

HABITAT-BASED SPECIES-SPECIFIC SPATIAL PREDICTION:  
GEOGRAPHICAL DISTRIBUTION OF SPIRANTHES DILUVIALIS

by

Leo Edward Pidgeon

A thesis submitted in partial fulfillment  
of the requirements for the degree

of

Master of Science

in

Earth Sciences

MONTANA STATE UNIVERSITY  
Bozeman, Montana

May 2005

© COPYRIGHT

by

Leo Edward Pidgeon

2005

All Rights Reserved

APPROVAL

of a thesis submitted by

Leo Edward Pidgeon

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Dr. Jian-Yi Liu    Chair of Committee

Approved for the Department of Earth Science

Dr. David R Lageson    Department Head

Approved for the College of Graduate Studies

Dr. Bruce McLeod    Graduate Dean

## STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Request for permission for extended quotation from or reproduction of this thesis (paper) in whole or in parts may be granted only by the copyright holder.

Leo Edward Pidgeon

May 2005

## TABLE OF CONTENTS

|                                                               |    |
|---------------------------------------------------------------|----|
| 1. INTRODUCTION (The American Conservation Tradition) .....   | 1  |
| <i>The Spiranthes diluvialis</i> .....                        | 3  |
| Historical Background .....                                   | 3  |
| General Description .....                                     | 4  |
| Field Characteristics .....                                   | 6  |
| Habitat .....                                                 | 7  |
| Soil Factors .....                                            | 9  |
| Geographical Distribution and Reproduction .....              | 9  |
| Legal Status .....                                            | 12 |
| 2. DATA SOURCES, TERMINOLOGY AND METHODOLOGY .....            | 15 |
| Decision of Project Site .....                                | 15 |
| Data Sources .....                                            | 17 |
| Computer Application Sources .....                            | 21 |
| Terminology and Definitions .....                             | 22 |
| Habitat Elements .....                                        | 22 |
| Qualitative Information .....                                 | 23 |
| Quantitative Data (site-specific) .....                       | 26 |
| Geographic Information Systems Applications .....             | 29 |
| 3. RESEARCH PROCESSES .....                                   | 32 |
| Information Compilation .....                                 | 33 |
| Mechanics of the Research Processes .....                     | 34 |
| 4. ANALYSIS .....                                             | 39 |
| Regional Characterizations .....                              | 39 |
| Quantitative Component Evaluation .....                       | 45 |
| Statistical Data Trend Summary .....                          | 56 |
| Covariant Relationship Analysis (Internal Dependencies) ..... | 58 |
| Hierarchical Grouping .....                                   | 65 |
| Discriminate Analysis by GIS Mapping .....                    | 67 |
| Prediction Displays of Suitable Habitat Distribution .....    | 76 |
| Associated Features Field Survey .....                        | 83 |
| 5. CONSERVATION STRATEGIES .....                              | 86 |

## TABLE OF CONTENTS – CONTINUED

|                                            |    |
|--------------------------------------------|----|
| Management Strategies .....                | 86 |
| Site Recommendations .....                 | 86 |
| 6. CONCLUSION .....                        | 89 |
| BIBLIOGRAPHY .....                         | 92 |
| APPENDIX A: ASSOCIATED PLANT SPECIES ..... | 95 |

## LIST OF TABLES

| Table                                                                                                                  | Page |
|------------------------------------------------------------------------------------------------------------------------|------|
| 1. Comparison of Occurrence Site Soil Components Values .....                                                          | 9    |
| 2. Definitions of Heritage Program Rankings .....                                                                      | 13   |
| 3. Species Occurrence Site Soils Component Evaluation Summary .....                                                    | 50   |
| 4. Statistical Summary Table of the Southwestern Montana Occurrence<br>Site Soils Survey Component Trend Analysis..... | 59   |
| 5. Order-of-Importance Value Index .....                                                                               | 66   |
| 6. Proximity Polygon Soils Component Statistical Summary Table .....                                                   | 68   |

## LIST OF FIGURES

| Figure                                                                       | Page |
|------------------------------------------------------------------------------|------|
| 1. <i>Spiranthes deluvialis</i> (Ute-Ladies' tresses) .....                  | 4    |
| 2. <i>Spiranthes deluvialis</i> in late August bloom .....                   | 5    |
| 3. Detail of <i>Spiranthes deluvialis</i> field characteristics .....        | 6    |
| 4. Photo of <i>Spiranthes deluvialis</i> field characteristics .....         | 7    |
| 5. Habitat: Meandered wetlands and swales in broad, open valleys.....        | 8    |
| 6. Southwestern Montana Species Occurrence Sites .....                       | 11   |
| 7. Missouri Headwaters State Park Study Site.....                            | 16   |
| 8. Logical Structure for Methods and Processes.....                          | 37   |
| 9. Geology Systems of southwestern Montana.....                              | 41   |
| 10. Land Cover 1 of southwestern Montana.....                                | 42   |
| 11. Land Cover 2 of southwestern Montana .....                               | 43   |
| 12. Land Use for southwestern Montana .....                                  | 44   |
| 13. Gallatin County Species Occurrence Site Soil<br>Type Name Polygons.....  | 46   |
| 14. Madison County Species Occurrence Site Soil<br>Type Name Polygons.....   | 47   |
| 15. Jefferson County Species Occurrence Site Soil<br>Type Name Polygons..... | 48   |
| 16. Available Water Supply (AWS) .....                                       | 52   |
| 17. Organic Matter.....                                                      | 52   |
| 18. CaCO <sub>3</sub> .....                                                  | 53   |

## LIST OF FIGURES - CONTINUED

| Figure                                                  | Page |
|---------------------------------------------------------|------|
| 19. pH.....                                             | 54   |
| 20. Electrical Conductivity .....                       | 55   |
| 21. Flooding Frequency .....                            | 56   |
| 22. Available Water Supply/Organic Matter .....         | 60   |
| 23. Available Water Supply/CaCO <sub>3</sub> .....      | 60   |
| 24. Available Water Supply/pH.....                      | 61   |
| 25. Available Water Supply/Electrical Conductivity..... | 61   |
| 26. Organic Matter/CaCO <sub>3</sub> .....              | 62   |
| 27. Organic Matter/pH.....                              | 62   |
| 28. Organic Matter/ Electrical Conductivity.....        | 63   |
| 29. pH/ Electrical Conductivity .....                   | 63   |
| 30. Electrical Conductivity/CaCO <sub>3</sub> .....     | 64   |
| 31. pH/CaCO <sub>3</sub> .....                          | 64   |
| 32. Proximity Soils Polygon Map Unit Type Name .....    | 69   |
| 33. Available Water Supply .....                        | 70   |
| 34. Percent Organic Matter .....                        | 71   |
| 35. CaCO <sub>3</sub> .....                             | 72   |
| 36. pH.....                                             | 73   |
| 37. Electrical Conductivity .....                       | 74   |

## LIST OF FIGURES - CONTINUED

| Figure                                                                         | Page |
|--------------------------------------------------------------------------------|------|
| 38. Flooding Frequency .....                                                   | 75   |
| 39. First Order Suitable Habitat Prediction Query<br>Expression Display .....  | 77   |
| 40. Second Order Suitable Habitat Prediction Query<br>Expression Display ..... | 78   |
| 41. Third Order Suitable Habitat Prediction Query<br>Expression Display .....  | 79   |
| 42. First Order Suitable Habitat Permutation Prediction.....                   | 80   |
| 43. Second Order Habitat Permutation Prediction.....                           | 81   |
| 44. Third Order Permutation Prediction .....                                   | 82   |

## ABSTRACT

Influenced by the spirit of the American conservation tradition, federal and state land management agencies are mandated to protect threatened plant species. Field surveys conducted by the Montana Natural Heritage Program indicated the presence of a rare orchid, *Spiranthes diluvialis*, in southwest Montana wetlands. A study of state-managed wetlands conducted at Missouri Headwaters State Park was requested to determine existing suitable species habitats, to identify species populations, and to develop a conservation management strategy based on habitat evaluation.

The objective of this project was to predict the location of suitable species habitats utilizing Geographic Information System (GIS) analysis and mapping technology. The project demonstrates the utility of a GIS in aiding land managers for developing an informed threatened plant species conservation strategy. By delineating suitable habitats in a selected area, excessive and redundant field surveys are significantly reduced while building on a data base of species- specific habitats for future studies.

Results of this study indicated several suitable habitat sites in the Park. Although species populations were not found at the predicted sites, field observations indicated adequate suitable habitat characteristics for recommending that an effective management strategy should be developed. A simple monitoring protocol was recommended at selected sites as the conservation management strategy.

## INTRODUCTION

The American Conservation Tradition

American conservation efforts began taking shape as society prospered and urbanized in the mid-1800's, George Perkins Marsh's Man and Nature, published in 1864, was to become the fountainhead of the conservation movement. Marsh expressed man's destructive effect on the environment and discussed the need to reform. Following Marsh's premise, the U.S. government realized the need to conserve our national heritage, with a retention policy, by developing a system of national parks beginning with Yellowstone National Park in 1872. By the late 1800's conservationist John Muir ingrained a national conservation consciousness by organizing America's first private national conservation organization, The Sierra Club, dedicated to the conservation and protection of natural resources. In the mid 1900's, Aldo Leopold stressed the importance of environmental protection with A Sand County Almanac (1949), perceived by many as the Holy Scripture of environmentalism. Rachel Carson's popular book, Silent Spring, published in 1962, ignited what is widely recognized today as the modern environmental movement. These noted authors represent the influences responsible for the public awareness of environmental protection leading to the single most powerful environmental legislation of the twentieth century, the federal Endangered Species Act (1973) from which this project is predicated.

Montana State conservation history dates to 1865 when the territorial legislature passed its first conservation law protecting wildlife (Brooks, 2000). In 1901, Montana

created the Montana Department of Fish, Wildlife and Parks to protect the states' environmental resources. In touch with the environmental movement of the 1960's, Montana became the first state in the nation to pass a stream protection act and established an Environmental Resources Division in the Department of Fish, Wildlife and Parks.

In keeping with the tradition of threatened plant species conservation, this study focuses on the spatial distribution of *Spiranthes diluvialis* in southwestern Montana. The technology of Geographic Information Systems (GIS) mapping and method of discrimination analysis are effectively used to deal with available data and to predict the location of the species-specific habitats. The research process was designed for information compilation and GIS modeling. The results of a series of analysis delineate suitable habitat sites in the study area. From these results, conservation management strategies are recommended based on the species-specific data analysis.

THE *SPIRANTHES DILUVIALIS*Historical Background

Prior to the description of *Spiranthes diluvialis* in 1984, specialists in orchid studies classified specimens from the western United States in three taxa of white flowered *Spiranthes*: *S. cernua* L. C. Richard, *S. romanzoffiana* Chamisso, and *S. porrifolia* Lindley (Montana Natural Heritage Program, 1998). In 1980, a specimen of *Spiranthes* was collected near Golden, Colorado that appeared, with some skepticism, to be *S. cernua*. Live plants were collected at the site and sent to Dr. Charles Sheviak, who had initiated taxonomic studies on the genus *Spiranthes* in the early 1970's. In 1982 and 1983, Dr. Sheviak visited the sites in Colorado and Utah. After an examination of herbarium specimens and live plants in the field, and after a cytological (functional history of cells) study, Dr. Sheviak described the Colorado-Utah plants as a new species, *Spiranthes diluvialis* (Sheviak, 1984, from U.S. Fish and Wildlife Service, 1992). Dr. Sheviak concludes:

“... this niche and the plants’ distribution suggest an origin in a Pleistocene pluvial period, when the region supported lush grasslands. Apparently *S. magnicamporum* was present, a conclusion supported by present disjunct populations in New Mexico. Under the cooler and wetter climate, *S. romanzoffiana* occurred at lower elevations than today, apparently sym-parapatrically with *S. magnicamporum*. Hybridization resulted in the production of the amphiploid, which successfully colonized extensive areas. As the climate became drier, the parental species and the amphiploid (intermediate species) responded differently due to differing habitat requirements. The boreal *S. romanzoffiana* retreated to higher, cooler and wetter areas; *S. magnicamporum*, requiring warm mesic sites, was extirpated from the region; and the amphiploid, combining adaptive features of both parents, persisted in warm wet situations. As aridity increased, the amphiploid became progressively more limited to scattered areas of permanent water.

The amphiploid condition and associated regular meiosis clearly are responsible for the preservation of the intermediate features of the plants in widely scattered populations over a broad geographic area. This stability, together with an inferred ancient origin, wide distribution, and fertility, dictate that these plants be recognized as a distinct species” (Sheviak, C. J. 1984: page 11).

In 1990 *Spiranthes deluvialis* was given the common name, Ute-ladies’ tresses, in recognition of the fact that the species historical range coincides with the ancestral home of the Ute Indian Tribe.

### General Description

*Spiranthes diluvialis* is a perennial orchid with mainly one stem 12-50 cm tall, arising from tuberously thickened roots (Figure 1).



Illustration by Carolyn Crawford

Figure 1. *Spiranthes deluvialis* (Ute-Ladies’ tresses).  
Illustration by Carolyn Crawford (Montana Natural Heritage Program, 1998).

Its narrow (1 cm.) leaves can reach 28 cm long, are longest at the base, and persist during flowering from late August to early September (Figure 2). The inflorescence consists of few to many white or ivory flowers clustered in a spike of three-ranked spirals at the top of the stem. The sepals are oriented perpendicular to the stem, the lateral sepals often spreading abruptly from the base of the flower, and all the sepals are free to the base. The lip petal is somewhat constricted at the median (U.S. Fish and Wildlife Service, 1995).



Figure 2. *Spiranthes deluvialis* in late August bloom (photo by Bonnie Heidel, 1998).

### Field Characteristics

*Spiranthes diluvialis* is field characterized by whitish, stout, ringent (gaping at the mouth) flowers, with slender, elongated petals and sepals that are white to ivory-colored and free to the base (Figure 3). The lip is exposed in lateral view; with an oval to lance or oblong outline, a marked median construction, divaricating in the lower half, and with crispy-wavy margins. The upper stem is sparsely to densely pubescent, the longest hairs are longer than 0.19 mm, and the glands are obviously stalked. The persistent leaves are mostly restricted to the base of the stem, reduced to bracts above (Figure 4) (adapted from U.S. Fish and Wildlife Service, 1995).



Figure 3. Detail of *Spiranthes deluvialis* field characteristics (photo by Kristi DuBois, 1998).



Figure 4. Photo of *Spiranthes deluvialis* field characteristics (photo by Bonnie Heidel, 1998).

### Habitat

The *Spiranthes diluvialis* regional habitat is described as broad low elevation intermontane valley plains (4080-4950 ft), with deltaic meandered wetland complexes, restricted to calcareous ( $\text{CaCO}_3$ ), temporary inundated wet meadow zones and segments of channels and swales where there is a stable subsurface and relatively low vegetation cover (Figure 5) (Montana State Library, 2001).



Figure 5. Habitat: Meandered wetlands and swales in broad, open valleys (Photo by Bonnie Heidel, 1998).

The rivers have a low gradient. The valleys are wide, with nearly-level floodplains across much of the valley width. In these flats, habitats are restricted to meandered wetland channels and meadow-filled swales that represent alluvial fans where habitat is restricted to discrete bands in segments and zones with seeps or at least subsurface moisture through the summer (Boast and Shelito, 1989). The abandoned wetlands represent one of two floodplain settings for this species, the other being successional river corridor banks and backwaters (U.S. Fish and Wildlife Service, 1992; Jennings, 1998; Montana Natural Heritage Program, 1998).

### Soil Factors

The micro-habitat of *Spiranthes deluvialis*, as with all orchids, is closely linked with soil factors (Wells, 1981). In 1998, a soils collection was conducted at the southwestern Montana species occurrence sites (Montana Natural Heritage Program, 1998) in conjunction with soil samples collected from sites in Nebraska and Wyoming and previous sample data from sites in Colorado and Utah (Arft, 1995) to define *Spiranthes deluvialis* micro-habitat descriptions (Table 1).

Soil samples from species' habitats were classified by their soil type names as well. For this study, the southwestern Montana sites were evaluated. Their soils type names and independent soils component values are evaluated for suitable habitat predictions.

| Soil Parameter        | Average Values for Agricultural Soils | Range of Values at CO & UT Species Occurrence sites (Arft, 1995) | Range of Values and Mean at NE, WY & MT Species Occurrence sites (Hiderbrand, 1998) |
|-----------------------|---------------------------------------|------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| pH                    | N/A                                   | 6.6-8.15                                                         | 7.66-8.25 (7.88)                                                                    |
| % Organic Matter      | 2.5                                   | 7.0-16                                                           | 2.24-26.35 (9.92)                                                                   |
| Conductivity mmhos/cm | 0-2                                   | 0.37-1.9                                                         | 0.3-1.5 (0.72)                                                                      |

Table 1. Comparison of Occurrence Site Soils Component Values (Arft, 1995; Hiderbrand, 1998; Montana Natural Heritage Program, 1998).

