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It is entitled A FRAMEWORK FOR ECOLOGICAL ANALYSIS OF RIPARIAN CORRIDORS

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A Framework for Ecological Analysis of Riparian Corridors

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Abstract

This thesis attempts to study the riparian ecosystems by analyzing the physical and ecological processes and the impacts from the land use and land cover. During the course of urbanization over many decades, riparian areas have been overlooked resulting into permanent loss of the riparian ecosystems. The thesis proposes a tool for the planners, which is simple, doable, and can be applied to study the riparian areas.

The methodology consists of studying the physical and ecological characteristics of the riparian ecosystems and the land use and land cover impacts on the system. The physical and ecological processes occurring within the riparian ecosystem is researched in detail and an attempt is made to find the roles of physical parameters in these processes. Similarly impacts of land use and land cover on the physical parameters of riparian ecosystem are studied. The physical parameters are categorized into high, medium, and low categories based on their roles in the physical and ecological characteristics and impacts by the land uses. The selected high and medium parameters, which are mapable and available are mapped and overlaid for a pilot study area.

GIS database is prepared for the selected parameters and after overlaying, three areas of high ecological importance are identified. Similarly, based on overlay of number of parameters, areas of medium and low ecological importance are identified. This tool helps the planner in making decision on the widths of the riparian buffers and serves as an early warning method by delineating areas of ecological importance, which should be

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conserved. The tool can be improved by doing survey of experts to rank the parameters; doing field survey to verify the ground situation; and using satellite imagery of higher resolution. The method prepares a baseline GIS data, over which further analysis can be done. This method can be further used for the suitability analysis for conservation and development and study of patch geometry to form riparian forest corridors.

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Chapter 1: Introduction

1.1: Background

River valleys are an integral part of urban and suburban development with many human settlements developing and prospering along river corridors. However, development of these settlements along river corridors impacts the ecology of the river and streams and the riparian ecosystem. The riparian areas of a river, stream, or other body of water consist of the land adjacent to the body of water that is, at least periodically, influenced by flooding.[1] The ecosystem in this area is known as the riparian ecosystem, which is an ecosystem with high water table because of proximity to the aquatic ecosystem or subsurface water.[2] The riparian ecosystems are transitional ecosystems existing between the aquatic ecosystem and upland ecosystem. The transitional ecosystems are also known as the ecotones. Historically, ecologists have studied homogeneous regions to characterize and understand ecosystem processes and have avoided the heterogeneous areas between the ecosystems.[3] As a result, transitional zones have often been ignored or reduced to lines on a map.[4] These transitional zones or ecotones are dynamic areas with plenty of materials and nutrients flowing through them. The role of a riparian ecosystem, besides being an ecotone along the river corridor, includes filtering run-off from the non-point sources, such as agricultural farms, before it mixes with the river water; stabilizing the banks of river corridor reducing debris in the river; providing shade to the aquatic animals; providing moisture control; and functioning as the wildlife corridors.

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[1] William J. Mitsch and James G. Gosselink, *Wetlands* (New York: John Wiley & Sons Inc., 2000), 514.
[2] *Id.*
[3] M.J. Fortin et al., "Issues related to the detection of boundaries," *Landscape Ecology* 15 (2000): 453.
[4] *Id.*

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The riparian ecosystems are affected by both the environmental pollution and land use-land cover changes generated in urban and suburban areas. The ecosystem is degenerating because of external interferences such as contamination by the organic and inorganic pollutants, change in land use and land cover, animal grazing, and change in temperature and moisture. Throughout history, man has altered, developed, and influenced the extent and condition of riparian ecosystems, and today only a portion of the original flood land area is occupied by natural vegetation.[5] There is a lack of documentation of pristine riparian ecosystems, which has caused an inadequate knowledge base of riparian ecosystems, their geographical distribution, and coverage. There has been no single comprehensive inventory of riparian ecosystems in the United States to determine the amount of land area originally covered by the riparian ecosystems and the proportion of that area presently supporting natural riparian communities.[6] Overall, it appears that more than 70% of riparian ecosystems have been altered, and natural riparian communities now make up less than 2% of the land area in the U.S.A.[7] Research by the United States Geological Survey on the status of riparian ecosystems in the United States finds that riparian areas are being destroyed in every part of the country. Through a literature review they find that over half of the wetlands and riparian areas have been destroyed in the 48 states. In the arid Southwest, native riparian ecosystems are disappearing rapidly and along the lower Colorado River, riparian vegetation is being removed at the rate of 1200 hectares per year.[8] Similarly, in the Southeast, 90% of the

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[5] U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status* (West Virginia: Information Transfer Center, 1981), 4.
[6] *Id.*
[7] *Id.*
[8] http://www.nprwc.usgs.gov/resource/literatr/ripareco/statrip.htm, Riparian Ecosystem Creation and Restoration: A Literature Summary, USGS, accessed on 05/16/2003.

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original bottomland forest has been converted into other land uses.[9] The riparian forests in the Southeast are known as the Bottomland forests.

1.2: Problem Statement

There are some tools and management practices in existence to control the continuing loss of riparian areas. These strategies for riparian management include legal regulations for rivers and stream bank development in urbanized areas and the best management practices in agriculture and live stock grazing along the riparian areas. The legal regulations used by the local authorities include designating riparian buffer zones along rivers and streams and thus prohibiting construction and ensuring planting of trees and vegetation on these lands. The other legal methods include making no development zones in the flood plains. The best management practices include purchasing conservation easements for riparian areas, point and non-point source pollution mitigation, making greenway corridors along the rivers and streams, better farming practices to reduce fertilizer and pesticide runoff, regeneration of riparian forests by planting trees, and stabilizing the river and stream banks. There is an underlying issue with the legal rules and planning for riparian buffers along the rivers and streams in the urbanized and semi-urbanized areas. Riparian buffers are often designed without conducting a comprehensive analysis of the ecology of the riparian ecosystem and how it is impacted by the existing land use and land cover. Without a comprehensive analysis, planning and management for riparian ecosystem become a piecemeal approach rather than a holistic approach. The planning authorities often make regulations for the riparian

[9] http://www.nprwc.usgs.gov/resource/literatr/ripareco/statrip.htm, Riparian Ecosystem Creation and Restoration: A Literature Summary, USGS, accessed on 05/16/2003.

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buffer strips based on the width and hierarchy of a stream. For example, the Department of Planning of the County of Santa Cruz, provides the following regulations for their riparian corridors: 50 feet of buffer for a year-round flowing stream; 30 feet of buffer for a natural standing body of water; and 10 to 50 feet for an arroyo, or gully, depending on the type of stream, vegetation, and slope of the arroyo banks.[10] Such decisions without any analysis either result in inclusion of more land area in the riparian buffers than necessary or result into inadequate riparian buffer width. Buffers that are undersized may place aquatic resources at risk.[11] Conversely buffers, which are larger than needed, may deny the landowners their rights for appropriate land use.[12] The correct size of these buffers remains an environmentally and politically explosive issue.[13] Land being a scarce resource, planners require an analytical tool for making such decisions. Moreover, landscapes are complex and changing systems and have highly interconnected components.[14] This type of analysis becomes interdisciplinary drawing from the fields of landscape planning, ecology, and biological sciences. So the requirement is for a tool, which is based on comprehensive analysis yet simple enough to be understood by planners.

1.3: Objectives

This thesis will attempt to prepare a framework for riparian ecosystem analysis, which can be understood and used by planners. The framework will be based on comprehensive

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[10] http:sccounty01.co.santa-cruz.ca.us/planning/riparian.htm, *Planning Department County of Santa Cruz: Riparian Corridors*, accessed on 10/31/2002.
[11] Sunil Narumalani et al., "Application of remote sensing and geographic information systems to the delineation and analysis of riparian buffer zones," *Aquatic Botany* 58 (1997): 408.
[12] *Id.*
[13] *Id.*
[14] Daniel S. Smith and Paul Cawood Hellmund, *Ecology of Greenways* (Minneapolis: University of Minnesota Press, 1993), xiii.

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study of the characteristics of riparian ecosystems including physical and ecological characteristics. It will also include the land use and land cover impacts on the riparian ecosystems. The framework will help planners to determine ecologically important areas within the riparian areas along the river and stream in their jurisdiction. The knowledge of such ecologically important areas will assist in making decisions regarding widths of the riparian forests or buffers. This framework will help prepare the groundwork, GIS data base, and primary level analysis of riparian areas, over which specific planning and scientific studies can be undertaken. Hence, the goal is to prepare a simple, doable framework for ecological analysis of riparian areas.

Three objectives guide this study:

1) Identify the parameters to define ecologically important areas.
2) Develop a GIS based method for planner that is not data intensive to identify existing ecologically important areas.
3) Complete a pilot test on a real site to evaluate the method.

Who will use the method: The local authorities and environmental organizations involved in conservation and management of riparian areas can use this framework to study and analyze their riparian areas and prepare the GIS database. It will assist them in understanding the riparian ecosystem and impacts of different land uses and land covers adjacent to it. The end product of using the framework is a Geographic Information System (GIS) Map with a relational database showing locations of important ecological areas within their riparian areas.

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1.4: What is Riparian Ecosystem?

There are various definitions in use for the riparian areas. The word riparian is derived from the Latin for bank or shore, and simply refers to land adjacent to a body of water.[15] However, depending on the purpose and user of the definition, its meaning can become more complex.[16] Differing definitions include definitions by the Willamette National Forest, the British Columbia Forest Practices Code, and the United States Environmental Protection Agency (USEPA). The Willamette National Forest defines a riparian area as an aquatic ecosystem and the portion of the adjacent terrestrial ecosystem that directly affects or is affected by the aquatic environment including streams, rivers, and lakes and their adjacent side channels, flood plains and wetlands.[17] This definition includes hill slopes serving as the habitat for streamside wildlife. The British Columbia Forest Practices Code defines riparian area as the land adjacent to the normal high water line in a stream, river, or lake, extending to the portion of land that is influenced by the presence of the adjacent ponded or channeled water.[18] The U.S. EPA definition identifies the movement of energy, material, and water through the system and differentiates between wetlands and riparian areas. The U.S. EPA defines riparian areas as "vegetated ecosystems along a water body through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent water body. These systems encompass wetlands, uplands, or some combination of these two landforms. They will not in all

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[15] Robert J. Naiman, ed., *Watershed Management: Balancing Sustainability and Environmental Change* (New York:Springer-Verlag, 1992), 442.
[16] *Id.*
[17] Joan, Voller and Scott, Harrison, ed., *Conservation Biology Principles for Forested Landscapes* (Vancouver: University of British Columbia Press, 1998), 98.
[18] *Id.*

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cases have all of the characteristics necessary for them to be classified as wetlands."[19] The U.S. EPA definition mentions the terrestrial extent of riparian areas to the land which is periodically flooded and includes wetlands. Scientists have included wetlands as a subset of the riparian ecosystems due to their proximity to a water body and similar characteristics. In 1989, Minshall incorporated the U.S. Fish and Wildlife Service wetland definition into his definition of riparian areas of the western states Great Basin region: "Land inclusive of hydrophytes and/or with soil that is saturated by ground water for at least part of the growing season within the rooting depth of potential native vegetation."[20] Based on the more restrictive wetland definition of water dependency, wetlands become a subset of riparian ecosystem.[21] For this thesis, I will be using the definition provided by the U.S. EPA and the extent of riparian areas is up to the land which is periodically flooded.

Functions of Riparian Areas: Riparian areas and wetlands perform many functions or ecological services. Ecologists such as William J. Mitsch describe riparian areas and wetlands as the "kidneys of the landscape." Similar to kidneys, which purify blood by filtering out salts, riparian areas and wetlands filter chemicals out from the surface water. The riparian areas usually exist as strips of trees and herbaceous vegetation along the rivers and streams. In case of planning and management of riparian areas, the decisions are made for the width of such strips. These strips act as buffers between streams and land. They are also known as riparian corridors because of their linear dimension along

[19] http://www.epa.gov/OWOW/NPS/MMGI/Chapter7/ch7-1.html#Wetlands, Guidance Specifying Management Measures for Sources of Non-point Pollution in Coastal Waters, accessed on 11/11/2002.
[20] William J. Mitsch and James G. Gosselink, *Wetlands* (New York: John Wiley & Sons Inc., 2000), 514.
[21] *Id.*

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the river and streams. These riparian corridors or buffers are a subset of greenway corridors and perform similar basic functions of the greenway corridor. The six basic corridor functions include habitat, conduit, barrier, filter, source, and sink.[22] In this thesis, these six basic functions or ecological services of riparian corridors are studied. The performance of a riparian corridor in each of the functions may differ by geographical area due to physical and climatic differences. However, the basic characteristics of these ecological services remain the same.

Habitat: Habitats are defined simply as the location where plants, animals, and people live.[23] Riparian areas act as habitat for trees, animals, insects, plants, and people. There is a diversity of flora and fauna that use riparian areas as their habitats in different geographical and climatic regions. Hardwood trees such as willow, black cottonwood, silver maple, and sycamore grow and thrive in the riparian forests. The floor is covered by grasses and non-woody plants. The plants growing in riparian areas are the floodplain plant communities. Animals in the riparian area include water-monitors, beavers, cranes, and other water birds. The riparian areas in a geographical region are unique in terms of habitat characteristics. One of the problems of dealing with riparian ecosystems from a national perspective is the great diversity in vegetation, fauna, and geomorphology.[24] Riparian forests support aquatic habitat by shading the river water. Many types of aquatic life forms, such as fish spawn in the cooler environment. Whereas, the loss of

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[22] Daniel S. Smith and Paul Cawood Hellmund, *Ecology of Greenways* (Minneapolis: University of Minnesota Press, 1993), 32.
[23] Daniel S. Smith and Paul Cawood Hellmund, *Ecology of Greenways* (Minneapolis: University of Minnesota Press, 1993), 31.
[24] U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status* (West Virginia: Information Transfer Center, 1981), 3.

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riparian forests has resulted in eradication of fish species in the warmer stretches of river water. Temperature has an important role in the metabolic processes of aquatic organisms and affects the amount of dissolved oxygen in the water. The riparian forest canopy brings the temperature down during summer by providing shade, while in winter it helps to maintain the temperature by reducing the heat loss. Studies have shown that a riparian area is more effective in controlling water temperature in small and medium-sized streams. In smaller streams, the incoming radiation may be reduced up to 85% by the forest canopy closure.[25] Studies have also found that stream temperature have increased up to 8^0 centigrade following the removal of streamside canopy. The result of such changes has been complete eradication of aquatic life or removal of cool water species.

Conduit: By functioning as a corridor for movement of plants, animals, people, and water, a riparian zone provides the ecological services of a conduit. Riparian zones developed as buffers can also be used as greenway corridors to connect patches of habitat and provide water filtration. Riparian zones can act as distribution corridors for seeds, restricted movement corridors for animals, and recreational corridors for people. To study the conduit functions of a riparian corridor in a local context, knowledge of native flora and fauna is essential. A movement corridor is useful for animals requiring more than one type of habitat for living. The conduit function is also essential for maintaining biodiversity in the region. One concern for usage of conduits however, is that they can help propagate disease and fire. As a conduit of water, an important function of the

[25] Joan, Voller and Scott Harrison, *Conservation Biology Principles for Forested Landscapes* (Vancouver: University of British Columbia Press, 1998), 105.

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riparian corridor is evapotranspiration, thus participating in the hydrological cycle. The evapotranspiration is vaporization of water taken by plant roots from the ground. As conduits for surface water and ground water, riparian zones or greenways supply humans, plants, and animals with water filtered by roots and microbial organisms in the soil.[26]

Barrier: The riparian zones can also provide functions of a barrier by stopping movement of upland animals, and humans across it, and thus protecting the riverbanks. In general a riparian zone is an edge; hence it acts as a barrier to many urban and suburban activities that may disturb the aquatic ecosystem. It also functions as a barrier to sediments, organic chemicals and inorganic chemicals by restricting their movement to water.

Filter: Riparian areas can filter dissolved chemicals as well as un-dissolved particles and sediments. The plant roots and soil microbes filter chemicals, especially fertilizers, out of soil water, but this filtering function is not limited to the dissolved materials in water. They can also trap eroded soils and thus prevent water pollution by soil nutrients, stream siltation, and soil borne pesticides and herbicides.[27] The physical filtering is done by riparian vegetation by slowing the movement of water and combing out sediments and debris. This helps in bank stabilization by preventing the scouring by fast moving water and deposition of sediments on the banks. It is found that stream channels, which were shallow, become deeper by having riparian vegetation on their banks. This is also known as the provision of hydraulic roughness by riparian vegetation. The riparian vegetation

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[26] Daniel S. Smith and Paul Cawood Hellmund, *Ecology of Greenways* (Minneapolis: University of Minnesota Press, 1993), 32.
[27] *Id.*

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stabilizes stream and river banks by binding soil particles to the plant roots. A diversity of plants such as grasses, rushes, sedges, shrubs, and trees in the riparian zone are more effective in bank stabilization than a single species. The deposition of sediments helps create wet meadows. Wet meadows are a type of wetland rich in nutrients and minerals. They are saturated wetlands but unlike wetlands they are not submerged continuously.

Source: Riparian areas act as source of native plants and animal species. In arid areas these may be the only green corridors in the landscape. The most important source function of a riparian zone is providing carbon to aquatic life. The leaves, which fall and make litter on the ground, eventually decompose and go to river water and become a food source for fish and other aquatic animals.

Sink: Riparian areas function as sink when they remove nutrients and chemicals from sediments thus removing pollutants from entering into the aquatic ecosystem. The two most important chemicals removed are nitrogen and phosphorous from fertilizers, pesticides, and herbicides. They are also a mortality sink of dead animals, which eventually become a carbon source for aquatic life.

1.5: Scope

Dimensions of the Riparian Ecosystem: Riparian ecosystems along the banks of rivers and water bodies have a linear form. There are two dimensions to this ecosystem. The first is the longitudinal direction along the length of the river which can continue through large geographical areas, such as the riparian ecosystem of the Mississippi River Basin.

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The other dimension is in the transverse direction of the river in which the riparian ecosystem exists between the aquatic ecosystem and upland ecosystem. It is an area in which ecosystems blend and mix and they are also known as an ecotone. In the longitudinal direction the characteristics of riparian ecosystems change due to changes in the climate. The transverse dimension is dynamic because of the processing of material and flow of energy. The change in physical and ecological characteristics resulted due to human activities cause changes in the functions in transverse dimension. The scope of this study is limited to the transverse dimension of riparian ecosystems. It is the area that is affected directly by urbanization and other interventions including livestock grazing.

1.6: Methodology

The methodology can be divided into three parts. The first part includes a developing an analytical framework to define and identify ecologically important areas within the riparian ecosystem. The analytical framework is developed in three steps. The first step includes identifying the parameters of physical characteristics and their role in the six ecological services of habitat, conduit, barrier, filter, source, and sink. The study helps to know the physical parameters, which have a role in the ecological services of the riparian ecosystems. The next step is to identify the interrelationship between parameters of physical characteristics and ecological characteristics. The study helps to know the role of the physical parameters in the ecological characteristics. The last step includes study of impacts of land use and land cover on the physical characteristics of the riparian ecosystem. The outcome of the three steps of analytical framework is three matrices. The second part of methodology includes translating the framework into a doable GIS

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tool. This part includes identifying the features to be digitized from an aerial photograph and procedure of developing a GIS database. The third part of methodology includes applying the tool in a real test site to evaluate the method. The three matrices required to develop the analytical framework in the first part of methodology is explained below.

Matrix between Parameters of Physical Characteristics and Ecological Services: Based on the research of physical characteristics of riparian ecosystem, a matrix will be made between the physical parameters and the ecological services. Participation of a physical parameter in any ecological service would be shown by a tick mark in the matrix. The physical parameters will be divided into high, medium, and low category based on the participation in number of ecological services.

Matrix between Parameters of Physical Characteristics and Ecological Characteristics: Based on the research of ecological characteristics of riparian ecosystem, a matrix will be made between the parameters of physical characteristics and ecological characteristics. Participation of any physical parameter in the ecological characteristics would be shown by a tick mark in the matrix. The physical parameters will be divided into high, medium, and low category based on the participation in number of ecological characteristics.

Matrix between Land Use and Land Cover and Parameters of Physical Characteristics: Based on the research of land use and land cover impacts on the riparian ecosystem, a matrix will be made between the land uses and physical parameters of

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riparian ecosystem. If a land use impacts a physical parameter, it would be shown by a tick mark in the matrix. The physical parameters will be divided into high, medium, and low category based on the impacts by different land uses.

