditions is provided in a report prepared by (Daugherty et al. 1996). The hydrology of South Mountain Park can best be described through a discussion of the condition of principal drainage corridors. Since the soils in this area are shallow and most of the terrain is granite outcrop, very little surface water percolates into the soil. The drainage corridors documented by Daugherty et al. (1996) are characterized by the topographic location, upper, middle and lower. The upper drainage corridors are in a near natural state. Flows move efficiently through these areas but the density of vegetative cover is lower, principally resulting from absence of suitable soils. The middle drainage corridors are also in a near natural state and have greater abundance and diversity of vegetation. The lower drainage corridors have signs of degradation resulting from more extensive human use and increased runoff resulting from soil compaction and paving. The changed hydraulics of the stream flows have started to cause some soil erosion and channel instability.

The habitat conditions are summarized by Daugherty et al. (1996) and classified into four zones relating to the level of disturbance or impacts. They note that the north side of the park is most severely impacted, principally relating to the primary access locations and heaviest use areas. These areas have also been adjacent to urban development since the early years of the parks existence in the 1930's and 1940's. Encroaching urban development on the southeast side of the park is now starting to result in similar impacts. The areas that are least impacted provide extensive near natural habitat and important links to the natural areas of the Gila River Indian Reservation and the Estrella Mountains further west. Throughout the park extensive areas of viable natural habitat exists. Recreational activity is prevalent throughout the park, however it is more concentrated on the northern and eastern sides. Hiking, equestrian and mountain bike trails extend throughout the park but none are paved. Several paved roads have been constructed to provide automobile access to key view stations and other destinations within the park. The dominant recreational activities are limited principally to trails and sites accessible by roads. Rangers monitor and manage recreational use to limit the damage to the park environment.

Overall, the park is in near natural condition and represents an important ecological resource . Encroaching urban development and continued recreational use are the main management issues that need to be addressed to maintain the high ecological value.

Recommendations for management action can be characterized as preservation. Several specific actions will help preserve the ecological values inherent in this patch and ensure that it will remain a viable component in an ecological network. They are:

1. Buffer the park from surrounding matrix.
2. Protect the core area.
3. Manage use patterns.
4. Manage human/wildlife conflicts.

Since park boundaries were established in the 1930's, urban development has continued to spread and creep ever closer to the park boundaries. Until the last 20 years, the park was surrounded mainly by native desert, some agriculture and a small amount of urban development. These compatible or benign adjacent land uses functioned as a suitable buffer for the critical habitat of the core area of the park. However, as urban development has encroached, the external buffer was lost and the edge effect has extended further into the park itself, effectively reducing the core habitat area of the park. Modification in the development pattern and use of appropriate native vegetation could make adjacent development areas more useful as habitat yielding a more effective external buffer rather than sacrificing critical core habitat of the park. The result is an increased matrix utility coefficient and increased core area value. Many park managers are fully engaged in the tasks of managing park use to minimize impact on the ecological functions of a park. Several strategies are already in place for South

Mountain and in future years there could be less impact by users on the parks systems. South Mountain actually provides habitat for large mammals and many other species. Rangers have even reported the sighting of a bobcat in recent years. The recommended strategy for limiting dilatory effects of human/wildlife interaction is to reduce access to more remote areas of the park and manage them with habitat quality as the primary objective.

5.4.2 Verde River Corridor

The Verde River corridor is an environmental corridor of regional significance on the northeastern edge of the urban matrix. The Verde River originates in northern Arizona and winds its way south to the confluence with the Salt River just above Granite Reef Dam. The length of the corridor that falls within this study area is 27 kilometers and the average corridor width is 1,500 meters. This is a perennial river with abundant native and some invasive vegetation along the banks and in upland areas. There have been modifications to the channel in places and heavy human use has impacted the ecological value. Adjacent land uses are limited to a small amounts of agriculture and some very low density residential development. The majority of this reach of the river falls within the bounds of the Fort McDowell Indian Community and a small portion within the Salt River Indian Community. A summary of the current hydrologic, habitat and recreational conditions is provided in a report by Bushbacher et al. (1996).

Natural fluctuations in flow along this reach of the Verde River ceased with the construction of the Bartlett Dam, just beyond the northern edge of this study area. A continuous flow is maintained and some seasonal fluctuations in flow are evident, but the hydrologic system is now managed rather than natural. The continual flows provide adequate moisture to maintain natural and introduced vegetation within the channel.

Some soil erosion is occurring and should be arrested before further channel instability occurs. The value of this particular river corridor as habitat is significant. Located on the edge of an urban matrix and with its connection to extensive native habitat areas of northern Arizona, it is an important conduit for many species. Some rare and endangered species are known to utilize this corridor extensively. The southern end of the corridor is more heavily impacted by human activity. Vegetative communities ranging from seep willow to mesquite bosques are present. There are still a few patches of cottonwood-willow gallery forest, however, these have been in decline since the regulation of flows in this river. Adjacent land uses and unorganized recreational activity are impacting habitat quality to some degree. Throughout the river corridor extensive natural habitat exists, with some exotic species such as salt cedar. Recreational activity along the Verde River corridor is unorganized and sporadic. Water-based activities such as fishing, canoeing, swimming and river floating or inner tubing are prevalent. Land based access is from an improved road on the Fort McDowell Indian Reservation and then on unimproved trails to the river's edge. Informal camping and picnicking occur throughout the area. The most significant problems are a result of off-road vehicle use, causing damage to vegetation and the persistent invasive plant species leading to decline in habitat diversity. Many of these activities are compatible with preserving the ecological functions of the river corridor if they occur in concentrated organized areas.

Overall, the river corridor is in near-natural condition and represents an important ecological resource. Unorganized recreation, reduced stream flow amounts and off-road vehicle damage to vegetation represent the most significant management problems. Also, anticipating future land use transformations on adjacent land will be important.

The overall management strategy for the Verde River corridor is preservation. Several specific management actions will help to preserve the ecological values inherent in this corridor and will ensure that it remains a viable component in an ecological network.

1. Establish a buffer zone from impending incompatible adjacent land uses.
2. Manage use patterns within the corridor.
3. Establish a release pattern from Bartlett Dam that mimics natural seasonal flooding of the Verde River.
4. Revegetation and bank stabilization in areas of significant erosion and vegetation loss.

Development on the Fort McDowell Indian Reservation has been modest in the last several decades. However, recent rulings concerning gaming on Indian reservations has created demand for construction of new casinos and associated facilities, so increased development pressures may soon jeopardize the river corridor. Clear delineation of a conservation zone within the 100-year flood plain and establishment of an external buffer zone will help protect this resource from pollutants and pressures from human impact. Within the corridor recreational use areas should be identified and developed in concentrated locations. Vehicle access should be limited to a small number of improved roads.

Recent experiments with releases that mimic natural events from dams on the Colorado River have demonstrated that some additional ecological benefits of re-establishing habitat, renewing nutrients and others. A regime of periodic releases from Bartlett Dam that mimic natural seasonal flood events, without extreme events that jeopardize human safety, can be established to allow the river corridor to naturally renew itself. In addition, revegetation and ecological bank stabilization projects should be undertaken in specific areas where channel stability is in question. Techniques for bank stabilization using plant materials exist that yield significantly greater ecological benefits than traditional approaches.

5.4.3 Indian Bend Wash

Indian Bend wash is an introduced cultivated corridor of local significance located in the southern portion of Scottsdale, roughly in the geographic center of the Phoenix metropolitan area. The corridor is approximately 20 kilometers in length and averages about 500 meters in width, ranging between 400 meters and 800 meters. The corridor is bounded by urban development throughout. It is developed as an urban linear park, but also is designed to accommodate runoff as an urban drainage corridor. The original condition was a series of small drainage corridors that were redirected and amalgamated into a large single corridor. Numerous active recreation facilities such as sport fields and golf courses have been designed into the park. The vegetation consists of predominantly cultivated exotic species and much of the corridor is covered with grass. Indian Bend Wash drains the 360 square km watershed that is bounded on the northeast by Tonto National Forest and the McDowell Mountains and on the southwest by the Phoenix Mountains and the Salt River. There are few problems with soil erosion within this corridor since it is well vegetated. Since this is now almost entirely an artificial corridor, it is impossible to compare it to any level of naturalness that previously existed. The watershed has changed dramatically since construction of Indian Bend Wash in the 1970's. It is now almost entirely urbanized, creating significant changes in runoff levels and the level of pollutants in the water. Several ponds created for aesthetic purposes and storage of nuisance water are lined to prevent percolation. There have been significant declines in groundwater levels in the Phoenix area resulting from years of drafting at rates greater than recharge. Frequency of flood events has increased in recent years also.

Current habitat values of Indian Bend Wash are low for native species because of the extensive use of exotic vegetation. The number of species present overall is quite high, but presence of highly valued natives is low. Merkle et al. (1996) classified the urban habitat of Indian Bend Wash into four subgroups: 1) aquatic, 2) wetlands, 3) cultivated parkland and 4) regenerating. Cultivated park land dominated with 75% of the total area, regenerating occupied 10%, aquatic 4% and wetland 1%. Merkle et al.'s (1996) assessment indicates that the overall ecological value for habitat is quite low because of the lack of native species. The presence of water is an important characteristic, but without suitable cover and forage habitat it will remain unsuitable for native species.

From an urban recreational perspective, Indian Bend Wash provides a wide range of opportunities. Merkle et al. (1996) provides a list of 30 activities that are accommodated. Activities range from organized sport to passive recreation such as walking and photography. Less than 50% of the area of this site is devoted to dedicated activity space, leaving approximately half as informal space. Because of its central location, Indian Bend Wash is heavily used for recreation.

Overall, the park is a cultivated corridor with predominantly exotic species. Its potential as an element to connect other patches or corridors may be important because of its location and the presence of water. However, the intensity of use and absence of native vegetation currently limits its ecological value.

The management strategy for Indian Bend Wash is re-naturalization. Several specific management actions can help to increase the ecological value of this park.

1. Naturalize wetland areas and aquatic elements by removing liners and introducing native vegetation along banks, and deepening lakes.
2. Revegetation of passive use areas with native plants that may provide suitable habitat for native wildlife species.

3. Establish vegetation buffer zones along the park perimeter and extend use of native vegetation into adjacent neighborhoods.

4. At major road crossings, establish wildlife friendly crossings to facilitate migration.

Wetland and aquatic areas are potentially highly valued ecological areas, particularly in a desert environment. The presence of water in Indian Bend Wash provides an opportunity to create an important habitat zone with the introduction of native vegetation and wetland design modeled after natural systems. Deepening existing lakes and removing liners to allow percolation will establish something like a natural system that provides more ecological value.

Passive use areas can be converted from exotic to native vegetation. This may occur on up to 50% of the total park area without disrupting current structured activity areas. The benefits include providing more habitat for native species but also more suitable migration corridor to help improve connectivity within the entire ecological network. Native vegetation will also require less fertilizer, pesticides, supplemental irrigation and maintenance.

Vegetation buffer zones along the park perimeter and extending into the neighborhoods will create a filter zone in the upland areas and reduce introduction of harmful materials and organisms and can effectively increase the interior zone of the wash. At several locations, major roads bisect the wash and effectively create barriers for species migration. In most cases accommodations are made for pedestrians and cyclists, but wildlife-friendly underpasses would substantially improve the connectivity of this corridor. Coupled with more native vegetation and naturalization of wetlands and aquatic areas, the ecological value would increase substantially.

5.4.4 Salt River Corridor

The Salt River originates in the White Mountains of eastern Arizona and flows through the central portion of the Phoenix urban area. Within the study area the Verde, Agua Fria, Gila and Rivers join it making it potentially the most important corridor in the region. The length of the corridor that falls within the study area is approximately 60 kilometers with a width that varies from 400 meters to 2,500 meters. Earlier in the 20th century this river had perennial flows through what is now the urban area and had abundant vegetation along the banks. The existing situation is now quite different. Since the water from the river has been diverted into the canal system, the water table has dropped and vegetation that relied upon soil moisture from the river has disappeared. The Salt River corridor is now a dry barren expanse passing through the urban area. Channel modifications have occurred throughout and intensive land uses have encroached. A summary of the existing condition and future restoration proposals is included in Cook's (1991) discussion of the Tempe Rio Salado project.

With the permanent diversion of Salt River water into the canal system, this corridor ceased to function as a living vital river. Significant flooding events do still occur, but because of the lack of vegetation exposing the banks and increasing urbanizing of the watershed, the events are more forceful and destructive. The ecological value of hydrologic functions is deteriorated and even the memory of this area as a vital river has faded.

The absence of vegetation throughout the length of the corridor has limited the habitat value of this reach of the Salt River substantially. There are small pockets of vegetation where nuisance water tends to collect and invariably, birds, insects and small mammals and other animals can be found there. The most significant loss, however, is that an important migration corridor, through what is now an urban area, has been eliminated.

Culturally, the Salt River corridor is still important, albeit undervalued and underutilized. As a landmark and an edge, it helps to establish identity and give orientation within the urban area. It has also been the focus of many studies in an effort to restore some of the river's lost qualities. As such, it has become an issue around which many people have rallied and the results are now being seen in the form of proposals and actual improvement to the corridor.

Overall, the Salt River corridor is a seriously disturbed resource. The water and vegetation are gone and the remaining cultural values are presently a small measure of what the original condition may have been or the potential that exists.

The management strategy for the Salt River corridor is restoration. Several specific proposals and plans have been developed for this corridor and some are now being implemented. The approach being taken is emblematic of the typical planning situation in the Phoenix urban area. Municipalities are individually undertaking restoration plans for the portion of the river within their jurisdiction. Although there are different goals and strategies in each municipality, the prospect of restoring many ecological functions to the river corridor exists. The following specific actions will help restore this river corridor.

1. Reintroduce a low flow channel with a permanent water source to the entire corridor.
2. Re-establish a facsimile of the original meander pattern to restore a range of ecological zones within the river corridor.
3. Revegetate the corridor using natural models for patterning landscape structure.
4. Re-establish links to adjacent patches and renew flows between other corridors that are part of the Salt River system.

5. Manage adjacent land uses so that they do not continue to encroach on the river corridor and to ensure they are not polluting surface or ground water.

The key to restoring any portion of this river corridor is to reintroduce water permanently. Arizona water rights law precludes recapturing water from the canal system and returning it to its original course. Consequently, alternative sources that include high quality treated effluent and purchased canal water are being developed. The continual flows will provide adequate moisture to support native vegetation within the low flow channel and along the upper banks. The relationship between the presence of water, reestablishing vegetation and restoring some semblance of the original meander cycle of the river will create an environment in which ecological functions will be restored.

As noted earlier, the Salt River is connected to several other rivers in the immediate study area. To help maintain and restore flows throughout the system, renewal of the Salt River is critical. It has been characterized as the spine of the existing open space system and links a number of patches and corridors in the central portion of the Phoenix urban area.

5.4.5 Phoenix Canals

Throughout the Phoenix urban area are more that 270 linear kilometers of irrigation canals. The canal corridors range from 20 to 30 meters in width, comprised of about 5 to 10 meters of water course and the remainder in canal banks and service roads. The canal system is owned by the U.S. Bureau of Reclamation and managed by Salt River Project, a local water management and utility company. A summary of the current canal system and a framework for multiple use of the canal system is provided in a study by Fifield et al. (1990).

The hydrologic situation with the canal system can best be described as a utilitarian water delivery system. However, since the study by Fifield et al. (1990), a series of proposals have been developed to transform the canals and canal banks into multifunctional corridors, contributing both ecologically and culturally to the urban area. The presence of water is perhaps one of the most important inherent characteristics of the canals. The source of water is principally the Salt River, although the Central Arizona Project canal carries water from the Colorado River, approximately 300 kilometers away. Presently, water flows in the primary canal system continuously, except for annual dry-ups during which time maintenance is conducted. The channels generally have concrete sides and dirt bottoms and the upper banks are usually dirt and gravel. Rarely is vegetation present.

The habitat conditions are best described as sparse. Some birds (usually waterfowl) utilize the water surface, but the lack of vegetative cover precludes the use of these areas by most other species. The soils on the upper banks are compacted. The continuity of many canal banks is also disrupted in numerous locations because of major street crossings.