### Geographical Distribution and Reproduction

To date, *Spiranthes diluvialis* are thought to represent an evolutionary product of the Pleistocene climates now confined to riparian systems of the semi-arid west. It is

associated with riparian successional processes and micro-habitats. The orchid is among the few species of plants with a Rocky Mountains distribution that is specifically confined to grasslands, as found in Montana, where it is associated with similar plant and soil features (Montana Natural Heritage Program, 1998).

Historical accounts and herbarium records indicate that this species was once more common within its present range (Coyner, 1990; Jennings, 1990; Coyner, 1991) and its' population decrease is most likely due to the disturbance and fragmentation of riparian habitat as a consequence of human impacts during the last 100 years (Coyner, 1990). The orchids' current known geographic range includes an eight state range: eastern Nevada, northern and south-central Utah, northern Colorado, eastern Idaho, western Nebraska, southwestern Wyoming, north-central Washington and southwestern Montana. The thirteen southwestern Montana occurrences have uniquely similar habitat characteristics that closely parallel with the study area's habitat. Species occurrence data are documented from twelve intermontane valley sites in five Montana counties. For this study, a three-county occurrence site analysis was focused on the Jefferson River and lower reaches of the Gallatin and Madison rivers at the headwaters of the Missouri River (Figure 6).

The reproduction biology (breeding system) of *Spiranthes diluvialis* was studied at Utah State University (Sipes and Tepedino, 1995). The results showed that no autogamous (self-fertilizing) or agamospermous (asexual) fruit set was observed, indicating that a pollen vector is required for reproduction. Observations indicated that bumblebees (*Bombus* spp.) are the most important pollinators of this species (Sipes and Tepedino, 1995).

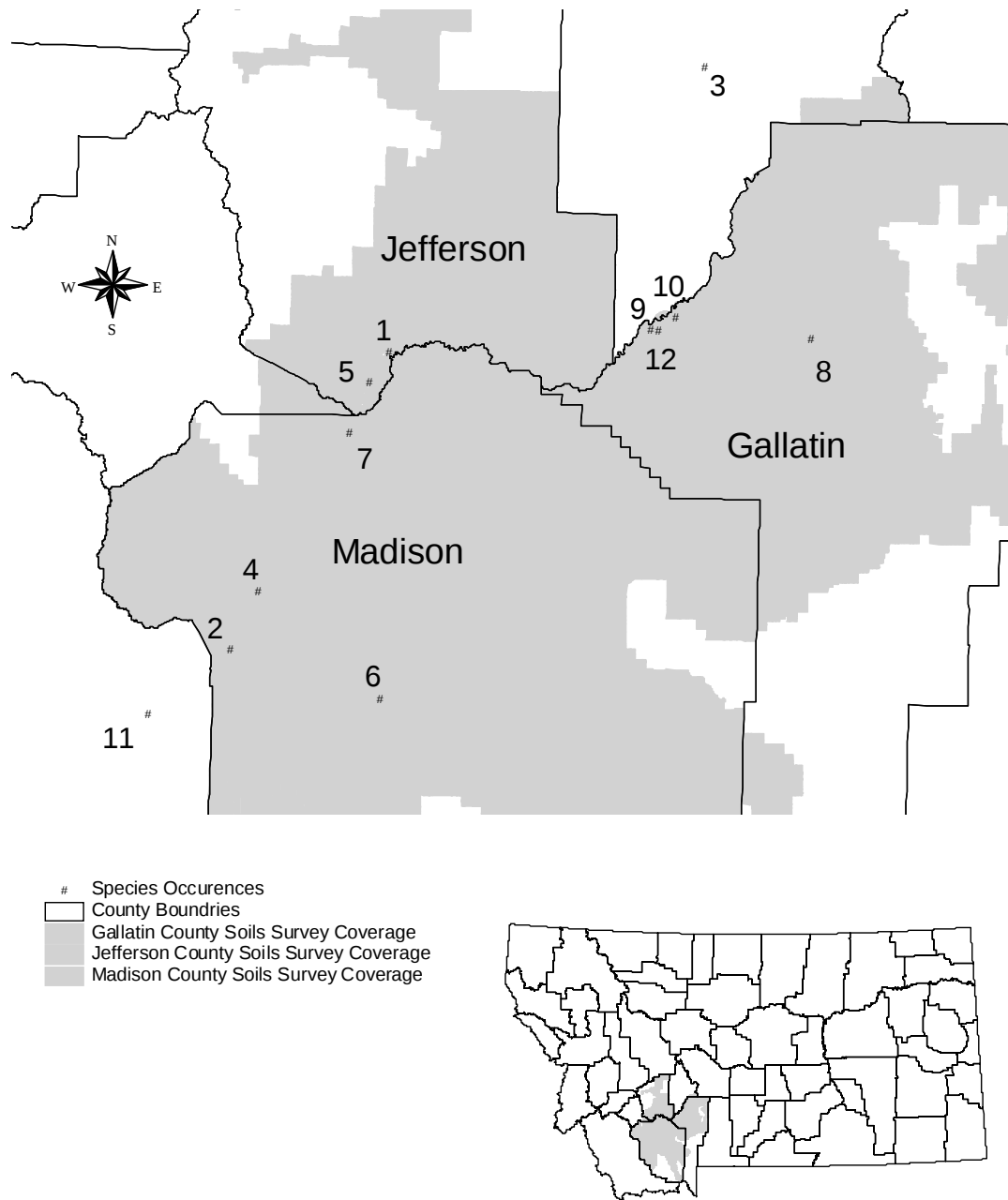


Figure 6. Southwestern Montana Species Occurrence Sites. 1:800,000. Shaded areas indicate soil survey data coverage (Heidel, 1997).

Legal Status

*Spiranthes deluvialis* was listed as a “threatened” species on January 17, 1992, under the authority of the Endangered Species Act of 1973 (U.S. Fish and Wildlife Service, 1992). The agency determined the species was threatened primarily by habitat loss and modification through its small populations and low reproductive rate, making it vulnerable to other threats as well. Complying with the Endangered Species Act (ESA) threatened species listing; federal agencies developed a draft consultation guideline for addressing potential impacts by prohibiting removal or possession of *Spiranthes deluvialis* on federal lands (U.S. Fish and Wildlife Service, 1995).

In addition to the original ESA listing and the draft Section 7(a) protection guidelines, the U.S. Fish and Wildlife Service has prepared a draft recovery plan that addresses critical habitat requirements (U.S. Fish and Wildlife Service, 1995). However, the U.S. Secretary of Interior had determined at this time that critical habitat requirements under ESA, Sec. 4 have not been determined because the designation is not presently prudent for *Spiranthes deluvialis*, due to its rarity and a lack of enforcement. The reason is that this species takes five to ten years to reach reproductive maturity and reproductively-mature plants do not flower every year. So, if flowers were collected, it would eliminate the plants’ reproductively for that year and probably several more years. Thus, an increase in rate of collection would have a greater impact on species population than would an unenforceable critical habitat designation. However, *Spiranthes deluvialis* is protected by ESA, Section 7(a) as well as several federal water quality and wetlands protection legislations.

A formal species status is designated by the Natural Heritage Program rankings (MHNP, 1998). The international network of Natural Heritage Programs employs a standardized ranking system to denote global (range-wide) and state status (Association for Biodiversity Information, 2001). Species are assigned numeric ranks ranging from 1 (critically imperiled) to 5 (demonstrably secure), reflecting the relative degree to which they are at risk (Table 2).

| Rank | Definition                                                                                                                       |
|------|----------------------------------------------------------------------------------------------------------------------------------|
| 1    | Critically imperiled because of extreme rarity and/or other factors making it highly vulnerable to extinction.                   |
| 2    | Imperiled because of rarity and/or other factors demonstrably making it vulnerable to extinction.                                |
| 3    | Vulnerable because of rarity or restricted range and/or other factors, even though it may be abundant at some of its locations.  |
| 4    | Apparently secure, though it may be quite rare in parts of its range, especially at the periphery.                               |
| 5    | Demonstrably secure, though it may be quite rare in parts of its range, especially at the periphery.                             |
| U    | Possibly imperiled, but status uncertain; more information needed.                                                               |
| A    | Native in nearby states, but in Montana believed to be accidentally introduced, deliberately planted, or escaped from plantings. |
| H    | Historical, known only from records over 50 year ago; may be rediscovered.                                                       |
| X    | Believed to be extinct; historical records only.                                                                                 |

Table 2. Definitions of Natural Heritage Program Rankings (Global and State) (MNHP, 1998).

A number of factors are considered in assigning ranks; the number, size and distribution of known occurrences or populations, population trends (if known), habitat sensitivity and threats. These factors in a species' life history that make it especially vulnerable are considered (Montana State Library, 2001). *Spiranthes diluvialis* is currently range-wide ranked as globally imperiled (Global rank 2, Table 2) owing to its

extreme rarity conditioned by quality, condition, viability and vulnerability of the occurrences along rivers (Heidel,1998).

First discovered in southwestern Montana in 1994, *Spiranthes deluvialis* was unconfirmed until cytological studies were conducted by Dr. Sheviak in 1995. It was then added as a new species to the Montana State Flora listing the following year (Heidel, 1996a). *Spiranthes deluvialis* is state-ranked as a critically imperiled species of special concern (State-rank 1, Table 2) in Montana owing to its extreme rarity, small occurrence population, habitat threat and lack of protection (Heidel,1998). It should be understood that state ranking is not a legal designation and does not require legal protection or regulation but merely suggests management guidelines.

## DATA SOURCES, TERMINOLOGY AND METHODOLOGY

### Decision of Project Site

Missouri Headwaters State Park is a 540 acre state-managed property where the Madison, Jefferson and Gallatin rivers form the headwaters of the Missouri River, four miles northeast of the town of Three Forks, Gallatin County, Montana (Figure 7). The elevation ranges from 4000-4600 feet. The general habitat is classified as semi-primitive lands (Montana State Library, 2001) consisting of arid grassland with micro-habitats representative of calcareous, wet-mesic, temporarily-inundated meadows in shallow wetlands along riparian channels similar to the twelve southwestern Montana species occurrence site habitats documented for this project.

There are several particular advantages to having the Missouri Headwaters State Park as the project study site:

1. The park provides open access to the study site.
2. The semi-primitive park status provides habitats minimized by external impact.
3. Local honey production near the prediction sites may contribute to plant propagation as a pollen vector.
4. The application of conservation management where Montana Fish Wildlife & Parks are in keeping with the conservation tradition protecting critical habitat.

Genetic research in Colorado and Utah suggests that *Spiranthes deluvialis* may have evolved from two separate hybridization events (Arft, 1995). Occurrences in southwestern Montana sites may have a separate origin from those in the rest of its range

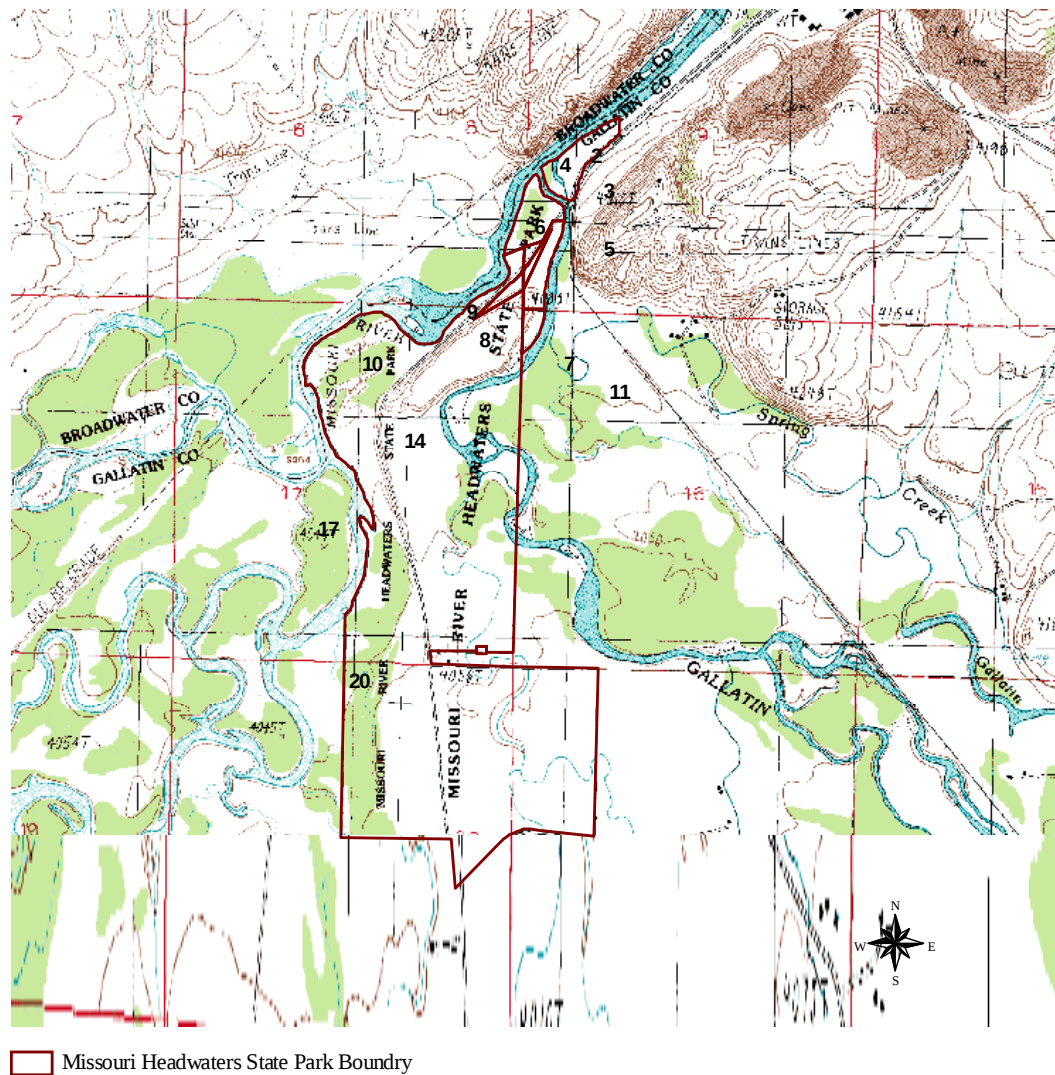


Figure 7. Missouri Headwaters State Park Study Site. Scaled at 1:39,000 from the U.S.G.S. Western United States topographic series – Bozeman Base.

so population discoveries or delineating potential habitat will contribute to the species study.

### Data Sources

The spatial displays of species-specific habitats in a Geographic Information System (GIS) is created by layering existing data from several sources to delineate regional variation, compile species-specific information and evaluate site-specific data.

Three primary sources were accessed in this study for establishing an adequate information base from which spatial predictions are mapped. The sources were the Montana State Library Information Series, the Montana Natural Heritage Program and the Natural Resource Conservation Service.

The Montana State Library Information Series (2001) ([www.nris.state.mt.us](http://www.nris.state.mt.us)) provides spatial coverage particularly useful in determining regional habitat variations and their relationships in several information displays: A geographic base data map from which the component layers are processed is downloaded as USGS 1:24,000 and / or 1:250,000 topographic series then translated to a Montana State Plane NAD 83 coordinate system for large scale (macro-habitat) delineation. These information series maps display the regional geologic variations and relationships at occurrence sites to the study site, a land cover map of the organic variations and the relationships of occurrence sites to the study site, and a land use information coverage map displaying regional patterns of human influences that may affect species population distribution.

The Montana Natural Heritage Program (MNHP, 1998) data was the primary literature resource for species-specific information accumulated from historical reviews

and occurrence site studies in defining the species' biology, soil characteristics and associated species-specific features. The Natural Heritage Program represents an international network of biological inventories from natural heritage programs or conservation data centers operating in all fifty states, Canada, Latin America and the Caribbean. Together, the Natural Heritage Programs collect, inventory and manage detailed information on plants, animals and ecosystems to develop management tools and conservation services to help meet local, national and global conservation needs. Scientific information collected about species and ecosystems developed by the Natural Heritage Programs are used by conservation groups, government agencies, corporations and academia as well as the general public to assist in making informed decisions about managing natural resources. Thus, the Natural Heritage Program and its network of natural heritage programs are the leading source for information about rare and endangered species and threatened habitat (Montana Natural Heritage Program, 1998).

The Montana Natural Heritage Program is the regional arm of the Natural Heritage Program. Created in 1974 with help from the Nature Conservancy as a membership organization of the Natural Heritage Program, the MNHP non-profit conservation organization provides scientific information and tools needed to help guide effective conservation action. Established by the Montana State Legislature in 1983 as Montana's clearinghouse for information on Montana native species and habitat, MNHP collects, validates and distributes information and assists natural resource managers in effectively applying the data. Montana Natural Heritage Program data is obtained from the Montana State Library as part of the Natural Resource Information System. MNHP is primarily responsible for compiling the definitive information on Montana's *Spiranthes deluvialis*

habitat. The program studies provide a detailed information base that reference species occurrence sites with geologic characteristics, topographic features and associated plant species as well as soils component data for several species-specific micro-habitat attributes.