A Geographic information System (GIS) database will be prepared for the selected physical parameters for the pilot study area. The physical parameters, which can be mapped is included in the GIS database. The physical parameters, which fall into high and medium categories in all the three matrices, would be selected for overlay analysis of the study area. The land within the riparian area, which has all of the physical parameters, should be conserved while making decisions for the riparian ecosystem.

The selected study area is along the Great Miami River within a short distance north to Oxbow Lake in Hamilton County. The reason for selection of this site is the availability of GIS data, aerial photograph, accessibility, riparian vegetation, and varied land uses along the banks of the Great Miami River.

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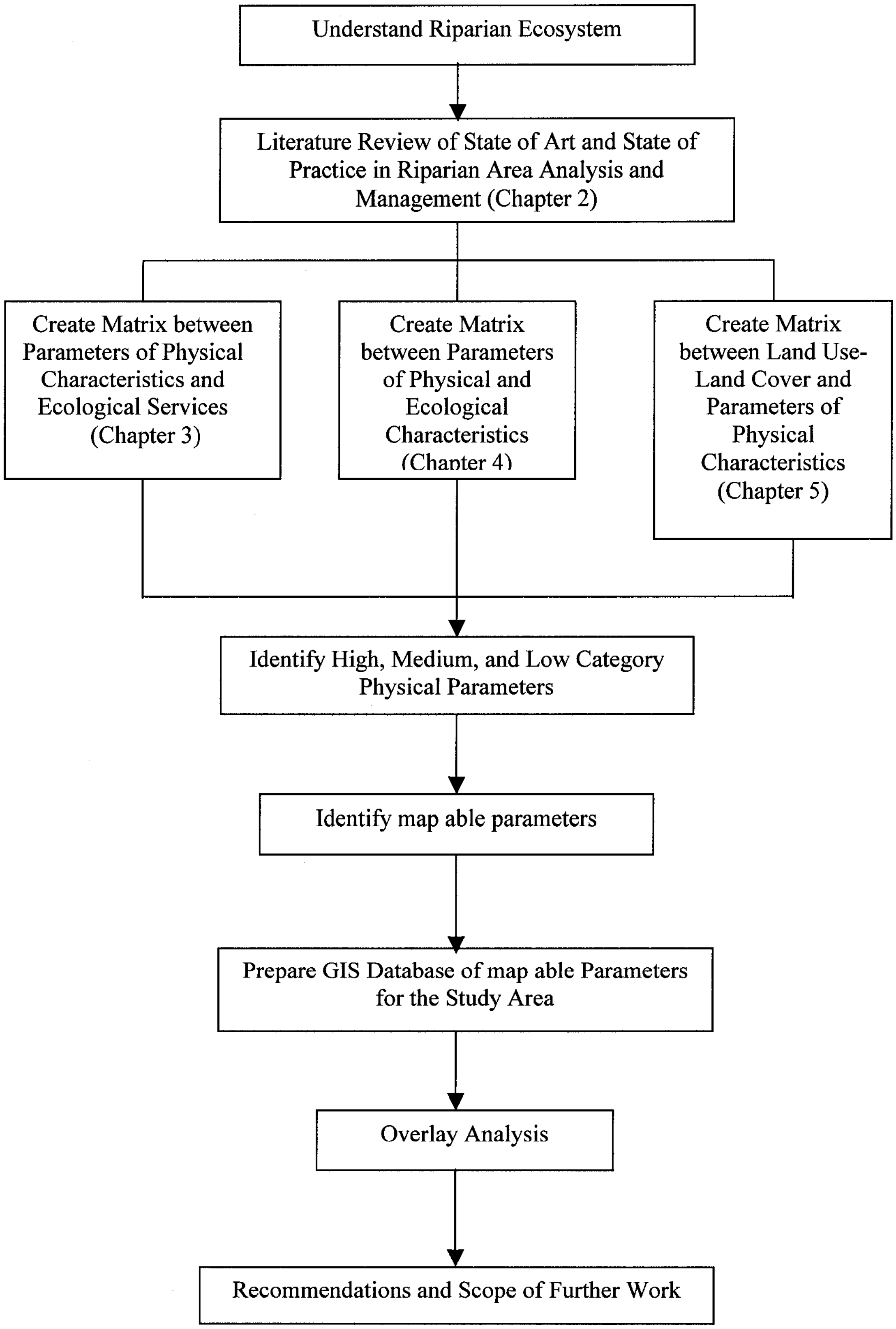
Figure 1.1: Flow Chart of Methodology



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Chapter 2: State of the Art and State of the Practice for Riparian Ecosystem Analysis and Management

This chapter looks into the state of the art and state of the practice available for riparian ecosystem analysis and management. The tools available for analysis and management of riparian resources can be classified into three broad categories. The first type is associated with assessing biological organisms in the river and streams; the second type is a method of mapping riparian trees and herbaceous vegetation using satellite imagery; and the third type is associated with methods for riparian area management. The tools for assessing biological organisms are mathematical indices and give index values for river stretches. The method associated with satellite imagery consists of mapping of trees and vegetation. The methods associated with management of riparian areas consist of variety of assessments requiring field work and can be used for making decisions such as grazing. The explanation of these tools is provided below.

2.1: State of the Art in Biological Indices

Scientists have developed indices to assess biological community in the rivers and streams. This forms an indirect assessment of the water quality. If the biological indices are not good, this indicates problems in the water quality of the river and steam indicating improper functioning of riparian ecosystems along the river or stream. Water quality standards originated because of requirements of the Clean Water Act to have a measurement for water quality. In the beginning, water quality standards consisted mainly of chemical and physical parameters and any water exceeding one of the parameters was considered impaired. Apart from federal standards, states prepared

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further standards for designated uses such as recreation. However, the focus of the Clean Water Act was on point sources of pollution such as industrial effluent pipe and programs to control and monitor them. Non point sources of pollution became an issue after 1980s amendments to the Act. Section 319 implementation strategy of the Act deals specifically with non point sources of pollution and remedial measures. Moreover, there was a growing concern that chemical and physical measurements merely state a part of the problem and there is a requirement for better and holistic water quality measurement tools. Biological indices are developed under these premises that any alteration to aquatic ecosystem is reflected in its biological community. The Ohio Environmental Protection Agency (EPA) pioneered in the usage of biological indices including Index of Biotic Integrity (IBI), Invertebrate Community Index (ICI), and Qualitative Habitat Evaluation Index (QHEI). These indices will be briefly explained showing their parameters, derivation, and usage.

2.1.1: Index of Biotic Integrity (IBI) - IBI is a multi-metric index assessing various characteristics of fish, invertebrate, and other animals in an aquatic habitat. A metric is a measure or calculated term representing some aspect of biological assemblage, structure, and function.[28] A single metric shows only one characteristic of the ecology, however, the impacts on the ecology happen at different levels and in different degrees. Hence a multi-metric approach is more suitable to show the overall impact on the ecosystem.

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[28] W.S. Davis and T.P. Simon, ed., *Biological Assessment and Criteria* (Boca Raton: Lewis Publishers, 1995), 63.

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Multi-metric method to make a fish index of biotic integrity was pioneered by James R. Karr. The parameters in his multi-metric approach can be broadly classified into community structure, taxonomic composition, individual condition, and biological processes. Community structure includes types of species present in the water body or diversity of species; number of particular species to the whole community to know the abundance of various species; and the dominant species. Taxonomy is a procedure used by biologists to classify various species into hierarchies of taxa, genera, and family based on genetic and biological characteristics. Within the taxonomic composition, various indicators include indicators of 'identity' such as key species, exotic species, nuisance species and indicators of 'sensitivity' such as pollution tolerant and intolerant species. The parameter of 'individual condition' show if the species growth is happening appropriately or not. It is measured by size and growth of the species, studying anomalies in the species, or identifying presence of a disease in the species. Biological processes can be broadly classified into indicators of trophic dynamics and production. The trophic dynamics is study of food chain, food web and its interrelationship. Similarly indicators of production are related to species abundance, number of species, and the total biomass production.

Various researchers used a combination of the parameters proposed by James R. Karr to prepare their own Index of Biotic Integrity (IBI). In this thesis, IBI prepared by the Environmental Protection Agency in Ohio (Ohio EPA) is discussed. In the past, water quality indicators were dominated by either chemical properties such as Dissolved Oxygen (DO), Biological Oxygen Demand (BOD) or physical properties such as

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Turbidity. Later, presence and level of toxic chemicals in aquatic species became an indicator for impairment of surface water bodies. Water quality research was dominated by chemical water quality and it is evident from many ongoing programs such as the National Pollutant Discharge Elimination System (NPDES) and Best Management Practices (BMP), which concentrated on controlling the flow of chemicals into the water bodies. However, none of the indicators were inclusive enough to include all the ecological aspects of the community. Controlling chemicals alone does not assure the ecological integrity of water resources.[29] Moreover, out of 645 stream and river segments analyzed, impairment revealed by biological community measures was evident in 49.8% of the segments where no impairments of chemical water quality criteria were observed.[30] During 1986 to1998 after introducing biological criteria into water quality studies, the non attainment in Ohio streams and river miles increased from 9% to 44%. Hence, the importance of biological criteria was established.

Ohio EPA studied the multi-metric approach of Index of Biotic Integrity and modified the original Karr's Index to make it suitable for different regions, although a single index produced by a multi-metric approach is often criticized by scientists for losing valuable ecological information by creating a single mathematical value. However, detailed indices for specific purpose can be prepared by using the specific data collected for making the IBI. It is well established that multi-metric indices, such as IBI are useful tools, if it is done in combination with mapping, measurement, and monitoring. As mentioned previously, the Karr's IBI consists of 12 biological measures showing species

[29] Chris O. Yoder and Edward T. Rankin, *The Role of Biological Criteria in Water Quality Monitoring, Assessment, and Regulation* (Columbus: Ohio EPA Technical Series, 1995), 8.
[30] *Id.*

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richness and composition, trophic composition, and fish abundance and condition. Some of them are positive metrics meaning their raw value would increase with increasing environmental quality and some are negative indicators meaning their value would decrease with increasing environmental quality. IBI also requires professional judgment by biologists to establish various standards to compare the samples and to give a value judgment for exceptional, good, poor, and very poor quality. After studying 60 different multi-metrics, the Ohio EPA modified the IBI to consider variations in stream size, species distributions, and sampling methods in different parts of the region.

They identified three types of IBIs, which are headwaters IBIs for steams and rivers with less than 20 square miles drainage area; wading site IBI for steams and rivers of greater than 20 square miles area; and boat site IBI. Each type of IBI has its own sampling procedure. The modified IBI of Ohio EPA includes measures such as number of native species, number of sensitive and intolerant species, omnivores, insectivores, carnivores, hybrids, and diseased individuals.

Calculation of IBI: The calculation of IBI requires collection of field data on the fish and macro-invertebrates and comparison to reference sites. In the State of Ohio, there is one reference site for each eco-region. This reference site is located where the river or stream system is least impacted. The biotic conditions of the sampled sites are compared to these referenced sites and indices are prepared. Selection of the organisms group, sampling methods for data collection, sampling sites may vary from region to region. As mentioned previously, three IBIs are prepared for each eco-region including Headwater

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IBI, Wading IBI, and Boat IBI. The reference standards are different for each type of IBI for each eco-region. Similarly, scientists have established ranges for ordinal ranking of good, poor, very poor for all types of IBIs. Based on IBI, a stream section is considered 'Full' if all the indicator species meet their respective standards such as size. If any one of the indicator species shows non-attainment of the standard, the stream section is considered 'Partial'. A stream section is considered 'non-attaining' if all the indicator species have shown non-attainment or one of the species have shown 'poor' or 'very poor' ranking.

Use of IBI: IBIs are prepared for every river or stream mile and data for each segment over time can be compared to show trends in the aquatic habitat quality. IBIs show the overall improvement including improvement in ecological, physical, geomorphological, and biological conditions. Improvement in the IBI index can be used to assess the success of conservation and restoration programs of streams. Similarly, IBIs collected for various segments of rivers indicate the situation and success of management practices in respective watersheds. Specific actions for management of aquatic resources can be taken for that river segment based on IBI. Research on the relationship between IBI and urbanization has mentioned an inverse relationship between the two. In different watersheds the percentage of impervious surface was determined and the respective IBI in the stream was calculated. The findings by comparing the two data are that as the percentage of imperviousness increases in the watershed, the respective IBI decreases, indicating that growth of urban areas are having a negative impact on river and stream quality.

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Limitations of IBI: IBI has limited usefulness in colder regions. Various studies have found that application of IBI to western U.S. Drainage and cold water streams produce results which are contrary to the assumptions of the IBI. For example, impairment of cold water stream may cause species richness because of invasion by warm water species, which is a positive indicator per the original IBI.[31]

2.1.2: Invertebrate Community Index (ICI) - ICI was the result of research by the US Environmental Protection Agency (USEPA) during the decade of 1990s, to quantify and prepare an index for macro-invertebrates in aquatic habitat similar to IBI. While Karr's IBI looks primarily into fish assemblages, ICI includes small insects, hydra, and other multi-cellular animals found in the aquatic habitat. ICI is used as an assessment tool by Ohio EPA macro-invertebrate biologists for monitoring and assessment activities in all the free flowing rivers and streams in Ohio.[32] The preparation of ICI requires fieldwork to collect macro-invertebrate samples from various locations within the selected stream. Lots of macro-invertebrates are found in the substrate of streams; hence these survey tools are specifically designed to collect data from the stream substrate. Macro-invertebrate species such as insects and non insects including worms, bugs, hydra, and snails are sensitive to changes in environmental conditions. The disturbance in their habitat such as sedimentation, influent sewage and sludge, changes in water chemistry, and changes in chemical parameters may cause complete eradication of the species from

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[31] Chris O. Yoder and Edward T. Rankin, *The Role of Biological Criteria in Water Quality Monitoring, Assessment, and Regulation* (Columbus: Ohio EPA Technical Series, 1995), 19.
[32] W.S. Davis and T.P. Simon, ed., *Biological Assessment and Criteria* (Boca Raton: Lewis Publishers, 1995), 217.

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that segment of the stream. Hence, ICI indicates species diversity in ecosystem as well as physical and chemical situation.

Calculation of ICI: The methodology for preparing the ICI index is similar to the IBI index, which is based on a multi-metric method of comparing the metrics to a reference site. Similar to IBI, the reference sites are relatively undisturbed habitat in the five eco-regions of Ohio. ICI consists of ten metrics or measures, out of which nine metrics are prepared from the substrate data collected by survey tools and the tenth metric is a qualitative measure. The metrics are selected to show the bio-diversity, presence and absence of sensitive species, presence and absence of tolerant species, and relative proportion of species. The scoring for each metric is 6, 4, 2, and 0; 6 indicates exceptional conditions, 4 indicates typical but good communities, 2 is a moderate condition, and 0 indicates condition worse than the good and moderate scale. Since there are ten metrics and each metric varies from 6 to 0, the total ICI score varies from 60 to 0. The score of 60 indicating exceptional conditions similar to the reference site, while 0 indicating the worst conditions. Once the samples are collected for the reference sites, scatter plots are prepared between the sample and drainage area for each variable. The drainage area is used as a surrogate measure for the stream size. Scatter plots are inspected to determine if a direct, inverse, or no relationship exists between variable and the drainage area. After determining the relationship, 95th percentile line is drawn and the data below that line is divided into four quadrants constituting ranges for the scores of 6, 4, 2, and 0.

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Metrics of ICI: The ten metrics for ICI include total number of taxa, number of Mayfly taxa, number of Caddisfly taxa, number of Dipteran taxa, percent Mayfly composition, percent Caddisfly composition, percent Tribe Tanytarsini Midge composition, percent other Dipteran and non-insect composition, percent Tolerant Organisms, number of qualitative EPT Taxa. The total number of taxa indicates the species diversity. The Mayfly and Caddisfly being pollution sensitive species indicate environmental conditions of the stream. The presence of only Dipteran taxa indicates heavy pollution in the stream. The percent Mayfly and Caddisfly indicates species diversity and good environmental conditions. The Tribe Tantarshini Midge is sensitive species and can decline under moderate environmental stress. Other Dipteran and non-insects are pollution tolerant species and a negative indicator. The percentage of Tolerant Organisms shows the share of pollution tolerant species in the community. The last metric of ICI, which is the number of qualitative EPT taxa, is the only qualitative indicator showing the species richness, habitat quality, and diversity.

2.1.3: Qualitative Habitat Evaluation Index (QHEI) - QHEI is the habitat index developed and used by Ohio EPA to assess conditions of habitat in the streams and rivers. Every state in the USA has some form of habitat indices in use since the 1980s. However, most of the habitat indices target game fish or sport fish. The managers use these indices to learn the relationship between game species and habitat conditions and how to improve the abundance of species by improving habitat conditions. QHEI was developed during 1980 and used by the Ohio EPA along with IBI and ICI. QHEI is a method requiring field work and visual estimates of surveyors. The Ohio EPA trains

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these surveyors for one year before embarking on any survey. The parameters for QHEI include habitat parameters affecting the concentration and abundance of warm water species. Scatter plots of QHEI and IBI show a strong positive correlation, which means high IBI values indicate high values in QHEI also. A stream segment showing good biological conditions should have a good physical habitat. The parameters for QHEI include are diverse including substrate type and quality, in-stream cover, channel morphology, riparian zone and bank erosion, riffle/run and pool/glide quality, riffle/run depth, substrate, and embedded ness. Similar to IBI and ICI, QHEI is an index consisting of parameters, which can be scored based on reference site conditions. The Ohio EPA QHEI field sheet has five parameters with different ranges and scores for differing conditions. These parameters are substrate type and quality; in-stream physical structure and cover; channel structure, stability, and modifications; riparian width and quality; and riffle-run, pool glide quality and characteristics. A surveyor visually inspects a site and put the scores and QHEI is the summation of all the individual scores.

2.2: State of the Art in Riparian Area Inventory by using Aerial Photography

2.2.1: Bureau of Land Management Method

The Bureau of Land Management developed a method to inventory and monitor riparian areas by using the aerial photographs in 1987. The Federal Land Policy and Management Act of 1976 (FLPMA) requires the Bureau of Land Management to inventory lands and resources on a continuing basis.[33] The technical report on riparian area was prepared to

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[33] U.S. Bureau of Land Management. *The use of aerial photography to inventory and monitor riparian areas*. (Denver: Dept. of Interior, Bureau of Land Management, 1987), 1.

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inventory and monitor riparian areas within their jurisdictions. Various types of aerial photographs can be used to monitor riparian areas for different objectives. If the objective only is to delineate riparian areas, then small scale aerial photographs of 1:24,000 scale covering large areas but less details are sufficient. However, if the objective is to differentiate between riparian vegetation such as trees, shrubs, and grasses, large scale and more detailed aerial photographs of 1:2,400 or more are needed. This technical document provides a step-by-step procedure to perform a riparian area inventory. These steps are explained below:

Selection of Area, Season, Film, and Scale for Inventory: The concerned stream area should be carefully selected and the beginning and end points should be clearly established. It is advised to take aerial photos adjacent to the delineated area so that any portion of the concerned area is not missed. The season and time can be determined by asking the local experts. However, the best season to photograph riparian area is when they have full leaf coverage. The choice of film type depends on the objective. For delineation of riparian areas a natural color film can be used, however, for vegetation analysis infrared film should be used. For delineation of riparian areas and calculation of acreage, scale of 1:24,000 is adequate. However, for detail vegetation analysis, the scale from 1:2,400 to 1:3,000 is recommended for narrow strips whereas scale from 1:3,000 to 1:6,000 is recommended for wider strips.

Project Preparation, Specification, and Bidding: The manual further informs on starting the project, preparing various specifications for aerial photographs, agencies, and

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the bidding process. It is advised to use the largest scale topographic maps for determining the flight path of the aircraft. If the study area has geographical features such as canyons, ridges, then location of shadows should be considered in determining the flight path. The manual also provides information on making ground target paneling so that air craft crew can identify the beginning and end of the flight path and also counter check the scale of the photographs. For substantiating the aerial photograph, the manual suggests on collecting ground data for one tenth of a mile stream segment by using color-photographs and identifying dominant vegetation, trees, and shrubs.