The cultural values, beyond the economic value of providing irrigation water, are significant (Yabes et al. 1997). Even though they are intended as utilitarian water delivery corridors, residents of nearby neighborhoods value the additional open space and often use them for recreational activities such as jogging, walking and cycling. They also provide important urban landmarks, provide aesthetic relief from the monotony of urban development and bring psychological relief with the cooling effect of water during the hot summer months.

Overall, the canals are introduced cultivated corridors with very little inherent ecological value. The cultural values are more evident. The potential to perform important ecological functions and contribute even more from a cultural perspective is significant. This will requite significant investment and commitment, but the Salt River Project and municipal governments have expressed interest in forming partnerships to transform these spaces.

The study by Fifield et al (1990) and other proposals being considered by municipalities in the urban area included a number of recommendations for accommodating multiple uses through the canal system. While many of these focus more specifically on cultural functions such as recreation, aesthetics, and increased human activity, opportunities also exist for improving the ecological functions in these corridors. The management strategy for the canal system is to introduce park-like treatments along these corridors. The most effective approach from an ecological perspective is to attempt to simulate stream or river corridors in the design, creating a more suitable habitat zone. Several specific design and management recommendations would facilitate this.

1. Introduce vegetation along the upper bank areas to simulate buffer or filter zones of natural corridors.
2. Study the potential for making alternate connections between severed natural corridors with revegetated canal segments.
3. Establish wildlife and human friendly crossings (serviducts) where major streets and canal corridors intersect.
4. Dedicate certain canal segments that link important natural features as "linking" corridors.

Along most canals approximately 70% of the corridor width is dedicated to upper bank and service roads. While it may be important to maintain a service road 4 to 5 meters wide, the balance of this zone could be planted with predominantly native vegetation species. The presence of water and increased cover will make this a much more hospitable environment for many organisms.

As the urban area developed, many natural corridors were severed, resulting in fragmented remnants of the original system. Reconnection of some of these now isolated fragments through creation of "synthetic" links along canal corridors will provide alternate loops within the system. Although these synthetic links cannot provide the same level of ecological function as the original corridors, they provide reasonable opportunities for restoring some functions.

The problem of existing barriers presented by intersection of canals with major roads is best solved with design solutions. Examples already exist of grade separation between river and stream corridors and roads to facilitate passage at both levels. In recent years wildlife bridges or serviducts have been introduced to overcome the gaps in ecological corridors due to road barriers. The preferable alternative from an ecological perspective is to ensure the widest possible passage way without using structures like wildlife bridges by taking the road overhead. This allows for continued flows of air, water, and organisms of all kinds.

5.4.6 Dobson Ranch Residential Community

Dobson Ranch is an established residential community in the southeast portion of the Phoenix urban area and is characteristic of the urban landscape matrix that encompasses the network of patches and corridors. The community occupies approximately 700 hectares and incorporates a range of land use types, including commercial, various residential densities, parks and open space and institutional. Brenda et al. (1997) summarized the current hydrologic, habitat and cultural conditions.

There are several hydrologic elements embedded within the Dobson Ranch area. The western edge of the community is bounded by a canal that abuts approximately 4 linear kilometers of housing. There is also an artificial lake that was built by the development company with a surrounding park. Water for the lake is diverted from the nearby canal and reintroduced to the canal once it has passed through the community. There is currently no evidence of previously existing natural drainage corridors, but some minor ones must have existed.

The vegetation throughout is primarily cultivated exotic vegetation. There are many species of birds present, mostly edge species. There is no indication that any native species reliant on interior or core habitat are present. Brenda et al. (1997) note that tree canopy currently covers about 10% of the total area. Compacted soils and paved or built surfaces occupy approximately 60% of the surface area.

Cultural and recreational opportunities are present in several different forms. Dobson Ranch is somewhat different from many residential communities in the Phoenix area in that it has a private park and lake system integrated within the community. In addition a public golf course is present. Dobson Ranch also has rather strong community identity because of a strong homeowners association and significant investment in the early planning stages that lead to a few innovative planning techniques being implemented.

Overall, Dobson Ranch is not high in overall ecological values and is a typical example of the nature of the urban matrix that spreads throughout much of the Phoenix urban area. The purpose of including a portion of the urban matrix is to show how it may become more compatible, particularly in those areas directly adjacent to important patches and corridors.

Recommendations for transforming the urban matrix in order to make it more compatible with adjacent patches and corridors in an ecological network are outlined for the example of Dobson Ranch. The overall goal is to improve the matrix utility value so that the matrix, in effect provides its own buffer for an adjacent patch or corridor, rather that causing the buffering to occur within the bounds of the network element (the patch or corridor). The lack of an external buffer or filter zone, causes the edge zone of the patch or corridor to function as the buffer or filter, effectively reducing the interior or core habitat area.

1. Over time, replace exotic vegetation species in residential, commercial and park landscapes with native species.
2. Rejuvenate areas with compacted soils and reduce paving where possible.
3. Increase multilevel vegetative cover to about 30% of total area.
4. Naturalize parks and golf courses within the community. (see Section 5.4.3).

In the Phoenix urban area preferences in landscape design have changed significantly in the past 15 years. In recent years a majority of homeowners have opted to use more native plants in residential landscape design. Since Dobson Ranch was developed in the 1970's, the majority of the landscaping was done with exotic vegetation. Incentives such as lower water use and lower maintenance are causing many people to transform their landscapes from exotic to native species. This should be encouraged, particularly in areas adjacent to ecological network elements, to provide ecological benefits in addition to cost savings. At the same time, treatments to rejuvenate compacted soils or to take some area out of paving can be incorporated.

Increase in planting density from groundcovers to shrub and canopy layer improves the habitat value of the urban matrix. The combination of increased planting density and the use of native species is important to all species and in particular birds. The previous discussion in Section 5.4.3 about naturalizing Indian Bend Wash Park is a useful model for private parks like those in Dobson Ranch and golf courses. Although the parks and golf course in Dobson Ranch are not sufficiently large to be specifically addressed at landscape scale, at the municipal level of planning, these places would become a part of the ecological network plans.

5.5 Summary

This chapter demonstrates how specific site improvements contribute to the quality of an ecological network that must be conceived at landscape or regional scale, but must also be link to specific places and actions. Examples include a natural patch (South Mountain Park), a cultural patch/corridor (Indian Bend Wash Park), a healthy natural corridor (Verde River), a degraded natural corridor (Salt River), cultivated underutilized corridors (Phoenix Canals), and an urban/suburban matrix (Dobson Ranch Residential Community). Each of these places, whether natural or cultural or healthy or deteriorated requires management, planning and design activity to maintain or improve its relative ecological value as an ecological network element.

Chapter Six

Assessing Ecological Network Viability

6.1 Introduction

This chapter demonstrates how landscape structure can be used to assess the viability of urban ecological networks. The objective of this analysis is to measure the difference between alternative ecological network scenarios using landscape structure indicators. Three analyses; patch content analysis, corridor content analysis, and network structure analysis, are undertaken to describe differences. Patch content analysis uses indicators including patch type, size, perimeter/area ratios, degree of naturalness, matrix utility factors, and isolation. Corridor content analysis uses indicators of corridor type, size, interior/upland ratios, matrix utility factors, connectivity, and degree of naturalness. Network structure analysis uses indicators of mesh density analysis, connectivity, circuitry, matrix resistance factors and degree of naturalness.

An ecological network plan (Figure 6.1) as described in earlier chapters includes recommendations for establishing an ecological network in the Phoenix, Arizona urban area. The plan focuses on three scales, landscape or regional, local or municipal, and site. At each scale optimal conditions are described for establishment of an ecological network. The plan is designed to enhance the overall ecological viability of the study area by reducing fragmentation, maintaining naturalness, and improving compatibility of the landscape matrix with the ecological network. The analysis demonstrates that the ecological network plan provides notable improvement over the current situation and management schemes.

6.2 Criteria for Assessing Viability

Assessment of ecological network viability can be undertaken by analyzing the inherent characteristics of the landscape elements, the interrelationships between landscape elements and external factors affecting the functioning of the ecological network. A range of landscape element attributes are assessed through patch and corridor content analysis. Inherent characteristics include size and type, vegetative structure and diversity, and naturalness. Interrelationships between individual landscape elements and the landscape matrix are assessed through a number of indicators that are described as context. Network structure analysis considers the overall effect of the interrelationship of patches and corridors within the context of the urban matrix. The network structure analysis includes mesh density, circuitry and connectivity. This process is undertaken using plans described in previous chapters for the Phoenix urban area, principally at landscape scale. Both the existing situation and an optimal situation are assessed.

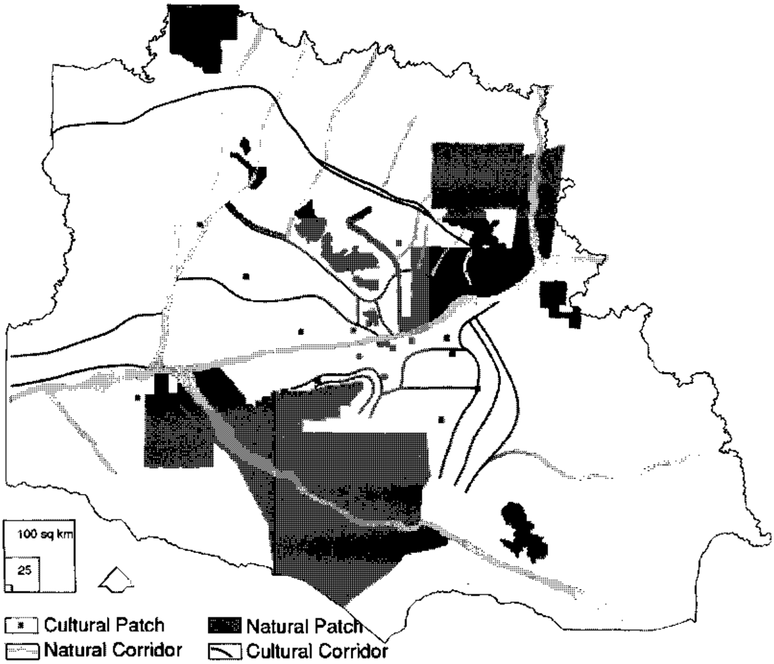

Figure 6.1 *Patches and corridors and landscape scale.*

6.2.1 Patch Content Analysis

The patch content analysis incorporates four principle variables, 1) patch size and type, 2) vegetative structure and diversity, 3) patch context and 4) patch naturalness. Each variable has several subvariables or attributes that are used to describe and assess patch characteristics. Each of the patches were analyzed using these variables. A summary of the results of the patch content analysis in included in Table 6.1. A more complete presentation of patch content analysis in presented in the appendix.

Patch Size and Type - Patch size and type have been shown to affect interactions of wildlife and affect ecological value. Forman (1995) uses five terms to classify patches, primarily based on origin and function. A remnant patch is one that is left in its original character following widespread disturbance that changes the surrounding matrix. A regenerated patch has been previously disturbed or changed and has since naturally reestablished vegetative cover. An introduced patch is similar to a regenerated patch in that it was previously disturbed, but the establishment of new vegetation is of human origin. An environmental patch is one that exists within a predominantly natural context and has significant natural values, but differs from the surrounding matrix. A disturbance patch is established by local disturbance of an area that changes the character, resulting in a patch that differs from its surroundings.

The size of patches also affects their viability and ecological value. Large patches are more valuable because they support large, persistent populations. Thus there is a relationship between patch area and wildlife abundance, persistence and diversity (Deurksen et al. 1997). Numerous researchers have demonstrated this species area relationship. Large patches preserve greater areas of interior habitat which is beneficial to many indigenous species that are not tolerant of edge habitats. Smaller patches have more edge area. Forman (1995 p. 47) lists ecological values of large and small patches.

> Large patches:
> 1. Water quality protection for aquifer and lake.
> 2. Connectivity of a low-order stream network. For fish and overland movement.
> 3. Habitat to sustain populations of patch interior species.
> 4. Core habitat and escape cover for large-home-range vertebrates.
> 5. Source of species dispersing through the matrix.
> 6. Microhabitat proximities for multihabitat species.
> 7. Near-natural disturbance regimes. Many species evolved with and require disturbance.
> 8. Buffer against extinction during environmental change.
>
> Small patches:
> 1. Habitat and stepping stones for species dispersal, and for recolonization after local extinction of interior species.
> 2. High species densities and high population sizes of edge species.
> 3. Matrix heterogeneity that decreases fetch (run) and erosion, and provides escape cover from predators.
> 4. Habitat for small-patch-restricted species. Occasional examples are known of species that do not persist in larger patches.
> 5. Protect scattered small habitats and rare species.
>
> The bottom line: large patches, large benefits, and small patches, small supplemental benefits.

Three measures of patch size and type are used to evaluate the various attributes of patches within this system; patch area, perimeter length and perimeter/area ratio. Data describing patch size and type are included in the appendix (Table A.1). Patch area is a simple measurement of the patch area in hectares and, with other factors, may be a good measure of long term viability of a patch. Perimeter length is used in combination with patch area to calculate the perimeter/area ratio. Perimeter/area ratio describes the relationship between patch area and boundary length and provides useful information about the potential edge effect that may be present in a specific patch. Perimeter/area is a simple ratio and is calculated using the following formula:

$$D_i = \frac{P}{2\sqrt{A\pi}}$$

D_i = perimeter area ratio for patch i (also referred to as patch shape index)

P = perimeter of the patch

A = area of the Patch

Vegetative Structure and Diversity - Vegetative structure and diversity is described using three principle attributes that provide some consideration of the inherent qualities of the vegetation of each patch. Included in this analysis are net percent area covered by vegetation or vegetative cover, percent native vegetation, and vegetative structural diversity. Vegetative cover is one factor that contributes to the ecological health and can be used as wildlife habitat (Matthews et al. 1988). Forman (1995) notes that plant growth (or biomass, the overall weight of living tissue) is an attribute that can be measured as an indicator of productivity, one of four components Forman believes can be used as a measure of ecological integrity. Vegetative cover was calculated for each patch using aerial photographs and field inventory. Multiple layers manifested as vertical stratification is another indicator of habitat value in particular. Overlap of vegetation is not measured in the computation of coverage. Alone, net area covered by vegetation is not sufficient to fully evaluate the vegetative structure. In urban areas, vegetation often consists largely of exotic species and while these may provide many ecological benefits, exotic species are usually not as important to native wildlife species as habitat. Hence, percent of vegetation in each patch that is indigenous is an indicator of ecological value. Native vegetation (Kearney and Peebles 1960) coverage was calculated for each patch as a percentage of total patch area (Shaw et al. 1998). Representative patches were sampled for each type and values applied over similar patch types.

Structural diversity is another vegetation attribute that is an indication of ecological value. Vertical stratification of vegetation is manifested in the form of tree canopy, shrub layer and ground cover. Structural diversity gives more possibilities for greater diversity of habitat types, yielding increased diversity and greater possibilities for species survival. Small mammals, lizards and birds will use shrub layers as escape cover, while insects may be more reliant upon ground cover. Evaluation of structural diversity was accomplished by assessing the area covered by each layer. In this assessment overlap of vegetative layers was included, potentially yielding a value of 3.0. Sampling occurred in a representative patch for each type. Results are reported in the appendix in Table A.2.

Patch Context - Several external attributes can also be used to describe a patch and affect its ecological value. Many external factors can make a patch more or less ecologically viable. These are analyzed with relation to the effect on each patch. Cumulative effects of external factors are analyzed later in the network structure analysis. Important considerations include the compatibility of the matrix (matrix utility) adjacent to the patch, the isolation of the patch and accessibility of the patch (T-Links). Matrix utility refers to the extent species may utilize the landscape adjacent to and immediately surrounding patch boundaries. An ideal condition is for a patch to be buffered with compatible land use types and vegetation. The absence of a suitable buffer of compatible land uses effectively increases the edge effect and reduces the interior or core area of a patch. Conditions that change the matrix utility value are intense land uses, significant human impact, absence of vegetation (in particular indigenous vegetation), presence of pollutants of toxic materials, and domestic predators (cats, dogs, etc.). Matrix utility is indexed on a scale in which a wholly compatible adjacent matrix landscape is valued at 1 and wholly incompatible matrix is 0.