A conservation status study of *Spiranthes deluvalis* in Montana was conducted by Bonnie L. Heidel (MNHP, 1997) in partnership with the Natural Heritage Program regional species study to document a regional habitat study of *Spiranthes deluvalis* in Montana (Heidel, 1996 b). The studies documented species occurrence sites to specific habitat attributes values for physical, chemical and hydrologic components as well as spatial features in determining a species-specific habitat. This study recognizes the MNHP as the primary information source on Montana native species and habitats emphasizing conservation concerns. These data provide the information for predicting suitable habitats at Missouri Headwaters State Park.

The Natural Resource Conservation Service (NRCS) was established in the mid 1930's as a result of the Soil Conservation Act of 1935, as the agency responsible for promoting the stewardship of U.S. soils. The NRCS is the resource for site-specific soils component digital data used for the quantitative analysis in this study.

A review of MNHP site data from Table 1 (page 9) shows that the range of soils component values covering a five-state region are too varied for determining suitable habitat relationships between occurrence sites and the study site soils components. To create definitive habitat predictions, a more manageable, southwest Montana species occurrence/study site component relationship was used for species-specific habitat

predictions. The NRCS soils survey data base provides the GIS digital resources through the Soils Survey Geographic Data Library ([www.nasis.usda.gov](http://www.nasis.usda.gov)).

The NRCS was the primary quantitative data source for this project in predicting species-specific micro-habitats. The soils survey component values are displayed in polygon maps with supporting tables, charts and graphs illustrating the component trends, distribution and their covariant relationships. Each polygon and associated interactive tabular data of the soils component values identifies the average unique characteristics of that particular polygon. By the statistical manipulation of the soils component data at the species occurrence sites, similar component characteristics are queried for the study site polygons. The suitable species habitat polygon predictions are statistically identified and presented in graphic distribution displays.

The National Cooperative Soil Survey Standards and Procedures were used for soil classification and unit values. The standards were employed by both the MNHP studies and the NRCS soils surveys, providing complimentary data sets for this project (USDA, 1993).

Soil survey polygon data was tabulated and mapped over a three-county area that included ten of the twelve southwestern Montana species occurrence sites. The study area soils polygon component values were tabulated and mapped as well. The NRCS soils polygon component data produce three important prediction evaluations: 1) generating a soils component data base of species occurrence sites for statistical analysis; 2) allowing a means to compare the two field studies (MNHP and NRCS) evaluating the combined data sets; and 3) creating species-specific attribute relationships within the study area soils polygons, delineating the suitable micro-habitats.

### Computer Application Sources

Two computer application sources were necessary for developing suitable habitat spatial predictions: 1) NRCS *Soil Data Viewer* is the application used to access the Soil Survey Polygon Data Base. The application is used for processing the soils component data into spatial map displays of soils properties at micro-habitat delineations; and 2) *ArcView 3.2 with Spatial Analyst* are the GIS mapping applications for generating the soils component value distribution in graphic displays. The GIS spatial analyst technology has the capabilities to manipulate the soils component trend values and the statistical relationships of tabular data, creating a graphic representation based on a weighted influence of soil components in a spatially-delineated display of suitable habitat values. A GIS query builder tool (Query Expression) in the Spatial Analyst application that creates digital layers of processed tabular data generated from the component values selected in predicting the suitable habitat criteria. Building a query is a powerful application tool in selecting suitable polygon features because an expression can include multiple attributes and calculations that are easily manipulated as a weighted value function. The GIS applications effectively produce a prediction display based on multiple data sources, delineating the soils polygon component values which reflect species-specific suitable habitats. The maps produced from these data significantly reduce the need for timely field surveys.

It should be noted here that while processing species habitat information on a GIS is a powerful application, predictions are based on the variables and relationships measured at a particular site or group of sites which may not be representative of the full range of

variation in habitat use. Therefore, their application to some locations may be questionable. It is possible that source errors may arise in the following ways:

- the quality of data collection and extrapolation of the data over space;
- the variations in biological systems;
- the model assumptions themselves.

Thus, errors or limitations are partly by-products of the intrinsic simplification that takes place in the development of the prediction. Even though computer prediction mapping saves considerable field effort, habitat models should serve as a supplemental function in management strategies.

Data sets regarding regional, species-specific and site-specific data are free public information that can be downloaded from the various agency web sites. The Soil Data Viewer application is downloaded as free public information. ArcView 3.2 and Spatial Analyst mapping and analysis applications can be purchased through an Environmental Systems Research Institute vendor.

### Terminology and Definitions

Developing suitable habitat predictions are dependent on understanding the relevant source terminology and component definitions incorporated into the processes.

Component terminology is categorically reviewed as either: 1) habitat elements; 2) qualitative information; 3) quantitative data; or 4) GIS applications.

#### Habitat Elements

Habitat is simply defined as a place where an organism is able to live either

temporarily or permanently. Habitat characterization identifies habitat attribute components important to a species. A multivariate ordination technique of principle component analysis is used to identify relevant relationships between species and habitat factors that affect its distribution. It is the identification of environmental element values that are important to a species for its survival under natural conditions.

Habitat evaluation is the procedure that quantifies the quality of habitat characterization. Habitat evaluation systems and habitat relationship predictions assume that habitats have a range of quality or suitability for a given organism, and that their range can be quantified as a measure of quality or suitability.

#### Qualitative Information

Habitat characteristics and features represent the qualitative information for this project. MNHP species occurrence site studies provide regional information for the exploratory analysis of the southwestern Montana species sites by delineating the spatial variations influencing habitat biology, ecology and soils features as well as historical distribution, propagation and human influences.

Biological characteristics are important macro-habitat features defining the southwestern Montana occurrence site habitats. The region is characterized by broad, open intermontane valley bottoms that represent Cenozoic basins filled with late Quaternary alluvium, forming flat valleys and low gradient rivers with swales promoting occasional flooding. Land cover at the occurrence sites is predominantly grassland along the abandoned channels and across the bottoms of wet meadow swales occupied by

habitat settings having short, sparse emergent vegetation (Montana Natural Heritage Program, 1998).

Ecological features discussed in the MNHP studies describe *Spiranthes diluvialis* habitat as restricted to small, sporadic ecosystems. Occurrence site habitats are represented by temporarily-inundated grassy meadow in shallow wetlands created in alluvial fans that include narrow channels and broader swales set back from the river without surface water connections (Montana Natural Heritage Program, 1989).

Soils features for those particular landscape segments that have wetland inclusions are mapped as Neen or Villys soil series among the seven western occurrences and as the Fairway-Threeriver-Rivra complex or Sapo soil series among the three eastern occurrence sites (Montana State Library, 2001). Neen soils are fine frigid aquic Calciorthids. Villy soils are fine silty mixed (calcareous) frigid typic fluvaquents. And Fairway soils are fine, loamy mixed Fluvaquentic Haploborolls (Heidel, 1997). They are all classified as wetland soils. The meandered wetlands are just inclusions that are not mapped separately. The distribution of these soils series corresponds with the distribution of alluvial fans laced by meandered wetlands (Boast and Shelito, 1989).

MNHP field studies indicate that the southwestern Montana *Spiranthes deluvialis* occurrence habitats are associated with riverside succession in the wetlands complexes (Heidel, 1997). In the Montana sites it appears that *Spiranthes diluvialis* occurrences are restricted to soil conditions rather than successional stages, and most consistently found in small zones and meandered segments where calcium carbonate concentrations are high (Heidel, 1997). And finally, it was noted that density and stature of the vegetation in those locales was usually sparse and short compared to surrounding wetland habitat.

MNHP habitat descriptions appeared to be similar to Missouri Headwaters State Park environments.

Physiographic and topographic characteristics are important macro-habitat features. The occurrence sites as well as the study site feature the broad, open intermontane valley bottoms and low gradient rivers with swales which promote occasional flooding in these settings. Land cover appears to be short, sparse, emergent vegetation and grassland along abandoned channels or across the bottoms of wet meadow swales as discussed in the MNHP literature (1998) reviews on species habitat settings.

Occurrence site soils component features were measured by the MNHP studies using NRCS Soils Survey Standards (USDA, 1993), creating the data value sets used for the micro-habitat computer evaluations. Soils component values recorded for occurrence site soils polygons by the NRCS surveys included: soil series type names, electrical conductivity (EC), calcium carbonate ( $\text{CaCO}_3$ ), acidity/alkalinity (pH), percent organic matter, available water supply (AWS), and flooding frequency.

MNHP literature (1998) suggests the soils that make up the landscapes surrounding *Spiranthes diluvialis* habitat are high in  $\text{CaCO}_3$  and salt-affected within the rooting zone. They are described as sub-irrigated range sites (functions of flooding frequency and available water supply). Soils at southwestern Montana species occurrence sites are typically moderately alkaline (a function of pH), and site samples tend to have twenty percent more organic content than the surrounding habitat which is comparable to productive farmland or histosols (Montana Natural Heritage Program, 1998).

Associated plant species provide important spatial relationships in predicting suitable species habitat. The various plants, or indicator species, associated with *Spiranthes*

*deluvialis* documented in the MNHP occurrence site surveys are categorized by five general groupings (see appendix for associated species photos):

1. Most common associated plants at Montana occurrence sites
2. Plants exclusive to Montana or Montana wetlands
3. Species exclusive to Gallatin county wetlands
4. Exotic species
5. Endangered species

For the southwestern Montana wetland complex landscapes, the soils series types and the collection of associated plants species have been evaluated by the MNHP to determine the presence/absence of *Spiranthes diluvialis* by their macro-habitat characteristics. The compilation of soils information was documented to critique the macro-habitat features for this study. The MNHP search within each occurrence setting is not considered exhaustive but the distribution is demarcated. A more complete evaluation of soils components are determined by the NRCS soils survey data complementing the MNHP evaluations to assist in predicting suitable micro-habitats in the proximity display.

#### Quantitative Data (site-specific)

NRCS soil survey data is a particularly important data base for establishing micro-habitat values from which suitable habitat is predicted and displayed in a GIS. Seven NRCS soils survey attributes are applied for quantitative analysis: two physical properties, three chemical properties and two spatial features. Both the physical and chemical properties can be measured or inferred from direct field observation or from

laboratory analysis, while the spatial features are not directly measured, but inferred from observations of dynamic conditions and from soil properties.

#### 1. Physical Properties:

Available Water Supply (AWS) is the total volume (in centimeters) that should be available to plants if the soil, inclusive of fragments, were at field capacity. It is commonly estimated as the amount of water held between field capacity and wilting point, with corrections for salinity, fragments, and rooting depth. AWS is reported as a single value of water for depth of soil. AWS is calculated based on the available water capacity times the thickness of each soil horizon to a specific depth (Natural Resource Conservation Service, 2001).

Organic Matter is the value of decomposed plant and animal residue, and is expressed as a weight percentage of the soil material  $< 2\text{mm}$  in diameter. Organic matter influences the physical and chemical properties of soils far more than the small quantities present would suggest. The distribution of organic carbon with depth indicates different episodes of soil deposition or soil formation. Soils that are very high in organic matter have poor engineering properties and subside upon drying (Natural Resource Conservation Service, 2001).

#### 2. Chemical Properties:

Calcium Carbonate ( $\text{CaCO}_3$ ) equivalent is the quantity of carbonate ( $\text{CO}_3$ ) in the soil expressed as  $\text{CaCO}_3$  and as a weight percentage of the  $< 2\text{mm}$  size fraction. The availability of plant nutrients is influenced by the amount of carbonates in the soil. This is a result of the effect that carbonates have on pH nutrient availability (Natural Resource Conservation Service, 2001).

The pH of the soil is a numerical expression of its relative acidity or alkalinity. Soil reaction is one of several properties used as a general indicator of soil corrosives or its susceptibility to dispersion. The most common soil laboratory measurement of pH is the 1:1 water method. A crushed soil sample is mixed with an equal amount of water, and a measurement is made of the suspension (Natural Resource Conservation Service, 2001).

Electrical Conductivity (EC) is a measure of the concentration of water-soluble salts in soils. It is used to indicate saline soils. High concentrations of salts, such as sodium chloride and sodium sulfate, may interfere with the absorption of water by plants because the osmotic pressure in the soil solution is nearly as high as or higher than that in the plant cells (Natural Resource Conservation Service, 2001).

### 3. Spatial Properties:

Map Unit Name is a collection of soil areas delineated in a soil survey. Each map unit is given a name that uniquely identifies that unit in the soil survey. These soil features are attributes that are not directly part of the quantitative soils data.

Flooding Frequency is the temporary covering of the soil surface by flowing water from any source, such as streams overflowing their banks, runoff from adjacent or surrounding slopes, inflow, or any combination of sources. Flooding frequency is based on the interpretation of soil properties and other evidence gathered during soil field work. Flooding Frequency Class is defined by the number of times flooding occurs over a period of time (Natural Resource Conservation Service, 2001). The classes are expressed as:

None: indicating no reasonable possibility of flooding or near 0 percent chance of flooding in any year, or less than 1 time in 50 years

Very rare: indicating that flooding is very unlikely but possible under extreme unusual weather conditions, less than 1 percent chance of flooding in any one year or less than 1 time in 100 years but more than 1 time in 500 years

Rare: indicating flooding unlikely but possible under unusual weather conditions, 1 to 5 percent chance of flooding in any one year or nearly 1 to 5 times in 100 years

Occasional: indicating flooding is expected infrequently under usual weather conditions, 5 to 50 percent chance of flooding in any year or 5 to 50 times in 100 years

Frequent: indicating flooding is likely to occur often under usual weather conditions, more than 50 percent chance of flooding in any year or more than 50 times in 100 years, but less than 50 percent chance of flooding in all months of the year

Very frequent: indicating flooding is likely to occur very often under usual weather conditions more than 50 percent chance of flooding in all months of the year

### Geographic Information Systems Applications

Several habitat-based data evaluations are incorporated in the GIS applications at various scales to compile sufficient information in predicting suitable habitat delineations for this study.

The ArcView/Spatial Analysis applications generate traditional ordination techniques (the ordering of attributes with respect to similarity groupings and environmental values) as the default statistical analysis. A compilation of species-specific habitat characteristics are mapped using various regional displays, soils feature data and other habitat components associated with a species-specific ecosystem. Tabulated data is translated

into digital graphic layers reflecting a spatial distribution of the best-fit, ordered value, habitat polygons in the proximity.

As an aid to understanding the techniques incorporated for the compilation of data at various levels of order, four geographic information systems processing concepts were utilized: 1) species habitat matrices, 2) value indices, 3) hierarchy order, and 4) discriminate analysis.

1. Species habitat matrices represent the Boolean operations of the qualitative information analysis expressed as delineated polygons rated on the inclusion or exclusion of a variable. Boolean expressions include regional information (i.e. geologic features, land use and land cover variation) as well as site-specific information on soil-type names.

2. A Value Index represents the quantitative soils properties order-of-importance, and their value limits for the capacity of a given component to support the species habitat. Quantitative values (micro-habitat) are identified as data sets, manipulated by their range of suitability and supported by the relationships of their limit values. A component is a dominate indicator of suitable habitat when the standard deviation is small, indicating the range of component values are closely arranged around the mean value. Where the value range or standard deviations indicate greater variation, the delineated values index is moderate and more substantial range variations are marginal indicators of suitable habitats.

3. Hierarchy prediction criteria are developed by the data compiled from habitat matrices and the component value index, creating the hierarchy of suitable habitat prediction attributes. GIS mapping processes the data summary into structure levels, layering in a hierarchical organization, delineating suitable habitats in spatial displays rated by their

degree of importance to species-specific properties. Boolean expressions are weighted as the primary layers followed by the first and second standard deviation mean limit values, with third order limit values weighted as least important.

4. Discriminate analysis is the classification display, developed from the collective data analysis, for assigning each proximity polygon with attribute values having the most representative multivariate set of characteristics of associated habitat conditions. The analysis-generated suitability displays are the data from which the conservation strategies are recommended. These data assist in making informative predictions in three general ways: 1) by testing predetermined assumptions on environmental conditions affecting population; 2) by providing statistical analysis of significant variable relationships; and 3) by extrapolating data to specific search areas, reducing extensive or redundant field surveys. Predictions are based on the variables and relationships measured at a particular site or group of sites (or even un-sampled, assumed relationships). These data may not be representative of the full range of possible variation in habitat so their application to their locations may be questionable. Modeling errors may arise in data collection and extrapolation, variation in biological systems, or from prediction assumptions themselves. Thus, any errors or limitations are partly by-products of the intrinsic simplifications in developing a prediction, and should serve as a supplemental function in guiding management strategies.