Interpretation: The last stage after aerial photography is the interpretation of the photographs. Before beginning the interpretation, the manual suggests on identifying the Minimum Mapping Unit (MMU) or the finest resolution for that area. MMU of one acre is recommended. Although, many aerial photos may have very detail information showing individual trees, however, it is necessary to determine a MMU for the interpretation. For vegetation analysis, the manual suggests to use stereoscope to measure the height of trees from the aerial photos. The suggested vegetation analysis framework includes identification of dominant riparian species and mixed communities. Each aerial photo is interpreted for herbaceous vegetation, shrubs, trees, vegetation scarce or absent, and mixed communities. The framework is as follows:

Herbaceous vegetation: MMU is one acre. Determine if the herbaceous vegetation is the dominant ground cover comprising of 75% or more area and calculate the total acreage.

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Shrubs: MMU is one acre. Determine if the shrubs are the dominant species comprising 75% or more of the canopy and calculate the total acreage.

Trees: MMU is one acre. Determine if trees of 10 feet or more height is dominant comprising of 75% or more of the canopy and calculate the total acreage.

Riparian vegetation scarce or absent: In case of absence of riparian vegetation and presence of bare soil measure the linear length and record scarce riparian vegetation 200 feet or longer and determine total miles.

Mixed communities: MMU is one acre. Patches of mixed communities can be determined if trees, shrubs, and herbaceous vegetation is present with one of the species covering 75% and others lesser amount. Various possible groups for mixed communities include shrub/herbaceous vegetation; tree/herbaceous vegetation; tree/shrub; tree/shrub/herbaceous vegetation. Determine acreages for each typology to finally determine the total riparian area.

Periodic Monitoring: The purpose of aerial photography is to help monitor the riparian areas. It is suggested to re-do the aerial photography after a period of 5 to 10 years and measure the acreage of previously mentioned categories and calculate the change. The dominant change suggested is reduction in riparian vegetation and increase in the bare soil.

2.3: State of the Practice in Riparian Area Management

2.3.1: United States Department of Agriculture Method

In 1987, the United States Department of Agriculture wrote a technical report to help land and water resources managers in decision making for the management of riparian

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areas. Although, riparian areas can be found adjacent to rivers, streams, lakes, ponds, and reservoirs, the emphasis of the report is on the streams.[34] The manual provides method to select samples, control groups, and parameters to be surveyed in the riparian area. The manual suggests the use of sampling techniques to collect information from riparian areas, since it is not feasible to collect all information at every stretch. The steps in the management process include determining the information required for management process; determining the approach for collecting information; pilot sampling; information collection; analysis and interpretation; and usage of the information.[35] It is not necessary to do survey of each and every part of the riparian area. Based on the information required a sample can be selected for the survey and then expanded for the whole study area. The manual provides a method for expanding the sample.

For monitoring the success of management practices, sample sites can be selected and compared to the control group sites. Control group sites do not receive management practices. The manual further suggests on selecting samples from each ecological type so that every combination of riparian vegetation is selected rather than applying simple random sampling to the whole riparian area. One disadvantage of simple random sampling is that certain combination of riparian vegetation area may not be selected in the samples. The study area can be divided into transects of fixed length and then samples can be selected from these transects. The manual provides specific information on measuring parameters such as vegetative use by animals, vegetative overhang, stream-bank stability, and the streamside cover.

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[34] U.S. Department of Agriculture. *Methods for evaluating riparian habitats with application to management,* (Ogden: Dept. of Agriculture, Forest Service, Intermountain research Station, 1987), 2.
[35] *Id.*

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Vegetative use by animals: The vegetative use by animals is inspected visually along a transect line or channel cross section perpendicular to the flow of the river or stream. The extent of grazing and trampling by the animals along the transect line is determined. A ranking is prepared based on light vegetative use, moderate vegetative use, high vegetative use, and extreme vegetative use.

Vegetative Overhang: The vegetative overhang indirectly provides fish food, directly provides cover, and shades the water from the solar radiation.[36] The vegetative overhang is measured along the transect line closer to 0.1 feet of the length. The protrusion of the tree over the water body is measured in feet and total overhang includes undercut plus the vegetative overhang.

Stream-bank Stability: This parameter measures the stability of the stream banks due to presence of vegetation, rocks, and boulders along the transect line. A ranking is prepared to show different ranges of bank coverage.

Streamside Cover: The land cover of the riparian area is surveyed along the transect line up to the stream banks. The survey of this parameter depends on the judgment of the surveyor. A ranking is prepared for different types of land cover. The ranking is also related to the different ranges of coverage.

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[36] U.S. Department of Agriculture. *Methods for evaluating riparian habitats with application to management,* (Ogden: Dept. of Agriculture, Forest Service, Intermountain research Station, 1987), 18.

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This manual further provides information on the riparian community classification methods, riparian soils, and flood plain geomorphology, which should be collected for the riparian management purposes. The riparian areas have a complex community of vegetation and different communities respond differently to management practices. The community classification is based on present vegetation rather than potential vegetation. Within the present vegetation, it is divided by over-story and under-story vegetation. The under-story vegetation is a useful parameter of riparian soil and hydrology. Riparian soils are characterized by longer periods of saturation by ground water at the rooting depth of the vegetation. Soils in the riparian area can be classified by soil taxonomy and soil morphology. The soil taxonomy is the hierarchical and scientific system of classification developed by the United States Department of Agriculture (USDA). The main constituent is Taxa or soils of different physical and chemical properties. Soil morphology consists of sediment deposition and Pedogenesis. Pedons are distinct vertical distribution of different soil types containing different organic matter. Floodplain geomorphology is the process of evolution of fluvial valley bottoms because of fluventic processes, which means the running water. The flow of water or stream discharge can scourge valley bottoms and depends on many factors including longitudinal slopes.

This manual gives different examples of impact on the aquatic community composition depending on changes in the riparian vegetation. For example, if riparian and terrestrial vegetation is removed by grazing or urbanization, the shredders will reduce and scrappers will increase in the aquatic community. This method is called as functional feeding group method, where aquatic community composition is assessed in terms of various trophic levels. The research on relationships between feeding groups and vegetation is

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under process. However, few findings by Minshall include that presence or absence of canopy shade does not increase or decrease the shredders. Similarly Hawkins and others found that open canopy (clear-cut) streams had a much higher ratio (14:1) of collectors to scrapers than did partial or closed canopy streams (4:1).[37] Similarly if the riparian area is grazed, ratio of collector to scrapers increases in the stream than the ungrazed area. The change in composition of feeding group can be used as a parameter to measure impacts of management practices.

2.4: Conclusion

The current state of the art and practice in riparian area inventory, analysis and management procedures concentrates only on few aspects of the riparian ecosystem. The biological indices methods such as IBI, ICI use biological community as surrogate for water quality whereas the management methods concentrate on certain parts of riparian corridors such as streamside cover, stream bank stability, and soil. None of the methods reviewed contain a holistic analysis of ecology of the riparian corridors. Given the fact that it is difficult to procure ecological data, a framework for comprehensive ecological analysis based on available data is required.

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[37] U.S. Department of Agriculture. *Methods for evaluating riparian habitats with application to management,* (Ogden: Dept. of Agriculture, Forest Service, Intermountain research Station, 1987), 109.

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Chapter 3: Physical Characteristics of the Riparian Ecosystems

Ecosystems are defined as entities or natural units that include living and nonliving parts interacting to produce a stable system, in which the exchange of materials between the living and nonliving part follows circular paths.[38] The riparian ecosystems are usually located in the flood plains along the streams and rivers. Riparian ecosystems are dynamic ecosystems with various processes happening within the ecosystem including the nutrient and material cycle. The physical constituents of riparian ecosystems such as flood plains, soil, ground cover, trees, and vegetation, participate in these processes. These physical constituents may differ in scale and state in different geographical regions due to difference in the climate. Hence ecological processes occurring through different riparian ecosystems may differ in intensity. For example, accumulation of foliage litter over the ground due to defoliation of riparian trees reduces the speed of runoff and hence increases the sedimentation of particles, thus cleaning the runoff before mixing with the stream water. However, the absence of large ground coverage of riparian trees, as in case of desert-area riparian ecosystem in western U.S., reduces the ability of sedimentation.

Riparian ecosystems differ in form than the other ecosystems such as the upland ecosystem. Riparian ecosystems are linear as a consequence of being associated with the streams.[39] However, the basic functions of an ecosystem that is flow of material and energy remain. The material flow is associated with the function that riparian ecosystems serve in providing corridors for the transport of water and erodible material derived from

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[38] Eugene P. Odum, *Fundamentals of Ecology* (Philadelphia: W.B. Sanders Company, 1953), 9.
[39] U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status* (West Virginia: Information Transfer Center, 1981), 17.

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the landscape.[40] The energy flow is associated with the transport and transformation of nutrients coming from the surrounding landscape. Although there is lack of sufficient quantitative data on the ecological characteristics of energy flow, nutrient cycling, and community structure for various ecosystems, however, there is sufficient information that riparian ecosystems process a larger amount of nutrients, materials, and energy than the other ecosystems.

This chapter looks into the physical characteristics of the riparian ecosystem. The physical characteristics are studied under three broad categories. The first type are the characteristics associated with the overarching broad characteristics of the landscape affecting the riparian ecosystem, the second type are the characteristics of the stream and aquatic part of the riparian ecosystem, and the third type are the characteristics of the land part of the riparian ecosystem. An attempt is made to study the parameters of these three types of physical characteristics by their function, measurement unit, positive or negative effects, and if possible establish a range for good to worse conditions. The function consists of the jobs performed by these parameters, measurement units measure the magnitude, positive or negative effect means whether a change in the parameter is good or bad for the riparian ecosystem, and establishing a range for good to worse conditions would help to know whether the given level of parameter is good or worse for the riparian ecosystem. The dictionary defines parameter as a distinguishing characteristic or feature.[41] The functions of these parameters in the ecological services provided by the riparian ecosystem would be utilized to prepare the first matrix between the riparian

[40] U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status* (West Virginia: Information Transfer Center, 1981), 17.
[41] http://dictionary.reference.com/search?q=parameter, accessed on 04/27/2003.

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parameters and the ecological services. These ecological services include habitat, barrier, conduit, filter, source, and sink identified by Daniel S. Smith and Paul Cawood Hellmund in their book "Ecology of Greenways."

3.1: Overarching Characteristics of the Riparian Ecosystem

Drainage Density or Channel Density: Drainage density is an overarching parameter affecting broadly the land and the aquatic components of the riparian ecosystems. It is defined as the length of a stream per square kilometer of land area with units of measurement such as Km/Km^2 or m/m^2. It is the ratio of the total channel length to the area of the watershed (Drainage density= Channel length/Area of the Watershed). Riparian ecosystems occur along the streams. The abundance or more number of streams in a watershed increase the probabilities for growth and sustenance of the riparian ecosystems. It means that a watershed with higher value of drainage density would have more amount of riparian landscape than the watershed with lower value of drainage density. Hence drainage density is a positive indicator for the riparian ecosystem. Drainage density participates in all the six ecological services provided by the riparian ecosystem, since they affect the total riparian ecosystem.

Geomorphology: Geomorphology is an overarching parameter affecting both the land and the aquatic components of the riparian ecosystems. The riparian ecosystem is affected by the changes in the flood plain caused by the geomorphological processes. One of the geomorphological processes is known as alluvium process, which consists of eroded, upstream alluvial or fine soil transporting downstream and depositing in the flood

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plain. This deposition causes changes in the flood plains. Even during the steady-state conditions, when all the eroded material is transported to the downstream without deposition, river channel meanders and changes the flood plains. Parameters affecting the alluvium process are hydroperiod and meandering of river channel. The hydroperiod is defined as the period of flooding and affect the hydrology of the riparian ecosystem by altering the surface water in the stream and ground water in the riparian ecosystem. Meandering of river channels alters the riparian landscape by inundating the existing riparian vegetation and creating the point bars. The point bars are the areas of the river channel left during meandering. New riparian vegetation grows on the point bars. Geomorphology does not have a single unit of measurement; however, parameters of geomorphology such as hydroperiod and meandering of river channel have units of measurement. Hydroperiod or the period of flooding is measured by the number of days and meandering of stream is measured by the variables such as total sinuosity, topographic sinuosity, or hydraulic sinuosity.

- The total sinuosity is the ratio of channel length to the shortest distance or air distance measured between the source and the mouth of a stream (Total sinuosity=Channel length/air distance between source and mouth of the stream). It is a ratio of the same units of measurement, such as meter/meter. Total sinuosity is a positive variable, which means that higher value indicates more meandering of channel in the watershed.
- The topographic sinuosity is the ratio of the valley length measured along the mid-valley line of the watershed to the shortest distance or air distance measured

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between the source and the mouth of the stream (Topographic sinuosity= Valley length along the mid valley line/ air distance between source and mouth of the stream). Similar to total sinuosity, the topographic sinuosity is a ratio of the same units of measurement and a positive variable.

- Hydraulic Sinuosity is a percentage measurement calculated by the following formula-{(total sinuosity- topographic sinuosity)/(total sinuosity-1)}*100. It is a positive variable with higher value indicating more meandering and more number of channels in the watershed.

The flooding initiates many geochemical processes in the riparian ecosystems beginning with the decomposition of leaf and litter. Flooding also brings sediments and deposits over the riparian ground cover affecting the ecological functions of filter and sink. It is source of nutrients such as phosphorous. Hence, flooding can be associated with the ecological services of filter, sink, and source provided by the riparian ecosystem. The meandering of channel destroys the existing riparian vegetation affecting the habitat services of the riparian ecosystem.

3.2: Aquatic Characteristics of the Riparian Ecosystem

The aquatic characteristics of the riparian ecosystems include hydrology of the riparian ecosystem and the streams in the watershed. The hydrology of the riparian ecosystem or the surface and ground water of the riparian ecosystems is explained below-

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Surface Water: In case of riparian ecosystems, surface water means the extent and the period of the flooding inundating the riparian landscape. It is a parameter of the aquatic characteristics of the riparian ecosystem. During flooding overflow of the water into the riparian forests not only deposits alluvial soil but also recharges the ground water by percolating into the soil. The two factors affecting the flooding are depth of flooding and period of flooding. Some of the factors influencing the depth of the flooding include climate, topography, channel slope, soils, and geology.[42] If all these factors remain constant, then the depth of flooding depends largely on size of the drainage basin or watershed and the storage capacity of the flood plain surface.[43] Thus, the size of the drainage basin or watershed of the riparian ecosystem is an important parameter determining the flooding. The flooding is also affected by the variations in the topographic features such as ditches or depressions, which become pools of water. The duration of flooding depends on the drainage area of the stream basin upstream from the site in question.[44] Various studies in the past have concluded that flooding is for a period of 5% to 7% of a year, if the drainage basin area in upstream is less than the 780 square Km; flooding is for a period of 10% to 18% of a year, if the drainage basin area is between 13,000 to 18,000 square Km; and flooding is for 40% of the year, if the drainage basin area is tens of thousands of square Km. This indicates that although there are many different factors affecting flooding, the size of the upstream drainage basin affect the period of flooding in the downstream riparian ecosystem. The surface water participates in the ecological services similar to flooding, which includes filter, sink, and source.

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[42] U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status* (West Virginia: Information Transfer Center, 1981), 23.
[43] *Id.*
[44] U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status* (West Virginia: Information Transfer Center, 1981), 24.

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Ground Water: Ground water is the parameter of the aquatic characteristics of the riparian ecosystems. The water level in the stream is affected by the groundwater and vice versa because of the process of discharge. During high water level in the stream, water flows from the stream into aquifer and during low water stages, the aquifer recharges the stream. The process of ground water discharge and recharge is affected by the size of floodplain, shape of floodplain, and the soil type. Where an area of floodplain is partially encircled by a sharp river meander, or where flood plain segments are narrow due to proximity of stream channel and valley wall, river stage and ground water levels will respond to each other more quickly.[45] It means that locations where stream or river turns sharply or where the flood plains are narrower with steep slopes between the uplands and the flood plains, the process of discharge is more and faster. If the soil in the river channel and flood plain consists of clay rather than the sand or silt, the time lag for the movement of water increases. Hence soil permeability affects the ground water and the process of discharge. The permeability is defined as the rate of flow of a liquid or gas through a porous material.[46] In our case, the liquid consists of water, while the porous material is the soil.

Studies of the hydrological cycle or inflow and outflow of water through a stream, flood plain, and riparian vegetation indicate that evapotranspiration, which is defined as the vaporization of the water through the leaves and foliage has a more significant role than the direct evaporation from the stream. During the study of the Gila River floodplain by Gatewood, measurements of water inflows from upstream and outflows at downstream

[45] U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status* (West Virginia: Information Transfer Center, 1981), 25.
[46] http://dictionary.reference.com/search?q=permeability, accessed on 04/27/2003.

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revealed that only 2.5% was due to evaporation from the river surface and wet sand bars, while 12.3% was due to evapotranspiration by the Bottomland vegetation.[47] The riparian vegetation is also known as the Bottomland vegetation. The process of evapotranspiration depends on the foliage density and leaf surface area of the riparian vegetation. Hence riparian vegetation affect the groundwater hydrological cycle. The process of groundwater discharge and recharge and thus maintaining the water level of the stream is significant for habitat of fish and aquatic animals. Hence the groundwater participates in the habitat services provided by the riparian ecosystems.

Riffles/Pools: Riffles and pools are the parameters of the aquatic characteristics of the riparian ecosystems. Riffles are defined as shallow rapids flowing over partially or completely submerged obstructions such as sand bars or rocky shoals.[48] Qualitative Habitat Evaluation Index (QHEI) provides score for the depth of the riffles giving high score to deeper riffles. The quality of the habitat in a riffle also depends on the substrate consisting mainly of pebbles and round sized stones. The interstices of these substrate become habitat for many macro and micro invertebrates. The substrates are the materials found in the river or stream bottom. The interstices are the narrow spaces found in the closely packed materials of substrate.

Pools are portions of the streams with reduced current velocity and with water deeper than the surrounding areas.[49] Qualitative Habitat Evaluation Index (QHEI) scores depth

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[47] U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status* (West Virginia: Information Transfer Center, 1981), 26.
[48] http://forestry.about.com/library/glossary/blforglr.htm, Riffle, accessed on 04/15/2003.
[49] http://forestry.about.com/library/glossary/blforglr.htm, Riffle, accessed on 04/15/2003.

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of pools giving higher score to deeper pools. The depth of pools is reduced by the erosion and sedimentation, which causes siltation or deposition of sediments over the substrate. The pools are habitat of various warm water fish and macro-invertebrates. There are three variables used to assess the riffle and pool habitats. The variables include the number of riffles and pools per mile length of the stream, the width of riffles and pools, and the depth of riffles and pools. The presence of riffles and pools is an indication of the aquatic habitat in that portion of the river. Hence riffles and pools participate in the habitat function of the riparian ecosystem.

Stream: Stream is a parameter of the aquatic characteristics of the riparian ecosystem. The streams are classified by order from the first order to the sixth or seventh order. Daniel S. Smith explains that headwaters with no tributaries are the first order streams. Two first order streams join to form a second order stream. Two streams of the same order should join to form a higher order stream, for example, two second order streams can join to form a third order stream. However, a second order and a first order stream cannot join to form a third order stream. Cascading mountain streams are usually the first or second order stream.[50] Large rivers are the sixth, seventh, or higher order stream. The order of a stream indicates width, flow, watershed size, slope, relief, length, and organic matter in the water. Large order streams or rivers have wider navigable channel, less flow, large watershed, less slope, less relief, and more organic matter in their water. The overall influence of the riparian ecosystem decreases as the stream becomes larger and therefore as the volume of the water relative to the area covered by the riparian forest

[50] Daniel S. Smith and Paul Cawood Hellmund, *Ecology of Greenways* (Minneapolis: University of Minnesota Press, 1993), 72.

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becomes larger.[51] It means that riparian areas and their ecological services are more effective in the lower order streams. There is no unit for the order of a stream. It is indicated only by a number. Stream is a habitat for all the aquatic organisms and source of water for the terrestrial animals. It is also a mortality sink for the aquatic and terrestrial animals. Streams function as conduit for sediments, organic matter, and debris. Hence stream in the riparian ecosystem participates in the ecological services of habitat, sink, source, and conduit.

3.3: Land Characteristics of the Riparian Ecosystem

Riparian Soil: Riparian soil is parameter of the land characteristics of the riparian ecosystem supporting trees, vegetation, ground cover, and biogeochemical processes. The riparian soil differs from the upland soil in moisture content, organic matter, aerobic, and anaerobic conditions. The presence or absence of oxygen is known as the aerobic or anaerobic condition. Similarly the presence or absence of gaseous or dissolved oxygen in soil affects the rate of oxidation or reduction reactions and biologically induced nutrient cycling.[52] The water content in the soil or the moisture affects the organic decomposition process. The nutrient cycling and organic decomposition process are associated with the filter and sink ecological services of the riparian ecosystem. Hence riparian soil participates in the ecological services of filter and sink.