Matrix utility is calculated by measuring percent adjacent land use or the patch perimeter multiplied by the land use intensity factor.

$$M = \Sigma\ (a_i\ u_i)$$

M = matrix utility index of patch

a = percentage of perimeter of land use i

u = intensity value of land use i

Σ = sum of

Patch isolation is a function of the proximity of patches or corridors within a landscape mosaic. While connectivity is measured among a series of landscape elements, isolation addresses the connectivity or lack of connectivity of an individual patch. It is simply an index of the distance between patches and the number of neighboring patches. Isolation is calculated using the following formula (Bowen and Burgess 1981).

$$R_i = \frac{1}{n}\ \Sigma\ d_{ij}$$

R_i = isolation index of the patch

n = number of neighboring patches considered

Σ = sum of

d_{ij} = distance between patch i and any neighboring patch j

Accessibility is a simple measure of the number of physical connections (described here as T-Links) of corridors or patches included within the ecological network. Patch context data are summarized in the appendix in Table A.3.

Table 6.1 *Summary of Patch Content Analysis*

Patch Size and Type		
Origin	17 natural	18 cultural
Type	17 remnant	18 introduced
Area (mean)	4,650 ha.	
Perimeter length (mean)	22,051 m.	
Perimeter/area ratio (mean)	1.48	
Patch Vegetative Structure and Diversity		
Vegetative Cover (mean)	0.33	
Native Cover (mean)	0.17	
Structural Diversity (mean)	0.62	
Total vegetation value (mean)	1.17	
Patch Context		
Matrix utility (mean)	0.59	
Isolation index (mean)	1.51	
T-Links (mean)	1.23	(43 total)
Patch Naturalness		
Native vegetation (mean)	0.17	
Soils (mean)	0.42	
Flows (mean)	0.35	
Total naturalness value (mean)	0.94	

Naturalness Index - Patch naturalness is essentially a function of the absence of human impact and is a measure of variability from the original ecological system. Indicators of human impact include the presence of exotic species, soil compaction or extent of paving, disruption of flow and function, disconnection from original location and form. Presence of native vegetation species as an indicator was discussed in the section on vegetative structure and diversity. In the absence of extensive biological wildlife surveys, known habitat preferences, threatened, rare or endangered species are used. Soil compaction and extent of pavement provides information concerning a patch's fundamental nutrient cycles. Compacted soils, pavement or areas of soil erosion are unproductive and cause secondary problems such as increased runoff, loss of nutrients and minerals and increased sediment in streams, reducing water quality. Disruption of flows and functions can be assessed using landscape structure by comparing original and current condition of movement of air, water and species.

Disturbed streams, migration corridors and presence of barriers are all examples of ways flows and function are disrupted. The patch naturalness index is summarized in the appendix in Table A.4.

6.2.2 Corridor Content Analysis

The viability of corridors is assessed using similar landscape structure indicators as with patches. The different types of corridors can be described using the same five terms Forman (1995) uses to classify patches, based primarily on origin and function; remnant, regenerated, introduced, environmental and disturbance. A remnant corridor is typically one that is a left over strip after a widespread disturbance. A regenerated corridor has evolved naturally following some other use or form, such as a hedgerow that has evolved naturally. Corridor's functions include habitat, conduit, filter, source and sink (Forman 1995). These basic functions can be further articulated as contributors to a range of more specific goals. Biological diversity is enhanced through the preservation and restoration of riparian corridors that are critical habitat and important dispersal routes for species. Water resource management including flood control erosion control and water quality are facilitated in drainage corridors. Agroforestry production is enhanced with windbreak corridors that also help to control erosion. Recreational activities typically occur in corridors such as hiking, game management, bicycling and greenbelts. Important attributes include size and type, vegetative structure and diversity, corridor context and naturalness. A summary of the results of the corridor content analysis in included in Table 6.2. A more complete presentation of corridor content analysis in presented in the appendix.

Corridor Size and Type - Corridor size and type affects the five basic functions (Forman 1995) in various ways. Two principle characteristics of width indicate how well a corridor may accommodate these functions. The internal area is important to accommodate stream flows, as conduit for species migration, as source pool, and as sink, controlling erosion nutrient runoff, sedimentation and flooding. In addition, the upland zone of a corridor may perform many of the same ecological functions but also filtering and buffering. In urban matrices the filter and buffer function is essential to maintain the usability of the internal entities. Dramstad et al. (1996) note that 2nd order to 4th order stream corridors should maintain upland habitat on both sides, enough to control dissolved-substance inputs from the matrix. This also provides conduit for interior species and suitable habitat for flood plain species displaced during flood events. For larger corridors such as rivers of 5th to 10th order, Dramstad et al (1996) recommend upland zones on both sides, but also a ladder pattern of larger patches crossing the flood plain. This structure provides a hydrologic sponge that traps sediment, provides nutrients and habitat for flood plain species. Forman (1995) notes that, overall, wider corridors are better and will enhance all five functions of habitat, conduit, filter, source and sink. He also notes that research is still needed to determine how wide a corridor needs to be to function effectively. One important indicator is known and that is that a corridor should be wide enough to accommodate an upland zone of vegetation to control and filter runoff. The corridors found within this study area are described in spatial terms by width and length in the appendix in Table A.5.

Vegetative Structure and Diversity - Internal structure of corridors has been discussed to some extent in the section describing patch structure and also in this section on corridors. One important distinction that can be made concerning the internal structure of corridors is that this attribute is one of several that is critical to improve connectivity of corridors. The presence of interior entities (i.e. water, flood plains, native vegetation, etc.) improves the connectivity value of a corridor. The physical structure of the upland zone is also important in that it contributes to the viability of the interior as well as providing buffer and filter functions. The type, structural diversity and preponderance of vegetative cover are used as an indicator and measured for each corridor. Results are reported in the appendix in Table A.6.

Corridor Context - External characteristics of corridors are examined in a similar manner to those of patches. Matrix utility values are assigned according to intensity of the adjacent land uses along the corridor. Corridors that traverse different habitat zones have potential to function as important conduits for many species. As corridors (principally riparian corridors) traverse the landscape through the upper reaches of a watershed to the lower elevations where they converge and form rivers and streams, they pass through a variety of ecosystem types. Thus, there is great potential for increased diversity, transmission of nutrients and continual exchange. Most often this condition yields greater ecological health. This consideration is a diversity gradient and is another indication of the relative ecological value of a corridor. Values are assigned for the purpose of this study according to the elevation change within the reach of the corridor that falls with this study area.

Continuity is a factor that when combined with others provide an indication of overall connectivity of a corridor. The presence or absence of gaps in a corridor can be evaluated to assess the continuity present in a corridor. In urban areas continuity is often broken by roads, channel reconfiguration or filling, or simply by disturbance or human impact resulting from use or abuse. Particularly for those species that are exclusively terrestrial, gaps in a corridor represent significant barriers to migration and other important functions. Each corridor is examined and a continuity value is assigned corresponding with the presence of gaps or barriers in the corridor. In the network analysis, the concept of continuity is extended and a measurement of connectivity is computed. Results of the corridor context analysis are in the appendix in Table A.7.

Naturalness Index - The naturalness index for corridors uses the same indicators as patches; native species, soils and flows. With stream or river corridors in particular, soil erosion and disruption of flows are very important factors. Because of the intermittent nature of many arid region river and stream corridors, extreme hydrologic events occur frequently and significantly change the structure of a channel. While these events may be of natural origin, the increases in runoff within watersheds due to urbanization, soil compaction and encroachment on flood plains exacerbates problems and rapidly reduces the natural character of the corridor and the functions that occur within it. The naturalness index is described in the appendix in Table A.8.

Table 6.2 *Summary of Corridor Content Analysis*

Corridor Size and Type		
Origin	15 natural	17 cultural
Type	15 environmental	17 introduced
Length (mean)	28,792 m.	
Average width (mean)	245 m.	
Average interior width (mean)	0.58	
Average filter width (mean)	0.11	
Area (mean)	1,079 ha.	
Corridor Vegetative Structure and Diversity		
Vegetative Cover (mean)	0.20	
Native Cover (mean)	0.16	
Structural Diversity (mean)	0.35	
Total vegetation value (mean)	0.71	
Corridor Context		
Matrix utility (mean)	0.56	
Diversity gradient (mean)	86.40 m.	
T-Gaps (mean)	1.84 (59 total)	
Longest cont. distance (mean)	18,870 m.	
Link segments (mean)	2.78 (89 total)	
Corridor Naturalness		
Native vegetation (mean)	0.16	
Soils (mean)	0.37	
Flows (mean)	0.40	
Total naturalness value (mean)	0.93	

6.2.3 Network Structure Analysis

The analysis of patch and corridor content is only significant at the landscape scale if data are integrated into a larger more comprehensive analysis. Network structure analysis introduces a process for aggregating results of patch and corridor analysis and incorporates indicators that describe interrelationships between landscape elements. The collection of these elements forms the whole landscape mosaic and as patches and corridors connect and intersect, they form a network of potentially high value elements in which ecological functions are preserved and/or restored. Several factors contribute to making an ecological network more viable. In urban landscapes, the competition of various land uses and exotic species is intense. Fragmentation and isolation contribute to deterioration of ecological functions and ultimately decline in native species. Thus, establishing or maintaining linkage between patches and corridors is essential to facilitate ecological functions. Two factors largely contribute to the successful ecological functioning of a network, 1) the overall density of suitable patches and corridors and 2) the extent to which they are linked.

Mesh Density/Naturalness Index- The density of suitable patches and corridors is measured through mesh density analysis. Mesh density has three factors that are analyzed, 1) the actual net area covered by patches and corridors in the network, 2) the matrix utility as related to those patches and corridors and 3) the relative quality of patches and corridors. The net area covered is computed by calculating the area occupied by network elements within the study area or within a particular sector. This is described as percent net density of the total area. The greater the value, the more area that is available where ecological functions can occur. The mesh density/naturalness index is described in Table 6.3.

Table 6.3 *Mesh Density/Naturalness Index*

	Area (ha.)	Per. Tot. Area	Nat. Value
Nat. Patch	161,137.00	0.22	1.79
Cul. Patch	1,632.00	0.00	0.15
Nat. Corridor	30,490.00	0.04	1.98
Cul. Corrridor	4,047.00	0.01	0.02
Total	197,306.00	0.27	
Study Area	739,218.00	1.00	

Matrix Utility Index - Matrix utility has been discussed previously in the sections describing patch and corridor content analysis. The values computed for each patch and corridor are aggregated and averaged for an overall matrix utility value. The relative quality of patches and corridors refers to the patch and corridor content analysis indicators of naturalness, vegetation, type and size. These values are also aggregated and averaged to assess overall network quality and are summarized in Table 6.4.

Table 6.4 *Matrix Utility Index*

	Area (ha.)	Per. Tot. Area	Matrix Util.	Area Mat. Util.
Nat. Patch	161,137.00	0.22	0.72	0.16
Cul. Patch	1,632.00	0.00	0.47	0.00
Nat. Corridor	30,490.00	0.04	0.73	0.03
Cul. Corrridor	4,047.00	0.01	0.54	0.00
Total	197,306.00	0.27		0.19
Study Area	739,218.00	1.00		

Circuitry and Connectivity - The linkage of various elements within the network can be explained with the concepts of circuitry and connectivity. Network circuitry is described as the extent to which loops or circuits are present in the network. The "alpha index for circuitry" measures the number of loops present divided by the maximum number of loops possible. Loops are important because they provide alternative migration routes for organisms that may need to avoid disturbances or predators.

Circuitry is measured using the following formula (Haggett et al. 1977, Tauffe and Gauthierr 1973, Forman and Godron 1986)

$$\alpha = \frac{L - V + 1}{2V - 5}$$

α = degree of network circuitry

L = number of linkages

V = number of nodes

The results of the circuitry analysis of the existing situation yielded the presence of 43 nodes (V) and 75 links (L) for a circuitry value of .39.

Connectivity is a measure of the extent to which all nodes are connected. As in previous discussions of naturalness and the preference for native species, two types of connectivity may exist. Natural connectivity utilizes existing or restored naturally originated corridors yielding potentially greater ecological benefits. Artificial connectivity is achieved through establishment of culturally derived corridors and in most cases ecological benefits will be less when compared to a natural corridor of similar characteristics. In urban areas utilization of artificial connectivity may be an essential dimension of a network. Since many natural corridors are likely to have been removed or destroyed, supplemental connections can be achieved through proper design of artificial corridors. Together the alpha index of circuitry and the gamma index of connectivity describe the level of network complexity (Forman and Godron 1986) and provides an overall index of the effectiveness of linkages (Dramstad et al. 1996).

The "gamma index of connectivity" is the ratio of the number of links in a network to the maximum number of links possible. The number of links present and the number of nodes are totaled from the network and applied in the following formula

(Lowe and Moryadas 1975, Haggett et al. 1977, Sugihara 1983, Forman and Godron 1986).

$$\gamma = \frac{L}{3(V-2)} (S)$$

γ = the gamma index of connectivity

L = number of linkages

V = number of nodes

S = link suitability factor

For the purposes of this analysis another factor was added, that of link suitability. This factor is an adjustment for corridor naturalness. In an urban context the potential for migration is significantly affected by the presence of suitable vegetative cover and the absence of human impact. The formula for computing a connectivity value is as follows.

The results of the connectivity analysis of the existing situation yielded the presence of 43 nodes (V), 89 links (L) and a link suitability value of .31 for a connectivity value of .22.

6.3.4 Summary of Existing Situation Analysis

The existing landscape mosaic of the Phoenix metropolitan area has a range of open space elements of varying ecological value. Many of the remnant patches and corridors have only recently become disconnected from the supporting landscape structure. Soulé (1991) notes, however, that as isolated fragments age, the number of species decline and overall ecological health deteriorates. The existing condition analysis assumes that current land use and landscape management practices will continue. No plan for reestablishing connections or improvement of vegetative cover is put into effect. In essence, the status quo reigns. The indicator values outlined in Tables 6.1-6.4 for patch content analysis, corridor content analysis and network structure analysis summarize this current condition.

6.3.5 Summary of Analysis of Optimal Condition

The implementation of an ecological network plan can yield changes in the overall ecological value. This analysis builds upon the same existing patch and corridor elements that are present in the Phoenix metropolitan area, but employs a series of management, preservation or restoration strategies to improve the ecological value. This situation is viewed as a system or a comprehensive ecological network. Specific recommendations are assumed to be implemented throughout the network on an individual patch or corridor basis.

The examples of site improvement strategies described in the ecological network plan are typical of the types of strategies that could be employed. These include actions such as revegetation of disturbed sites, creating artificial or synthetic corridors or patches, expanding buffers by extensifying adjacent land uses, and others. Based on these strategies adjusted patch content, corridor content and network structure analyses are undertaken and a summary is displayed in Tables 6.5-6.9. Complete tables of adjusted values are included in the appendix. The changed values are noted in bold and italics type in each case representing the increased ecological value in the optimal condition plan.

Optimal Plan Patch Adjustments - For the purpose of this study, patch size and type were not adjusted for the optimal plan. Significant improvement in ecological values can, however, occur with enlargement of patch size or reduction of perimeter area ratios to increase interior or core areas. Although the scope of this study did not address this strategy, it should be a part of any ecological network plan where feasible. Optimal patch vegetative structure and diversity values are adjusted by introducing native vegetation in patches, principally where it is absent in cultivated parks. The site study focusing on Indian Bend Wash Park (Section 5.4.3), demonstrates that in cultivated urban parks approximately 50% of the area currently covered by exotic vegetation could be converted to native species with no significant loss of traditional park functions. The resulting adjustment increases the mean native vegetation coverage for patches from 0.17 to 0.27.

Optimal patch context values are adjusted by increasing native vegetation plantings in land uses adjacent to existing patches improving matrix utility values. Increase in matrix utility value, in effect, helps establish a more significant buffer external to the boundaries of the patch. In turn, the negative aspects of edge effect (i.e. loss of interior or core habitat area of patches) is reduced. The site study for Dobson Ranch Residential Community (Section 5.4.6), illustrates how existing land uses can be "extensified" to make them more usable as habitat and for other ecological functions. The adjustment is an increase in matrix utility values from the existing condition (0.59) to the optimal (0.73) of 14%. As with delimitations noted concerning patch size and type, context indicators such as isolation and terrestrial links can be improved by adding more usable patches or corridors to the network. This was beyond the scope of this study.