## RESEARCH PROCESSES

The main objective of this project was to spatially delineate suitable habitat in the study area. To accomplish this goal, five specific questions were addressed:

1. What are the environmental factors affecting this species habitat? These are the regional data defining the macro-scale species habitat similarities compiled from the literature.
2. What are some of the characteristics/trends associated with the species site components, and how might they be affected by regional information? These data define part of the meso-scale analysis of processing component trends and covariant dependencies in creating a value-order index.
3. How do external impacts affect habitat? This evaluation is a second process of the meso-scale relationships based on land use/land cover impacts on component values.
4. Do/can species populations survive in the selected polygons as predicted from the information analysis? These data provide the micro-scale discriminate analysis process for the qualitative attributes of associated species-specific habitat features.
5. What is the status of species population habitats and what might be their prospects for future distribution/propagation, based on study conclusions? These are the conclusive, conservation recommendations derived from the compilation of processed data from which management strategies are recommended. This question is the purpose for the project.

### Information Compilation

Compiling the information to be processed in developing suitable habitat characterizations involved using a systematic, four-tiered data compilation consisting of:

1. The first tier displays a macro-scale examination of the regional habitat characteristics. These are data processed from a series of regional maps delineating geologic features, land cover and land use relationships at species occurrence sites and the study area.
2. The second tier or meso-scale quantitative relationships are developed from species site numerical data. The component trends are statistically manipulated, creating an ordered index of limit values suitable for species habitat. A covariant relationship analysis is generated from the trend data to reveal component dependencies.
3. The micro-scale tier displays proximity site discriminate analysis. The map shows the proximity polygons most suitable for species habitat. The component query is based on the statistical analysis of species occurrence site polygon component values.
4. The field survey is the prediction site evaluation for associated species-specific features. These are visual characteristics discussed in the literature about associated features (i.e. vegetation, topography and human impacts).

The organization of the information sets do not imply that each set is independent of one another. On the contrary, for this study, each information tier successfully provides more precise information about species habitat characteristics, delineating select proximity

polygons of suitable habitat thus, eliminating the need for timely field surveys while providing adequate data from which to formulate conservation recommendations.

### Mechanics of the Research Processes

The mechanics of predicting the suitable habitat involve a six step procedure:

1. Base maps display the regional information identifying the southwestern Montana species occurrence locations, the variation of topographic features and the delineated study area. Base maps display regional features or macro-habitat characteristics, the relationships of species occurrence locations and create the template for meso-scale and micro-scale data map layers.
2. Developing a species-specific data base of the relative soil components micro-ecology is formulated on attributes compiled from the species-specific site evaluations. In developing the prediction criteria, the soil component characteristic values measured at occurrence sites and queried in the study display, delineate the species-specific component values of each polygon. The component summary data are mapped as order-of-importance suitable habitat displays. The species-specific numerical data provide important evaluation in the following ways:
  - 1) generating a soils component data base of occurrence sites for statistical analysis.
  - 2) allowing a means to compare soil attribute data from the Natural Resource Conservation Service data to the Montana Natural Heritage Program field studies in providing validity of the combined data sets.
  - 3) creating species-specific relationships in the proximity polygon delineating the micro-scale habitat suitability prediction.

3. Formulating the GIS analysis of the tabular data and trend relationships to suitable species-specific habitats is processed with the GIS default statistical summary analysis. The component distribution maps utilize the computer mapping applications discussed in the previous chapter (see pg. 23). The Soil Data Viewer application processes the soils data for creating graphic distribution displays of the micro-habitat components. The ArcView/Spatial Analysis application is applied to the component data generating the statistical analysis of trends and relationships. Data are represented in trend value charts and covariant attribute relationship graphs and then translated into spatial displays of suitable component polygons. The ArcView Query Builder tool creates the spatial layers generated from the statistical analysis. The query expression, the process of selecting features, includes multiple attributes, operators and calculations by a function of their weighted values, and/or by the importance determined in the literature and statistical summary.
4. Creating the discriminate analysis produces the species-specific habitat prediction display of best-fit proximity polygons. Suitable habitat polygon delineations are predicted, for this study, from evaluating a limited data base, available as free public internet access information. This project demonstrates that GIS analysis and mapping capabilities, when applied to these data resources, is an effective resource management tool.

The advantage of developing statistical component delineations in a GIS as a resource management tool is the capabilities of computer applications to produce large-scale spatial delineations over large area coverage. Habitat predictions may involve several characteristic variations and/or complex element relationships. By

applying the GIS processes of manipulating tabular data as relationships change or new data becomes available, a revised display is easily created.

5. Field observation surveys of associated elements relate the soils component evaluations with descriptive features. While the soils component values delineate the suitable habitat polygons, the final evaluation is conducted by the field survey of associated species-specific features. The objective of this procedure is two-fold; 1) to verify the presence of *Spiranthes deluvalis* and/or suitable species habitats and, 2) to identify physiographic features, human impacts and plant species associated with habitat suitability not delineated in the digital data but represent important properties for conservation recommendations. Topographic subtleties and other environmental impacts on natural water holding capacity, or introduced vegetation may alter the species-specific conditions. And a critical component in habitat suitability is the associated plant species. Compiled from the MNHP occurrence site field studies, associated plant species are grouped into the five indicator categories discussed earlier in this study (see pg. 27).
6. Recommendations for conservation management were developed from the results of the processes demonstrated by this study. The method involves proposing management strategies based on the compiled quantitative data and qualitative information. Developed from GIS analysis and associated visual properties, a conservation management strategy was recommended for each of the proximity polygons predicted as suitable species habitat.

The following flow chart (Figure 15) represents the logical structure of the methods and mechanics processes developed for this study. The chart illustrates the

logical structure order from which the data is processed. The southwestern Montana species distribution is explored to determine regional similarities of occurrence sites

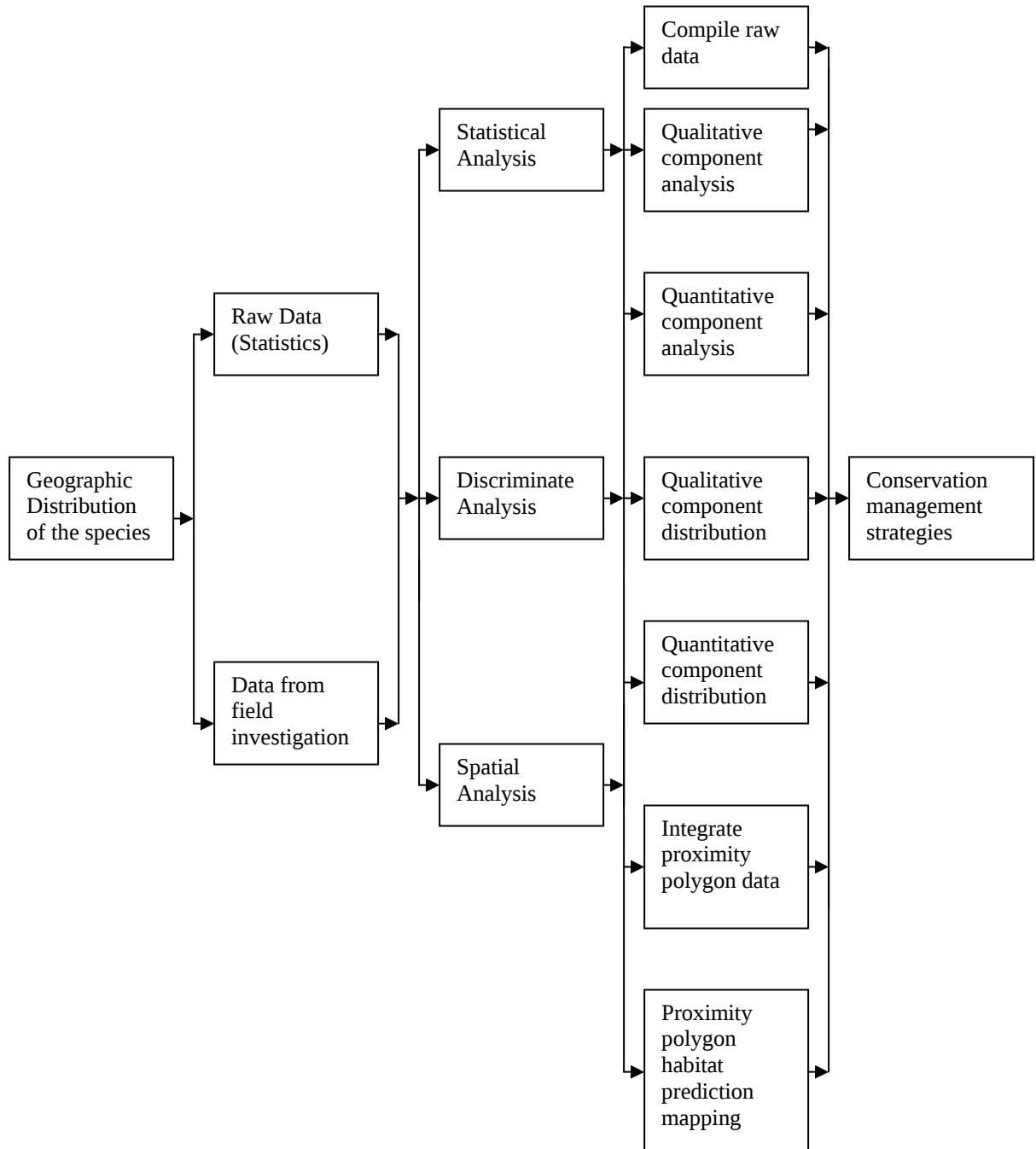


Figure 8. Logical Structure for Methods and Processes

with the study area. Extensive research is then conducted for species-specific attributes. Tables of data are created in the GIS from which the three phases of analysis are conducted (statistical, discriminate and spatial). The GIS creates map displays of suitable habitat delineations in the study area based on the collective occurrence site values. Field surveys are conducted at the delineated sites and conservation management strategies are recommended.

## ANALYSIS

Habitat evaluation, the procedure that quantifies the predictive quality of a habitat, presumes species presence and/or its habitat distribution is/are not known. The analysis procedures for this project are designed to demonstrate GIS technology as an effective tool for conservation management. By first delineating suitable habitats in proximity, unnecessary redundancies in field efforts are reduced.

Predicting suitable species habitats was predicated on reviewing the available data resources. By definition of these data, the analysis processes applied in this study involved a straight-forward, component-ordered, value approach in predicting suitable habitats.

Utilizing regional habitat characterization of species populations, followed by a statistical trend analysis of the soils components, suitable habitats were delineated in the study area. These processes evaluate species-distinct requirements, creating an ordered component probability, displaying suitable habitats in a compilation of spatial scales evolving from the data layering (See page 35).

### Regional Characterizations

A regional habitat characterization was determined from a series of southwest Montana regional maps. The literature describe *Spiranthes deluvalis* habitat as predominantly restricted to edaphic (earth/water) factors rather than successional properties, so soils characteristics dominated the evaluations (MNHP, 1998).

The Montana Natural Heritage Program describe species occurrence sites characteristic of broad, open valley basins, consisting of low-gradient rivers at 4080 to 4950 feet elevation on level flood plains and wetlands soils at the southwest Montana sites (Montana Natural Heritage Program, 1998). The study area (see Figure 7) is also representative of broad, open valley topography, at the target elevations with low-gradient rivers, indicating habitat similarities and the probability of suitable species-specific habitat.

Additional regional habitat consistencies were determined by evaluating land characteristic maps showing the geology systems, land use, and land cover represented at the species occurrence sites as well as the study site. From these data, regional habitat continuity was established and determined that the study area had suitable species habitat. The geology system map (Figure 9) shows the entire western Montana species occurrence sites, as well as the study site, are dominated by a Quaternary system surrounded by Tertiary systems indicating a geologic habitat consistency. The land cover map (Figure 10), reveals that the southwestern Montana species occurrence sites fall within the intermountain grasslands while the four Gallatin County sites and the study area are predominantly within riparian ecosystems. However, a larger scale land cover display (Figure 11) shows occurrence sites, not appearing as riparian environments, are mapped as irrigated cropland, which suggests that an adequate water supply is essential in delineating a suitable species habitat. The land use map (Figure 12), displayed in a smaller scale, is important in that it shows the occurrence sites in crop or pasture use, indicating, again, the importance of an adequate water supply for suitable species habitat.

The southwestern Montana regional characterizations support the availability of suitable species habitat at the study site. The quantitative component analysis delineates suitable species habitat with-in the study area site.

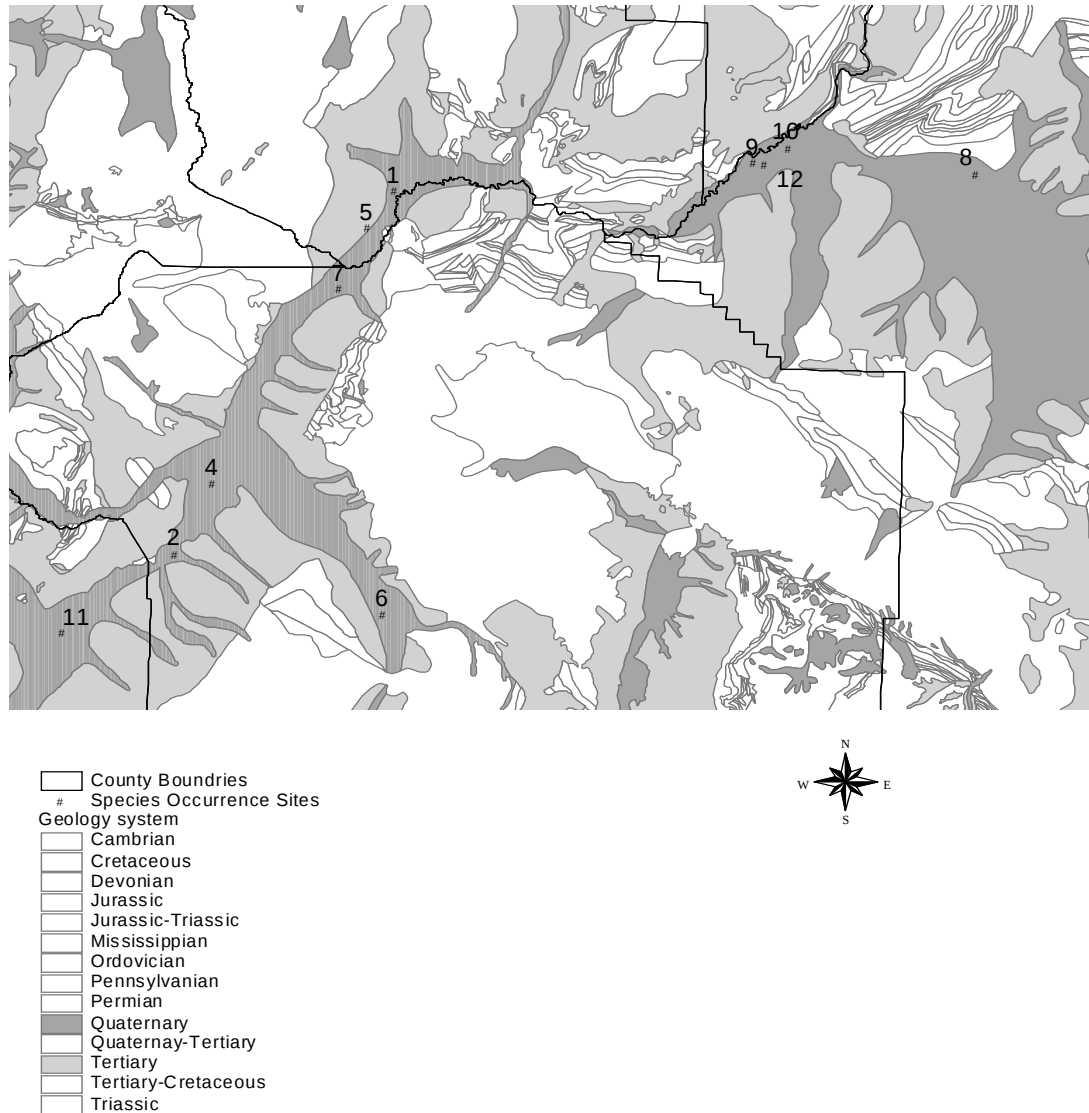


Figure 9. Geology Systems of southwestern Montana. 1:838,500 (Montana State Library, 2001). A regional display of the geology systems at species occurrence sites and the study area. Polygons that are not shaded represent geology systems in the region. They are delineated and listed in the legend but their unique identifications are not necessary for this study.