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[51] Daniel S. Smith and Paul Cawood Hellmund, *Ecology of Greenways* (Minneapolis: University of Minnesota Press, 1993), 73.
[52] U.S. Department of Agriculture. *Methods for evaluating riparian habitats with application to managemen,* (Ogden: Dept. of Agriculture, Forest Service, Intermountain research Station, 1987), 43.

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Soil moisture is an important variable because small topographic variations in a level floodplain can cause a waterlogged, anaerobic environment or a well drained, aerated environment.[53] The riparian ecosystems extend up to floodplains, however, within the leveled surface of floodplains, minor differences in elevation can cause water pools and areas with periodic flooding. The plant life is very different in the water logged areas and areas having periodic flooding due to higher moisture in the soil. Hence riparian soil also participates in the habitat function of the riparian ecosystem.

Relative Relief: Relative relief is a parameter of the land characteristics of the riparian ecosystem. It is defined as the difference between the highest and lowest elevation in a land parcel. The unit of measurement for relative relief is either centimeter or meter. As mentioned in case of soil moisture, little variations in elevation can cause changes in moisture content due to formation of pools resulting into changes in plants. Abrupt changes in species composition may occur in floodplains with elevation variations of only a few centimeters.[54] The elevation variations are described by the Relative relief. Hence relative relief participates in the habitat services affecting the species composition in the riparian ecosystem.

Slope: Slope is the inclination of the surface. It is a parameter of the land characteristics of the riparian ecosystem and one of the indicators of topography. Depending on the inclination or steepness, slopes can increase the speed of runoff increasing possibility of

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[53] U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status* (West Virginia: Information Transfer Center, 1981), 17.
[54] U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status* (West Virginia: Information Transfer Center, 1981), 18.

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the erosion. Steep slopes can become unstable and erode by caving in. Hence slope in the flood plains, particularly along the stream banks is an important variable. The landscape literature provides ranges for the slopes, such as 0-3% is the rolling slopes; 3%-12% is suitable for the development; 12%-15% is the high slope; and 15% and greater is higher and unstable slope. Slopes of 15% or greater than the 15% inclination is not suitable for development and may require ground cover such as vegetation and trees to bind the soil. However, in case of flood plains, forests, and riparian landscapes, steep slopes can be found depending on the topography in the region. The slopes affect runoff by increasing the speed of the runoff, thus reducing filter and sink functions of the riparian ecosystem. Steep slopes increase the sediments in the stream, thus altering the aquatic habitat in the riparian ecosystem. Slopes also support trees and vegetation. Hence, slopes affect the habitat function of the riparian ecosystems. Steep slopes are difficult to climb and inaccessible, hence animals and humans avoid these slopes. Steep slopes filled with vegetation along the stream banks function as barrier. Thus, slopes participate in the ecological services of habitat, barrier, filter, and sink in the riparian ecosystems.

Tree Cover/Riparian Herbaceous Vegetation: The forests in the flood plain consisting of trees and herbaceous vegetation such as shrubs, bushes, and grass are the land part of the riparian ecosystems. Trees and riparian herbaceous vegetation are parameters of the land characteristics of the riparian ecosystem. Depending on their locations, which could be above ground, above channel, in channel, stream banks, and flood plains; riparian trees and vegetation perform multiple functions. Every part of the tree including roots,

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trunk, stems, leaves, and canopy participates in processing the nutrients, materials, and energy.

Based on the research by the United States Fish and Wildlife Service and W.R. Meehan, canopy and stems of the trees located above the ground and channels provide shade to the stream, thus control the temperature in the stream and protect the habitat for the aquatic species living near the stream banks. An increase in the temperature of water results into removal of many fish species. The canopy is also a source of the large and fine plant detritus consisting of leaves and stems, which is food for the aquatic animals. Trees and vegetation are also habitat for insects, birds, and mammals.

Vegetation within the channel consists of debris such as logs and inundated plants and trees. These logs, trees, and plants help in shaping stream habitats such as riffles and pools. They reduce the flow of water making micro habitats within the stream. They help protect siltation of the stream banks and spur the decomposition of the organic matter providing home and food for many aquatic macro-invertebrates. Roots of the trees located on the stream banks increase the bank stability. Trunks, stems, and low lying canopy of trees located on the floodplains decrease the speed of runoff, reduce the movement of the sediments and organic debris thus increasing the contact period between organisms and organic debris. The reduction of the run-off movement from upland as well as the reduction in the movement of flood waters in the flood plains increases the contact period between water, organisms, litter, and nutrients. This initiates the processes of sink and filter in the riparian ecosystems. Trees and herbaceous vegetation also act as

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barriers against grazing animals and help maintain the stream banks. Grazing animals trample the stream bank; graze grass and vegetation leaving the ground cover bare. Clumps of trees and herbaceous vegetation along the stream banks create a linear corridor of green space through which the animals migrate. They function as conduit for the movement of animal species. Hence trees and herbaceous vegetation in the riparian ecosystem participates in all the six ecological services including habitat, barrier, conduit, filter, source, and sink.

Wetlands: The Clean Water Act defines the wetlands as areas that are inundated and saturated by surface or groundwater at a frequency or duration sufficient to support prevalence of vegetation typically adapted for saturated soil conditions.[55] Technically wetlands and riparian areas are two different ecosystems, however sometimes, wetlands are found within the floodplains or within the extent of the riparian ecosystems. It is a parameter of the land characteristics of the riparian ecosystem but wetlands perform their own ecological services. Wetlands include open water, ponds, marshes, and wet meadows. They are habitat for specific plants, animals, and insects. Similar to riparian ecosystems, wetlands function as sink for sediments and nutrients, when they filter runoff. Wetlands recharge aquifers and help in maintaining the ground water level. They are sources of water to the aquifers. Hence, wetlands within the riparian ecosystem participate in the ecological services of habitat, sink, source, and filter. Wetlands within the riparian ecosystem are an important area requiring conservation.

[55] http://www.epa.gov/OWOW/wetlands/facts/fact11.html, accessed on 04/21/2003.

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3.4: Analysis

Table 3.1 is the compilation of physical parameters, factors affecting these parameters, unit of measurement, and references. Table 3.2 is the matrix between the riparian parameters and the ecological services. Table 3.3 is the distribution of the physical parameters into high, medium, and low value of importance based on their participation in number of ecological services. The parameters under overarching, aquatic, and the land characteristics are further ranked in importance as high if they participate in five to six ecological services; medium if they participate in three to four ecological services; and low if they participate in one to two ecological services. The distribution of physical parameters into high, medium, and low importance depends on their participation in number of ecological services. It does not indicate that a parameter working in one type ecological service has lesser value than the parameter working in more than one type of ecological service. Each of the six ecological services is equally important for the riparian ecosystem. However, this indicates that parameters of the high and medium values should be monitored in managing a riparian ecosystem and should be considered while mapping and making decisions for the riparian ecosystem. The physical parameters into high, medium, and low values of importance are compiled in Table 3.3. The parameters of the high importance are drainage density and tree cover/riparian vegetation; medium importance are hydroperiod, stream, surface water, slope, soil, and wetlands; and low importance are channel meandering, ground water, riffles/pools, and relative relief.

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Table 3.1: Physical parameter, unit of measurement, and references

	Parameter	Factors affecting the parameter	Unit of Measure-ment	References
1	Drainage Density	Drainage Network	Km/Km^2	Daniel Smith et. al.
2	Geomorphology	Hydroperiod/flooding	in Days	Daniel Smith et. al
		Meandering of channel • Total sinuosity • Topographic sinuosity • Hydraulic sinuosity	Dimension-less	Daniel Smith et. al.
3	Surface Water • Depth of Flooding	Climate, topography, channel slope, soils, geology, size of drainage basin, storage capacity of floodplain surface	In Meters	U.S. Fish and Wildlife Service
	• Period of Flooding	Size of upstream drainage basin	In Days	U.S. Fish and Wildlife Service
4	Ground Water	Size of flood plain, shape of flood plain, soil type		U.S. Fish and Wildlife Service
5	Riffles-Pools	Sand bars, rocky shoals, flow of water	Numbers, depth in meters	Edward T. Rankin in Biological Assessment and Criteria
6	Stream	Order	Number	Daniel S. Smith
7	Riparian Soil	Moisture, Dissolved oxygen and gases	Taxa	U.S. Department of Agriculture, U.S. Fish and Wildlife Service
8	Relative Relief	Topography	Meter, Centimeter	U.S. Fish and Wildlife Service
9	Slope	Topography	Percentage	Frederick Steiner

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	Parameter	Factors affecting the parameter	Unit of Measure-ment	References
10	Tree Cover/riparian herbaceous vegetation	Climate, soil, geographical region	Acres	U.S. Fish and Wildlife Service, W.R. Meehan.
11	Wetlands		Acres	EPA, Iowa Environmental Council

Source: Compiled by the author

Table 3.2: Interrelationship matrix between physical parameter vs. ecological services

	Parameter	Habitat	Conduit	Barrier	Filter	Source	Sink
Overarching	Drainage Density/Channel Density	✓	✓	✓	✓	✓	✓
	Geomorphology (Hydroperiod)				✓	✓	✓
	Geomorphology (Channel Meandering)	✓					
Aquatic	Surface Water				✓	✓	✓
	Ground Water	✓					
	Riffles/pools	✓					
	Stream	✓	✓			✓	✓
Land	Soil	✓			✓		✓
	Relative Relief	✓					
	Slope	✓		✓	✓		✓
	Tree Cover/Riparian herbaceous Vegetation	✓	✓	✓	✓	✓	✓

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	Parameter	Habitat	Conduit	Barrier	Filter	Source	Sink
Land	Wetlands	✓			✓	✓	✓

Source: Compiled by the author

Table 3.3: Distribution of physical parameters into high, medium, and low importance.

Category	High	Medium	Low
Overarching	Drainage density	Hydroperiod (Geomorphology)	Channel meandering (Geomorphology)
Aquatic		*Stream*, Surface water	Ground water, *Riffles/Pools*
Land	*Tree cover/Riparian herbaceous vegetation*	*Slope, Soil, Wetlands*	*Relative Relief*

Note: Italics designate map able parameters

Source: Compiled by the author

Every riparian parameter included in the study cannot be mapped. Some of these parameters such as drainage density require calculation and have one value for the watershed. Some of the parameters change in a longer period of time and changes are minute requiring sophisticated technology and high resolution mapping such as ground water and aquifers. However, some of the parameters can be mapped and monitored such as tree cover/riparian vegetation, slopes, relative relief, riffles and pools, and wetlands. The parameters, which have high to medium importance in the ecological services and which could be mapped would be used to prepare GIS layers for the pilot study area. These parameters are tree cover/riparian vegetation, slope, soils, and wetlands.

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Chapter 4: Ecological Characteristics of the Riparian Ecosystems

Every ecosystem has the basic ecological characteristics of primary productivity and flow of material and energy. The primary productivity in a riparian ecosystem includes litter fall consisting of leaves and stems, and the bio-mass accumulation in the trees, vegetation, and organisms. Within the riparian ecosystem, large amounts of energy flow during the primary productivity processes in addition to litter fall and biomass accumulation. One more fundamental functions of the primary productivity, in addition to providing energy flow to food webs, is that of maintaining the structure and integrity of ecosystems.[56] Every ecosystem including riparian ecosystem is dynamic, where new plant and animal biomass replaces the dead plants and animals maintaining the structure of the ecosystem. The food web mentioned previously consists of many food chains and shows the hierarchy of producers and consumers in food pattern in an ecosystem. The primary productivity is an overarching concept and can be measured by assessing the biomass and flow of materials. The flow of material in a riparian ecosystem includes nutrients in addition to sediments. The flow of energy happens during the processes of bio-mass accumulation and the flow of material.

This chapter looks into the ecological characteristics of the riparian ecosystems by studying the parameters of biomass and flow of materials including nutrients. The parameter is defined as a feature or distinguishing characteristic. The attempt is to study these parameters by their function, measurement unit, positive or negative effects, and if possible, establishing a range for good to worse conditions. There are three broad

[56] U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status* (West Virginia: Information Transfer Center, 1981), 26.

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parameters for primary productivity or the ecological characteristics in a riparian ecosystem, which includes biomass, food chains and food webs, and the flow of materials. The biomass is the total mass of a living matter within a given unit of area.[57] The living matter includes plant life and animal life. The plant life in case of riparian ecosystem consists of trees and vegetation. The biomass of trees and vegetation is the mass of leaves, stems, and trunks above the ground and mass of roots below the ground. The characteristics of the biological community particularly animal life are the food chains and food webs mentioned previously. In general, food chains and food webs represent food patterns in an ecosystem, where the primary consumers such as herbivores eat plants and then the secondary consumers such as carnivores eat the herbivores. The energy flows in the food chain from primary consumers at the lower trophic levels to the secondary consumers at the higher trophic levels. Various consumers such as herbivores and carnivores take hierarchical levels known as the trophic levels in a food pyramid. However, the study of food chain specific to a riparian ecosystem requires field work and data collection, which is beyond the scope of this thesis. Hence, the emphasis will be on the flow of nutrients and materials. The examples of the nutrient and material cycling in a riparian ecosystem are organic matter, nitrogen cycle, phosphorous cycle, and sedimentation. The flow of energy is a common characteristic to the biomass accumulation, food chain, and nutrients and materials cycle.

[57] http://dictionary.reference.com/search?q=biomass, accessed on 04/29/2003.

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4.1: Biomass Characteristics of the Riparian Ecosystem

The different parameters included by the U.S. Fish and Wildlife Service research on riparian ecosystems are stem density, leaf-fruit and litter fall, basal area, stem wood production, and the total biomass production.

Stem Density: Stem density is a parameter of the biomass production in the riparian forests. It is defined as the number of stems or tree trunks per unit of land area. The unit of measurement is number of stems per hectare (number/hectare). The high value of stem density indicates high forest growth and density. The stem density can be used to compare different riparian forests.

Basal Area: Basal area is a parameter of the biomass production in riparian forests. It is the cross-sectional area of a tree measured 4.5 feet above the ground.[58] The basal area is usually used to calculate the total wood production in a forest. The unit of measurement is square meter per hectare (m^2/hectare). The higher value of basal area for a tree indicates more accumulation of biomass in that tree.

Leaf and Fruit Litter fall: This parameter of biomass measures the litter or fallen leaves and fruits on the forest floor, which becomes a source of organic matter in the riparian ecosystem. It is calculated as the total weight of fallen leaves, stems, and fruits on the forest floor. The unit of measurement used is grams per square meter per year (g/m^2 per year). This is the weight of the fallen leaves, stems, and fruits in grams per square meter

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[58] http://www.extension.umn.edu/distribution/naturalresources/DD6981.html, Making and Using Measurement Tools-Basal Area, University of Minnesota Extension Service, accessed on 02/18/2003.

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of the surface area of the forest floor in one year. The higher magnitude of litter fall indicates high release of the accumulated biomass in the riparian ecosystem. The litter fall is used to compare different riparian forests.

Stem Wood Production: This parameter of biomass measures the total production of stem wood in a riparian forest in one year. Similar to the leaf and fruit litter-fall, the unit of measurement is grams per square meter per year (g/m^2 per year). It is the weight of the stem wood produced per square meter surface area in one year. The high value of stem wood production shows high growth in the riparian forests. The stem wood production can also be used to compare different riparian forests.

It can be observed from these parameters that some parameters such as basal area can be used to compare trees of different species, while some parameters such as stem density, leaf and fruit littler fall, and stem wood production can be used to compare different forests. None of these parameters is inclusive enough to show the total biomass. In fact the total above ground biomass in the riparian ecosystem will be the sum of the values of different parameters including leaf and fruit litter fall and stem wood production. However, the share of stem wood production in the above ground biomass is more than the leaf and fruit litter fall. The production of stem wood biomass accounts for about 54% of the aboveground biomass production.[59]

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[59] U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status* (West Virginia: Information Transfer Center, 1981), 28.

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Factors affecting the biomass characteristics: There are various researches on factors affecting the litter fall and stem growth in a riparian ecosystem. Minshall observed that riparian areas having periodic flooding or alternate dry and wet period has more biomass growth in comparison to areas, which are either dry or wet. In general, floodplain wetlands that have an annual unaltered cycle of wet and dry periods have an above ground net biomass production, which is the sum of litter fall and stem growth greater than 1000 grams per square meter per year.[60] This level of productivity is generally higher than that of forested wetlands that are permanently flooded or have sluggish flow.[61] This indicates that periodic flooding is an important factor affecting the biomass of riparian ecosystems. Similarly the U.S. Fish and Wildlife research indicates that flood frequency and groundwater supply are the major environmental factors controlling the growth of floodplain trees.[62] Flooding helps the riparian forests in three ways by providing adequate water supply, nutrient supply, and more oxygen to roots than the stagnant water.

4.2: The Characteristics of Flow of Materials

It is mentioned previously that the flow of materials consist of nutrients cycle requiring various chemical processes and the sediment removal. The flow of materials in the riparian ecosystem can be classified into sink and filter ecological services of the riparian ecosystem. The physical and chemical processes occurring in the flow of materials, which include phosphorous, nitrogen, organic matter, and sedimentation is as follows.

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60 William J. Mitsch and James G. Gosselink, *Wetlands* (New York: John Wiley & Sons Inc., 2000), 556.
61 *Id.*
62 U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status* (West Virginia: Information Transfer Center, 1981), 31.

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Phosphorous Cycle: Phosphorous enters the wetlands and riparian ecosystems as either particle phosphorous or dissolved phosphorous.[63] Both the states of phosphorous are interchangeable that means particle phosphorous can become dissolved phosphorous and vice-versa in the water column or sediments. The phosphorous enters the riparian ecosystem through the litter fall, inflow of flood water, and the agricultural run-off. The phosphorous is released when the litter fall decomposes or during sedimentation of the agricultural or surface run-off and the flood waters. If the sedimentation takes place in a wetland, ditch, or a water body within the riparian ecosystem, they become permanent sink for the phosphorous. During the litter fall decomposition, the released phosphorous remaining in the soil is taken by the woody bio-mass including stem and roots, leaves and fruits, and the remaining finally goes into the surface water. For example, the data on phosphorous distribution in riverine forests show that the rank, from the highest to the lowest standing stocks of phosphorous, is usually 1) soil, 2) aboveground wood, 3) belowground wood, 4) canopy leaves, 5) litter layer, and 6) surface water.[64] The phosphorous flow is affected by the flooding process and also the concentration of phosphorous in the effluent or run-off. In riverine forests or riparian forests with periodic flooding, the flow of phosphorous is more than the upland forests. Similarly uptake of phosphorous by the woody biomass is more, if the phosphorous rich effluent enters into the ecosystem. William T. Peterjohn and David Correll studied the nutrient dynamics of an agricultural watershed and the role of a riparian forest near the Chesapeake Bay in Maryland and published their results in 1984. Of the total phosphorous export from the

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[63] Naiming Wang and William .J. Mitsch, "A Detailed Ecosystem Model of Phosphorous Dynamics in created Riparian Wetlands," *Ecological Modelling*, 126(2000): 109.
[64] U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status* (West Virginia: Information Transfer Center, 1981), 37.

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cropland about 16% goes in surface agricultural runoff. The calculated phosphorous retention by the riparian forest was 80%.[65] The width of the riparian forest (study area) was 50 meters. Similarly William J. Mitsch developed a nutrient budget for an alluvial river swamp in southern Illinois and findings were that ten times more phosphorous is deposited with sediments during river flooding (3.6 g-P per square meter per year) than was returned from the swamp to the river during the rest of the year.[66] Periodic flooding has an important role in phosphorous retention and the 'sink' ecological service of the riparian ecosystem. Similarly in terms of phosphorous intake, riparian trees uptake a large amount of phosphorous. The removal of phosphorous is shown as percent and the unit of measurement used is grams per square meter per year. The higher value of phosphorous removal by the riparian ecosystems is good for the streams.

Nitrogen Cycle: Riparian ecosystem removes nitrogen from the surface runoff and stream water during flooding. The surface runoff includes runoff from the agricultural fields and urban areas. In case of nitrogen removal, riparian forests become 'sink' for the nitrogen. However, the processes of nitrogen removal from the surface runoff and flood waters are different. Moreover, there is more than one process of nitrogen removal in the riparian ecosystem. The filtering mechanisms for nitrogen (N) in riparian ecosystems include sediment trapping, plant uptake, microbial immobilization, and denitrification.[67]

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[65] W.T.Peterjohn and D.L.Correll, "Nutrient Dynamics in an Agricultural Watershed: Observations on the Role of a Riparian Forest," *Ecology* 65(1984) issue5.
[66] William J. Mitsch, "Restoration of our Lakes and River Wetlands-an Important Application of Ecological Engineering," *Water Science Technology* 31(1995): 171.
[67] Peter M. Groffman, Arthur J. Gold, and Pierre-Andre Jacinthe, " Nitrous Oxide production in riparian zones and groundwater," *Nutrient Cycling in Agroecosystems* 52(1998), 181.