Optimal patch naturalness adjustments include increase in area covered by native vegetation, reduction of area with paving, compacted or eroded soils, and site adjustments to improve flows (i.e. removal of obstructions or barriers) to return site functions to a more natural condition. Adjustments, as with those previous, are generally confined to cultivated patches since natural patches have retained much of their original condition. Adjustments for native vegetation are reflective of those noted previously. Soils adjustments are introduced by specific improvements to site conditions, principally by eliminating or reducing paving where feasible or managing parks and other sites to limit the areas where soil becomes compacted due to excessive use. The increase in the mean of soils values is 0.17 (0.42 to 0.59) and is linked to the introduction of native vegetation in areas currently in a more cultivated condition. Flows are improved in cultivated patches by reconnecting severed links or drainage corridors or providing alternatives for movement of water, air, nutrients and other elements. This is also accomplished through cultivated park site redesign (see Indian Bend Wash Park recommendations, Section 5.4.3). Overall, patch naturalness values increase from 0.94 to 1.39.

Table 6.5 *Summary of Patch Content Analysis - Optimal*

Patch Size and Type		
Origin	17 natural	18 cultural
Type	17 remnant	18 introduced
Area (mean)	4,650 ha.	
Perimeter length (mean)	22,051 m.	
Perimeter/area ratio (mean)	1.48	
Patch Vegetative Structure and Diversity		
Vegetative Cover (mean)	***0.38***	
Native Cover (mean)	***0.27***	
Structural Diversity (mean)	0.62	
Total vegetation value (mean)	***1.27***	
Patch Context		
Matrix utility (mean)	***0.73***	
Isolation index (mean)	1.51	
T-Links (mean)	1.23	(43 total)
Patch Naturalness		
Native vegetation (mean)	***0.27***	
Soils (mean)	***0.59***	
Flows (mean)	***0.53***	
Total naturalness value (mean)	***1.39***	

Optimal Plan Corridor Adjustments - As with patches, the overall size and type of corridors have not been adjusted for this study. Optimal corridor size and type, also includes data concerning corridor interior and filter widths. Adjustments to the filter width of corridors represent an increase in mean corridor width of 19% (.11 to .30). The most common adjustment is for canals. The site study for canals (Section 5.4.5) demonstrates that currently underutilized canal banks can become important filters and buffers of incompatible use and flows. In addition, restoration of river and stream corridors (see Section 5.4.4 Salt River corridor) revitalizes buffer and filter functions and provides significant ecological benefits.

Optimal corridor vegetative structure and diversity values are adjusted in similar ways as the patch values. Specifically, native vegetation is introduced where feasible, and in the case of canals, adjustments to vegetative cover and structural diversity are noted because in the current situation, there is no vegetation present. Further illustration of adjustments are included in the site studies of the Salt River corridor (Section 5.4.4) and the canal system (Section 5.4.5). The most notable adjustment is the increase in the mean of percent of area covered by native vegetation from 0.16 to 0.25.

Optimal corridor context values are adjusted in two ways. First, matrix utility values are adjusted in the same fashion as with patches. The mean value of matrix utility is increased from 0.62 to 0.77. Second, site scale corridor studies (Sections 5.4.2 Verde River corridor, 5.4.3 Indian Bend Wash Park, 5.4.4 Salt River corridor and 5.4.5 Canal system) all recommend the removal of barriers or gaps in corridors that would negate flow of species, nutrients and other important elements. With all gaps eliminated or alternative connections established, the total of 59 gaps in the existing condition is reduced to 0 in the optimal plan.

Optimal corridor naturalness is adjusted essentially the same way as patch naturalness. Existing cultural corridors are those with most significant adjustments. Specifically, the values for canals have the greatest promise for improvement since existing naturalness values are practically nonexistent. Mean values for native vegetation (0.17 to 0.27), soils (0.37 to 0.60) and flows (0.40 to 0.62) are improved and the total naturalness value increases from 0.94 to 1.47.

Table 6.6 *Summary of Corridor Content Analysis - Optimal*

Corridor Size and Type		
Origin	15 natural	17 cultural
Type	15 environmental	17 introduced
Length (mean)	28,792 m.	
Average width (mean)	245 m.	
Average interior width (mean)	0.58	
Average filter width (mean)	***0.30***	
Area (mean)	1,079 ha.	
Corridor Vegetative Structure and Diversity		
Vegetative Cover (mean)	***0.27***	
Native Cover (mean)	***0.25***	
Structural Diversity (mean)	***0.48***	
Total vegetation value (mean)	***1.00***	
Corridor Context		
Matrix utility (mean)	***0.77***	
Diversity gradient (mean)	86.40 m.	
T-Gaps (mean)	***0*** ***(0 total)***	
Longest cont. distance (mean)	18,870 m.	
Link segments (mean)	2.78 (89 total)	
Corridor Naturalness		
Native vegetation (mean)	***0.25***	
Soils (mean)	***0.60***	
Flows (mean)	***0.62***	
Total naturalness value (mean)	***1.47***	

Optimal Plan Network Adjustments - Adjustments for mesh density/naturalness (Table 6.7) and the matrix utility index (Table 6.8) are extrapolated from the previous patch and corridor adjustments. Since actual area devoted to the ecological network does not change from the existing to the optimal plan, the change in the overall mesh density/naturalness index is not significant. The principle reason is that in this context, over 82% of the area within the ecological network is in natural patches that require management strategies that support the current functioning ecosystems as opposed to restoring or introducing viable ecosystems. More importantly, the matrix utility index (Table 6.8) works toward preserving these important ecological nodes. The adjustment in the matrix utility index is modest but notable (0.19 to 0.22) and could provide important buffering and filtering functions from adjacent land uses.

Table 6.7 *Mesh Density/Naturalness Index - Optimal*

	Area (ha.)	Per. Tot. Area	Nat. Value
Nat. Patch	161,137.00	0.22	1.79
Cul. Patch	1,632.00	0.00	***1.01***
Nat. Corridor	30,490.00	0.04	***2.03***
Cul. Corrridor	4,047.00	0.01	***0.97***
Total	197,306.00	0.27	
Study Area	739,218.00	1.00	

Table 6.8 *Matrix Utility Index - Optimal*

	Area	Per. Tot. Area	Matrix Util.	Area Mat. Util.
Nat. Patch	161,137.00	0.22	***0.82***	***0.18***
Cul. Patch	1,632.00	0.00	***0.64***	***0.00***
Nat. Corridor	30,490.00	0.04	***0.84***	***0.03***
Cul. Corrridor	4,047.00	0.01	***0.70***	***0.00***
Total	197,306.00	0.27		***0.22***
Study Area	739218	1		

The computation of the degree of network circuitry in the existing situation includes a network of 45 nodes and 75 links. This tabulation eliminates any links (such as canals) from the network that have negligible ecological values. The adjusted values based on the optimal plan allow for 14 (total 89) additional links, boosting the degree of network circuitry from 0.39 to 0.59.

Connectivity in the optimal plan is increased in two ways. First, adjustments are made to the suitability of links or corridors. In the existing situation the overall suitability value for links is 0.31 (corridor naturalness value), while in the optimal plan it increases to 0.48. Adjustment to the gamma index of connectivity increases the value from 0.22 to 0.34.

6.4 Filter for Ecological Integrity

Forman (1995) notes that ecological integrity could be measured as the single most important or sensitive attribute of an ecological system. He also states that "a system with ecological integrity has near natural conditions for four broad characteristics: productivity, biodiversity, soil and water." If we accept this premise, then ecological integrity should be the goal of any sustainable environment. Productivity, as an indicator of ecological integrity, should be at near natural levels as an average for a landscape. This means it should be maintained at a level not far from that which would prevail if the landscape had native ecosystems. Specific elements that could be measured include biomass, animal or secondary production, length of food chains, herbivory and decomposition. Biodiversity is represented by a number of native species for each major group (i.e. mammals, trees). The condition should be relatively few extirpated species and measurements could include assessment of community types, keystone species, rare species and genetic diversity. Soil is best measured by the amount of soil erosion, compaction or the amount of area sealed by paving. Measures could include soil moisture, runoff of minerals and nutrients and toxic materials in soils. Water can be assessed by quality and quantity. Quality indicators include measures of turbidity, nutrient status and fish populations. Forman (1995) notes that fish communities may be the best overall measure of water quality. Water quantity is best measured through indicators such as the ability to accommodate floods, low flow events, evapotranspiration, water tables, stream flow and aquifer recharge.

The greatest challenge of using these four indicators is the extensive amounts of data required to make proper assays. In the case of the Phoenix metropolitan area ecological network, some of these indicators can be applied. It is still uncertain what near natural levels may be interpreted to mean. Perhaps the most useful standard may be to set levels that are appropriate goals for the context in which the assessment is to be undertaken.

6.5 Conclusion

This analysis shows that notable improvement in ecological value can be achieved by implementing a planning strategy for open space systems that embraces the concept of ecological networks. The results shown here use a series of landscape structure indicators at a single point in time. Longer term studies and a broadening of data collected and analyzed may yield additional information about the viability of "natural systems" in an urban context. This chapter does not address the range of related benefits provided by an urban ecological network (i.e. recreational opportunities, aesthetic quality, cultural identity), but it is important to include these factors in any comprehensive study to understand the full benefits of this approach.

Chapter Seven

Discussion and Conclusions

7.1 Introduction

This study examines a method for planning and the viability of ecological networks in urban landscapes. In particular, the southwestern U.S. urban area of Phoenix, Arizona is used to test this case. The overall goal of this research is to find ways in which planning can preserve or restore the ecological integrity of critical natural systems while allowing for compatible human activities within the network and continued productive (economic) use of adjacent lands. The fundamental questions relates to the viability of planning an ecological network in an urban landscape. The objectives of the study were to 1) develop and articulate a planning method that will demonstrate how ecological concepts, and in particular, the concept of ecological networks can be integrated into the urban planning process; and 2) to examine the viability of an ecological network in an urban context. It is intended that the establishment of a planning method and procedure for testing viability of an ecological network will make this applicable in other contexts.

The concept of ecological integrity provides a useful goal toward establishing sustainable environment and in particular, urban environments. Several indicators of the four attributes (production, biodiversity, soil and water) of ecological integrity noted by Forman (1995) are used in the assessment of viability undertaken in this study. Forman (1995) suggests that the goal of ecological integrity can be reached by sustaining near natural levels of functioning of the indicators. While the goal is worthwhile, establishing a standard for "near natural" conditions and then obtaining suitable data to measure this condition is difficult. In this study the concept or ecological integrity was used to guide the assay of ecological network viability and if in the future standards are established and data are available, then it could be more fully integrated into the process.

7.2 Discussion of Planning Methods and Results

The planning method articulated in this study used a hierarchical approach; specifically at landscape (regional), community (local) and site scale. In addition, the method employs a systems approach so that ecological relationships are studied within a given context. The method allows for flexibility in analysis because many elements are relevant at more that one scale, connected between scales and exist within a larger system. The hierarchical approach is critical not only to understand the ecological relationships, but is also important within the urban planning context. It does, however, have some weak links that should be clarified before adopted in this or similar methods.

Discussion of Planning Method - In Arizona, as in many U.S. states, planning authority rests mainly at the municipal level. Each city has responsibility for planning within its boundaries and also the influence area surrounding the municipality. In an urban area like metropolitan Phoenix, with more that twenty separate municipalities, the task of coordinating planning activities is daunting. The Maricopa Association of Governments (MAG) is an organization that meets to formulate planning strategies for the Phoenix urban area. Its board is comprised of representative from the various municipalities. This body is best suited to guide the establishment of the landscape (regional) scale ecological network since its purview is the entire metropolitan area. The difficulty is that this group has historically been ineffective in acting for the collective good and more focused on providing for individual municipal interests. Consequently, it is important to ensure that the planning method is geared to municipal scale decision making. The example outlined in this study, requires detailed analysis and coordination at landscape or regional scale, but recognizes that implementation is managed at the municipal level through specific area plans, open space master plans, site restoration or improvement plans and others. Individual site studies on private property are also generally controlled at the municipal level. If ecological network goals have been adopted by the municipality then appropriate tools may be used to provide incentive or exercise leverage to implement. The key is that implementation in this context will occur incrementally as opportunities for site improvements and landscape change to occur. As a result, it is important that there be a long-term perspective, accompanied by specific planning and design strategies at the municipal level.

Discussion of Viability Assessment - The assessment of ecological network viability indicates that modest but notable improvements in ecological values can be achieved following the optimal ecological network plan as outlined in this document. The limitations established in this study concerning the use of existing open space elements to construct an ecological network result in a conservative, yet practical approach. Clearly, greater emphasis on acquisition of open space to be incorporated into the ecological network would substantially increase the viability. However, one of the most significant limitations in an urban context with limited planning will or authority, is that the economics must be clearly supportive for municipalities to acquire expensive land for open space.

In the patch content analysis, the most notable adjustments are:

1) increase in the mean native vegetation coverage of 10%,
2) increase in matrix utility value of 14%, and
3) increase in naturalness by 15%.

The implication of these adjustments in the condition of patch content is important. Replacement of exotic vegetation species with natives will increase the importance of these patches for higher valued native species of wildlife. There are numerous other social benefits including water conservation, reduction of maintenance, and regional aesthetic quality. In an urban landscape, the importance of compatibility of adjacent land uses can not be overstated. The historical pattern of land development is for urbanization to spread and encapsulate remnant patches, severing them from their supporting structure and introducing invasive species and predators along the patch edge effectively reducing the interior or core area. Increase in matrix utility value reduces the pressure on the patch and helps to slow or stop deterioration. Increase in naturalness is a useful overall indicator that ecological systems are healthier.

A review of the most notable adjustments resulting from the corridor content analysis reveals that there is an:

1) increase of mean corridor filter width of 19%,
2) increase in the mean native vegetation coverage of 9%,
3) increase in matrix utility values of 15%,
4) elimination of 59 gaps or barriers in existing corridors, and
5) increase naturalness by 17%.

In urban areas corridor filters or buffers are the first defense against introduction of harmful elements into some of the most critical ecosystems (watercourses). The importance of increasing native vegetation coverage and matrix utility values have been described previously. Elimination of gaps or barriers makes the flow within an ecological network possible. Typically, corridors are not viewed as parts of a system in urban areas and become segmented. Maintaining or restoring continuity improves ecological functioning throughout. Increase in naturalness, as with patches, is one of the best indicators of the intrinsic health of ecological systems.

The network analysis includes the following notable adjustments:

1) the overall matrix utility index increased 3%,
2) the degree of network circuitry increased by 20%, and
3) the gamma index of connectivity increased by 12%.

The modest increase in the overall matrix utility index is a function of the adjustment for percent of total area included in the analysis. In essence the matrix utility index becomes a measure of the additional usable area beyond the immediate area of patches and corridors within the ecological network. The notable increase in network circuitry is important as an indicator of the extent to which alternative migration corridors are being made available. In urban areas where the introduction of temporary barriers or domestic predators can be frequent, the presence of alternate loops has significant value. The gamma index of connectivity and the adjustment for suitability indicates that there the opportunity to sustained viability and ongoing recharge of patches and corridors is more likely.

7.3 Conclusions

This ecological network plan provides modest but important improvement in ecological systems in the Phoenix urban area. It is apparent that implementation of an ecological network in an urban area utilizing only existing open space elements is feasible and the investment required on an incremental basis is modest. More elaborate plans that include extensive property acquisition or greater land use control could increase the ecological benefits substantially and may be suitable in other urban areas. Although this method as outlined in this study is geared to a specific planning context, it may have broader application because many communities in the United States and other rapidly developing areas are faced with the problems of rapidly changing natural systems within the context of urban sprawl. The principal benefit of this approach is that it can be developed incrementally and without extensive commitment of resources. Another important result of implementing an ecological network plan in this way, may be to stop the decline of the existing ecosystems.

7.4 Future Research

The completion of this study opens many new paths of inquiry for research on ecological networks in urban landscapes. Several of the most important as noted by this author include:

1) establishing better definitions and standards for ecological integrity in urban landscapes,

2) establishment of long term data sets to test the effects of ecological network planning efforts,

3) examination of changes in urban patches and corridors over time to document the nature of landscape change,

4) develop additional measurement tools for assessing ecological network viability,

5) refine existing tools for assessing ecological network viability,

6) develop concrete information about edge effects in urban areas, and

7) develop more urban planning strategies for incorporating ecological concepts into the planning process.