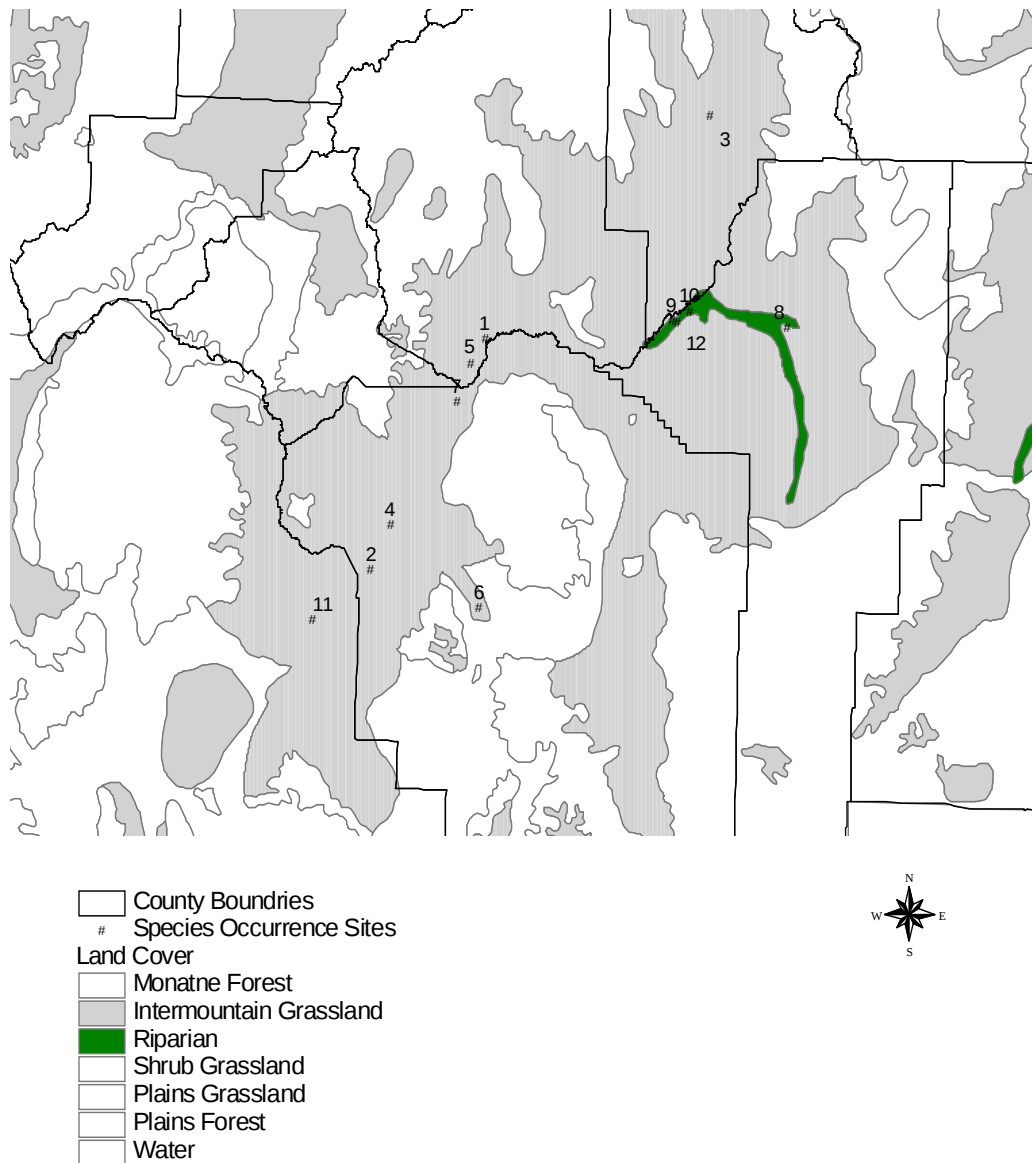


Figure 10. Land Cover 1 of southwestern Montana. 1:1,500,000 (Montana State Library, 1998). The southwest Montana species occurrence sites are mapped as intermountain grassland with the sites near the study area displayed in the riparian zones of intermountain grassland. To simplify the illustration, only the occurrence site polygons are color shaded. Other land cover polygons are delineated and listed in the legend but are not evaluated for this study.

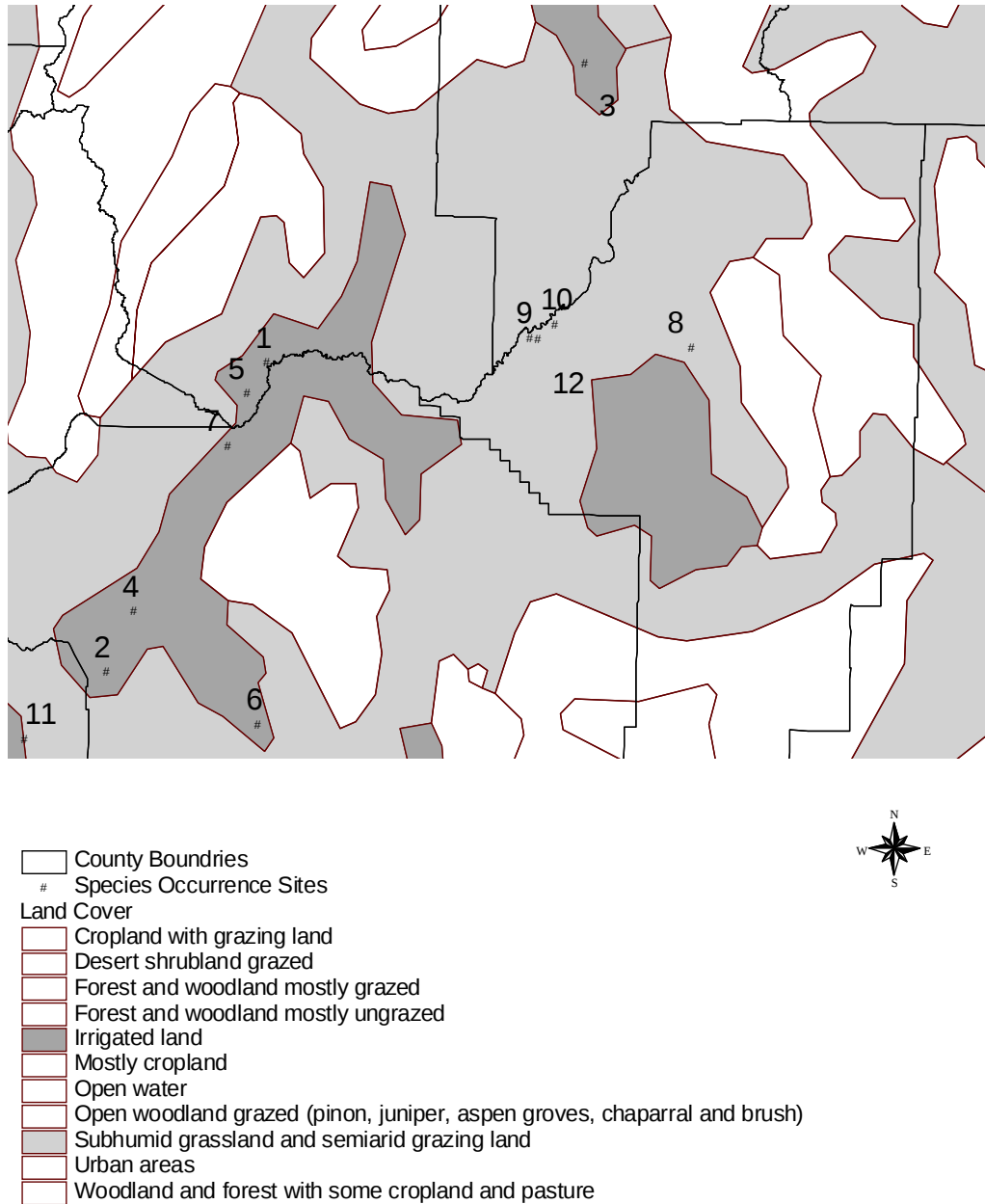


Figure 11. Land Cover 2 of southwestern Montana. 1: 936,000 (Montana State Library, 1998). The larger scaled land cover map displays the occurrence sites as grassland, with the Gallatin county sites in riparian zones (refer to fig. 16). The remaining sites are mapped in irrigated land. The importance of water on species habitat is emphasized by this display. Several other land cover polygons are delineated and listed in the legend but are not evaluated for this study.

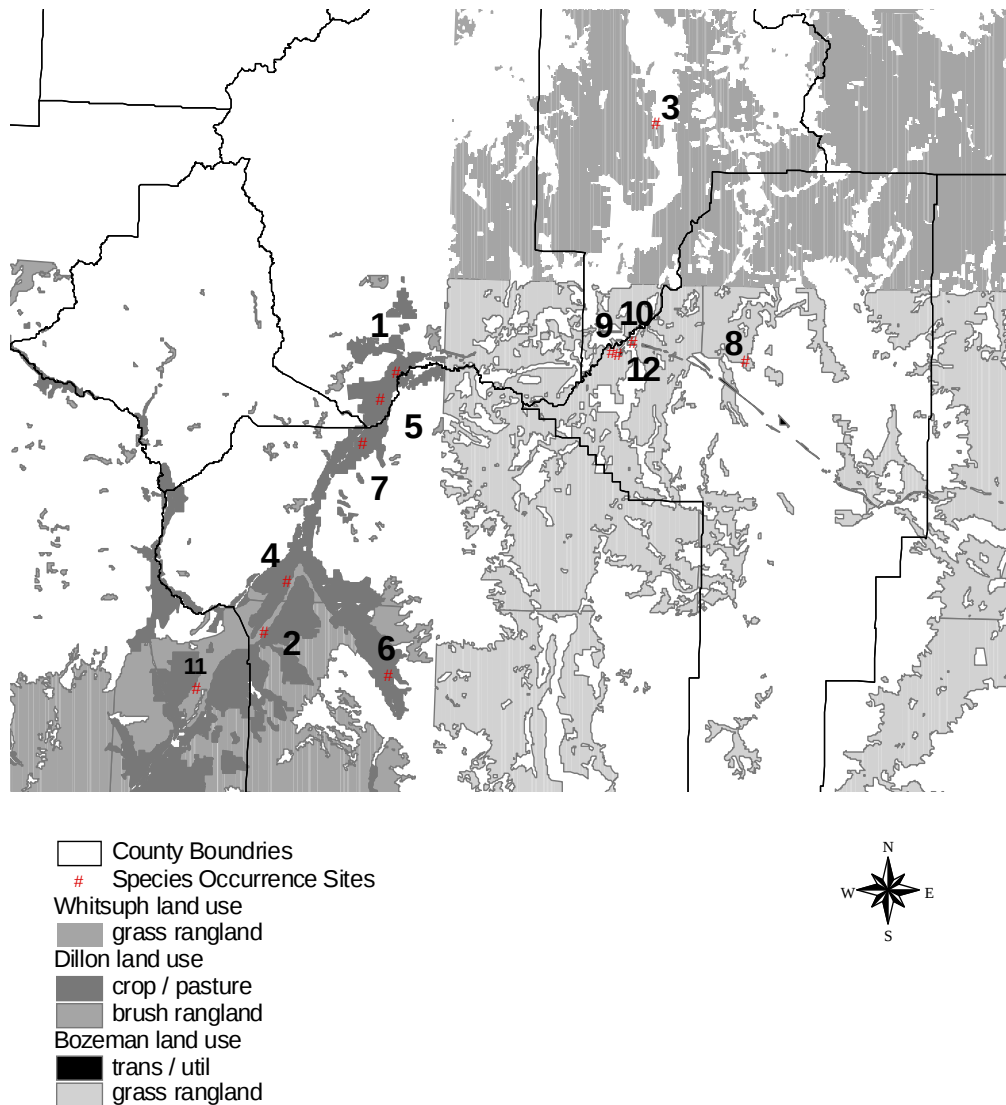


Figure 12. Land Use for southwestern Montana. 1:1,675,000 (Montana State Library, 1998). The land use map is displayed to determine external impacts on habitats. All occurrence sites are shown in grass rangeland. Note that the Dillon land use is dominated by crop/pasture, indicating the importance of water for species habitat. The Bozeman land use does not show external impacts at the sites, nor does the White Sulfur site. Several other land use polygons are delineated and listed in the legend but are not evaluated for this study.

### Quantitative Component Evaluation

Regional characteristics describing geologic and land use/cover delimitations suggest the probability of suitable species habitats occurring in the Missouri Headwaters State Park.

The quantitative component evaluation represents the meso-scale analysis created from a two-part compilation of soil series type name descriptions and soils component values. Evaluating the species-specific soils components established an order of attribute importance based on site soil similarities and component property values that were determined by statistical summation of the measured data. These are the data from which the prediction model was developed.

Soil Series Type Name Evaluation: Montana Natural Heritage Program defines the site soil series type name as “Fairway-Three River-Rivia Complex” or “Sapo Series Complex”, consisting of a fine loamy mix of high  $\text{CaCO}_3$ , salt-affected and sub-irrigated range for the four eastern, or Gallatin County species occurrence sites. The remaining six, Jefferson and Madison county sites are defined as “Neen or Villy” soil series, consisting of fine silty mix with the Villy series being high in  $\text{CaCO}_3$ . Fairway, Neen and Villy series are all representative of wetland habitats.

The following displays (Figures 13-15) show the soils polygon delineations representing the dominate soil series type names at each species occurrence site. The meso-scaled soil analysis identifies the soil complex series which suitable habitats may be defined for the study area predictions. The display sets show variations of soil type possibilities where *Spiranthes deluvalis* may exist.

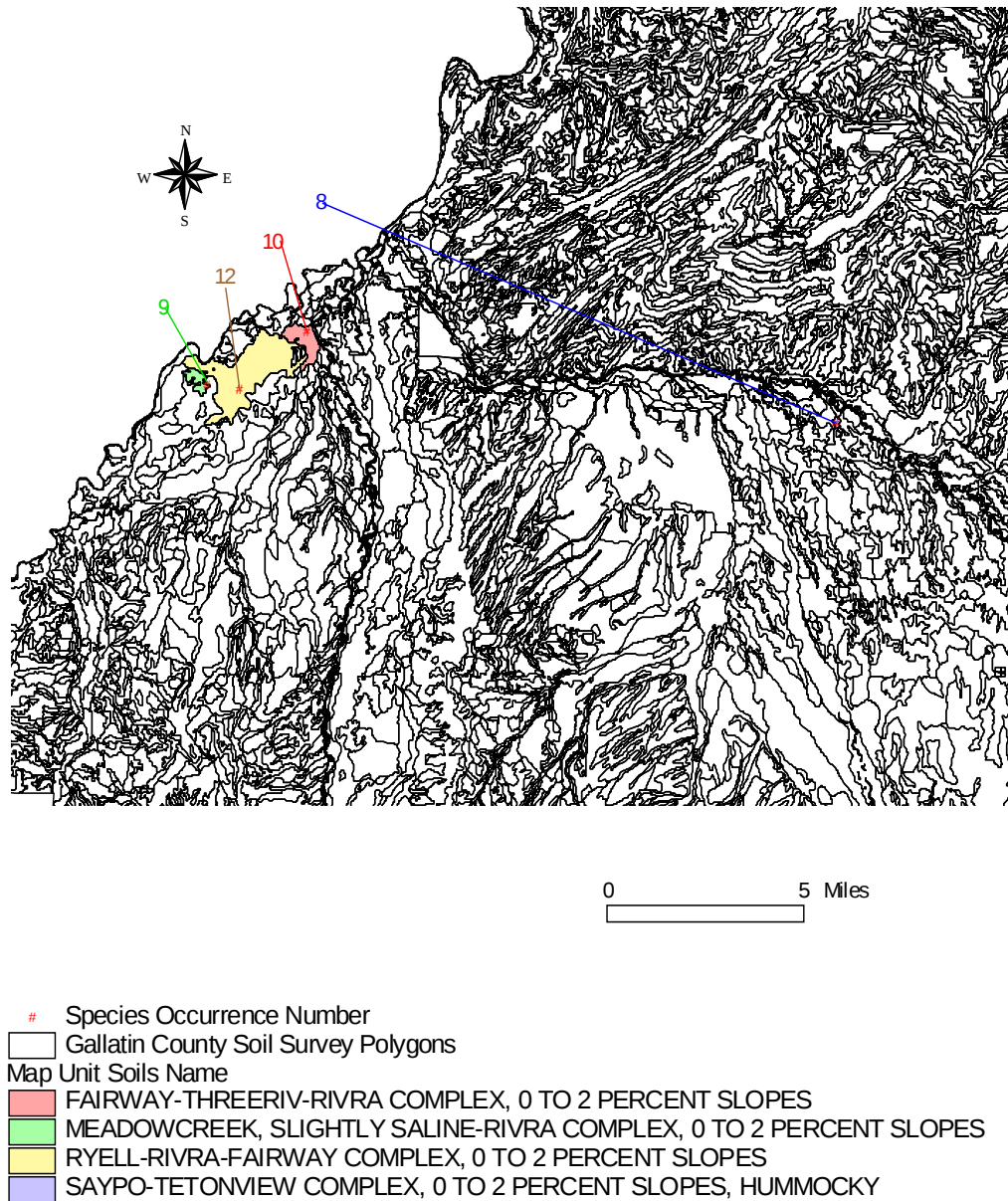
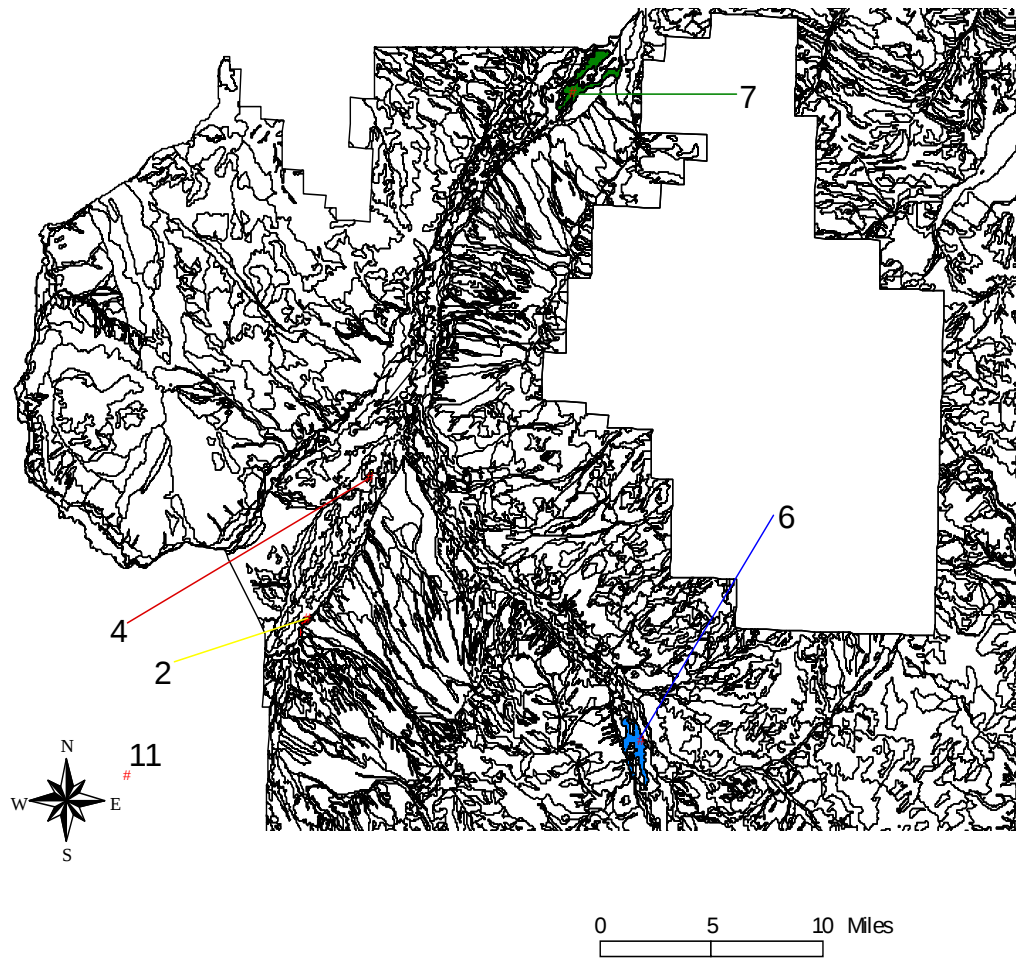