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The processes of nitrogen removal include removal from the flood waters, natural cycle of nitrogen, and removal from the surface runoff.

Removal of nitrogen during flood: This process is documented in the U.S. Fish and Wildlife Service research on riparian ecosystems. During winter, the riparian forest floor is covered with litter fall and due to flooding and impounding of water, anaerobic conditions occur within the upper surface of the forest floor. The sedimentation occurs due to slow movement of the flood waters. The particulate nitrogen settles down with sediments over the leaf detritus while dissolved nitrogen percolates into the soil. The filamentous algae appear because of the sunshine and the algae take the nitrogen under the anaerobic conditions. In the spring, flood water reduces and the trees grow new leaves blocking the sun rays to the forest floor. The filamentous algae die because of the blocking of the sun rays and the detritus starts decomposing under warm conditions. The nitrogen released by the detritus is taken by the tree. During summer, the surface water is removed due to evapotranspiration and the sediments are exposed thus increasing the nitrogen processing and nitrogen uptake by the trees. In the fall, trees shed their leaves returning a significant amount of uptake nitrogen to the ground and in the winters, flood water returns and the nitrogen cycle is repeated.

During summer, the process of ammonification takes place, where the organic N (nitrogen) within the detritus is processed into NH_4 (ammonium), which is taken by the tree. The ammonium converts into NO_3 (Nitrate form) by nitrification. After nitrification, the nitrate form leaches into the ground and some part converts into N_2

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(Nitrogen gas) and N_2O (Nitrous Oxide) by the process of denitrification and released into the atmosphere.

Natural Cycle: The natural cycle of nitrogen within the riparian ecosystem in absence of any external input of nitrogen such as flooding is as follows. The roots of the riparian trees fix the atmospheric nitrogen converting to organic N (nitrogen) and ammonium nitrate (NH_4N). The Ammonium Nitrate diffuses into the tree and by upward diffusion goes into the upper soil, where nitrification occurs. The ammonium nitrate converts into nitrous acid and nitric acid. Due to downward diffusion, part of the acid generated leaches into the ground. While some part of the acid converts into nitrogen and nitrous oxide gas and released back into the atmosphere.

Figure 4.1: Process of Nitrogen Cycle in Riparian Ecosystems

Atmospheric Nitrogen gas → fixation by tree roots → Organic N → Ammonium Nitrate (NH_4N).
NH_4N → (Nitrification) → HNO_2 (Nitrous Acid) → HNO_3 (Nitric Acid) → Downward diffusion and Denitrification.
Downward diffusion → Leaching into the ground
Denitrification → N_2, N_2O gas released back into the atmosphere.
Part of NH_4N (Ammonium Nitrate) (Volatization)→ NH_3 (Ammonia gas).

Source: U.S. Fish and Wildlife Service, *Riparian Ecosystems: Their Ecology and Status*, compiled by the author.

Removal of nitrogen from the surface runoff: Riparian forests are effective in removing nitrogen from the external sources such as urban area runoff and agricultural runoff. In case of agriculture runoff, fertilizer used for the crops contains nitrogen.

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However, in agricultural land, only a portion of the nitrogen is taken by the crop. Some part of the nitrogen seeps into the ground and flows under the ground into the riparian area and the rest goes directly to the riparian area with the surface runoff. Peterjohn and Correll studied the nitrogen flow and removal of nitrogen by the riparian forests in an agricultural watershed and found that 17% of the total nitrogen to the riparian forest comes from the bulk precipitation, 61% by the ground water flow, and 22% by the surface runoff. The riparian forest was found to be effective in removing the nitrogen. The nitrogen retained by the riparian forest was 89% and much higher than the 8% nitrogen retained by the cropland.[68] Of the 11% nitrogen lost to the stream, 75% was through the ground water flow and the rest through the direct runoff to the stream.

Usually external nitrogen is in the form of nitrate or NO_3, hence scientists studied the denitrification process by which nitrate is converted to nitrogen gas and nitrous oxide. If the factors enhancing the denitrification process are present in the riparian forest, the ecosystem will function as better nitrogen filter. Peter M. Groffman studied this role of riparian forests in nitrous oxide production in a case study of watershed at Norway. The nitrate from the agricultural land use or residential land use flows towards the riparian forest by the surface flow; perched water within the subsurface soil; ground water flow; and underflow or deep recharge. Out of these, surface flow is the fastest and a portion of the ground water flow is deep enough to be out of the biological zone of riparian tree roots. If there is friction to the surface flow in the riparian area and water moves slow, more nitrogen is removed. Riparian areas having grass and vegetation as land cover have

[68] W.T.Peterjohn and D.L.Correll, "Nutrient Dynamics in an Agricultural Watershed: Observations on the Role of a Riparian Forest," *Ecology* 65(1984) issue5, 1473.

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more capacity to remove nitrogen from the surface water. The filtering capacity of the riparian ecosystems is strongly regulated by the hydrologic factors controlling the flow and residence time of NO_3, as it moves from the upland areas through the riparian areas.[69] The presence of wet soil in riparian forests affects denitrification or removal of nitrate. There is abundant evidence that riparian forests dominated by inherently wet surface soils have a high capacity to consume NO_3 via denitrification.[70] Hence hydrologic conditions of periodic flooding, soil moisture, trees, grass and vegetation cover are the physical factors affecting the nitrogen removal.

The other methods of nitrogen removal such as trapping of sediments take place at a greater rate, if the riparian forest has ditches, wetlands, and moist soils. The trapped sediments become the permanent sink for nitrogen. However, if the riparian ecosystems are altered and drained and stream is channelized restricting the periodic flooding process, then the riparian ecosystems become a source rather than the sink for the nitrogen. In this case more nitrogen loading happens in the watershed downstream to the riparian forest. The nitrogen removal is shown as the percent and the unit of measurement used is grams per square meter per year (Refer to Table 4). The higher removal of nitrogen by the riparian ecosystem is good for the streams.

Organic matter- litter fall: The litter fall in riparian ecosystems consist mainly of the leaves, stems, reproductive parts, flowers, and fruits. They are the major food sources for the aquatic organisms and in part determine their community structure and function. The

[69] Peter M. Groffman, Arthur J. Gold, and Pierre-Andre Jacinthe, " *Nitrous Oxide production in riparian zones and groundwater*," Nutrient Cycling in Agroecosystems 52(1998), 181.
[70] *Id.*

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maintenance of the community structure and function in small stream is largely dependent on the input of organic matter from the watershed through which the stream flows.[71] The leaves, stems, and other litter either fall in the stream or fall over the floodplain floor. The litter falling into the stream is from the overhanging riparian trees and vegetation. The processing of litter fall in both cases is somewhat similar and researched by Richard W. Merritt and Daniel L. Lawson in their study of leaf litter processing in floodplain and stream communities at a Michigan woodland floodplain and published in the USDA publication "Strategies for Protection and Management of Floodplain Wetlands and other Riparian Ecosystems."

Any leaf entering the stream loses soluble organic matter by leaching in the first 24 hours as it become wet. They are colonized by the microorganisms, which make the leaves palatable for other macro invertebrates. The first type of macro invertebrates eating the leaves are large particle detritivores known as shredders. After shredding of the leaves, the small particle feeders known as collectors feed on the leaves. Hence, the coarse particulate organic matter converts into fine particulate organic matter and by the fall and the following winter; any recognizable form of the leaf does not remain.

Any leaf falling on the ground cover of the floodplain goes through the similar process as in the stream. However, the period for decomposition and the seasonal impacts are different. The first thing is the rapid loss of the soluble leaf components by leaching. The precipitation in the fall causes more leaching and colonization by microorganisms.

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[71] R. R. Johnson and J. F. McCormik, ed., *Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems* (Washington, D.C.: USDA, 1978), 94.

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The weathering and processing by microorganisms increases the palatability of the leaves. This process continues for weeks and by the spring due to rise in the temperature, moisture, macro-invertebrates, and annual flooding, rapid decomposition of the leaves happen. In the summer due to increasing soil temperature and decreasing precipitation, the decomposition continues and major parts of the leaves are processed. In their research, they found that different concentration of macro-invertebrates in different parts of the floodplains affect the rate of decomposition. For example, large concentration of macro-invertebrates in the point bars is the primary reasons for faster decomposition of the leaves. The colony of macro-invertebrates also depends on the soil types and their characteristics. The reasons for more colonies of macro-invertebrates in the point bars include high moisture content. Hence the factors affecting organic matter processing are soil types, temperature, moisture content, flooding, and macro-invertebrate community. Any leaf falling into a ditch or wetland remains a permanent part of the sink. The unit of measurement for annual litter fall is kilograms dry mass per hectare per year. The higher processing of the litter in the stream as well as on the ground cover is good for maintaining the structure and function of the biological community.

Sedimentation: One of the ecological services provided by the riparian ecosystem is trapping of sediments. The sediments generated in the adjacent land uses are transported by runoff to the streams. Riparian forests or buffers retain these sediments reducing the sediment load on the stream. The deposit of sediments into the streams and rivers can reduce the channel width and destroy the aquatic habitats and may require dredging to restore the river channels. The dictionary defines sediments as the solid fragments of

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inorganic or organic material coming from the weathering of the rocks and are carried and deposited by wind, water, or ice.[72] The deposition of sediments over the stream beds destroys the sites for spawning of fish affecting the aquatic habitat.

Different researches on sediments and riparian ecosystems in the past include the optimal width of riparian forests required to trap the maximum sediments coming from the adjacent land use. Gred Sparovek et al. studied the optimal width of riparian forest to trap sediments from the agricultural land use in Brazil. The Brazilian official legal recommendation was a 30 meters wide riparian buffer strip. However, after their research they found that the optimal width required is 52 meters wide riparian forests, which can retain 54% of the sediments.

During research, they found that the deposited sediment is directly proportional to the riparian forest width. The riparian forest width affects the sediment reduction by two ways. The first is the reduction in the total runoff in the watershed because of the larger area under forest land cover. The second is the greater surface roughness due to residue (litter fall) cover in large area and a high soil water infiltration rate. Increasing the riparian forest width not only increases the trapping area for the sediments but also reduces the mean rate of sediment generation in the watershed by reducing the land area exposed to the sediment generation process. The increase in W_f (Riparian forest width) increases the sediment deposition by extending the trapping area and decreases the

[72] http://dictionary.reference.com/search?q=sediments, Dictionery.com, accessed on 03/07/2003.

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sediments to be trapped.[73] The relationship between W_f (riparian forest width) and S_d (sediment deposition) is expressed in the quadratic equation form:

$S_d = aW_f^2 + bW_f + c$, *where a, b, c are constants.*[74]

The maximum efficiency width (W_{max}) used in this calculation is defined as the W_f value, when the first-order derivative of the sediment deposition (S_d) as a function of W_f becomes zero.[75] By increasing the riparian forest width more than the W_{max}, sediment reduces due to reduction in sediment generation rather than the trapping of sediments by the riparian forests. Gred Sparovek applied the methodology on a Brazilian Watershed of predominantly agricultural land use. They studied the different scenarios of riparian forest width, yield of sediments, and deposition of sediments. They collected data for slope, soil taxonomy, and current soil use and use them as the input data in the Water Erosion Prediction Project (WEPP) program to calculate the soil erosion and deposition. The reasons for studying soil taxonomy include that different soil types have different erosion rates. Similarly same soil type under different uses can have different erosion rates. The climate is the external factor affecting erosion. Regression equations were made between the sediment deposition and riparian forest width; and the sediment yield and riparian forest width. The results were plotted on a graph. The graph between sediment deposition and riparian forest width indicates that after certain width the sediment deposition starts decreasing instead of increasing. However, the graph between sediment yield and riparian forest width indicates that the yield decreases with the increasing width.

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[73] Gred Sparovek et.al., "A Conceptual framework for the definition of the optimal width of riparian forests," Agriculture Ecosystems and Environment 90(2002), 171.
[74] *Id.*
[75] Gred Sparovek et.al., "A Conceptual framework for the definition of the optimal width of riparian forests," Agriculture Ecosystems and Environment 90(2002), 172.

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The equation between S_d (Sediment deposition) and W_f (Riparian forest width) is as follows.

$Y= -0.0005X^2 + 0.0696X + 1.2624, R^2 = 0.80$ [76]

The equation between S_y (Sediment yield) and W_f (Riparian forest width) is as follows.

$Y=0.0012 X^2 -0.3392X + 26.437, R^2 = 0.99$[77]

Of the values of coefficient of determination (R^2), the equation between the sediment yield and riparian forest explains better than the equation between the sediment deposition and the riparian forest width. However, a positive and large R^2 for both the equations explains that sediments and riparian forest width are correlated. For achieving the target sediment yield of 12 Mg per hectare per year, which is 80% of the current sediment yield, they found that 52 meter wide riparian buffer is the most efficient width. Hence, riparian forest width is a parameter determining the sediment generation and deposition. Since the generation of sediments depends on the erosion, which in turn depends on the current soil use, soil taxonomy, and slope; the sedimentation process is affected by these parameters. Any sedimentation happening in wetlands and ditches within the riparian ecosystem becomes permanent sink for the sediments. By removing the sediments from the runoff, riparian forests help in maintaining the aquatic habitat. The deposition of sediments over the forest floor increases the friction against the runoff thus increasing the filtering of nutrients in the runoff. Hence, the sedimentation process and the riparian parameters working in sedimentation help in the two ecological services of habitat and filter. The measurement for sediment removal is shown as percent while the unit of measurement for sedimentation used is mega grams (10^6) per hectare. The

[76] Gred Sparovek et al., "A Conceptual framework for the definition of the optimal width of riparian forests," Agriculture Ecosystems and Environment 90(2002), 174.
[77] *Id.*

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removal of sediments by the riparian ecosystem is good for the streams and aquatic habitats.

4.3: Analysis

Table 4.1 is the compilation of parameters of the ecological characteristics, factors affecting the parameters, unit of measurement, and references. Table 4.2 is the matrix between parameters of physical and ecological characteristics showing their interrelationship. The interrelationship between parameters of physical and ecological characteristics is shown by a tick mark. The ecological characteristics include the parameters of biomass, flow of materials, and flow of nutrients. The four parameters of biomass are included in one column. Table 4.3 is the distribution of physical parameters into high, medium, and low category based on their interrelationship with the parameters of ecological characteristics. The physical parameters participating in 4 to 5 ecological characteristics have high value of importance; 3 ecological characteristics have medium value of importance; and 1 to 2 ecological characteristics have low value of importance. The different parameters of ecological characteristics have same ranking. Since all the parameters are related to the ecology of riparian ecosystem, it is assumed that they are equally important. Tree cover/riparian vegetation, wetlands, and relative relief are of high importance; flooding and soil is of medium importance; and slope, ground water, stream is of low importance.

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Table 4.1: Ecological parameter, unit of measurement, and references

	Parameter	Factors affecting the parameter	Unit of Measurement	References
1	Stem Density	Biomass production (Trees, vegetation)	Number/Hectare	U.S. Fish and Wildlife Service
2	Basal Area	Biomass production (Trees, vegetation)	Square meter/Hectare	University of Minnesota Extension
3	Leaf and fruit litter fall	Biomass production (Trees, vegetation)	Grams/square meter per year	U.S. Fish and Wildlife Service
4	Stem Wood Production	Biomass production (Trees, vegetation)	Grams/square meter per year	U.S. Fish and Wildlife Service
5	Phosphorous cycle	Periodic flooding, Riparian forest width, Riparian trees, wetlands, ditches	Grams/ square meter per year	William T. Peterjohn, David Correll, William J. Mitsch
6	Nitrogen cycle	Periodic flooding, soil moisture, riparian trees, grass and vegetation cover, ditches, wetlands, climate	Grams/ square meter per year	Peter M. Groffman, U.S. Fish and Wildlife Service
7	Organic matter	Temperature, soil moisture, annual flooding, macro-invertebrates	Kilograms dry mass per hectare per year	R. R. Jhonson and J.F. McCormik
8	Sedimentation	Slope, soil taxonomy, current soil use, riparian forest width	Mega-grams per hectare	Gred Sparovek et al.

Source: Compiled by the author

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Table 4.2: Interrelationship matrix between physical parameters vs. ecological characteristics

<table>
<tr><th rowspan="2"></th><th rowspan="2">Parameter</th><th colspan="4">Biomass</th><th rowspan="2">Phosphorous cycle</th><th rowspan="2">Nitrogen cycle</th><th rowspan="2">Organic matter-litter fall</th><th rowspan="2">Sedimentation</th></tr>
<tr><th>Stem density</th><th>Basal area</th><th>Litter fall</th><th>Stem wood</th></tr>
<tr><td rowspan="3">Overarching</td><td>Drainage Density/ Channel Density</td><td colspan="4"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Geomorphology (Hydroperiod/ flooding)</td><td colspan="4"></td><td>✓</td><td>✓</td><td>✓</td><td></td></tr>
<tr><td>Geomorphology (Channel Meandering)</td><td colspan="4"></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">Aquatic</td><td>Surface Water(depth and period of flooding)</td><td colspan="4"></td><td>✓</td><td>✓</td><td>✓</td><td></td></tr>
<tr><td>Ground Water</td><td colspan="4">✓</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Riffles/ pools</td><td colspan="4"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Stream</td><td colspan="4"></td><td></td><td></td><td>✓</td><td></td></tr>
<tr><td rowspan="4">Land</td><td>Soil-moisture, temperature, taxa</td><td colspan="4"></td><td></td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Relative Relief</td><td colspan="4"></td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Slope</td><td colspan="4"></td><td></td><td></td><td></td><td>✓</td></tr>
<tr><td>Tree Cover/Riparian Herbaceous Vegetation</td><td colspan="4">✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr>
</table>

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	Parameter	Biomass				Phosphorous cycle	Nitrogen cycle	Organic matter-litter fall	Sedimentation
		Stem density	Basal area	Litter fall	Stem wood				
Land	Wetlands					✓	✓	✓	✓

Source: Compiled by the author

Table 4.3: Distribution of physical parameters into high, medium, and low importance

Category	High	Medium	Low
Overarching		Hydroperiod (Geomorphology)	
Aquatic		Surface water	*Stream*, Ground water
Land	*Tree cover/Riparian herbaceous vegetation, Wetlands, Relative Relief*	*Soil*	*Slope*

Note: Italics designate map able parameters
Source: Compiled by the author

As previously mentioned in the chapter 3, all the physical parameters cannot be mapped. Some of the parameters such as drainage density, riffles and pools do not play any role in the ecological characteristics. However, the parameters, which have a role in the ecological characteristics, are categorized into high, medium, and low categories. The selected parameters of high and medium importance, which can be mapped for GIS include tree cover/riparian herbaceous vegetation, wetlands, relative relief, and soil.

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Chapter 5: Land Use Impacts on the Riparian Ecosystems

The first human impacts on the riparian ecosystems were in the beginning of establishment of human settlements. The early settlers cleared the forests on the banks of the rivers and streams to establish their settlements. Riparian forests provided timber and fuel and with the growth of urban settlements, bank side forests were removed to make the rivers accessible from the land. Later, because of the higher growth in urbanization and rise in the impervious areas in watersheds, the runoff increased in magnitude and intensity resulting into more export of pollutants and toxics into the river water. Now, the population growth including the current pattern of land development is a threat to the existing riparian ecosystems and water quality in the rivers and streams. The rate of the urbanization or the rate by which land is being developed exceeds the rate of population growth resulting into low density sprawling development pattern. The effect of this development pattern is large impervious areas in the watersheds. Various researches are now being done to study impacts of different land uses on the riparian ecosystems and water quality of the rivers and streams. This chapter looks into the impacts of different land use and land covers on the riparian ecosystems, physical characteristics, and the river water quality. An attempt is made to describe the impacts of various land uses and land covers and wherever possible provide parameters for these impacts. In case of land covers, impacts are usually because of human usage of the land covers. Finally, impacts of various land uses on the physical characteristics of riparian ecosystem are compiled in Table 5.2.