Forman's (1995) four broad characteristics of ecological integrity provide a useful theoretical framework by which sustainability can be attained. However, in varied situations measures for each of these four characteristics are not clear. Forman indicates that near natural conditions should prevail, yet the literature is thin concerning how one can establish the mark for near natural. Indicators need to be made clear and more specific understanding of implications for urban landscapes need to be developed.

The establishment of an ecological network is a process that begins with the planning process, but should not end with implementation of planning concepts. Ongoing monitoring is required to determine the level of effectiveness of each recommendation. A long-term data gathering process that provides continual insight into the changes of ecological systems will inform future planning efforts.

More information is needed concerning the effects of urbanization on ecological systems over time. This study examined the current conditions of the Phoenix urban area. Although some information was available concerning the extent of urbanization that has occurred, equivalent data concerning the changes in ecological systems was not available.

Additional tools for assessment of ecological network viability are needed. This study utilized landscape structure indicators to assess viability, however, more measures are needed to fully describe the state of many biological functions.

Refinement of the tools utilized in this study is also important. Specifically, measures for naturalness need refinement. The three indicators used in this study were native vegetation cover, soils and flows. Native vegetation cover and soils are easily computed and clear indicators of naturalness. However, flows is a very important aspect of an ecosystems naturalness, yet methods to determine the level of disruption of flows are not well developed. For the purposes of this study, estimates were used based on the presence of gaps, barriers or diversion. Further research could improve this measure substantially.

Edge effect as a theoretical concept for understanding ecological interactions is well developed and understood. Effects of edge functions and edge species on interior or core habitats is also known. Problems exist, however, with the use of these concepts in spatial terms when planning for compatibility of adjacent uses or functions. In addition, mush less is know about the true effects of urbanization along the edge of remnant patches. Specific methods for determining the extent of edge influence into patch interiors would be very useful. Variations on these methods for urban, rural and other types of landscapes are also needed.

The urban planning process is principally driven by social and economic variables. The inclusion of ecology as a variable that dictates planning decisions is important. The understanding and use of ecological concepts as demonstrated in the ecological network plan in this study are important and incorporation into the planning process is feasible. However, there is currently few automatic mechanisms for ensuring they are properly addressed in any plan. These strategies need to become more fully developed.

Summary

Summary

This research focuses on the topic of ecological networks in urban landscapes. Analysis and planning of ecological networks is a relatively new phenomenon and is a response to fragmentation and deterioration of quality of natural systems. In agricultural areas and with existing nature preserves this work has been advancing. In urban areas, however, the problems of land use intransigence, political and jurisdictional issues create a difficult environment for implementing ecological networks. Differences also exist between Europe and North America. In North America, and in particular the western United States, planning authority rests with individual municipalities, making planning at landscape or regional scale difficult.

The specific questions addressed in this research program revolve around the viability of planning an ecological network in an urban landscape. Can such a concept withstand the tests it will be given in a political and economic context of an urban planning process? To address this question, two principal research objectives were established. First, the development and articulation of a planning method will demonstrate that ecological concepts, and in particular the concept of ecological networks, can be integrated into the urban planning process. Second, the establishment of an ecological network will improve the viability of ecological systems in an urban context. This research provides a theoretical framework and a model to test this proposition. A planning method is articulated and a series of assays of landscape structure are used to examine the viability of an ecological network in the Phoenix, Arizona urban area. It is intended that the establishment of a planning method and a structure for assay will make this concept applicable in various urban situations.

The planning method is most appropriately characterised as a hierarchical systems approach. Analysis and planning occur at three scales: 1) landscape (regional); 2) community (municipal); and 3) site (local). At landscape scale, the Phoenix, Arizona urban area (7,300 sq. km.) is studied. At the community level, the city of Scottsdale Arizona (480 sq. km.) is examined. And, at site scale, a number of patches and corridors ranging from 15 to 75,000 hectares are studied. The systems studied include hydrological, habitat and cultural. These are examined independently to ensure integrity from each specific perspective and then integrated to establish a multiple use perspective in the ecological network.

The planning method includes 10 steps. First is the definition of the study area by integrating political and natural boundaries. Second is examination of the regional context. Third is documentation of landscape change within the study area by examining historical aerial photographs and other records. Fourth is assessment of natural and cultural resources at landscape scale and determination of existing and potential value as ecological network components. Fifth is formulation of independent landscape scale system plans for hydrology, habitat and cultural opportunities. Sixth is formulation of a multiple use ecological network plan at landscape scale, establishing priorities for ranking of integrated uses and identification of sites for restoration, preservation or management. Seventh is development of community level system plans for hydrology, habitat and cultural opportunities. These are prepared at the scale of individual municipalities. Eighth is development of a multiple use network plan at community scale that ties back to the landscape scale plan. Ninth is development of local or site plans for network elements to facilitate preservation, restoration or management. And tenth is continual monitoring and feedback.

Based on the previously described method, an optimal plan was developed for the Phoenix urban area, the municipality of Scottsdale and six prototypical network sites. An assessment of the optimal plan was undertaken using landscape structure indicators. Three principal analyses were utilized: 1) patch content analysis; 2) corridor content analysis; and 3) network structure analysis. Patch and corridor content analyses examined the internal characteristic and immediate context for each of the 89 ecological network elements. The network structure analysis incorporates a process for aggregating results of patch and corridor analyses and incorporates indicators that describe interrelationships between landscape elements. For each of these analyses the existing condition was compared to the optimal plan to demonstrate the level of change that can be expected.

The most notable results of this assessment indicate the following. The patch content analysis reveals 1) an increase in mean native vegetation coverage of 10%, 2) an increase in matrix utility value of 14%, and 3) an increase in naturalness of 15%. The corridor content analysis reveals 1) an increase in mean corridor filter width of 19%, 2) an increase in mean vegetation coverage of 9%, 3) an increase in matrix utility values of 15%, 4) elimination of 59 gaps or barriers in existing corridors, and

5) an increase in naturalness of 17%. The network structure analysis reveals 1) an increase in overall matrix utility index of 3%, 2) the degree of network circuitry increased by 20% and 3) the gamma index of connectivity increased by 12%.

The conclusions of this research are that an ecological network plan provides modest but important improvement in ecological systems in the Phoenix urban area. It is apparent that implementation of an ecological network in an urban area utilising existing open space elements is feasible and the investment required is modest. Although this method, as outlined in this study, is geared to a specific planning context, it may have applications in other similarly expanding communities in North America or elsewhere. The principal benefit of this approach is that it can be developed incrementally and without initial commitment of extensive resources. Finally, the use of landscape structure indicators provides another useful tool for assessing viability of ecological networks. As these indicators are used more extensively thresholds can be recognized that will help understand the health of these systems.

Samenvatting

Samenvatting

Het onderzoek richt zich op het concept van ecologische netwerken in verstedelijkte landschappen. Analysen en planning van ecologische netwerken is een relatief nieuw fenomeen als een reactie op versnippering en verlies van natuurlijke systemen. Dit type benaderingen vindt reeds vele toepassingen in landbouwgebieden en in natuurgebieden. In verstedelijkte gebieden echter zijn er problemen met betrekking tot landgebruiksveranderingen, politieke en gerechtelijke aspecten. Deze maken het moeilijker om het concept van ecologische netwerken toe te passen. Ten aanzien van dit punt bestaan er bovendien grote verschillen tussen Europa en Noord-Amerika. Planning vindt in Noord-Amerika alleen plaats op gemeentelijk niveau. Dit maakt planning op landschapsniveau of op regionale schaal moeilijk.

De speciale vraagstukken die in het onderzoek aan de orde komen concentreren zich rond de levensvatbaarheid van het concept ecologische netwerken in een verstedelijkt landschap. De vraag doet zich voor of een dergelijk concept opgewassen is tegen politieke en economische processen binnen een stedelijk planningsproces. Om hierop een antwoord te kunnen geven, werden er twee principiële onderzoeksdoelstellingen geformuleerd:

- Op de eerste plaats zal de ontwikkeling en toepassing van een planningsmethode aantonen dat ecologische principes en, zeer in het bijzonder, het concept van een ecologisch netwerk geïntegreerd kunnen worden in het stedelijk planningsproces.

- Op de tweede plaats zal de ontwikkeling van ecologische netwerken de levensvatbaarheid van ecologische systemen in een stedelijke omgeving verbeteren.

Het onderzoek creëert zowel een theoretische achtergrond als een model om deze twee uitgangspunten te testen. De planningsmethode wordt uitgelegd en een aantal beschouwingen over landschapsstructuur worden gebruikt om de levensvatbaarheid van een ecologisch netwerk in het verstedelijkt gebied van Phoenix (Arizona, USA) te onderzoeken. De uiteindelijke bedoeling is om een plannings- en analysemethode te ontwikkelen die het mogelijk maakt het concept toe te passen in verschillende verstedelijkte gebieden.

De planningsmethode kan het beste omschreven worden als een hiërarchische-systeem-benadering. De analysen en de planning worden op 3 niveaus uitgevoerd:

1. het landschap (of regionale) niveau;
2. het gemeentelijke niveau;
3. het gebieds- of locale niveau.

Voor wat het landschapsniveau betreft is het gebied van Phoenix (Arizona, USA) bestudeerd (7.300 km^2). Op gemeentelijk niveau is de stad Scottsdale (Arizona, USA) bestudeerd (480 km^2). En voor het gebiedsniveau zijn een aantal habitatplekken (patches) en verbindingszones, variërend van 15 tot 75.000 hectares bestudeerd. De bestudeerde systemen omvatten hydrologische, habitat- en socio-economische aspecten. Deze aspecten worden onafhankelijk van elkaar bestudeerd teneinde de integriteit van elk specifiek te verzekeren. Daarna worden ze geïntegreerd teneinde een meervoudig gebruiksperspectief van het ecologische netwerk tot stand te brengen.

De planningsmethode omvat 10 stappen. Op de eerste plaats is het studiegebied afgebakend door zowel politieke als natuurlijke grenzen in beschouwing te nemen. Op de tweede plaats is het studiegebied bekeken in zijn regionale context. Ten derde zijn de landschapsveranderingen vastgelegd, door bestudering van historische luchtfoto's en andere bronnen. Ten vierde zijn de natuurlijke en socio-economische "bronnen" op landschapsschaal-niveau op elkaar afgestemd en zijn de bestaande en potentiële waarden binnen de componenten van het ecologische netwerk bepaald. Op de vijfde plaats worden er plannen gemaakt, onafhankelijk van elkaar, voor de hydrologie, habitat en socio-economische mogelijkheden. Ten zesde is een meervoudig ecologisch netwerk op landschapsschaal-niveau ontworpen, waarbij een prioriteitsvolgorde voor geïntegreerd gebruik is gemaakt. Tevens zijn gebieden vastgesteld die in aanmerking komen voor herstel, behoud of beheer. Op de zevende plaats komt de ontwikkeling van plannen op gemeentelijk niveau met betrekking tot de hydrologische habitats- en socio-economische mogelijkheden. Deze plannen zijn gemaakt voor elk van de gemeenten afzonderlijk. Ten achtste wordt een meervoudig netwerkplan gemaakt op gemeentelijk niveau dat gebaseerd is op het landschapsschaal-plan. Op de negende plaats worden locale en gebiedsplannen gemaakt met betrekking tot het voorzien van elementen ten behoeve van het behoud, herstel en beheer. De laatste stap bestaat uit een continu bijhouden van de ontwikkelingen en een feedback in het planningssysteem.

Gebaseerd op de beschreven planningsmethode is een optimaal plan ontwikkeld voor de gebieden in het verstedelijkte en stedelijke gebied rond en in Phoenix, alsook voor de gemeente Scottsdale en voor zes typische netwerkgebieden.

Dit optimale plan werd aangepast door gebruik te maken van landschapsstructuurindicatoren.

Daarbij werden drie principiële analysen uitgevoerd:

1. habitatinhoud-analyse;
2. corridorinhoud-analyse;
3. netwerkstructure-analyse.

De eerste twee analysen bestudeert de interne karakteristieken en de feitelijke inhoud van elk van de 89 ecologische-netwerkelementen. De netwerkstructuur-analyse omvat een proces dat de resultaten van de habitat- en corridoranalysen verzamelt en inbrengt in de indicatoren die het verband tussen landschapselementen beschrijven. Voor elk van deze analysen werd de bestaande situatie vergeleken met het optimale plan om zo de omvang van veranderingen, die verwacht kunnen worden, te laten zien.

De meest opvallende resultaten van deze aanpassing zijn gegeven in het hiernavolgende. De habitatinhoud-analyse laat zien:

a) een toename van de gemiddelde bedekkingsgraad door de oorspronkelijke vegetatie met 10%;

b) een toename van de matrix-gebruikswaarde met 14%;

c) een toename in natuurlijkheid met 15%.

De corridorinhoud-analyse laat zien:

a) een toename van de gemiddelde corridorwijdte met 19%;

b) een toename in de gemiddelde bedekkingsgraad met 9%;

c) een toename van de matrix-gebruikswaarde met 15%;

d) het verdwijnen van 59 gaten of barrières in bestaande corridors;

e) een toename in natuurlijkheid met 19%.

De netwerkstructuur-analyse laat zien:

a) een toename van de overall matrix gebruiksindex met 3%;

b) de mate van netwerksamenhang nam met 20% toe;

c) de j-index voor samenhang nam met 12% toe.

De bevindingen van het onderzoek zijn op de eerste plaats dat een ecologisch netwerkplan voorziet in bescheiden maar belangrijke verbeteringen in het verstedelijkt gebied in Phoenix. Het maakt zonder meer duidelijk dat toepassing van ecologische netwerken in verstedelijkte gebieden, door gebruik te maken van elementen in de open ruimte, zeer goed mogelijk is, terwijl tegelijkertijd de investeringen niet hoog zijn. Ofschoon de methode, zoals in het proefschrift omschreven, vooral gericht is op een speciale planningscontext, kan het ook toegepast worden in andere, vergelijkbare, gebieden in Noord-Amerika en elders. Het belangrijkste resultaat van de beschreven aanpak is dat het per onderdeel verder ontwikkeld kan worden, zonder dat direct belangrijke nieuwe bronnen nodig zijn.

Het gebruik van landschapsstructuur-indicatoren, tenslotte, geeft nieuwe waardevolle hulpmiddelen om de levensvatbaarheid van ecologische netwerken aan te passen. Daar deze indicatoren veel gebruikt worden, kunnen tekortkomingen snel ontdekt worden die op hun beurt de kwaliteit van het systeem helpen begrijpen.