Figure 13. Gallatin County Species Occurrence Site Soil Type Name Polygons. 1:330,000. (Soil Data Viewer, 2001). Only those soil type name polygons containing species sites and the study area are color shaded and identified. The remaining polygons need not be evaluated for this study.



- # Species Occurrence
- Madison County Soil Survey Polygons
- Map Unit Soils Name
- |  |                                                             |
|--|-------------------------------------------------------------|
|  | HAVRE LOAM, COOL, 0 TO 2 PERCENT SLOPES                     |
|  | NEEN SILTY CLAY LOAM, 0 TO 2 PERCENT SLOPES                 |
|  | NEEN SILTY CLAY LOAM, WET, 0 TO 2 PERCENT SLOPES            |
|  | VILLY SILTY CLAY LOAM, COOL, DRAINED, 0 TO 2 PERCENT SLOPES |

Figure 14. Madison County Species Occurrence Site Soil Type Name Polygons. 1: 500,000 (Soil Data Viewer, 2001). Only those soil type name polygons containing species sites are color shaded and identified. The remaining polygons need not be evaluated for this study.

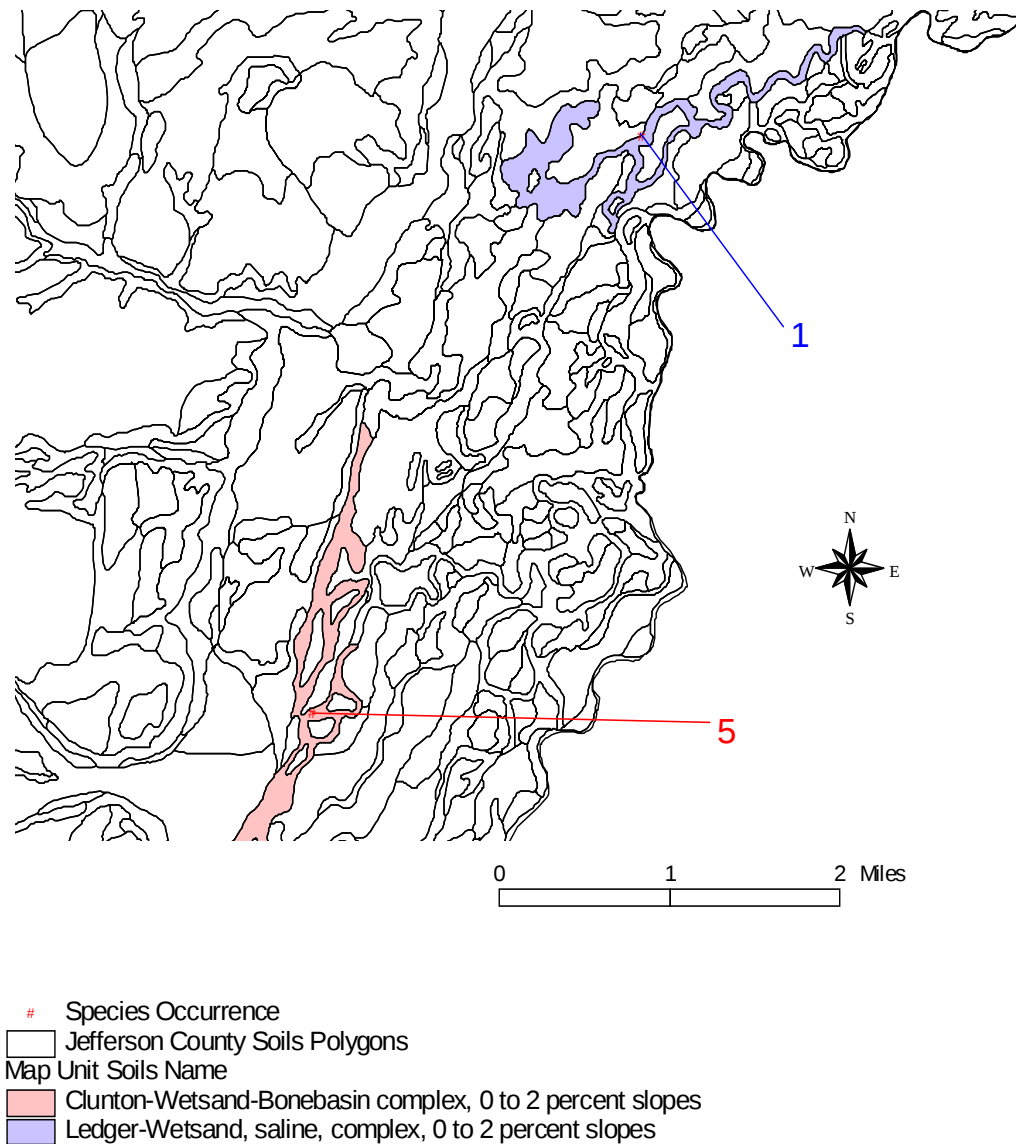


Figure 15. Jefferson County Species Occurrence Site Soil Type Name Polygons. 1: 56,000. (Soil Data Viewer, 2001). Only those soil type name polygons containing species sites are color shaded and identified. The remaining polygons need not be evaluated for this study.

The soils-survey polygon maps confirm the MNHP descriptions on species habitat soil type names.

Gallatin County occurrence site number 10 (see Figure 13) is particularly important as an indicator because it is the site nearest to the study area and is specifically included as a species-habitat soil type name. The remaining three Gallatin County occurrence site polygons are mapped as variations of the wetland complexes or soil series.

Three of the four Madison County occurrence site polygons (see Figure 14) are mapped with similar MNHP wetland soils descriptions. Site polygon number 4 is not identified in the MNHP literature but is a variation of wetlands soil types.

The Jefferson County occurrence sites are not mapped as a soil type name defined in the MNHP data (see Figure 15). It should be noted that these soil types are all representative of the wetland complex series. These sites are displayed in the land cover map (see Figure 10) in irrigated lands, emphasizing two important components; an adequate water supply and the external impacts on a habitat.

The graphics illustrate the various soil type possibilities where *Spiranthes diluvialis* could exist. These data also emphasize the importance of formulating the quantitative soil component data sets for developing a more detailed prediction.

Referring to the species occurrence site component chart (see Table 1), three quantifiable soils components; pH, organic matter and Electrical Conductivity are presented in measured values. Three other soils components; Flooding Frequency,  $\text{CaCO}_3$  and Available Water Supply are described in descriptive terms. The component values and their relationships as species-specific habitat indicators are displayed in the occurrence site evaluation summary (Table 3, MNHP 1998).

| Property      | Soils Component         | Component Evaluation          | Relationship as Species-Specific Indicator                                           |
|---------------|-------------------------|-------------------------------|--------------------------------------------------------------------------------------|
| Physical      | Available Water Supply  | Producing seasonal moist soil | Indicates importance of adequate water supply. Needs measurable data                 |
|               | % Organic Matter        | 2.24% - 26.35%                | Range of values indicates an inconsistent indicator                                  |
| Chemical      | CaCO <sub>3</sub>       | High value – salt affected    | High component value. Needs measurable data                                          |
|               | pH                      | 7.66% - 8.25%                 | Consistent values suggest moderately alkaline soil as a species-specific indicator   |
|               | Electrical Conductivity | 0.3 – 1.5 mmhos               | Consistent values suggest an indicator dependent on CaCO <sub>3</sub>                |
| Water Feature | Flooding Frequency      | Occasional                    | Spatial component dependent on the available water supply and environmental features |

Table 3. Species Occurrence Site Soils Component Evaluation Summary (Montana Natural Heritage Program, 1998). Compiled from the literature reviews evaluating regional components values as species-specific habitat indicators.

Table 3 was created to explore independent soils properties as species-specific habitat indicators. The regional evaluation summary suggests that Missouri Headwaters State Park is suitable for species habitat. While these evaluations are helpful in formulating regional habitat relationships, the goal of this project was to delineate species-specific habitats within the park. Developing the criteria was achieved by the following processes:

- 1) evaluating only the southwest Montana occurrence site soils components
- 2) using a single source of data to establish a component value continuity
- 3) use of a GIS for statistical trend analysis of the data sets, develop ordered value limits and create maps of suitable habitat polygons within the study area

With the GIS mapping and analysis capabilities, quantitative, value-ordered, predictions were developed where NRCS occurrence site trend data is queried to the site polygons. The following data charts (Figures 16-21) display the NRCS polygon component values and examines their relationship as species-specific indicators.

#### Physical Properties:

Figure 16 shows that most site polygons measure substantial soil moisture at the target depth suggesting AWS as an indicator of suitable species habitat. The low value site (# 9) is plotted in the regional land cover display (Figure 10) as riparian habitat and the high value site (# 5) is plotted as irrigated grassland from the land cover map (Figure 11). Both sites display species habitats supported by adequate water influence. Both sites display species habitats supported by adequate water influence.

Figure 17 shows that forty percent of the site polygons are at, or below, the MNHP evaluated low range. Site # 5 is near the MNHP average value at 6% weight. Data suggest a minimum value prediction. NRCS data variances are too large to suggest the average value as an indicator, but a first mean limit may be a moderately suitable habitat indicator. The literature indicates a wide range of organic matter values supporting species habitat (MNHP, 1998) for the southwest Montana species occurrence sites.

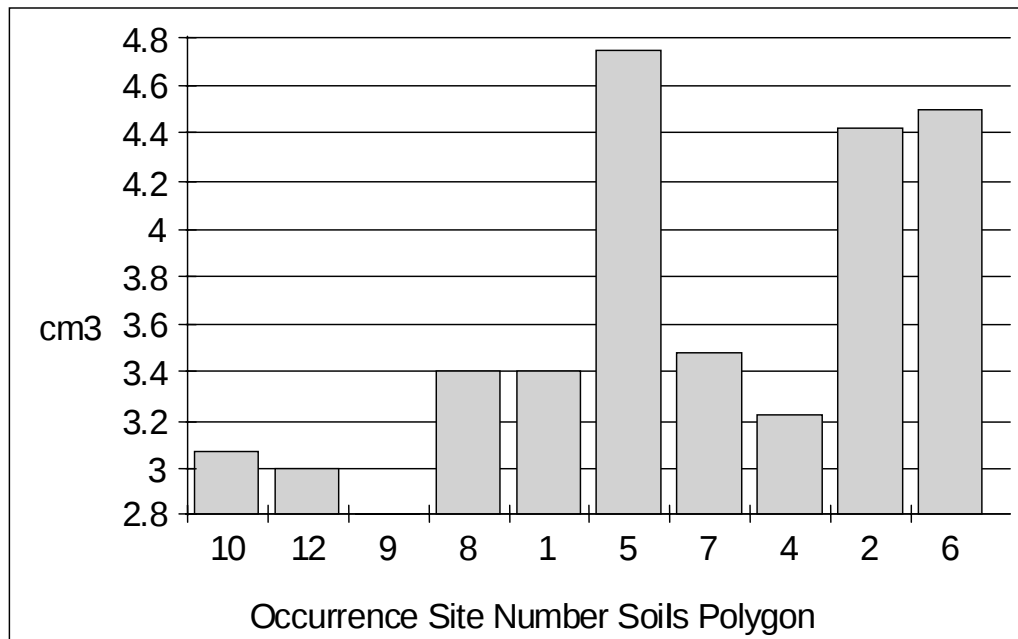


Figure 16. Available Water Supply (AWS) (cm<sup>3</sup> / volume at 1-10 inches soil depth).

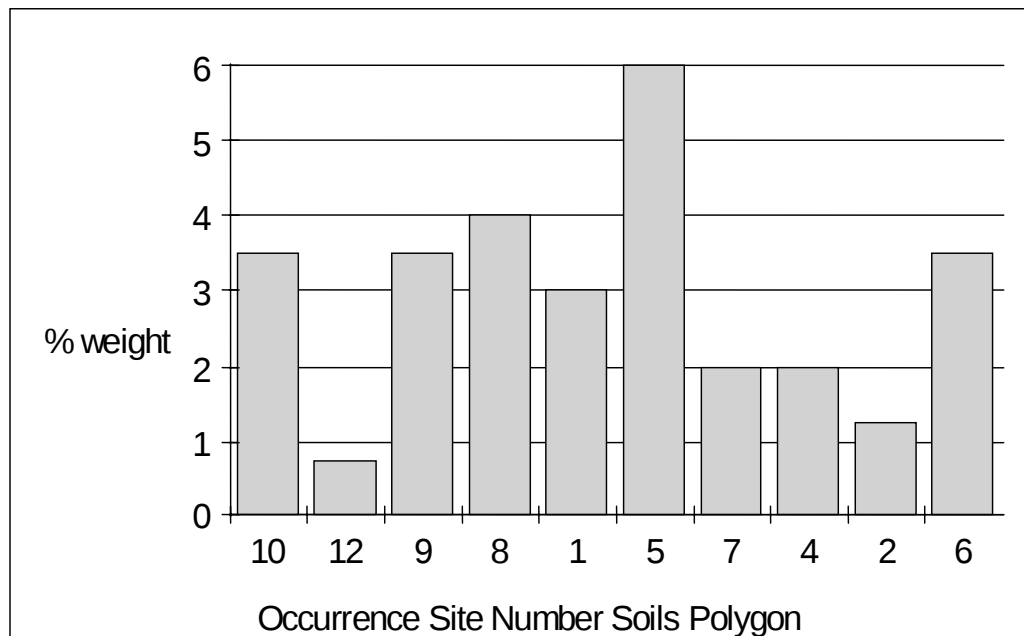


Figure 17. Organic Matter (% weight / soil material < 2mm dia.).

### Chemical Properties:

Figure 18 graph shows 60% of occurrence sites exceeding the average weight/volume at >7%. Sites 5 and 12 are < .05%. These values create high variances and are not used as a habitat indicator for this study. However, the literature defines suitable habitat high in  $\text{CaCO}_3$ . Sixty percent of the occurrence sites measured above the mean (5.7%) and 80% above 3% weight/volume. It is safe to predict that polygons with mid to high range of  $\text{CaCO}_3$  values are suitable habitat indicators.