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Land use corresponds to the socio-economic description of areas such as residential, industrial or commercial purposes, farming or forestry, recreational or conservation purposes.[78] Whereas land cover is the bio-physical description of the earth's surface showing what overlays or covers the ground.[79] Often land uses are human induced changes over the ground surface, whereas land covers are the natural coverage of the ground surface. The example of land cover includes trees, natural vegetation, bare soil, rocks, mountains, and water bodies. Land covers being natural and part of terrestrial ecosystems exist in harmony with the riparian ecosystems. However, land uses are induced changes in the terrestrial ecosystems and impact riparian and other ecosystems.

Urban Land Use: The first type of impact of urbanization is removal of riparian forests and clearing the stream banks. The deep rooted trees of riparian forests are cut down and replaced by grass and ornamental plants, which cannot stabilize the stream channels. The impacts are wider channels with reduced flow. Moreover, removal of trees from the banks removes shade and organic debris from the stream water. This increases the temperature and decreases the food source resulting into degradation of the aquatic habitat.

The next type of impact is due to runoff. The process of urbanization results into changing large pervious areas into impervious surfaces with no infiltration capacity. These changes r esult from vegetation clearing, soil compaction, ditching and draining,

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[78] http://glossary.eea.eu.int/EEAGlossary/L/land_use, European Environment Agency, accessed on 05-10-2003.
[79] *Id.*

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and finally covering the land surfaces with impervious roofs and roads.[80] In addition to construction of buildings, parking areas, paved areas, and roads, large areas of land are stripped and compacted with almost zero infiltration capacity. Some areas may have surface coverage such as grass-cover, however, continuous human usage and compaction results into low infiltration capacity. During rains and storms, these areas behave similar to the paved areas with no water percolating into the subsoil. The urbanization results into making of drains, gutter, and storm water systems, which have smooth surfaces due to concrete lining and replace the natural drainage channels. During storms large areas drain into the storm water channels, which carry rain water in large magnitudes, intensity, and scouring speed into the rivers and streams. One more effect of urbanization and related activities is generation of finer sediments or dust, which collects over the paved surface and storm water channels. With the runoff, these sediments are transported into the river and the sediment load can be large depending on the intensity of urbanization in the watershed. These sediments make the water murky and settle on the river bed thus directly impacting habitats of the aquatic organisms.

The runoff is due to impervious surfaces, which is a result of the urbanization. However, within the urbanized areas different land uses have different shares of pervious and impervious surfaces. Scientists have usually used impervious cover as an indicator of urbanization within the watershed. Because of different impervious surfaces generated by different land uses, scientists have used these impervious areas to study impacts of different land uses on the riparian ecosystem and the water quality in the river. Any land

[80] Derek B. Booth, and C. Rhett Jackson, "Urbanization of Aquatic Systems- Degradation Thresholds, Stormwater Detention, and the Limits of Mitigation", *American Water Resources Association* 22, no. 5 (1997): 3.

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use generating more impervious area will have more impact due to greater amount of runoff than the land use generating less impervious areas. There are two types of measurement for impervious areas known as total impervious area (TIA) and effective impervious area (EIA).

The total impervious area (TIA) is sum of all the impervious surfaces build in the watershed including buildings, concrete, asphalt, and roads. However, one limitation of the total impervious area (TIA) is that it does not include compact pervious surfaces such as grass lawns or bare soil, which have almost negligible permeability and put same amount of runoff as the impervious surfaces. One more limitation of TIA is that it includes impervious surfaces, which may not make any hydrological changes in the watershed. For example, as mentioned by Derek B. Booth and C. Rhett Jackson, a gazebo or small hut in the middle of parkland may not have any significant hydrological changes or runoff changes. The concept of effective impervious area (EIA) was discovered to use instead of total impervious area (TIA). The effective impervious area (EIA) is defined as the impervious surfaces with direct hydraulic connection to the downstream drainage or stream system.[81] This means that impervious surfaces draining into pervious areas such as green lawns are not included in the effective impervious area (EIA). Scientists have calculated both the total impervious area (TIA) and effective impervious area (EIA) for different land uses (Refer to Table 7). However, effective impervious area (EIA) is a better measure to show the hydrological impacts of different

[81] Derek B. Booth, and C. Rhett Jackson, "Urbanization of Aquatic Systems- Degradation Thresholds, Stormwater Detention, and the Limits of Mitigation", *American Water Resources Association* 22, no. 5 (1997): 7.

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land uses. Based on different magnitudes of effective impervious area (EIA), we can qualitatively suggest impacts of different land uses.

Table 5.1: Land use and percent imperviousness

Land Use	Total Impervious Area (TIA)	Effective Impervious Area (EIA)
Low density residential (1 unit per 2-5 acres)	10%	4%
Medium density residential (1 unit per acre)	20%	10%
Suburban density (4 units per acre)	35%	24%
High density (multi-family or 8 + units per acre)	60%	48%
Commercial and Industrial	90%	86%

Source: Derek B. Booth and C. Rhett Jackson, 1997.

Given the different effective impervious areas (EIA) of different land uses, it can be inferred that commercial and industrial land uses generate maximum runoff followed by high density, suburban density, medium density, and low density residential land uses for the same size of development. Within a watershed, including the land in the flood plains, commercial and industrial land uses will have maximum impact followed by high density and low density residential development. There is a general trend of constructing

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buildings for various uses within or near the flood plains. In many instances, these are industries and commercial areas, which impact the streams by high discharge of runoff. The construction activities of land uses within or near the riparian ecosystems remove tree cover and riparian vegetation; drain wetlands; cause soil compaction and reduce its water holding capacity; levels the slopes and changes the relative relief; changes the width of the stream channel by high discharge of runoff; alters the flood plain affecting the surface water or depth of the flooding. Hence urban land use development impacts almost all the physical parameters of the riparian ecosystem.

Mining: Various types of mining activities occurring within the flood plains or within the riparian ecosystems include gravel mining in the flood plains, alluvial gold and gem mining, and in stream mining extractions. The gravel mining lowers the ground water table and heavy metals associated with the discharge of mines pollutes the stream water. Any form of in-stream mining widens the channel impacting geomorphology or meandering of the channel; re-suspends the silt disrupting aquatic habitat; disrupt the pool-riffle sequences; and lower the flood plains water level. Mining activities in the flood plains impact the stream, riffles-pools, ground water, and meandering of the stream channel.

Agriculture: Agriculture is a common land use occurring within the flood plains. However, agriculture impacts riparian ecosystems in many ways. The first type of impact is excessive nutrient loading in the stream due to usage of fertilizers. The herbicides and pesticides used in farming mixes into the stream water with the runoff.

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They consist of toxic chemicals impacting aquatic organisms. Various agricultural activities including ploughing produce silt and finer sediments, which goes into the stream with the runoff. Often stream side forests are cleared, wetlands drained, and riparian trees and vegetation is removed for the agriculture. Similarly, in many places slopes are leveled for the terrace farming. Hence, the activity of agriculture impacts tree cover, riparian vegetation, wetlands, slopes, soil, and stream.

Livestock: Another common activity within the flood plains is livestock framing and grazing. The land use associated to the livestock activities is range lands, grazing lands, and livestock industries such as piggeries. The livestock remove the riparian vegetation and grass cover and trample the slopes and ground causing soil compaction. They also add nutrients to the stream consisting of organic waste. Large stock such as cattle and horses re-suspend silt in the stream water affecting the aquatic habitat. Livestock industries such as piggeries can add excessive organic nutrients to the stream water. Livestock activities impact riparian vegetation, slopes, soil, and stream.

Recreation: Recreation is a common activity occurring along the stream banks within the flood plains. Usually existing riparian trees and vegetation are removed, slopes are leveled, wetlands are drained, and soil is compacted to make parks, picnic grounds, golf courses, and gardens for recreation. The native plants are removed and exotic ornamental species are introduced, which often become invasive. The flood plains are altered by making berms or mounds affecting the depth of the flooding. Similarly stream banks are smoothened by using concrete for human access impacting the geomorphology or

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meandering of channels. Hence, recreational activities impact tree cover, riparian vegetation, wetlands, slopes, soil, stream, depth of flooding, and channel meandering.

5.1: Analysis

Table 5.1 is the compilation of total impervious area and effective impervious area for different types of residential land uses and commercial and industrial land use. The percentage of impervious area in different land uses enables us to compare the impacts of these land use on the riparian ecosystem. Table 5.2 is the matrix between different land use-land cover and parameters of physical characteristics. If a land use or land cover impacts a physical parameter, it is shown by a tick mark. Table 5.3 is the compilation of physical parameters in high, medium, and low categories based on the number of land uses impacting the parameters. The residential, commercial, and industrial land uses are compiled into one category of urban land use. The other types of land uses include mining, agriculture, livestock, and recreation. If a physical parameter is impacted by 4 to 5 types of land uses, it becomes a parameter of high importance. If a physical parameter is impacted by 3 types of land uses, it is considered as parameter of medium importance. The physical parameters impacted by 1 to 2 land uses are considered as parameter of low importance. The parameters of high and medium importance should be conserved, since they are impacted by most of the land uses. Similar to the analysis in chapter 3 and chapter 4, land uses are not ranked within themselves and considered of having same value.

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Table 5.2: Land use impacts on riparian ecosystems

<table>
<tr><th rowspan="2"></th><th rowspan="2">Parameter</th><th colspan="3">Urban Land Use</th><th rowspan="2">Mining</th><th rowspan="2">Agriculture</th><th rowspan="2">Livestock</th><th rowspan="2">Recreation</th></tr>
<tr><th>Commercial</th><th>Industrial</th><th>Residential</th></tr>
<tr><td rowspan="3">Overarching</td><td>Drainage Density/ Channel Density</td><td colspan="3"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Geomorphology (Hydroperiod/ flooding)</td><td colspan="3"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Geomorphology (Channel Meandering)</td><td colspan="3"></td><td>✓</td><td></td><td></td><td>✓</td></tr>
<tr><td rowspan="4">Aquatic</td><td>Surface Water(depth and period of flooding)</td><td colspan="3">✓</td><td></td><td></td><td></td><td>✓</td></tr>
<tr><td>Ground Water</td><td colspan="3"></td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td>Riffles/ pools</td><td colspan="3"></td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td>Stream</td><td colspan="3">✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td rowspan="4">Land</td><td>Soil-moisture, temperature, taxa</td><td colspan="3">✓</td><td></td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Relative Relief</td><td colspan="3">✓</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Slope</td><td colspan="3">✓</td><td></td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Tree Cover/ Riparian Vegetation</td><td colspan="3">✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td></tr>
</table>

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	Parameter	Urban Land Use			Mining	Agriculture	Livestock	Recreation
		Commercial	Industrial	Residential				
Land	Wetlands		✓		✓	✓		✓

Source: Compiled by the author

Table 5.3: Distribution of physical parameters into high, medium, and low importance

Category	High	Medium	Low
Overarching			Channel Meandering (Geomorphology)
Aquatic	*Stream*		Surface water, Ground water, *Riffles and Pools*
Land	*Tree cover/Riparian herbaceous vegetation, Soil, Slope, Wetlands*		*Relative Relief,*

Note: Italics designate map able parameters

Source: Compiled by the author

Based on Table 5.3, tree cover/riparian herbaceous vegetation, soil, slope, stream, and wetlands are under high category and also map able. In the background of land use impacts on riparian ecosystem, these parameters would be considered for preparing the GIS database for the pilot study area.

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Chapter 6: Identification of Important Parameters

In the previous three chapters on physical characteristics, ecological characteristics, and the land use impacts, the physical parameters of high, medium, and low importance are identified. The physical parameters having high or medium importance in all the three categories have an overall importance because they have an important role in physical and ecological characteristics and they are impacted by most of the land uses and human activities occurring near the riparian areas. The next level of assessment is to identify the mapable parameters and the availability of secondary data. Based on Table 3.3, Table 4.3, and Table 5.3 of distribution of physical parameters into high, medium, and low categories, the parameters occurring in high and medium categories in these tables include tree cover/riparian herbaceous vegetation, drainage density, stream, surface water, hydroperiod (geomorphology), slope, soil, wetlands, and relative relief. The parameters under low category include channel meandering (geomorphology), ground water, and riffles/pools. Of the high and medium categories parameters, drainage density is a calculation at the level of a watershed; hydroperiod requires data on the frequency and depth of flooding; and relative relief is a map able calculation. However, the data on *tree c over/riparian h erbaceous v egetation* is mapable and can be digitized from aerial photographs; *stream* is mapable and available; *surface water* shows the extent of flooding or the flood plains, which is mapable and available; *slope* is mapable and available; *soil* is mapable and available; and *wetlands* are mapable and available. The parameters of high and medium importance, which are mapable and available, would be used for the overlay in the pilot study area. Of the low categories parameters, riffles/pools are mapable from

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aerial photograph; channel meandering requires temporal data or aerial photographs in time series; and ground water data is usually not available.

It can be further inferred from Table 3.3, Table 4.3, and Table 5.3 that tree cover/riparian herbaceous vegetation is the most important part of riparian ecosystems as it is under high category in all the three tables. The tree cover/riparian herbaceous vegetation participate in all the ecological services, have a role in all the ecological characteristics, and are impacted by all types of land uses and activities. Wetlands, slope, and soil are also important parameters since they participate in most of the ecological services, have a role in many ecological characteristics, and are impacted by most of the land uses. The GIS database would be prepared for all the mapable parameters so that the local authority can make further planning decisions. However, for identifying the ecologically important areas, overlays of *tree cover/riparian herbaceous vegetation, wetlands, slope, and soil* will be prepared. Lands within the riparian ecosystem, which have trees, herbaceous vegetation, wetlands, slope, and relevant soil taxa, would constitute important areas for conservation.

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Chapter 7: Application on the Pilot Study Area

This chapter explains the geographic information system (GIS) methodology applied for the pilot study area; preparing the GIS database; the overlay process; intermediate results; and the final results. The 5 important parameters of the riparian ecosystems determined in the previous chapter are delineated by drawing polygons and lines in the geographic information system (GIS) to prepare a relational database and do overlay analysis for the pilot study area.

Location: The selected pilot study area is located along the Great Miami River in Hamilton County (See Figure 7.1). The U.S. 50 Route goes to the study area, whereas the State Route 128 and the Village of Cleves Road form the western and eastern boundaries of the study area. Some part of the Village of Cleves is within the study area, while the Town of Hooven is abutted to the study area. The Great Miami River makes two large meanders in the study area. The river flows from the north to the south towards the Ohio River.

Delineation of the Study Area: The available GIS data of flood plains, contours, and road network are utilized to delineate the study area along the existing riparian corridor. The study area is delineated in such a way that it encompasses the flooding area, whereas roads and contour lines are used to form the boundaries. The reason for using the roads is that they form artificial ridge lines. However, wherever flood plains exceed the road line or contour that land is included in the study area. An attempt is made to include a geographical area larger than the flood plains. The delineated study area has a linear

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dimension of 3.6 miles. The length of the study area is limited by considering the number of hours required to digitize and prepare the GIS data base and the field visits.

GIS Database Preparation Method: The GIS data available in the Cincinnati Area Geographic Information System (CAGIS) is used to prepare the GIS database for the study area. The colored georeferenced aerial photograph of one foot resolution of Hamilton County taken in the year 2001 is used as the base map to delineate the study area and draw polygons for various data layers. Since the aerial photograph is georeferenced, polygons digitized have the same projection system, which is the Ohio State Plane South, North Atlantic Datum (NAD), 1983. It is the standard projection system for the southern part of the State of Ohio. Various data layers are digitized in ArcView 3.3, whereas ArcMap and ArcView3.3 are utilized for editing.

For each data layer a new theme is created in ArcView 3.3 and features are digitized in that theme. For example, clumps of trees are digitized in the Riparian Tree theme and herbaceous vegetation is digitized in the Riparian herbaceous Vegetation theme. The ArcMap is used to create a unique feature identity (FID) for each polygon within a theme. The themes with FID included in their attribute table are brought back in the ArcView 3.3 package for the overlay analysis. Various data layers digitized from the satellite imagery and procured from the CAGIS database are included in Table 7.1. As mentioned in Chapter 5, Land Use Impacts on the Riparian Ecosystems; different land uses and land covers existing within the study area are digitized in separate themes. The land use and land covers available in the study area are shown in Figure 7.2.

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Table 7.1: GIS data layers of the study area

	Data Layer	Source	Type
1	Riparian Trees	Digitized	Polygon
2	Riparian Herbaceous Vegetation	Digitized	Polygon
3	Residential Area	Digitized	Polygon
4	Commercial Area	Digitized	Polygon
5	Agriculture	Digitized	Polygon
6	Industrial/Sheds	Digitized	Polygon
7	Grass-Cover	Digitized	Polygon
8	Bare-Compact Land	Digitized	Polygon
9	Water Bodies	Digitized	Polygon
10	Riffles and Pools	Digitized	Line
11	Contours	CAGIS	Line
12	Flood Plains	CAGIS	Polygon
13	Slope	CAGIS	Polygon
14	Soil	CAGIS	Polygon
15	Roads	CAGIS	Line
16	Wetlands	CAGIS	Polygon
17	Streams	CAGIS	Line
18	Digital Elevation Model	USGS (United States Geological Survey)	Raster Grid

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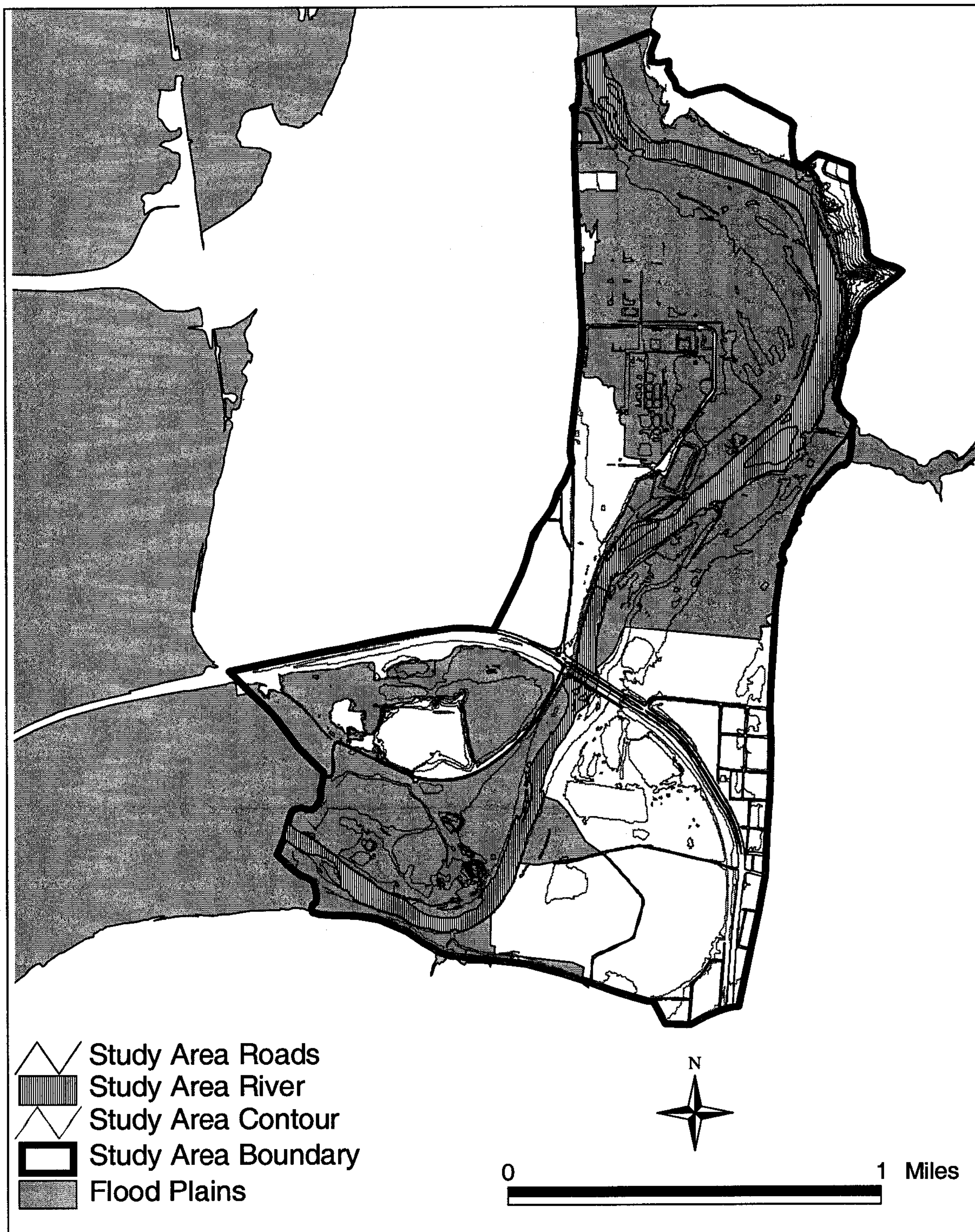
Figure 7.1: Location of the Study Area