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Appendix

Figure A.1 *Modification Gradient*

Figure A.2 *Isolation*

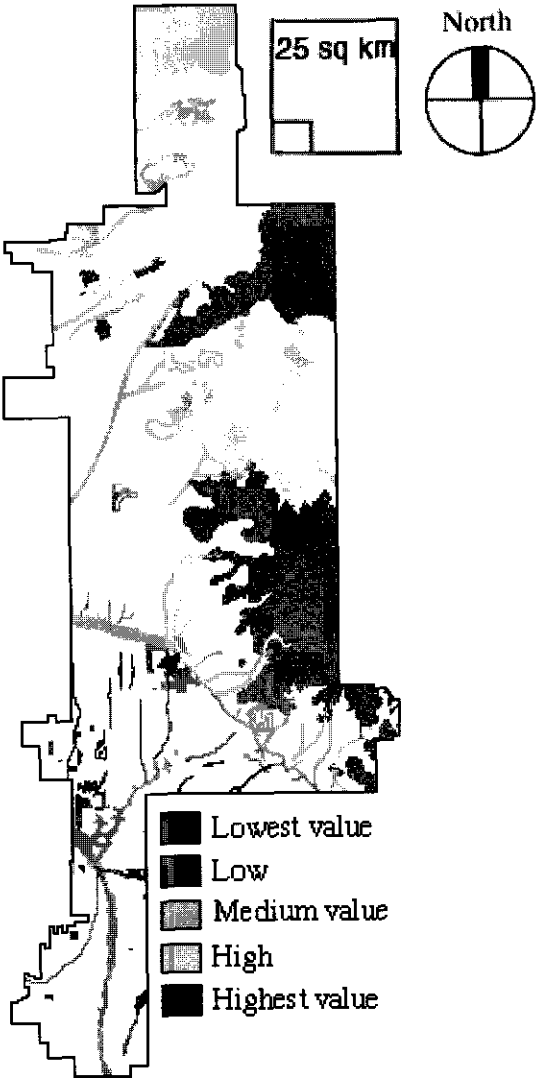

Figure A.3 *Barriers*

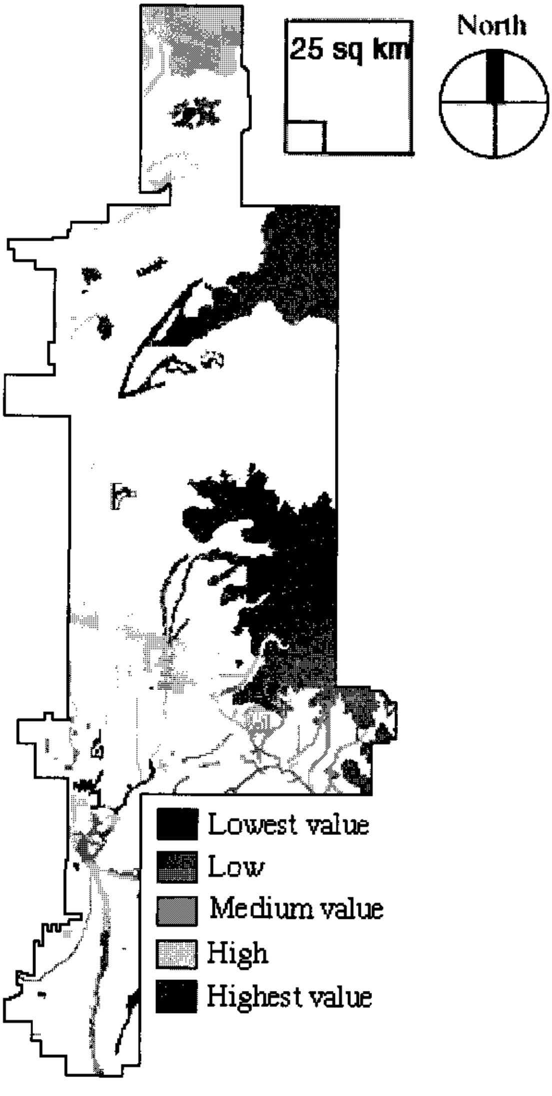

Figure A.4 *Connectivity*

Figure A.5 *Uniqueness*

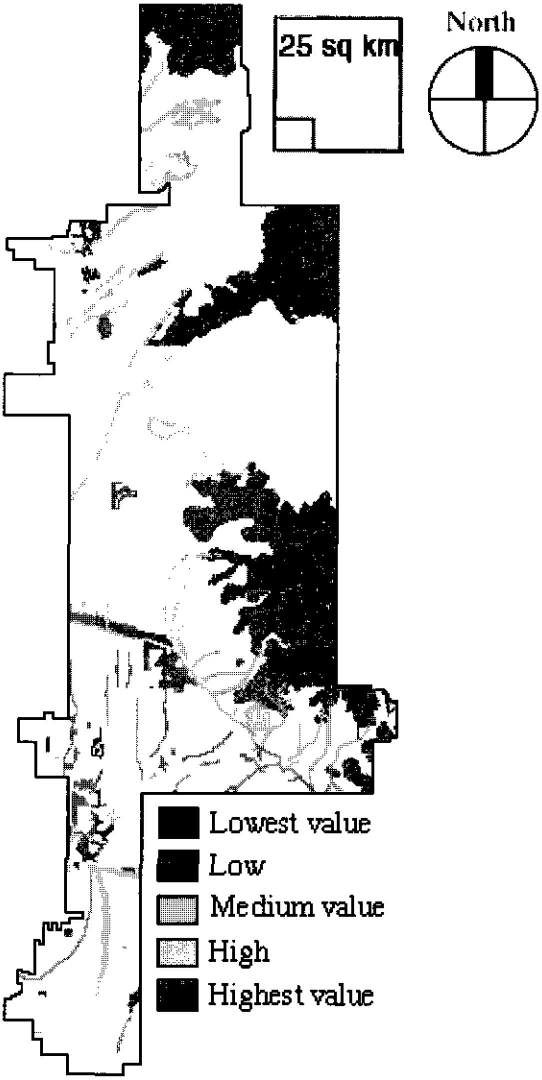

Figure A.6 *Naturalness*

Figure A.7 *Biodiversity*

Figure A.8 *Physical Diversity*

Table A.1: Patch Size and Type

No./Name	Origin	Type	Area (ha.)	Perimeter (m.)	P/A Ratio
PN1- A Mtn	Natural	Remnant	52.00	3,914.00	0.15
PN2-Camelbk	Natural	Remnant	369.00	11,158.00	1.51
PN3-EstrMP	Natural	Remnant	11,468.00	53,121.00	1.40
PN4-FtMcDIR	Natural	Remnant	9,830.00	43,463.00	1.23
PN5-GilaIR	Natural	Remnant	75,336.00	163,551.00	1.68
PN6-Hedgpth	Natural	Remnant	698.00	21,219.00	2.26
PN7-Hedgpth2	Natural	Remnant	752.00	15,402.00	1.58
PN8-LkPlsnt	Natural	Remnant	6,420.00	42,819.00	1.50
PN9-McDPk	Natural	Remnant	15,155.00	50,868.00	1.16
PN10-PapPk	Natural	Remnant	947.00	15,987.00	1.46
PN11-PhxMt	Natural	Remnant	3,146.00	61,243.00	3.09
PN12-SRIR	Natural	Remnant	17,674.00	68,897.00	1.46
PN13-SanTan	Natural	Remnant	3,809.00	42,497.00	1.94
PN14-SthMtn	Natural	Remnant	9,093.00	48,936.00	1.44
PN15-McDPr	Natural	Remnant	3,537.00	32,839.00	1.56
PN16-Usery	Natural	Remnant	2,816.00	3,316.00	0.14
PN17-Wstcrt	Natural	Remnant	35.00	245.00	0.11
PC1-ASUCamp	Cultural	Introduced	93.00	3,804.00	1.11
PC2-ASUWest	Cultural	Introduced	128.00	4,829.00	1.20
PC3-BosnPk	Cultural	Introduced	58.00	3,073.00	1.13
PC4-CircKPk	Cultural	Introduced	15.00	1,609.00	1.17
PC5-EncanPk	Cultural	Introduced	83.00	5,707.00	1.76
PC6-EstrGC	Cultural	Introduced	43.00	4,792.00	2.06
PC7-SanMaGC	Cultural	Introduced	74.00	4,353.00	1.43
PC8-FreesPk	Cultural	Introduced	26.00	2,195.00	1.21
PC9-GaineyRc	Cultural	Introduced	158.00	25,097.00	5.63
PC10-HohokP	Cultural	Introduced	53.00	3,622.00	1.40
PC11-KiwanP	Cultural	Introduced	48.00	3,878.00	1.57
PC12-PionPk	Cultural	Introduced	18.00	2,121.00	1.41
PC13-PlazPk	Cultural	Introduced	45.00	3,841.00	1.61
PC14-Pueblo	Cultural	Introduced	59.00	3,292.00	1.20
PC15-RiverP	Cultural	Introduced	83.00	4,170.00	1.29
PC16-Tovrea	Cultural	Introduced	19.00	1,865.00	1.20
PC18-AdobeD	Cultural	Introduced	629.00	14,085.00	1.58
Subtotal Natural Patch			161,137.00		
Subtotal Cultural Patch			1,632.00		
Total			162,769.00	771,808.00	
Mean			4,650.54	22,051.65	1.48

Table A.2: Patch Vegetative Structure and Diversity

No./Name	Veg. Cover	Native Cover	Struct. Div.	Total Veg. Val.
PN1- A Mtn	0.15	0.15	0.22	0.52
PN2-Camelbk	0.30	0.30	0.55	1.15
PN3-EstrMP	0.33	0.33	0.58	1.24
PN4-FtMcDIR	0.33	0.32	0.58	1.23
PN5-GilaIR	0.34	0.26	0.53	1.13
PN6-Hedgpth	0.33	0.33	0.58	1.24
PN7-Hedgpth2	0.33	0.33	0.58	1.24
PN8-LkPlsnt	0.28	0.28	0.48	1.04
PN9-McDPk	0.33	0.33	0.58	1.24
PN10-PapPk	0.39	0.32	0.67	1.38
PN11-PhxMt	0.33	0.33	0.58	1.24
PN12-SRIR	0.35	0.24	0.42	1.01
PN13-SanTan	0.33	0.33	0.58	1.24
PN14-SthMtn	0.31	0.31	0.54	1.16
PN15-McDPr	0.33	0.33	0.58	1.24
PN16-Usery	0.33	0.33	0.58	1.24
PN17-Wstcrt	0.28	0.07	0.35	0.70
PC1-ASUCamp	0.10	0.00	0.17	0.27
PC2-ASUWest	0.24	0.00	0.35	0.59
PC3-BosnPk	0.58	0.00	0.98	1.56
PC4-CircKPk	0.33	0.00	0.58	0.91
PC5-EncanPk	0.58	0.00	0.98	1.56
PC6-EstrGC	0.58	0.00	0.98	1.56
PC7-SanMaGC	0.58	0.00	0.64	1.22
PC8-FreesPk	0.58	0.00	0.98	1.56
PC9-GaineyRc	0.58	0.00	0.98	1.56
PC10-HohokP	0.58	0.00	0.98	1.56
PC11-KiwanP	0.58	0.00	0.98	1.56
PC12-PionPk	0.58	0.00	0.98	1.56
PC13-PlazPk	0.58	0.00	0.98	1.56
PC14-Pueblo	0.33	0.33	0.58	1.24
PC15-RiverP	0.58	0.00	0.58	1.16
PC16-Tovrea	0.33	0.33	0.58	1.24
PC18-AdobeD	0.33	0.26	0.58	1.17
Mean	0.38	0.17	0.62	1.17

Table A.3:
Patch Context

No./Name	Matrix Util.	Isolation Index	T-Links
PN1- A Mtn	0.38	2.34	0.00
PN2-Camelbk	0.69	2.43	0.00
PN3-EstrMP	1.00	1.35	3.00
PN4-FtMcDIR	0.97	1.03	4.00
PN5-GilaIR	0.71	1.77	4.00
PN6-Hedgpth	0.70	0.62	2.00
PN7-Hedgpth2	0.97	1.60	0.00
PN8-LkPlsnt	1.00	1.00	1.00
PN9-McDPk	0.95	1.38	4.00
PN10-PapPk	0.38	2.35	0.00
PN11-PhxMt	0.50	0.65	0.00
PN12-SRIR	0.84	1.48	10.00
PN13-SanTan	1.00	1.00	0.00
PN14-SthMtn	0.45	2.03	1.00
PN15-McDPr	0.65	1.36	6.00
PN16-Usery	0.89	2.80	0.00
PN17-Wstcrt	0.20	3.46	0.00
PC1-ASUCamp	0.50	2.48	1.00
PC2-ASUWest	0.50	1.40	0.00
PC3-BosnPk	0.50	3.65	0.00
PC4-CircKPk	0.65	1.53	1.00
PC5-EncanPk	0.50	0.95	0.00
PC6-EstrGC	0.59	1.60	0.00
PC7-SanMaGC	0.50	2.68	0.00
PC8-FreesPk	0.45	0.01	2.00
PC9-GaineyRc	0.50	2.50	0.00
PC10-HohokP	0.50	2.32	0.00
PC11-KiwanP	0.50	3.06	1.00
PC12-PionPk	0.50	2.47	0.00
PC13-PlazPk	0.61	2.41	0.00
PC14-Pueblo	0.30	2.11	0.00
PC15-RiverP	0.44	2.55	1.00
PC16-Tovrea	0.20	2.27	0.00
PC18-AdobeD	0.71	2.40	2.00
Total			43.00
Mean	0.59	1.51	1.23

Table A.4: Patch Naturalness

No./Name	Native Veg.	Soils	Flows	Total Nat. Val.
PN1- A Mtn	0.15	0.60	0.40	1.15
PN2-Camelbk	0.30	0.90	0.40	1.60
PN3-EstrMP	0.33	1.00	0.90	2.23
PN4-FtMcDIR	0.33	0.90	0.90	2.13
PN5-GilaIR	0.26	0.75	0.60	1.61
PN6-Hedgpth	0.33	0.90	0.80	2.03
PN7-Hedgpth2	0.33	0.90	0.80	2.03
PN8-LkPlsnt	0.28	0.80	0.70	1.78
PN9-McDPk	0.33	0.90	0.80	2.03
PN10-PapPk	0.32	0.60	0.60	1.52
PN11-PhxMt	0.33	0.90	0.80	2.03
PN12-SRIR	0.24	0.80	0.70	1.74
PN13-SanTan	0.33	0.90	0.90	2.13
PN14-SthMtn	0.31	0.70	0.70	1.71
PN15-McDPr	0.33	0.90	0.90	2.13
PN16-Usery	0.33	0.90	0.90	2.13
PN17-Wstcrt	0.07	0.20	0.20	0.47
PC1-ASUCamp	0.00	0.00	0.00	0.00
PC2-ASUWest	0.00	0.00	0.00	0.00
PC3-BosnPk	0.00	0.00	0.00	0.00
PC4-CircKPk	0.00	0.00	0.00	0.00
PC5-EncanPk	0.00	0.00	0.00	0.00
PC6-EstrGC	0.00	0.00	0.20	0.20
PC7-SanMaGC	0.00	0.00	0.00	0.00
PC8-FreesPk	0.00	0.00	0.00	0.00
PC9-GaineyRc	0.00	0.00	0.00	0.00
PC10-HohokP	0.00	0.00	0.00	0.00
PC11-KiwanP	0.00	0.00	0.00	0.00
PC12-PionPk	0.00	0.00	0.00	0.00
PC13-PlazPk	0.00	0.00	0.00	0.00
PC14-Pueblo	0.33	0.20	0.00	0.53
PC15-RiverP	0.00	0.00	0.00	0.00
PC16-Tovrea	0.33	0.40	0.00	0.73
PC18-AdobeD	0.26	0.70	0.20	1.16
Mean	0.17	0.42	0.35	0.94

Table A.5: Corridor Size and Type

No./Name	Origin	Type	Length	Ave. Width	Int. Width
CN1-AguaFria	Natural	Environmental	57,950.00	790.00	0.90
CN2-CaveCrk	Natural	Environmental	37,100.00	200.00	0.85
CN3-GilaRivr	Natural	Environmental	90,146.00	1,500.00	0.80
CN4-GranRf	Natural	Environmental	9,500.00	800.00	0.80
CN5-NewRiver	Natural	Environmental	45,100.00	680.00	0.90
CN6-QueenCr	Natural	Environmental	35,400.00	75.00	0.70
CN7-SaltRivr	Natural	Environmental	52,300.00	400.00	0.95
CN8-VerdeRv	Natural	Environmental	27,000.00	1,500.00	0.70
CN9-WtrmnW	Natural	Environmental	17,700.00	75.00	0.70
CN10-Shea1	Natural	Environmental	12,800.00	60.00	0.80
CN11-Shea2	Natural	Environmental	8,000.00	60.00	0.80
CN12-Shea3	Natural	Environmental	6,500.00	60.00	0.80
CN13-Shea4	Natural	Environmental	6,000.00	60.00	0.80
CN14-SkunkC	Natural	Environmental	48,300.00	200.00	0.85
CN15-IdBndN	Natural	Environmental	14,500.00	80.00	0.80
CC1-AzCanal	Cultural	Introduced	51,500.00	50.00	0.30
CC2-AzCrCut	Cultural	Introduced	5,800.00	50.00	0.30
CC3-BckeyeC	Cultural	Introduced	22,500.00	50.00	0.30
CC4-CAPCanal	Cultural	Introduced	85,500.00	50.00	0.30
CC5-ConsCan	Cultural	Introduced	37,000.00	50.00	0.30
CC6-CrCutCan	Cultural	Introduced	3,850.00	50.00	0.30
CC7-EMarFl	Cultural	Introduced	35,400.00	50.00	0.60
CC8-EastCanal	Cultural	Introduced	32,400.00	50.00	0.30
CC9-GrndCan	Cultural	Introduced	35,800.00	50.00	0.30
CC10-IndBdS	Cultural	Introduced	20,000.00	500.00	0.80
CC11-KyrCan	Cultural	Introduced	22,500.00	50.00	0.30
CC12-OldVrdC	Cultural	Introduced	19,300.00	50.00	0.30
CC13-RsvltCan	Cultural	Introduced	25,700.00	50.00	0.30
CC14-SBrHigh	Cultural	Introduced	16,100.00	50.00	0.30
CC15-TmpCan	Cultural	Introduced	15,200.00	50.00	0.30
CC16-WstrnC	Cultural	Introduced	15,000.00	50.00	0.30
CC17-ThnPas	Cultural	Introduced	9,500.00	65.00	0.80
Total			921,346.00		
Mean			28,792.00	245.00	0.58