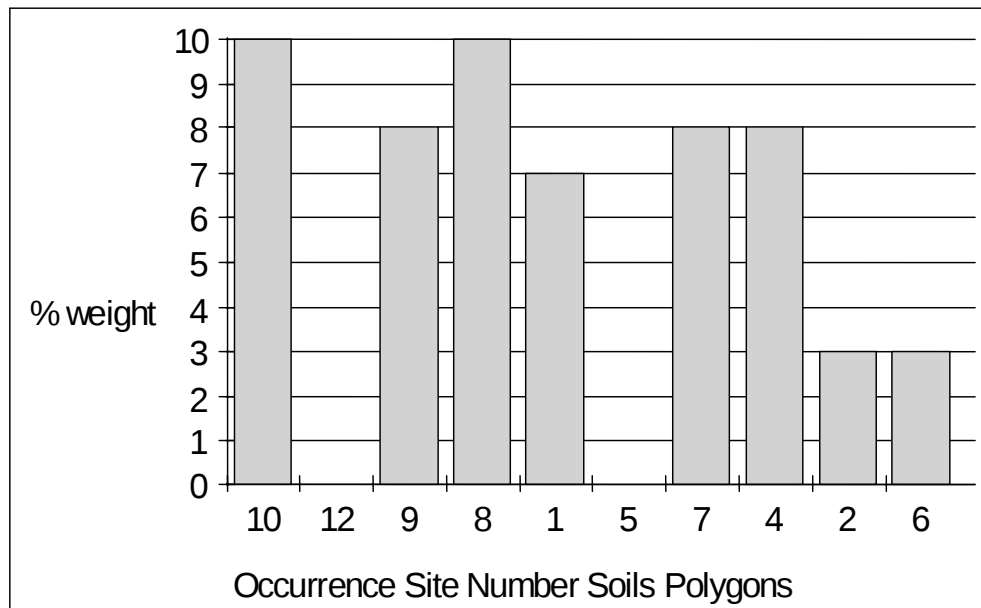


Figure 18.  $\text{CaCO}_3$  (% weight / volume soil material < 2%).

Figure 19 chart shows occurrence site pH values with a clustered variance range (mean value at 7.99). The literature describes species habitat as moderately alkaline (7.88), with the exception of site # 5, at well below average (6.7), presuming some external impact or error in data processing. By disregarding the extreme value, a small standard deviation results, indicating a suitable habitat indicator component.

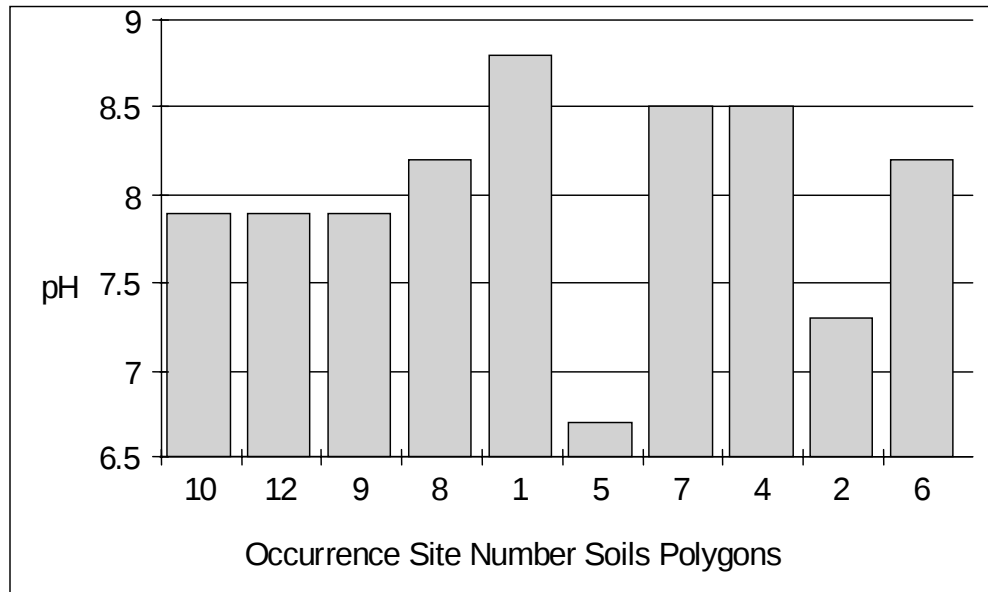


Figure 19. pH (1:1 Water).

For figure 20, the literature describes habitat values ranging from 0.37 – 1.9 mmhos/cm<sup>3</sup>. The NRCS site values range from 0.00 – 12.00 mmhos / cm<sup>3</sup>. The large NRCS variances create values that are not suitable as habitat indicators for this project. The values suggest an error in the data or may be influenced by some other impacts. The literature describe species habitat as high in CaCO<sub>3</sub> and salt affected.

For figure 21, the soils survey data are inconsistent with the Heritage Program flooding frequency description. While the regional studies suggests the ‘occasional flooding’ as species-specific, 80 % of the NRCS soils survey occurrence site polygons record ‘rare flooding’ for occurrence sites. Only one site polygon, # 4, is represented as ‘occasional flooding’ and site # 8 is represented as ‘no flooding’. Flooding frequency may be influenced by AWS and may affect other component values, but as an independent component, flooding frequency data is inconclusive as a habitat indicator.

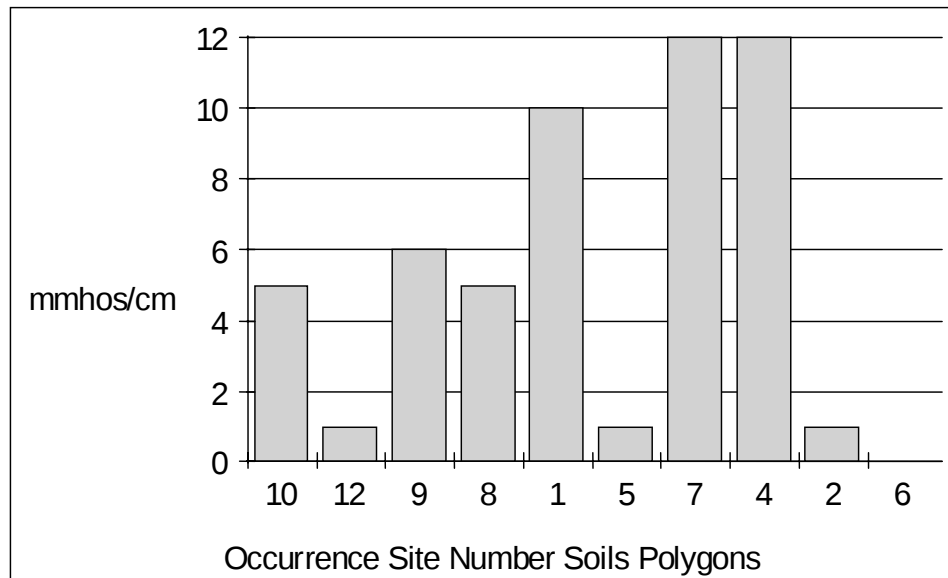


Figure 20. Electrical Conductivity (water-soluble salts) (mmhos /  $\text{cm}^3$ ).

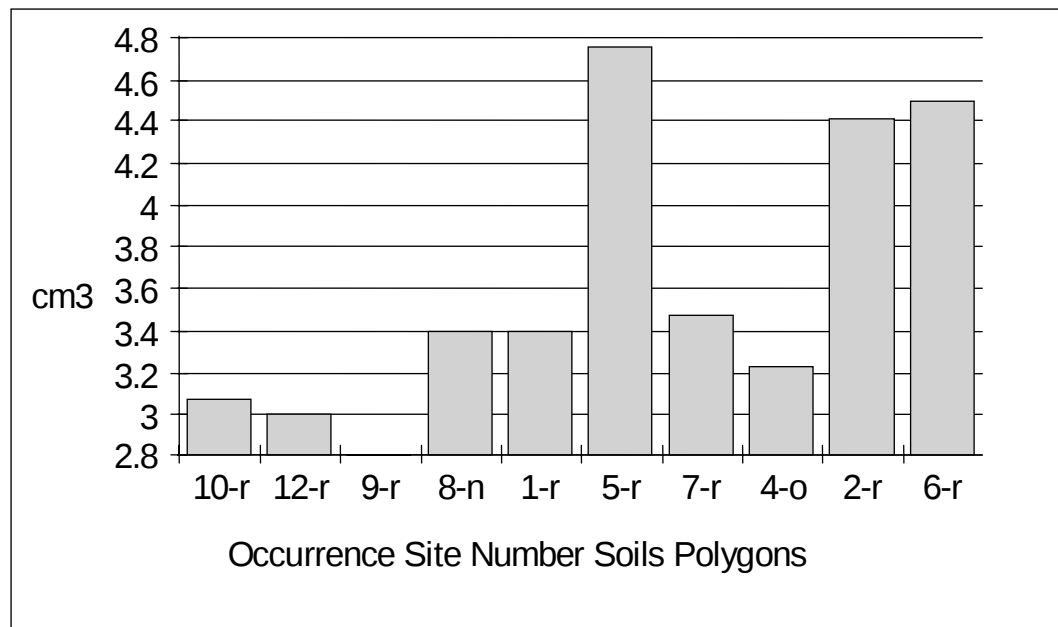


Figure 21. Flooding Frequency (rare, occasional, frequent) respective of AWS ( $\text{cm}^3/\text{volume}$ ).

The NRCS 'rare flooding' frequency was chosen for this study to maintain data consistency. However, a better water indicator may be the AWS at target depth.

Charting the descriptive flooding feature respective of the quantitative AWS value is created as a way of exploring the relationship between/with the two water components. It is assumed, by evaluating these data, a codependency does not exist, suggesting that flooding frequency is influenced by physical features or other impacts (i.e. topography, weather or development) and not as a function of the available water supply.

### Statistical Data Trend Summary

The arithmetic mean is the simple, one-number value for predicting an attribute trend where the order of importance is determined by the variance of values around the mean. However, a variance does not explain how values are arranged around the mean. Thus a standard deviation is calculated giving values a more accurate ordered significance.

The advantage of standard deviation over variance is that standard deviation of a set of values is almost always considerably less than the variance. The variance of a set of data can easily be a very large number, larger even than any of the individual values in a data set. This is a direct consequence of all the squaring involved in the calculation of variance. By taking the square root of variance to produce standard deviation a more manageable number results (Ebon, 1985).

The standard deviation is the measure of dispersion most commonly applied to geographical data. It also forms the basis of a number of statistical methods concerned with making estimates from samples.

There are a number of simple 'rules-of-thumb' that are useful for making rough estimates in statistics. The most commonly used, the empirical rule, describes how values in sets of data or populations which obey the normal distribution are clustered

around the mean value. It is exact for situations which are exactly normally distributed, and it can be a reasonable approximation in situations where the normal distribution is approximately followed. The empirical rule has a very useful evaluating property. For a normally distributed set of data or normally distributed data the following relationships hold:

1. Approximately 68% of all elements will fall within one standard deviation.
2. Approximately 95% of all elements will fall within two standard deviations.
3. Approximately 99.7% of all elements will fall within three standard deviations.

However, biological data can rarely make the assumption that values are normally clustered around the mean or even approximately normal, thus the rule may cause erroneous assumptions defeating the purpose of this project.

To formulate the component values in delineating the suitable habitat field surveys for this project, Tchebysheff's theorem is used where the following relationships hold for any data set (Ebon, 1985, page 28):

1. Space between 1.5 standard deviations contains 56% of samples.
2. Space between 2 standard deviations contains 75% of samples.
3. Space between 3 standard deviations contains 89% of samples.
4. Space between 4 standard deviations contains 94% of samples.

These relationships are always true regardless of the shape of the frequency distribution of the sample data. Tchebysheff's theorem suggests that value consistencies determine order-of-importance by providing an accurate spatial prediction based on mean standard deviation limits.

Keeping in mind that the prediction values were projected from small data sets and that very specific species habitats are delineated across a relatively small study area, I modified Tchebysheff's theorem where the index values are created by the following criteria:

1. Element values having a less-than-one standard deviation were assigned as a first-order or dominate indicators.
2. Element values having a standard deviation greater than one but less than two were assigned second-order or moderate indicators.
3. Element values having a greater than two but a less than three standard deviation are initially assigned third-order or marginal indicators.
4. Element values where standard deviation is greater than three, a spatial delineation was not considered to be of value for this demonstration.

However, it can be noted that when extreme trend values were excluded from a query, the marginal indicator may have provided useful field indicators. Table 4 summarizes the data set trend values (flood frequency component excluded) generated from the southwest Montana occurrence site soils survey polygon evaluations.

#### Covariant Relationship analysis (internal dependencies)

The examinations of the internal soils component relationships are useful in determining attribute importance for habitat predictions. The application of a Boolean logic based on qualitative information and the quantitative trend value analysis produces a simple category of prediction. It is suggested then, that another useful indicator can be

provided by examining covariant component relationships. By determining if linear dependencies exist between any two components, a value relationship is processed. The following series of graphs (Figures 22–31) display the covariant relationships of the soils component trend analysis values to determine if any values are predicated on internal dependencies.

|                    | AWS         | Organic     | pH          | CaCO <sub>3</sub> | EC          |
|--------------------|-------------|-------------|-------------|-------------------|-------------|
| Sum                | 36.06       | 29.50       | 79.90       | 57.00             | 53.00       |
| Count              | 10.00       | 10.00       | 10.00       | 10.00             | 10.00       |
| <b>Mean</b>        | <b>3.61</b> | <b>2.95</b> | <b>7.99</b> | <b>5.70</b>       | <b>5.30</b> |
| Maximum            | 4.75        | 6.00        | 8.80        | 10.00             | 12.00       |
| Minimum            | 2.81        | 0.75        | 6.70        | 0.00              | 0.00        |
| Range              | 1.94        | 5.25        | 2.10        | 10.00             | 12.00       |
| Variance           | 0.48        | 2.32        | 0.38        | 14.90             | 21.79       |
| Standard Deviation | 0.69        | 1.52        | 0.62        | 3.86              | 4.67        |

Table 4. Statistical Summary Table of the Southwestern Montana Occurrence Site Soils Survey Component Trend Analysis.

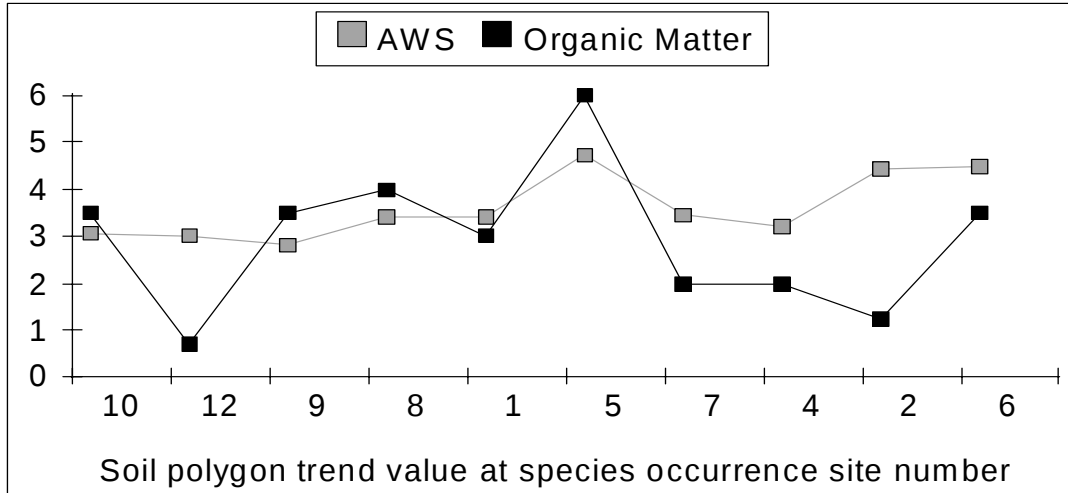


Figure 22. Available Water Supply ( $\text{cm}^3$ ) / Organic Matter (% weight). The graph indicates that a relationship may exist between the independent component trend values. However, the organic matter trends produce a variance range that does not represent a linear dependency.