Source: Drawn by the author using CAGIS database

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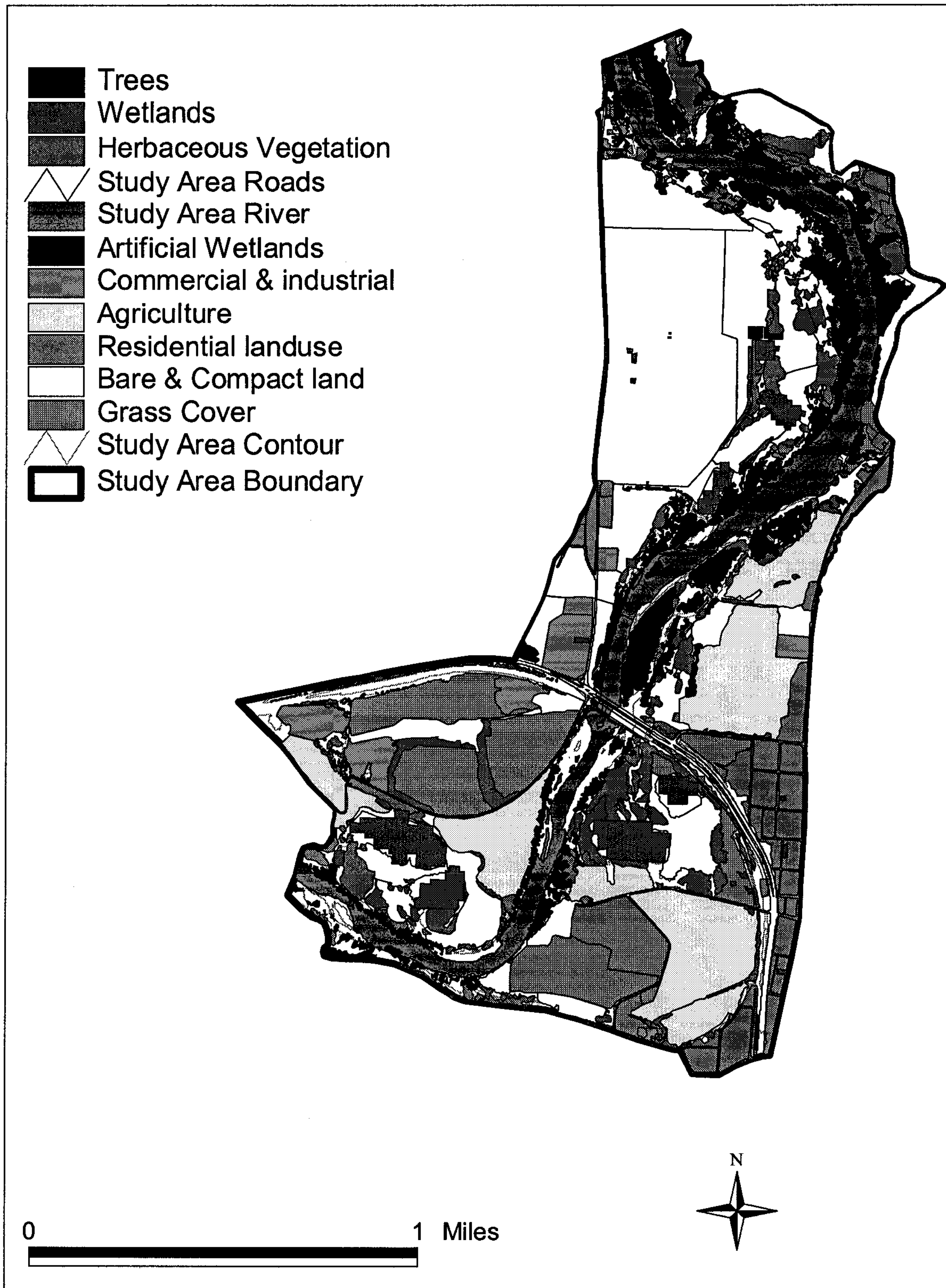
Figure 7.2: Land Use and Land Cover in the Study Area



Source: Drawn by the author using CAGIS database

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During a field visit of the study area, some newly constructed commercial establishments and paved areas not included in the aerial photograph were found. These polygons were drawn by approximation by referencing the existing Kroger Store in the site. Similarly, a constructed wetland is also included by approximation. Various land uses in the study area include agricultural land, parks, sewage treatment plant, residential areas, commercial areas, warehouses, abandoned gravel mines, land covered with grass, bare compacted land, and an abandoned industrial usage. The abandoned gravel mines are filled with water and act as a sink for various nutrients and toxics. However, being gravel mines, there is risk of the toxics and nutrients falling into the pit eventually contaminating the ground water. The land parcels along the river are privately owned and most of the stretch is inaccessible to the common public. Wherever possible, photographs of the existing riparian corridor along the Great Miami River are taken, particularly along the Route U.S. 128, where it goes near the Great Miami River. The stretch of the study area includes various islands within the Great Miami River, which makes riffles. The sequence of riffle and pool can be observed in the satellite imagery and they are drawn as line feature in the GIS.

Important Parameters: It is mentioned in the Chapter 6, Identification of the Important Parameters, that trees, herbaceous vegetation, slopes, wetlands, and soil are important parameters. The trees and herbaceous vegetation in the riparian area are digitized from the aerial photograph. They can be identified from the differences in their textures. Figure 7.3 show the important parameters of the riparian area.

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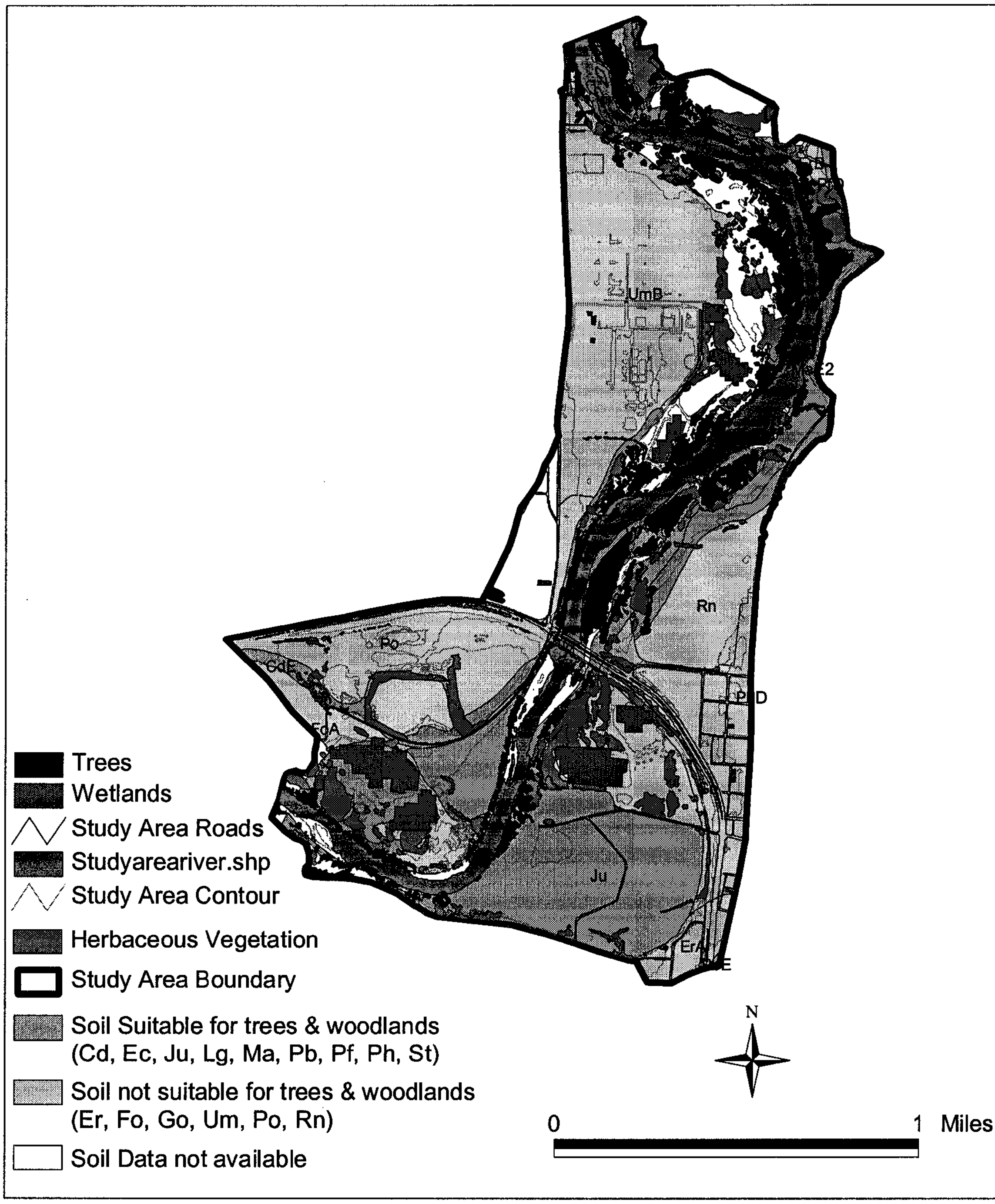
Figure 7.3: Important Parameters of the Riparian Areas



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Separate maps are prepared for the slopes, soil, and wetlands and they are analyzed separately to assess the variations within the study area.

Slope: The major part of the study area is leveled ground with less than 10% slopes. The slopes are gentle going towards the river. A small part in the north-east and south-west of the study area has steep slopes between 20-30%. Small land parcels of 10-15% slopes are scattered in the study area. It can be inferred that study area is comparatively flat. Hence during overlay process slopes are not considered because there is not much variation in the study area. Figure 7.4 indicates slopes in the study area.

Soil: The study area has 15 types of soil. The Soil Survey Handbook of Hamilton County, United States Department of Agriculture; is used to identify the soils which are suitable to grow trees and woodlands. A new thematic map is prepared showing the soils suitable and not suitable to grow trees and woodlands. The suitable soil to grow trees and woodlands is along the river, water bodies, and the high sloped areas. A major part of the study area does not have suitable soil. Some part of the study area does not have soil survey; however by visual inspection of the ground in the aerial photograph, which is bare and compact with scattered herbaceous vegetation and comparing with similar pattern in other parts of the study area, it can be inferred that soil in that area is not suitable. Figure 7.5 indicates suitable and not suitable soil in the study area.

Wetlands: The distribution of wetlands is shown in conjunction with land uses. Figure 7.6 indicates wetlands and the land uses affecting the wetlands in the study area.

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Figure 7.4: Slopes in the Study Area

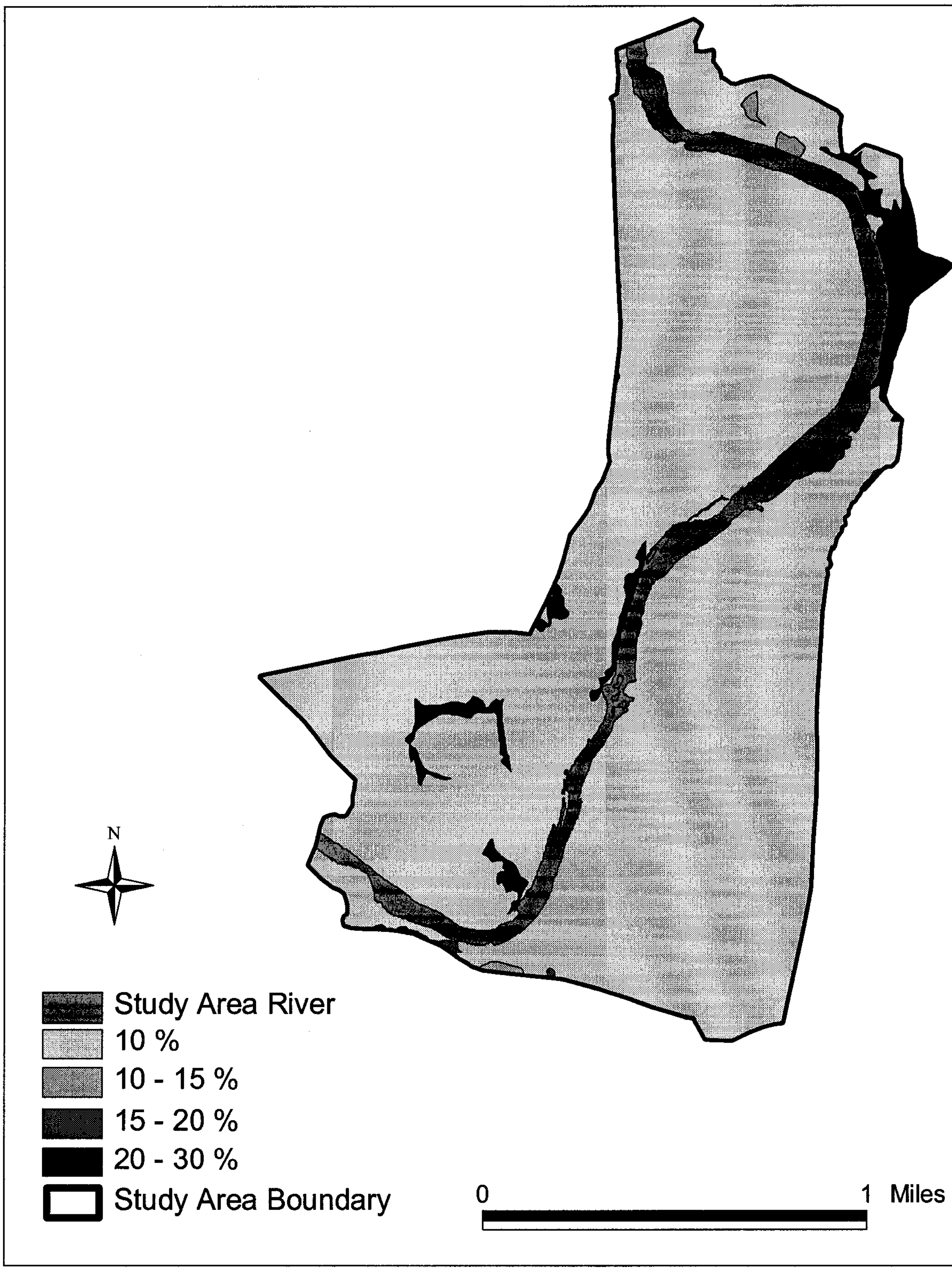

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Figure 7.5: Suitable and not suitable soil in the Study Area

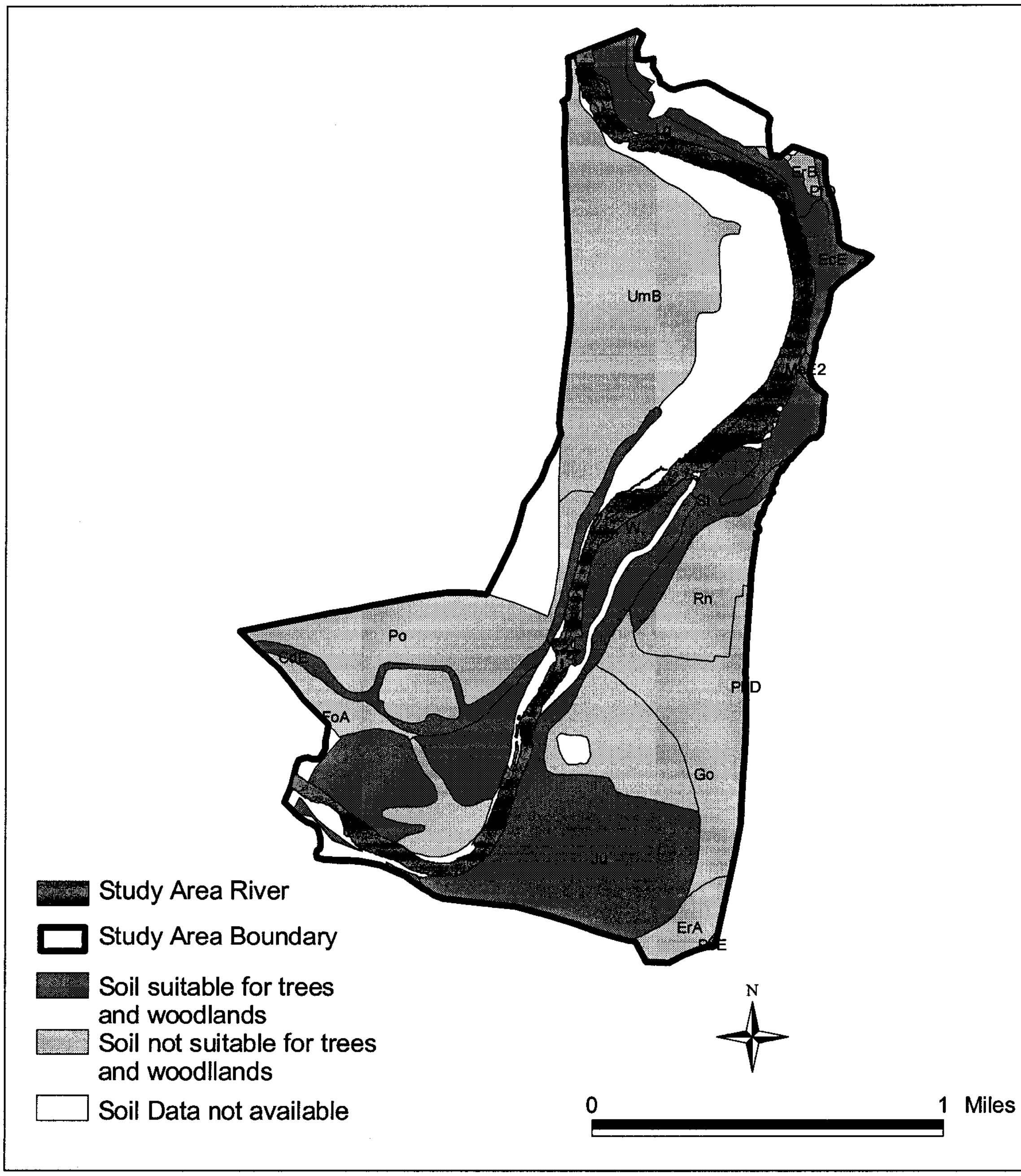

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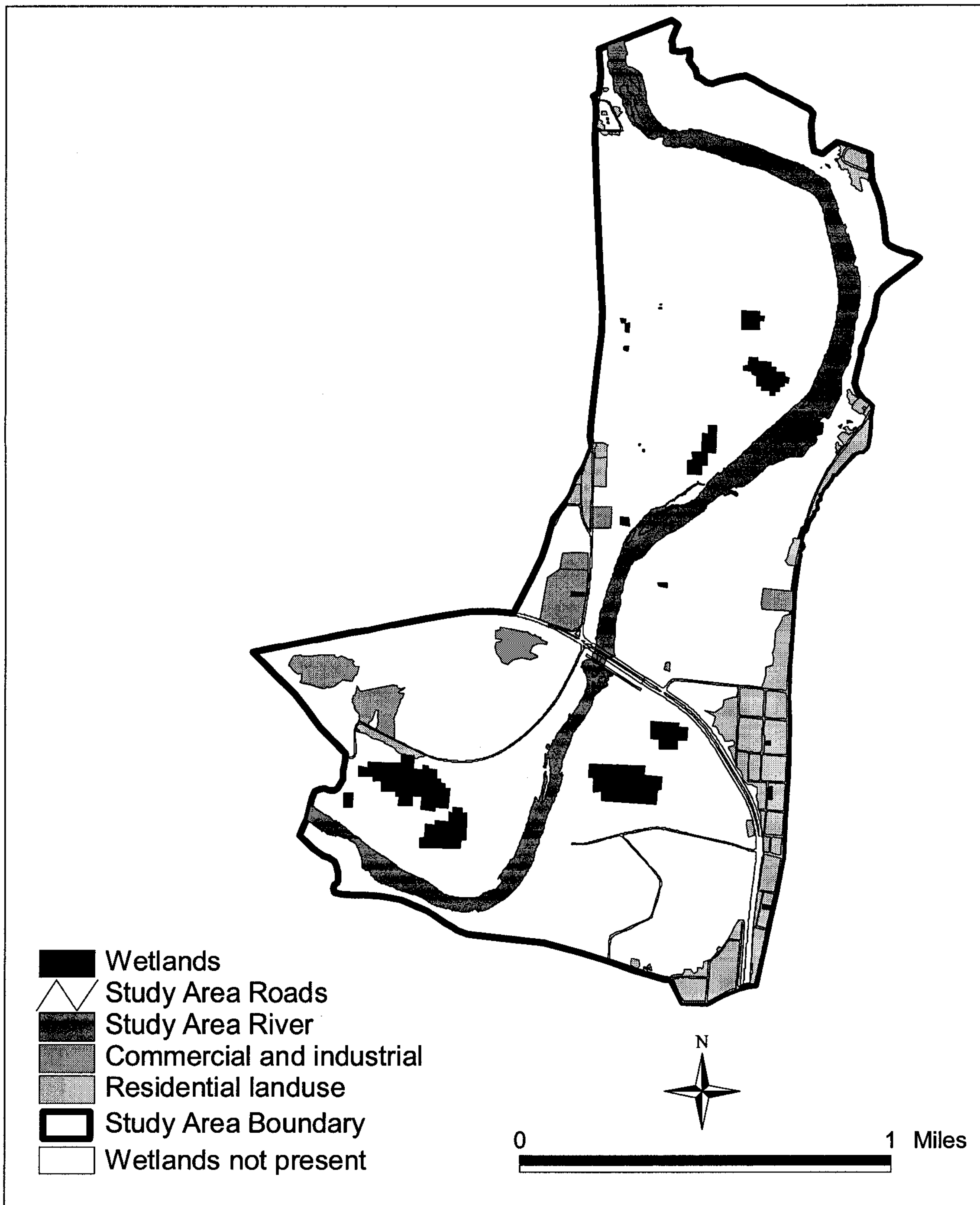
Figure 7.6: Distribution of Wetlands in the Study Area



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The wetland data available in CAGIS is old and when the current land use and land cover is overlaid, it is found that few wetlands were removed during construction of commercial and residential areas. Some wetlands are gravel mining pits. During visual inspection of aerial photograph, it is found that extent and coverage of some wetlands have reduced. Few wetlands are near the existing riparian areas.