Table A.5: Continued

Filter Width	Area (ha.)
0.10	4,578.00
0.15	742.00
0.20	13,521.90
0.20	760.00
0.10	3,066.80
0.30	265.50
0.05	2,092.00
0.30	4,050.00
0.30	132.70
0.20	76.80
0.20	48.00
0.20	39.00
0.20	36.00
0.15	966.00
0.20	116.00
0.00	257.50
0.00	29.00
0.00	112.50
0.00	427.50
0.00	185.00
0.00	19.20
0.40	177.00
0.00	162.00
0.00	179.00
0.20	1,000.00
0.00	112.50
0.00	965.00
0.00	128.50
0.00	80.50
0.00	76.00
0.00	75.00
0.20	61.70
	34,538.60
0.11	1,079.33

Table A.6: Corridor Vegetative Structure and Diversity

No./Name	Veg. Cover	Native Cover	Struct. Div.	Total Veg. Val.
CN1-AguaFria	0.30	0.30	0.51	1.11
CN2-CaveCrk	0.30	0.30	0.51	1.11
CN3-GilaRivr	0.38	0.38	0.66	1.42
CN4-GranRf	0.38	0.38	0.66	1.42
CN5-NewRiver	0.30	0.30	0.51	1.11
CN6-QueenCr	0.38	0.38	0.66	1.42
CN7-SaltRivr	0.18	0.18	0.31	0.67
CN8-VerdeRv	0.38	0.38	0.96	1.72
CN9-WtrmnW	0.38	0.38	0.66	1.42
CN10-Shea1	0.38	0.38	0.66	1.42
CN11-Shea2	0.38	0.38	0.66	1.42
CN12-Shea3	0.38	0.38	0.66	1.42
CN13-Shea4	0.38	0.38	0.66	1.42
CN14-SkunkC	0.30	0.30	0.51	1.11
CN15-IdBndN	0.38	0.38	0.66	1.42
CC1-AzCanal	0.00	0.00	0.00	0.00
CC2-AzCrCut	0.00	0.00	0.00	0.00
CC3-BckeyeC	0.00	0.00	0.00	0.00
CC4-CAPCanal	0.00	0.00	0.00	0.00
CC5-ConsCan	0.00	0.00	0.00	0.00
CC6-CrCutCan	0.00	0.00	0.00	0.00
CC7-EMarFl	0.00	0.00	0.00	0.00
CC8-EastCanal	0.00	0.00	0.00	0.00
CC9-GrndCan	0.00	0.00	0.00	0.00
CC10-IndBdS	0.58	0.00	0.98	1.56
CC11-KyrCan	0.00	0.00	0.00	0.00
CC12-OldVrdC	0.00	0.00	0.00	0.00
CC13-RsvltCan	0.00	0.00	0.00	0.00
CC14-SBrHigh	0.00	0.00	0.00	0.00
CC15-TmpCan	0.00	0.00	0.00	0.00
CC16-WstrnC	0.00	0.00	0.00	0.00
CC17-ThnPas	0.58	0.00	0.98	1.56
Mean	0.20	0.16	0.35	0.71

Table A.7: Corridor Context

No./Name	Matrix Util.	Div. Gradient	T-Gaps	Long. Con. Dist.	Link Seg.
CN1-AguaFria	0.56	245.00	0.00	57,950.00	4.00
CN2-CaveCrk	0.50	240.00	5.00	22,260.00	2.00
CN3-GilaRivr	0.76	150.00	0.00	90,146.00	3.00
CN4-GranRf	1.00	50.00	1.00	9,500.00	1.00
CN5-NewRiver	0.54	360.00	0.00	45,100.00	2.00
CN6-QueenCr	0.40	200.00	0.00	35,400.00	1.00
CN7-SaltRivr	0.66	275.00	0.00	52,300.00	12.00
CN8-VerdeRv	0.99	50.00	0.00	27,000.00	4.00
CN9-WtrmnW	0.76	30.00	0.00	17,700.00	1.00
CN10-Shea1	0.81	80.00	0.00	12,800.00	3.00
CN11-Shea2	0.81	80.00	0.00	8,000.00	3.00
CN12-Shea3	0.81	50.00	0.00	6,500.00	3.00
CN13-Shea4	0.81	50.00	0.00	6,000.00	2.00
CN14-SkunkC	0.50	300.00	1.00	33,810.00	2.00
CN15-IdBndN	0.97	150.00	1.00	14,500.00	1.00
CC1-AzCanal	0.43	30.00	7.00	7,500.00	7.00
CC2-AzCrCut	0.78	5.00	1.00	7,500.00	1.00
CC3-BckeyeC	0.48	15.00	3.00	7,500.00	1.00
CC4-CAPCanal	0.90	50.00	1.00	51,300.00	10.00
CC5-ConsCan	0.50	40.00	5.00	7,500.00	5.00
CC6-CrCutCan	0.38	5.00	0.00	3,850.00	1.00
CC7-EMarFl	0.53	40.00	5.00	7,500.00	2.00
CC8-EastCanal	0.55	40.00	4.00	7,500.00	1.00
CC9-GrndCan	0.40	40.00	5.00	7,500.00	2.00
CC10-IndBdS	0.44	65.00	4.00	7,500.00	4.00
CC11-KyrCan	0.51	25.00	3.00	7,500.00	3.00
CC12-OldVrdC	0.90	25.00	3.00	7,500.00	3.00
CC13-RsvltCan	0.36	20.00	3.00	7,500.00	1.00
CC14-SBrHigh	0.51	15.00	2.00	7,500.00	1.00
CC15-TmpCan	0.47	15.00	2.00	7,500.00	1.00
CC16-WstrnC	0.50	15.00	2.00	7,500.00	1.00
CC17-ThnPas	0.50	10.00	1.00	4,750.00	1.00
Total		2,765.00	59.00		89.00
Mean	0.62	86.40	1.84	18,870.00	2.78

Table A.8: Corridor Naturalness

No./Name	Native Veg.	Soils	Flows	Total Nat. Val.
CN1-AguaFria	0.30	0.70	0.90	1.90
CN2-CaveCrk	0.30	0.70	0.90	1.90
CN3-GilaRivr	0.38	0.80	0.80	1.98
CN4-GranRf	0.38	0.90	0.80	2.08
CN5-NewRiver	0.30	0.70	0.80	1.80
CN6-QueenCr	0.38	0.90	0.90	2.18
CN7-SaltRivr	0.18	0.60	0.60	1.38
CN8-VerdeRv	0.38	0.90	0.90	2.18
CN9-WtrmnW	0.38	0.90	0.90	2.18
CN10-Shea1	0.38	0.80	0.80	1.98
CN11-Shea2	0.38	0.80	0.80	1.98
CN12-Shea3	0.38	0.80	0.80	1.98
CN13-Shea4	0.38	0.80	0.80	1.98
CN14-SkunkC	0.30	0.70	0.90	1.90
CN15-IdBndN	0.38	0.90	0.90	2.18
CC1-AzCanal	0.00	0.00	0.00	0.00
CC2-AzCrCut	0.00	0.00	0.00	0.00
CC3-BckeyeC	0.00	0.00	0.00	0.00
CC4-CAPCanal	0.00	0.00	0.00	0.00
CC5-ConsCan	0.00	0.00	0.00	0.00
CC6-CrCutCan	0.00	0.00	0.00	0.00
CC7-EMarFl	0.00	0.00	0.00	0.00
CC8-EastCanal	0.00	0.00	0.00	0.00
CC9-GrndCan	0.00	0.00	0.00	0.00
CC10-IndBdS	0.00	0.00	0.40	0.40
CC11-KyrCan	0.00	0.00	0.00	0.00
CC12-OldVrdC	0.00	0.00	0.00	0.00
CC13-RsvltCan	0.00	0.00	0.00	0.00
CC14-SBrHigh	0.00	0.00	0.00	0.00
CC15-TmpCan	0.00	0.00	0.00	0.00
CC16-WstrnC	0.00	0.00	0.00	0.00
CC17-ThnPas	0.00	0.00	0.00	0.00
Mean	0.17	0.37	0.40	0.94

Table A.9: Optimal Patch Size and Type

No./Name	Origin	Type	Area (ha.)	Perimeter (m.)	P/A Ratio
PN1- A Mtn	Natural	Remnant	52.00	3,914.00	0.15
PN2-Camelbk	Natural	Remnant	369.00	11,158.00	1.51
PN3-EstrMP	Natural	Remnant	11,468.00	53,121.00	1.40
PN4-FtMcDIR	Natural	Remnant	9,830.00	43,463.00	1.23
PN5-GilaIR	Natural	Remnant	75,336.00	163,551.00	1.68
PN6-Hedgpth	Natural	Remnant	698.00	21,219.00	2.26
PN7-Hedgpth2	Natural	Remnant	752.00	15,402.00	1.58
PN8-LkPlsnt	Natural	Remnant	6,420.00	42,819.00	1.50
PN9-McDPk	Natural	Remnant	15,155.00	50,868.00	1.16
PN10-PapPk	Natural	Remnant	947.00	15,987.00	1.46
PN11-PhxMt	Natural	Remnant	3,146.00	61,243.00	3.09
PN12-SRIR	Natural	Remnant	17,674.00	68,897.00	1.46
PN13-SanTan	Natural	Remnant	3,809.00	42,497.00	1.94
PN14-SthMtn	Natural	Remnant	9,093.00	48,936.00	1.44
PN15-McDPr	Natural	Remnant	3,537.00	32,839.00	1.56
PN16-Usery	Natural	Remnant	2,816.00	3,316.00	0.14
PN17-Wstcrt	Natural	Remnant	35.00	245.00	0.11
PC1-ASUCamp	Cultural	Introduced	93.00	3,804.00	1.11
PC2-ASUWest	Cultural	Introduced	128.00	4,829.00	1.20
PC3-BosnPk	Cultural	Introduced	58.00	3,073.00	1.13
PC4-CircKPk	Cultural	Introduced	15.00	1,609.00	1.17
PC5-EncanPk	Cultural	Introduced	83.00	5,707.00	1.76
PC6-EstrGC	Cultural	Introduced	43.00	4,792.00	2.06
PC7-SanMaGC	Cultural	Introduced	74.00	4,353.00	1.43
PC8-FreesPk	Cultural	Introduced	26.00	2,195.00	1.21
PC9-GaineyRc	Cultural	Introduced	158.00	25,097.00	5.63
PC10-HohokP	Cultural	Introduced	53.00	3,622.00	1.40
PC11-KiwanP	Cultural	Introduced	48.00	3,878.00	1.57
PC12-PionPk	Cultural	Introduced	18.00	2,121.00	1.41
PC13-PlazPk	Cultural	Introduced	45.00	3,841.00	1.61
PC14-Pueblo	Cultural	Introduced	59.00	3,292.00	1.20
PC15-RiverP	Cultural	Introduced	83.00	4,170.00	1.29
PC16-Tovrea	Cultural	Introduced	19.00	1,865.00	1.20
PC18-AdobeD	Cultural	Introduced	629.00	14,085.00	1.58
Total			162,769.00	771,808.00	
Mean			4,650.54	22,051.65	1.47

Table A.10: Optimal Patch Vegetative Structure and Diversity

No./Name	Veg. Cover	Native Cover	Struct. Div.	Total Veg. Val.
PN1- A Mtn	0.15	0.15	0.22	0.52
PN2-Camelbk	0.30	0.30	0.55	1.15
PN3-EstrMP	0.33	0.33	0.58	1.24
PN4-FtMcDIR	0.33	0.32	0.58	1.23
PN5-GilaIR	0.34	0.26	0.53	1.13
PN6-Hedgpth	0.33	0.33	0.58	1.24
PN7-Hedgpth2	0.33	0.33	0.58	1.24
PN8-LkPlsnt	0.28	0.28	0.48	1.04
PN9-McDPk	0.33	0.33	0.58	1.24
PN10-PapPk	0.39	0.32	0.67	1.38
PN11-PhxMt	0.33	0.33	0.58	1.24
PN12-SRIR	0.35	0.24	0.42	1.01
PN13-SanTan	0.33	0.33	0.58	1.24
PN14-SthMtn	0.31	0.31	0.54	1.16
PN15-McDPr	0.33	0.33	0.58	1.24
PN16-Usery	0.33	0.33	0.58	1.24
PN17-Wstcrt	0.28	0.07	0.35	0.70
PC1-ASUCamp	***0.15***	***0.15***	0.17	***0.47***
PC2-ASUWest	0.24	***0.15***	0.35	***0.74***
PC3-BosnPk	0.58	***0.29***	0.98	***1.85***
PC4-CircKPk	0.33	***0.29***	0.58	***1.20***
PC5-EncanPk	0.58	***0.29***	0.98	***1.85***
PC6-EstrGC	0.58	***0.29***	0.98	***1.85***
PC7-SanMaGC	0.58	***0.29***	0.64	***1.51***
PC8-FreesPk	0.58	***0.29***	0.98	***1.85***
PC9-GaineyRc	0.58	***0.29***	0.98	***1.85***
PC10-HohokP	0.58	***0.29***	0.98	***1.85***
PC11-KiwanP	0.58	***0.29***	0.98	***1.85***
PC12-PionPk	0.58	***0.29***	0.98	***1.85***
PC13-PlazPk	0.58	***0.29***	0.98	***1.85***
PC14-Pueblo	0.33	0.33	0.58	1.24
PC15-RiverP	0.58	***0.29***	0.58	***1.45***
PC16-Tovrea	0.33	0.33	0.58	1.24
PC18-AdobeD	0.33	0.26	0.58	1.17
Mean	***0.38***	***0.27***	0.62	***1.17***

Table A.11: Optimal Patch Context

No./Name	Matrix Res.	Isolation Index	T-Links
PN1- A Mtn	***0.58***	2.34	0.00
PN2-Camelbk	***0.89***	2.43	0.00
PN3-EstrMP	1.00	1.35	3.00
PN4-FtMcDIR	***1.00***	1.03	4.00
PN5-GilaIR	***0.81***	1.77	4.00
PN6-Hedgpth	***0.83***	0.62	2.00
PN7-Hedgpth2	***1.00***	1.60	0.00
PN8-LkPlsnt	1.00	1.00	1.00
PN9-McDPk	***0.97***	1.38	4.00
PN10-PapPk	***0.58***	2.35	0.00
PN11-PhxMt	***0.70***	0.65	0.00
PN12-SRIR	***0.92***	1.48	10.00
PN13-SanTan	1.00	1.00	0.00
PN14-SthMtn	***0.65***	2.03	1.00
PN15-McDPr	***0.79***	1.36	6.00
PN16-Usery	***0.90***	2.80	0.00
PN17-Wstcrt	***0.40***	3.46	0.00
PC1-ASUCamp	***0.70***	2.48	1.00
PC2-ASUWest	***0.70***	1.40	0.00
PC3-BosnPk	***0.70***	3.65	0.00
PC4-CircKPk	***0.80***	1.53	1.00
PC5-EncanPk	***0.70***	0.95	0.00
PC6-EstrGC	***0.75***	1.60	0.00
PC7-SanMaGC	***0.70***	2.68	0.00
PC8-FreesPk	***0.65***	0.01	2.00
PC9-GaineyRc	***0.70***	2.50	0.00
PC10-HohokP	***0.70***	2.32	0.00
PC11-KiwanP	***0.70***	3.06	1.00
PC12-PionPk	***0.70***	2.47	0.00
PC13-PlazPk	***0.68***	2.41	0.00
PC14-Pueblo	***0.48***	2.11	0.00
PC15-RiverP	***0.64***	2.55	1.00
PC16-Tovrea	***0.40***	2.27	0.00
PC18-AdobeD	***0.82***	2.40	2.00
Total			43.00
Mean	***0.73***	1.51	1.23