7.1: Overlay Analysis

It can be inferred that the land within the flood plains and near the flood plains is being used for various purposes including agriculture, commercial, and residential. They are stressors adding various contaminants to the river and causing high magnitude of runoff. The trees along the Great Miami River or the riparian tree cover are not consistent along the whole stretch of the study area. At some places, particularly on the eastern bank of the Great Miami River, riparian tree cover is not continuous. Similarly distribution of riparian herbaceous vegetation is scattered and do not exist at many places. The only stretch, where riparian tree cover is wide followed by herbaceous vegetation is on the eastern banks to the north of the U.S. 50 Bridge over the Great Miami River. The GIS layers of riparian trees, riparian herbaceous vegetation, wetlands, slope, and soil are overlaid to identify ecologically important riparian areas. The land parcel, where more than one feature is present is sensitive and should be conserved to include in the riparian corridor. For example, a land parcel within the flood plains having riparian trees, wetlands, higher slope, and proper soil is suitable; since it can perform most of the ecological services and must be conserved to be included in the riparian corridor.

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During the overlay process, slopes are not used, since it is already mentioned that the study area is almost flat ground. Since distribution of riparian trees and herbaceous vegetation is unique, which means a particular location can either have trees or herbaceous vegetation, overlay processes are run separately for trees and herbaceous vegetation. The layer of trees is overlaid with the layer of suitable soil to identify the land parcels having both the trees and suitable soil. Similar process is done with herbaceous vegetation and suitable soil layer. The intermediate result of trees on suitable soil and herbaceous vegetation on suitable soil is shown in the Figure 7.7.

The next level of the overlay process is including wetlands in the intermediate layers of trees plus suitable soil and herbaceous vegetation plus suitable soil. After overlaying wetlands; we get one site for trees, suitable soil, and wetlands; and two sites for herbaceous vegetation, suitable soil, and wetlands. It is already mentioned that ranking of parameters is beyond the scope of this thesis. Hence, all the three final sites identified become equally important for conservation. These sites are located in the southern part of the study area along the southern bend of the Great Miami River and are small in area. Hence, an enlarged map of the three sites and a key map of the study area is shown in the Figure 7.8. This map includes the three sites after final overlay analysis, which comes out as the most important area for conservation. It can be observed in the Figure 7.8 that these important sites are at different distances from the river. Hence, the fixed width riparian buffers proposed by regulations may exclude such ecologically important areas resulting into permanent loss of such areas by development. Such overlay analysis will be helpful before making any regulations for the width of riparian buffers.

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Figure 7.7: Intermediate Overlay Results

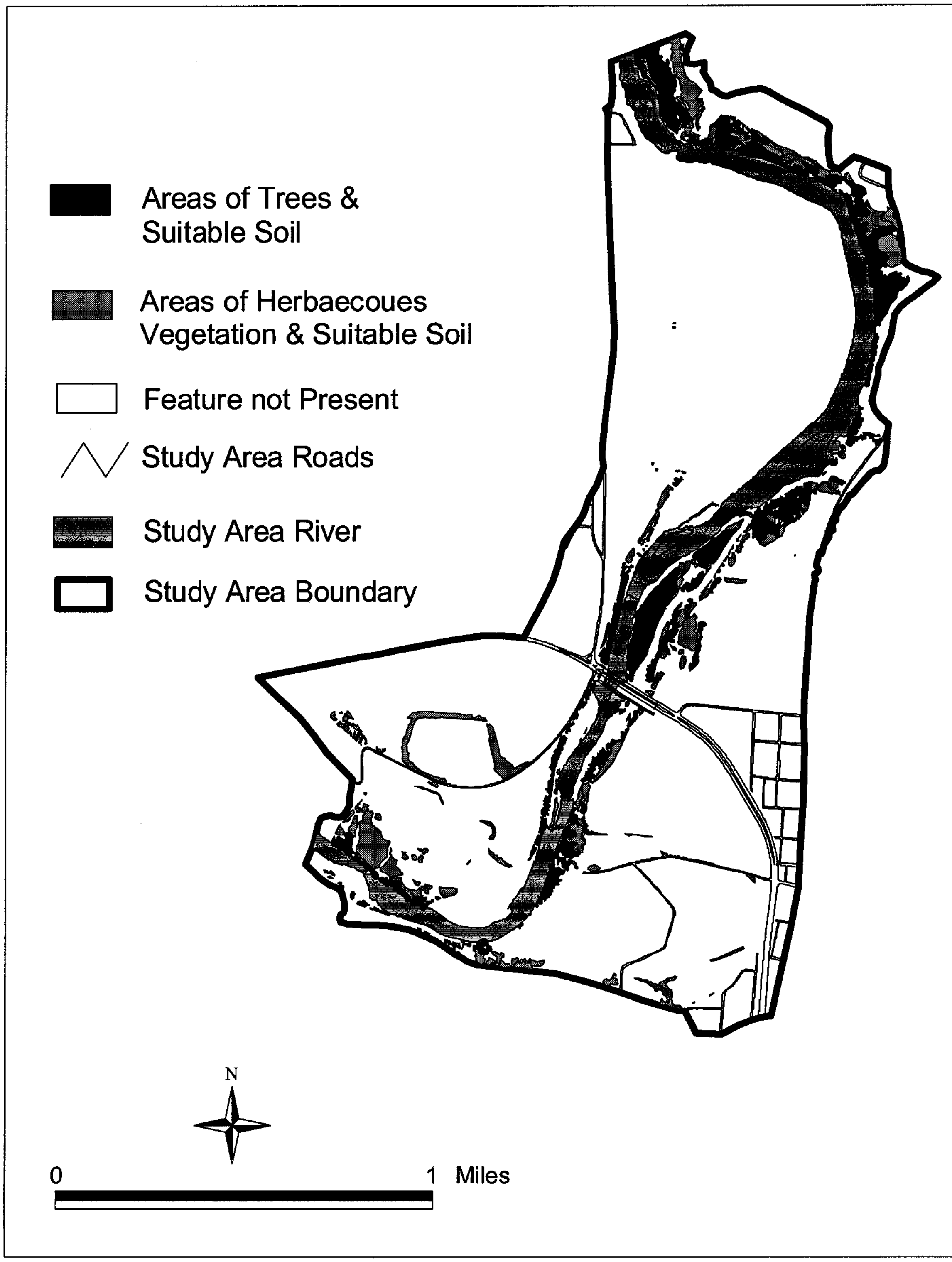

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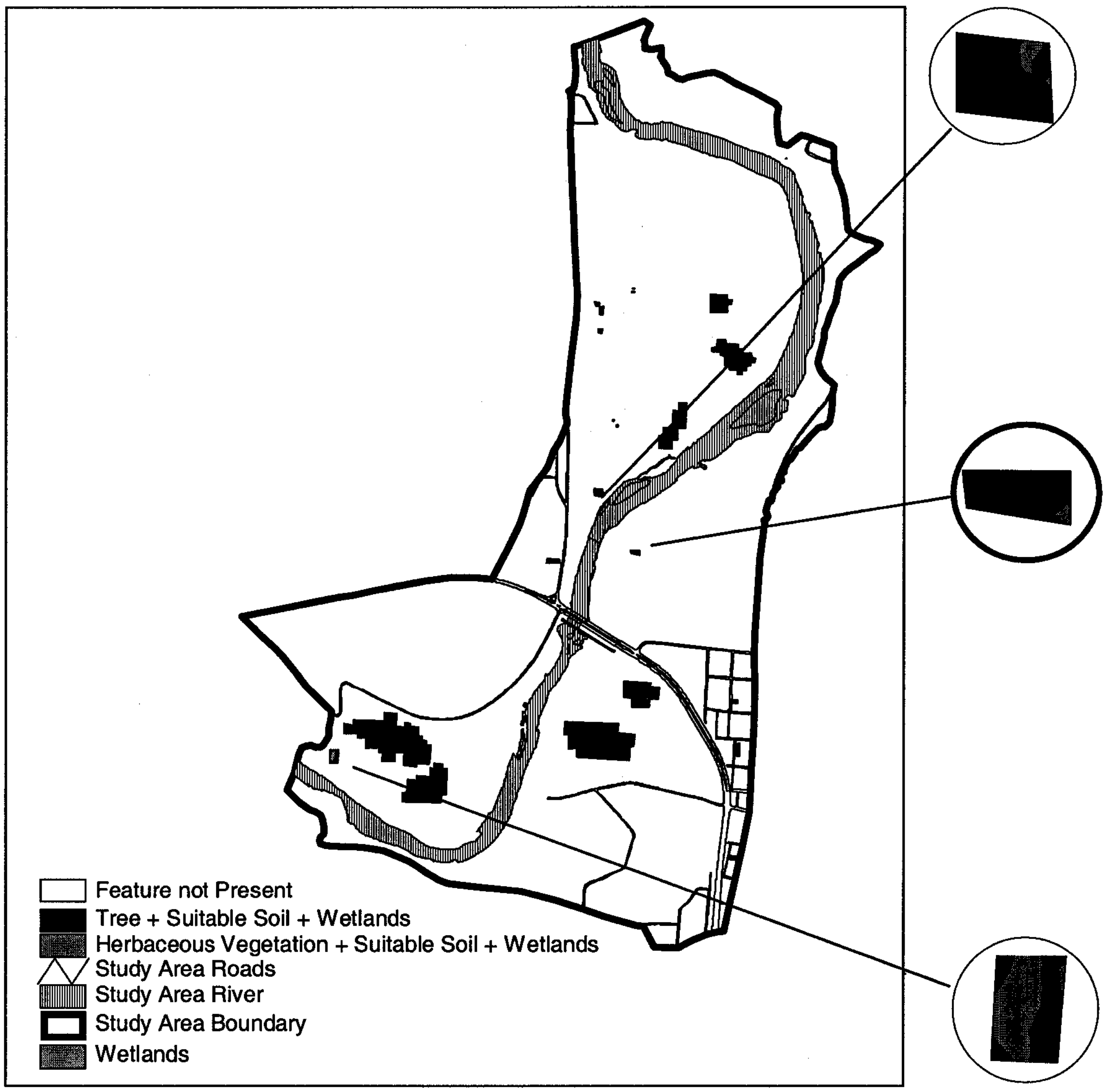
Figure 7.8: Final Sites after Overlay



Note: Circle of thin line indicates herbaceous vegetation + suitable soil + wetlands; circle of thick line indicates trees + suitable soil + wetlands; three sites are equally important since parameters are not ranked.

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The three ecologically important sites are found by using the overlay analysis within the 3.6 miles stretch of the Great Miami River. Similar process should be done for the whole stretch of a stream or river. The overlay analysis gives intermediate results of locations having two parameters o f either tree or herbaceous vegetation and suitable soil. Such locations become sites of medium importance. Hence, a map can be made showing locations of medium and high importance of ecologically important areas. Such an overlaid map will help a planner in making decisions regarding conservation and development in the riparian area. Figure 7.9 is the compilation of intermediate and final sites after overlay analysis showing areas of high and medium ecological importance. Areas having trees or herbaceous vegetation and suitable soil are ecological areas of medium importance. Whereas, areas having trees or herbaceous vegetation, suitable soil, and wetlands are ecological areas of high importance. Since, all the parameters are assumed to have same rank, the overlays of trees or herbaceous vegetation and suitable soil is shown in the same color to indicate areas of medium importance. The overlays trees or herbaceous vegetation and suitable soil and wetlands are shown in some color to indicate areas of high importance. Such mapping forms the base work for land suitability analysis to identify locations for conservation and development in the riparian area.

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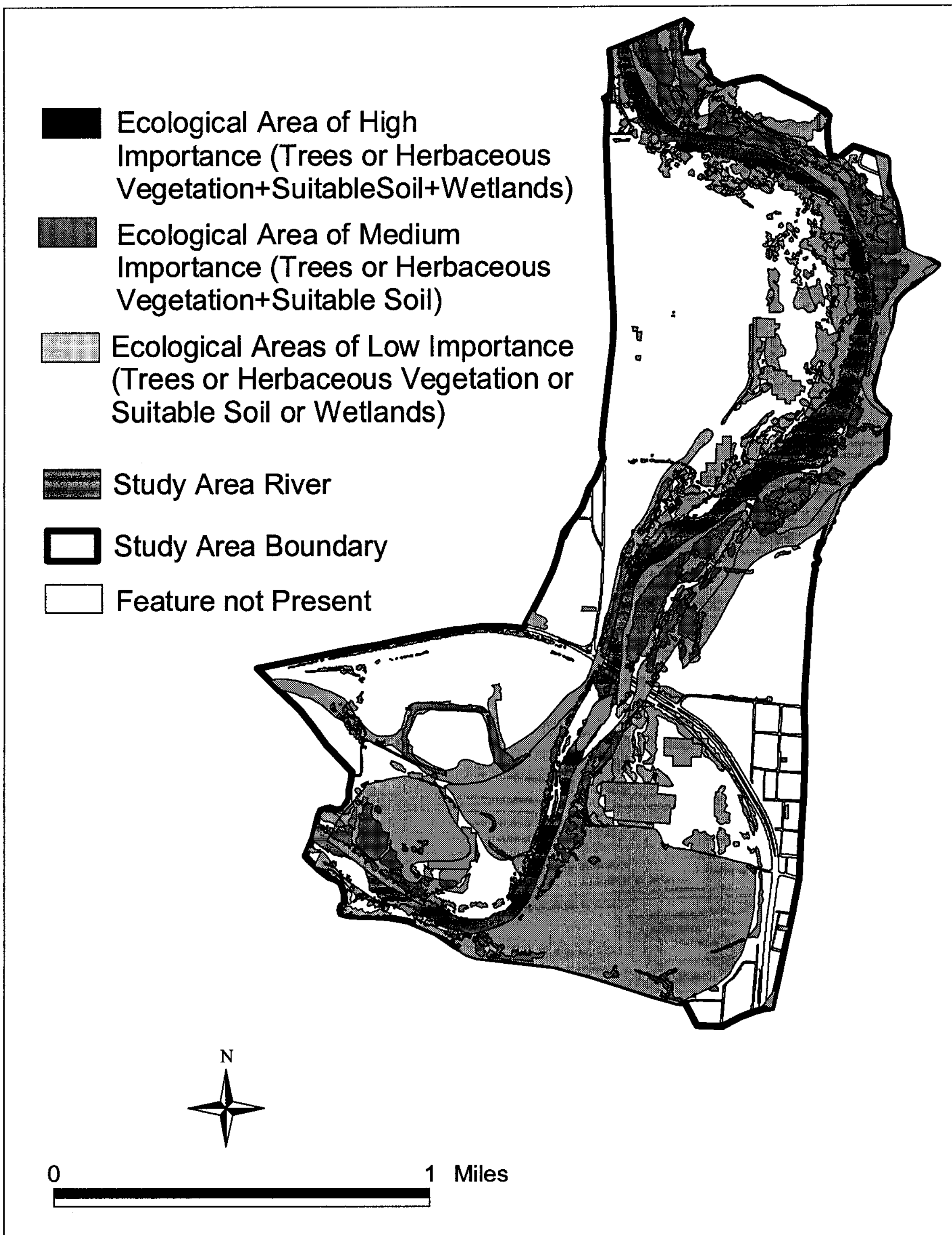
Figure 7.9: Intermediate and final Overlay Results



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Chapter 8: Recommendations

This methodology provides a preliminary, simple framework for planners, which can be used for riparian areas at different geographical regions. It gives a process of selecting the parameters based on physical and ecological characteristics and the land use impacts. It also provides a method to prepare the GIS database for the riparian areas. It can be used as an early warning method to identify ecologically important riparian areas to conserve them from development. The analysis is based on available secondary data and does not require a detailed field survey. Planners can easily understand and perform such analysis prior to making any decision for the width of the riparian corridors.

8.1: Strengths and Weaknesses of the Framework

The strengths of the framework are that it is doable and simple and do not require costly detailed field surveys and GIS expertise. The framework is based on mapable data, which is generally available. The framework does not include parameters requiring sophisticated data collection methods. Hence, planners can apply the framework within reasonable budget and time. The framework does have weaknesses including lack of ranking between different parameters and lack of ranking for different range of values within the same parameter. The digitization of features including trees and herbaceous vegetation can be confirmed by the ground-truthing at the site. The digitization of polygons requires training and experience in identifying the textures from the aerial photograph. The vegetation data layer can be prepared better by using the satellite imagery.

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However, based on the application on the pilot study area, the following recommendations are provided:

Moving from a visual tool to numerical tool

1) This preliminary ecological analysis can be improved by conducting an expert opinion survey to determine a weight for various ecological services, ecological characteristics, and the land use impacts.
2) Based on the number of ecological services, ecological characteristics, and impacts by different land uses a physical parameters can be ranked by importance.
3) During overlays, the ranks of physical parameters can be added for a land parcel to determine a score.
4) Each parameter can have different range of values. The score for these ranges can be determined by surveying experts. For example, the polygons drawn for clumps of trees can be divided into highly dense, dense, and sparse polygons based on the density of trees.

Implementation of Process

5) Giving initial training for digitization of the polygons from aerial photograph before preparing the GIS database.
6) Doing field survey for ground truthing of the digitized polygons.
7) Based on the objectives of the riparian ecosystem management, a data layer of historical land uses and activities can be prepared in the GIS, which may give insights on the causes of ecosystem deterioration.

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8.2: Ideas for Expansion of the Planning Tool

This preliminary framework provides a basic GIS database for riparian area analysis, which can be improved and used for further analysis and decision making. The scope of further works includes:

1) *Integrate with a land suitability analysis.* This can be done to determine suitability for the land parcels. The suitability analysis can be done for the conservation potential. This analysis can be done prior to preparation of the land use plan. The land suitability analysis for conservation can be useful for planners in making policy decisions for the riparian areas.
2) *Integrate with a connectivity analysis of riparian tree polygons or patches.* This can be done by determining perimeter, area, and nearness of the tree patches to each other to locate the patches, which can be suitably connected to form a forest corridor. The area and perimeter of the trees and herbaceous polygons can be calculated in the GIS.
3) *Utilize detailed field survey.* This can be done to determine species of the trees to locate suitable species to grow the riparian forest. Similarly, field survey can be done to identify the species of herbaceous vegetation including herbs, shrubs, and bushes.
4) *Improve soil quality designations.* The soil layer can be improved by ranking the soils in high, medium, and low suitability to grow trees and woodlands.
5) *Utilize satellite imagery.* The GIS data of trees and herbaceous vegetation can be improved by collecting temporal spectral data from the satellite imageries providing data at regular intervals.

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