A.12: Optimal Patch Naturalness

No./Name	Native Veg.	Soils	Flows	Total Nat. Val.
PN1- A Mtn	0.15	0.60	0.40	1.15
PN2-Camelbk	0.30	0.90	0.40	1.60
PN3-EstrMP	0.33	1.00	0.90	2.23
PN4-FtMcDIR	0.33	0.90	0.90	2.13
PN5-GilaIR	0.26	0.75	0.60	1.61
PN6-Hedgpth	0.33	0.90	0.80	2.03
PN7-Hedgpth2	0.33	0.90	0.80	2.03
PN8-LkPlsnt	0.28	0.80	0.70	1.78
PN9-McDPk	0.33	0.90	0.80	2.03
PN10-PapPk	0.32	0.60	0.60	1.52
PN11-PhxMt	0.33	0.90	0.80	2.03
PN12-SRIR	0.24	0.80	0.70	1.74
PN13-SanTan	0.33	0.90	0.90	2.13
PN14-SthMtn	0.31	0.70	0.70	1.71
PN15-McDPr	0.33	0.90	0.90	2.13
PN16-Usery	0.33	0.90	0.90	2.13
PN17-Wstcrt	0.07	0.20	0.20	0.47
PC1-ASUCamp	***0.15***	***0.20***	0.20	***0.55***
PC2-ASUWest	***0.15***	***0.40***	***0.40***	***0.95***
PC3-BosnPk	***0.29***	***0.40***	***0.40***	***1.09***
PC4-CircKPk	***0.29***	***0.40***	***0.40***	***1.09***
PC5-EncanPk	***0.29***	***0.40***	***0.40***	***1.09***
PC6-EstrGC	***0.29***	***0.40***	***0.40***	***1.09***
PC7-SanMaGC	***0.29***	***0.40***	***0.40***	***1.09***
PC8-FreesPk	***0.29***	***0.40***	***0.40***	***1.09***
PC9-GaineyRc	***0.29***	***0.40***	***0.40***	***1.09***
PC10-HohokP	***0.29***	***0.40***	***0.40***	***1.09***
PC11-KiwanP	***0.29***	***0.40***	***0.40***	***1.09***
PC12-PionPk	***0.29***	***0.40***	***0.40***	***1.09***
PC13-PlazPk	***0.29***	***0.40***	***0.40***	***1.09***
PC14-Pueblo	0.33	0.40	***0.40***	***1.13***
PC15-RiverP	***0.29***	***0.40***	***0.40***	***1.09***
PC16-Tovrea	0.33	0.40	***0.40***	***1.13***
PC18-AdobeD	0.26	0.70	***0.40***	***1.36***
Mean	***0.27***	***0.59***	***0.53***	***1.39***

Table A.13: *Optimal* Corridor Size and Type

No./Name	Origin	Type	Length	Ave. Width	Int. Width
CN1-AguaFria	Natural	Environmental	57,950.00	790.00	0.90
CN2-CaveCrk	Natural	Environmental	37,100.00	200.00	0.85
CN3-GilaRivr	Natural	Environmental	90,146.00	1,500.00	0.80
CN4-GranRf	Natural	Environmental	9,500.00	800.00	0.80
CN5-NewRiver	Natural	Environmental	45,100.00	680.00	0.90
CN6-QueenCr	Natural	Environmental	35,400.00	75.00	0.70
CN7-SaltRivr	Natural	Environmental	52,300.00	400.00	0.95
CN8-VerdeRv	Natural	Environmental	27,000.00	1,500.00	0.70
CN9-WtrmnW	Natural	Environmental	17,700.00	75.00	0.70
CN10-Shea1	Natural	Environmental	12,800.00	60.00	0.80
CN11-Shea2	Natural	Environmental	8,000.00	60.00	0.80
CN12-Shea3	Natural	Environmental	6,500.00	60.00	0.80
CN13-Shea4	Natural	Environmental	6,000.00	60.00	0.80
CN14-SkunkC	Natural	Environmental	48,300.00	200.00	0.85
CN15-IdBndN	Natural	Environmental	14,500.00	80.00	0.80
CC1-AzCanal	Cultural	Introduced	51,500.00	50.00	0.30
CC2-AzCrCut	Cultural	Introduced	5,800.00	50.00	0.30
CC3-BckeyeC	Cultural	Introduced	22,500.00	50.00	0.30
CC4-CAPCanal	Cultural	Introduced	85,500.00	50.00	0.30
CC5-ConsCan	Cultural	Introduced	37,000.00	50.00	0.30
CC6-CrCutCan	Cultural	Introduced	3,850.00	50.00	0.30
CC7-EMarFl	Cultural	Introduced	35,400.00	50.00	0.60
CC8-EastCanal	Cultural	Introduced	32,400.00	50.00	0.30
CC9-GrndCan	Cultural	Introduced	35,800.00	50.00	0.30
CC10-IndBdS	Cultural	Introduced	20,000.00	500.00	0.80
CC11-KyrCan	Cultural	Introduced	22,500.00	50.00	0.30
CC12-OldVrdC	Cultural	Introduced	19,300.00	50.00	0.30
CC13-RsvltCan	Cultural	Introduced	25,700.00	50.00	0.30
CC14-SBrHigh	Cultural	Introduced	16,100.00	50.00	0.30
CC15-TmpCan	Cultural	Introduced	15,200.00	50.00	0.30
CC16-WstrnC	Cultural	Introduced	15,000.00	50.00	0.30
CC17-ThnPas	Cultural	Introduced	9,500.00	65.00	0.80
Total			921,346.00		
Mean			28,792.00	245.00	0.58

Table A.13: Continued

Filter Width	Area (ha.)
0.20	4,578.00
0.20	742.00
0.20	13,521.90
0.20	760.00
0.20	3,066.80
0.30	265.50
0.20	2,092.00
0.30	4,050.00
0.30	132.70
0.20	76.80
0.20	48.00
0.20	39.00
0.20	36.00
0.20	966.00
0.20	116.00
0.40	257.50
0.40	29.00
0.40	112.50
0.40	427.50
0.40	185.00
0.40	19.20
0.40	177.00
0.40	162.00
0.40	179.00
0.20	1,000.00
0.40	112.50
0.40	965.00
0.40	128.50
0.40	80.50
0.40	76.00
0.40	75.00
0.20	61.70
	34,538.60
0.30	1,079.33

Table A.14: Optimal Corridor Vegetative Structure and Diversity

No./Name	Veg. Cover	Native Cover	Struct. Div.	Total Veg. Val.
CN1-AguaFria	0.30	0.30	0.51	1.11
CN2-CaveCrk	0.30	0.30	0.51	1.11
CN3-GilaRivr	0.38	0.38	0.66	1.42
CN4-GranRf	0.38	0.38	0.66	1.42
CN5-NewRiver	0.30	0.30	0.51	1.11
CN6-QueenCr	0.38	0.38	0.66	1.42
CN7-SaltRivr	***0.30***	***0.30***	***0.51***	***1.11***
CN8-VerdeRv	0.38	0.38	0.96	1.72
CN9-WtrmnW	0.38	0.38	0.66	1.42
CN10-Shea1	0.38	0.38	0.66	1.42
CN11-Shea2	0.38	0.38	0.66	1.42
CN12-Shea3	0.38	0.38	0.66	1.42
CN13-Shea4	0.38	0.38	0.66	1.42
CN14-SkunkC	0.30	0.30	0.51	1.11
CN15-IdBndN	0.38	0.38	0.66	1.42
CC1-AzCanal	***0.15***	***0.15***	***0.26***	***0.56***
CC2-AzCrCut	***0.15***	***0.15***	***0.26***	***0.56***
CC3-BckeyeC	***0.15***	***0.15***	***0.26***	***0.56***
CC4-CAPCanal	***0.15***	***0.15***	***0.26***	***0.56***
CC5-ConsCan	***0.15***	***0.15***	***0.26***	***0.56***
CC6-CrCutCan	***0.15***	***0.15***	***0.26***	***0.56***
CC7-EMarFl	***0.15***	***0.15***	***0.26***	***0.56***
CC8-EastCanal	***0.15***	***0.15***	***0.26***	***0.56***
CC9-GrndCan	***0.15***	***0.15***	***0.26***	***0.56***
CC10-IndBdS	0.58	***0.29***	0.98	***1.85***
CC11-KyrCan	***0.15***	***0.15***	***0.26***	***0.56***
CC12-OldVrdC	***0.15***	***0.15***	***0.26***	***0.56***
CC13-RsvltCan	***0.15***	***0.15***	***0.26***	***0.56***
CC14-SBrHigh	***0.15***	***0.15***	***0.26***	***0.56***
CC15-TmpCan	***0.15***	***0.15***	***0.26***	***0.56***
CC16-WstrnC	***0.15***	***0.15***	***0.26***	***0.56***
CC17-ThnPas	0.58	***0.29***	0.98	***1.85***
Mean	***0.27***	***0.25***	***0.48***	***1.00***

Table A.15: Optimal Corridor Context

No./Name	Matrix Util.	Div. Gradient	T-Gaps	Long. Con. Dist.	Link Seg.
CN1-AguaFria	***0.74***	245.00	0.00	57,950.00	4.00
CN2-CaveCrk	***0.70***	240.00	0.00	22,260.00	2.00
CN3-GilaRivr	***0.84***	150.00	0.00	90,146.00	3.00
CN4-GranRf	1.00	50.00	***0.00***	9,500.00	1.00
CN5-NewRiver	***0.72***	360.00	0.00	45,100.00	2.00
CN6-QueenCr	***0.60***	200.00	0.00	35,400.00	1.00
CN7-SaltRivr	***0.79***	275.00	0.00	52,300.00	12.00
CN8-VerdeRv	***1.00***	50.00	0.00	27,000.00	4.00
CN9-WtrmnW	***0.91***	30.00	0.00	17,700.00	1.00
CN10-Shea1	***0.91***	80.00	0.00	12,800.00	3.00
CN11-Shea2	***0.91***	80.00	0.00	8,000.00	3.00
CN12-Shea3	***0.91***	50.00	0.00	6,500.00	3.00
CN13-Shea4	***0.91***	50.00	0.00	6,000.00	2.00
CN14-SkunkC	***0.70***	300.00	***0.00***	33,810.00	2.00
CN15-IdBndN	***0.98***	150.00	***0.00***	14,500.00	1.00
CC1-AzCanal	***0.60***	30.00	***0.00***	7,500.00	7.00
CC2-AzCrCut	***0.86***	5.00	***0.00***	7,500.00	1.00
CC3-BckeyeC	***0.68***	15.00	***0.00***	7,500.00	1.00
CC4-CAPCanal	***1.00***	50.00	***0.00***	51,300.00	10.00
CC5-ConsCan	***0.70***	40.00	***0.00***	7,500.00	5.00
CC6-CrCutCan	***0.58***	5.00	0.00	3,850.00	1.00
CC7-EMarFl	***0.73***	40.00	***0.00***	7,500.00	2.00
CC8-EastCanal	***0.75***	40.00	***0.00***	7,500.00	1.00
CC9-GrndCan	***0.60***	40.00	***0.00***	7,500.00	2.00
CC10-IndBdS	***0.64***	65.00	***0.00***	7,500.00	4.00
CC11-KyrCan	***0.67***	25.00	***0.00***	7,500.00	3.00
CC12-OldVrdC	***1.00***	25.00	***0.00***	7,500.00	3.00
CC13-RsvltCan	***0.56***	20.00	***0.00***	7,500.00	1.00
CC14-SBrHigh	***0.67***	15.00	***0.00***	7,500.00	1.00
CC15-TmpCan	***0.67***	15.00	***0.00***	7,500.00	1.00
CC16-WstrnC	***0.70***	15.00	***0.00***	7,500.00	1.00
CC17-ThnPas	***0.50***	10.00	***0.00***	4,750.00	1.00
Total		2,765.00	***0.00***	603,866.00	89.00
Mean	***0.77***	86.40	***0.00***	18,870.00	2.78

Table A.16: Optimal Corridor Naturalness

No./Name	Native Veg.	Soils	Flows	Total Nat. Val.
CN1-AguaFria	0.30	***0.80***	0.90	***2.00***
CN2-CaveCrk	0.30	***0.80***	0.90	***2.00***
CN3-GilaRivr	0.38	0.80	0.80	1.98
CN4-GranRf	0.38	0.90	0.80	2.08
CN5-NewRiver	0.30	***0.80***	0.80	***1.90***
CN6-QueenCr	0.38	0.90	0.90	2.18
CN7-SaltRivr	***0.30***	***0.80***	***0.80***	***1.90***
CN8-VerdeRv	0.38	0.90	0.90	2.18
CN9-WtrmnW	0.38	0.90	0.90	2.18
CN10-Shea1	0.38	0.80	0.80	1.98
CN11-Shea2	0.38	0.80	0.80	1.98
CN12-Shea3	0.38	0.80	0.80	1.98
CN13-Shea4	0.38	0.80	0.80	1.98
CN14-SkunkC	0.30	***0.80***	0.90	***2.00***
CN15-IdBndN	0.38	0.90	0.90	2.18
CC1-AzCanal	***0.15***	***0.40***	***0.40***	***0.95***
CC2-AzCrCut	***0.15***	***0.40***	***0.40***	***0.95***
CC3-BckeyeC	***0.15***	***0.40***	***0.40***	***0.95***
CC4-CAPCanal	***0.15***	***0.40***	***0.40***	***0.95***
CC5-ConsCan	***0.15***	***0.40***	***0.40***	***0.95***
CC6-CrCutCan	***0.15***	***0.40***	***0.40***	***0.95***
CC7-EMarFl	***0.15***	***0.40***	***0.40***	***0.95***
CC8-EastCanal	***0.15***	***0.40***	***0.40***	***0.95***
CC9-GrndCan	***0.15***	***0.40***	***0.40***	***0.95***
CC10-IndBdS	***0.15***	***0.40***	***0.80***	***1.35***
CC11-KyrCan	***0.15***	***0.40***	***0.40***	***0.95***
CC12-OldVrdC	***0.15***	***0.40***	***0.40***	***0.95***
CC13-RsvltCan	***0.15***	***0.40***	***0.40***	***0.95***
CC14-SBrHigh	***0.15***	***0.40***	***0.40***	***0.95***
CC15-TmpCan	***0.15***	***0.40***	***0.40***	***0.95***
CC16-WstrnC	***0.15***	***0.40***	***0.40***	***0.95***
CC17-ThnPas	***0.15***	***0.40***	***0.40***	***0.95***
Total	***7.85***	***19.30***	***19.90***	***47.05***
Mean	***0.24***	***0.60***	***0.62***	***1.44***

About the Author

Edward A. Cook was born on 18 February 1955 in Lethbridge, Alberta, Canada. In 1979 he graduated from Washington State University in Pullman, Washington, U.S.A. with a Bachelor of Science in Landscape Architecture degree. After several years of practice as a landscape architect in Wyoming and Canada, he began graduate studies in the Department of Landscape Architecture and Environmental Planning at Utah State University in Logan, Utah, U.S.A. He earned his Master of Landscape Architecture degree there in 1984. In August of 1984 he joined the faculty at Arizona State University in the Department of Planning (now School of Planning and Landscape Architecture) in Tempe, Arizona, U.S.A.

Following promotion to associate professor at Arizona State University, he began his doctoral studies at Wageningen University during a sabbatical leave in 1992. He spent 6 months in Wageningen, during which time the book "Landscape Planning and Ecological Networks" (edited by E. Cook and H. van Lier) was started and then published in 1994. This provided a useful foundation for this thesis. He is still at the School of Planning and Landscape Architecture where is engaged in teaching and research related to open space systems, landscape ecology and stream and river corridor restoration.