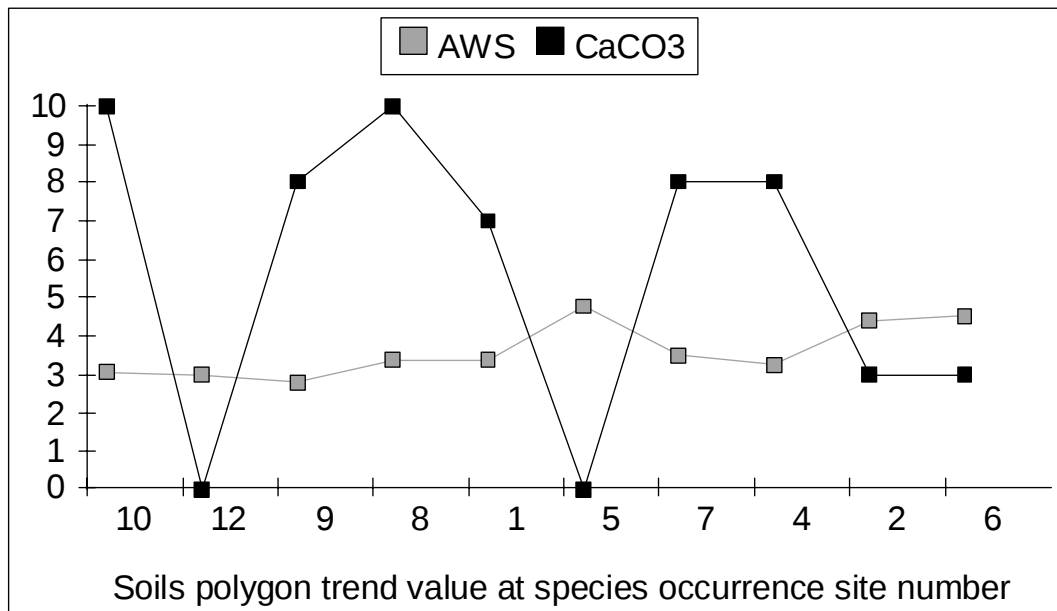


Figure 23. Available Water Supply ( $\text{cm}^3$ ) /  $\text{CaCO}_3$  (% weight). The graph does not suggest a codependent relationship. The literature defines  $\text{CaCO}_3$  as a geologic property dependent on other processes having little effects directly related to the available water supply.

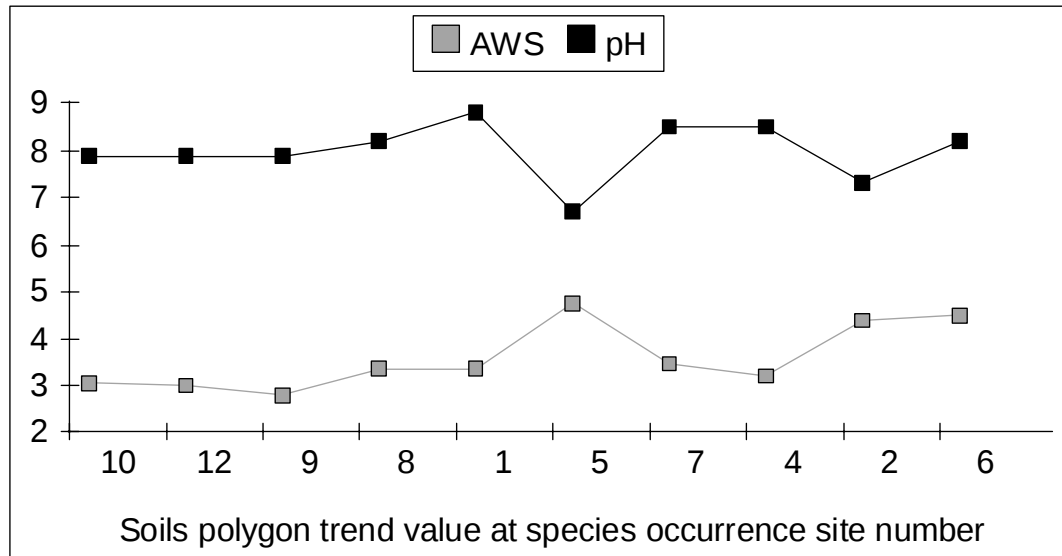


Figure 24. Available Water Supply (cm<sup>3</sup>) / pH (1:1 water).

Based on the trend variance values, the graph suggests a component relationship but a linear codependency is not evident. It should be noted, both component trend values are clustered around the mean, representative of a dominate indicator.

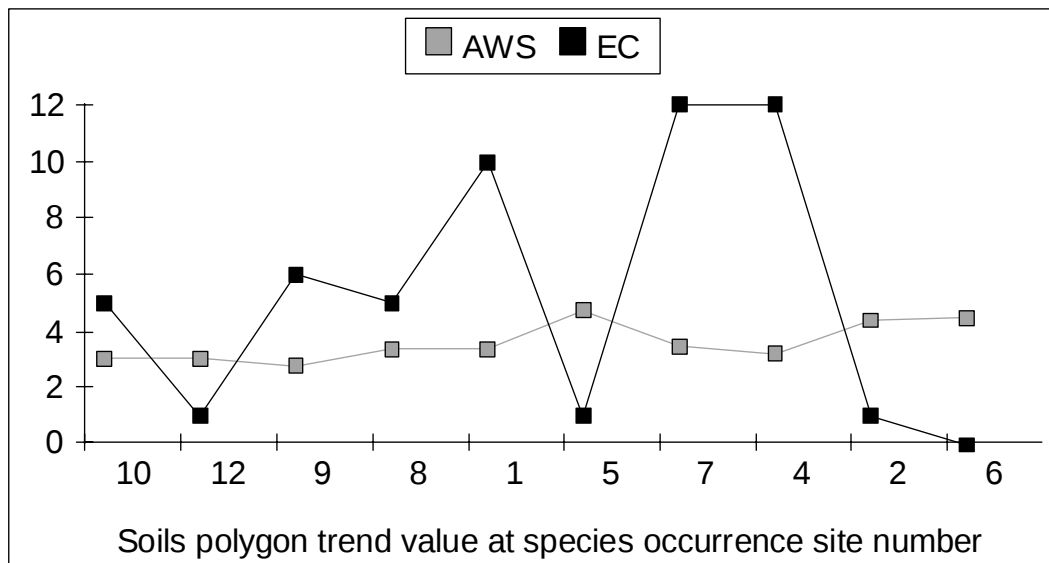


Figure 25. Available Water Supply (cm<sup>3</sup>) / Electrical Conductivity (mmhos/cm<sup>3</sup>).

The graphic does not display a component dependency. Electrical conductivity variance values are too large to suggest a codependent correlation of the independent values.

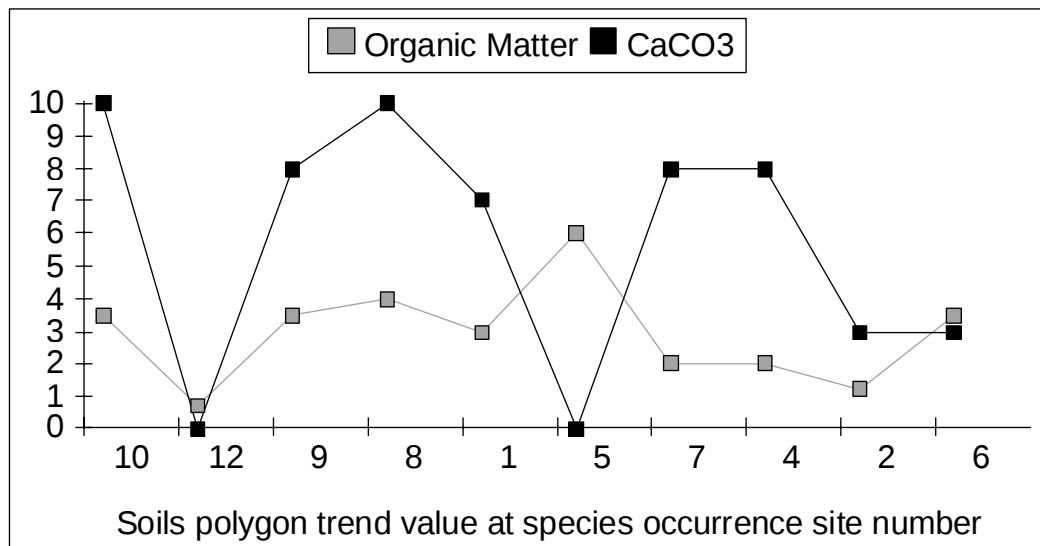


Figure 26. Organic Matter (%weight) / CaCO<sub>3</sub> (% weight).  
The data indicates that a trend value relationship may exist. But, again, the CaCO<sub>3</sub> variance is too large to recognize a linear codependency.

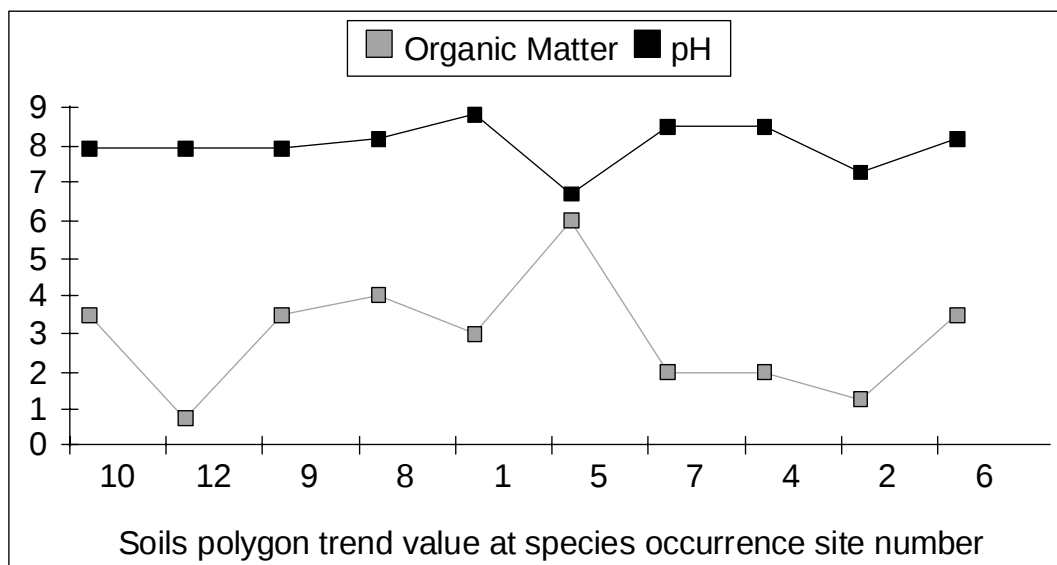


Figure 27. Organic Matter (%weight) / pH (1:1 water)  
The graph does not indicate a trend value codependent relationship. Both of the independent variances are clustered around the average value (representative of dominate indicators) suggesting that a component value relationship may exist.

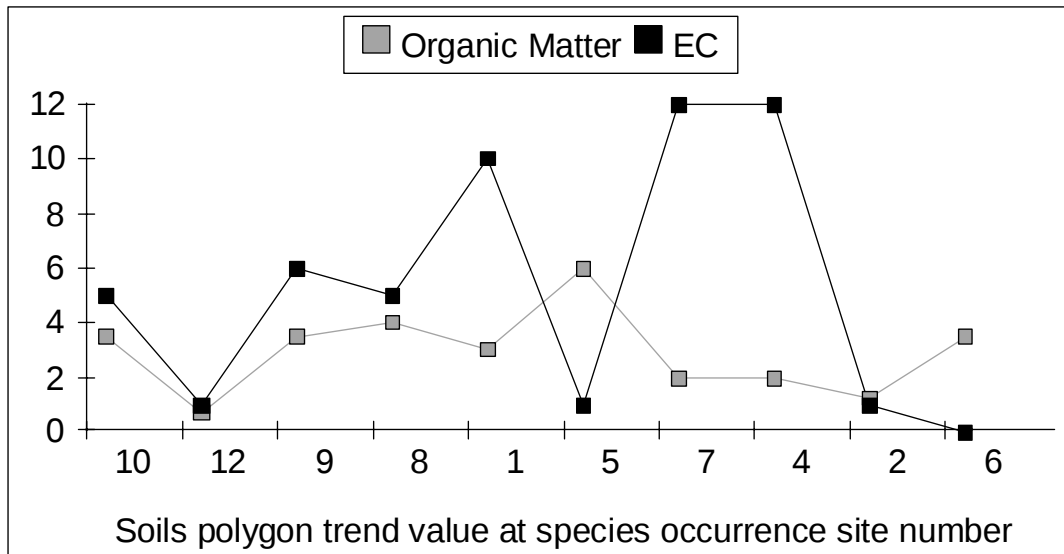


Figure 28. Organic Matter (%weight) / Electrical Conductivity (mmhos/cm<sup>3</sup>). A codependent relationship can not be established, the electrical conductivity variance is too great.

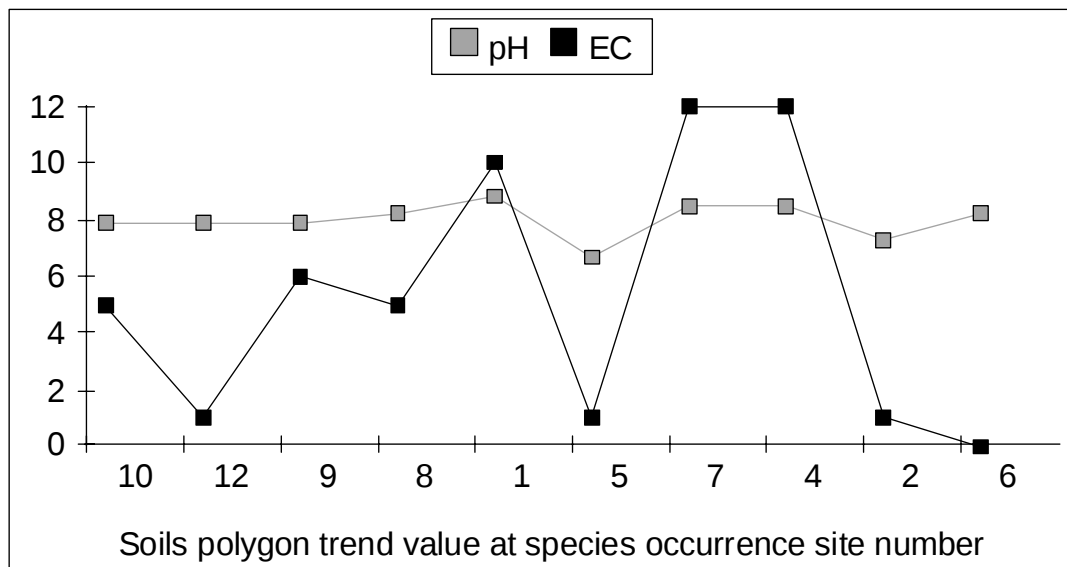


Figure 29. pH (1:1 water) / Electrical Conductivity (mmhos/cm<sup>3</sup>)  
A codependent relationship is not indicated between the trend values. As seen from the previous electrical conductivity covariant analysis, variance values essentially eliminate the electrical conductivity as a codependent component.

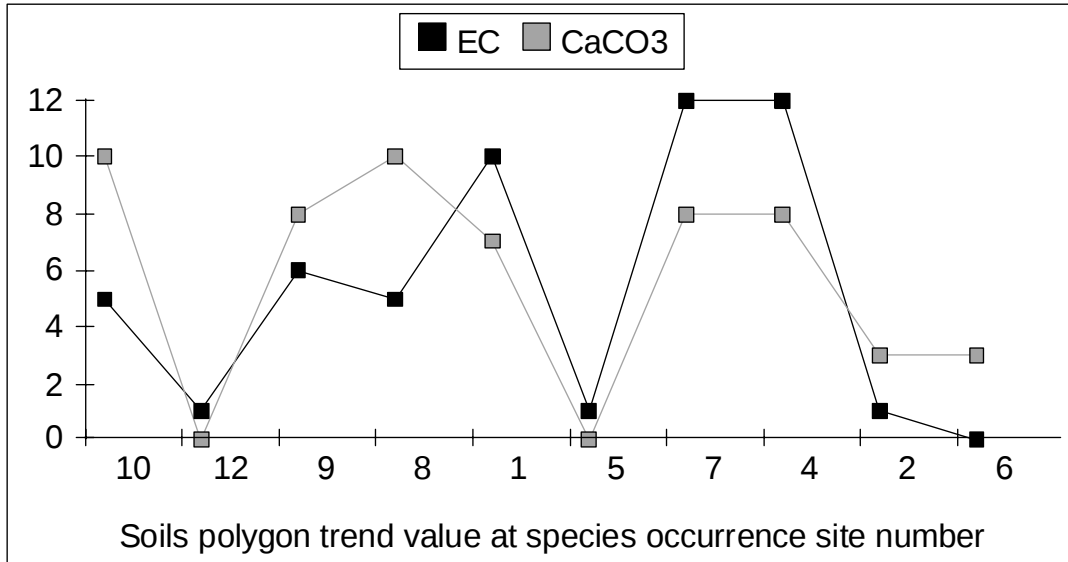


Figure 30. Electrical Conductivity (mmhos/cm<sup>3</sup>) / CaCO<sub>3</sub> (%weight).  
The graphic does not support a linear codependent trend relationship. However, the graph shows a relationship does exist. It should be noted that the literature define species habitats high in CaCO<sub>3</sub> with high electrical conductivity (salt affected) values as suitable species habitats.

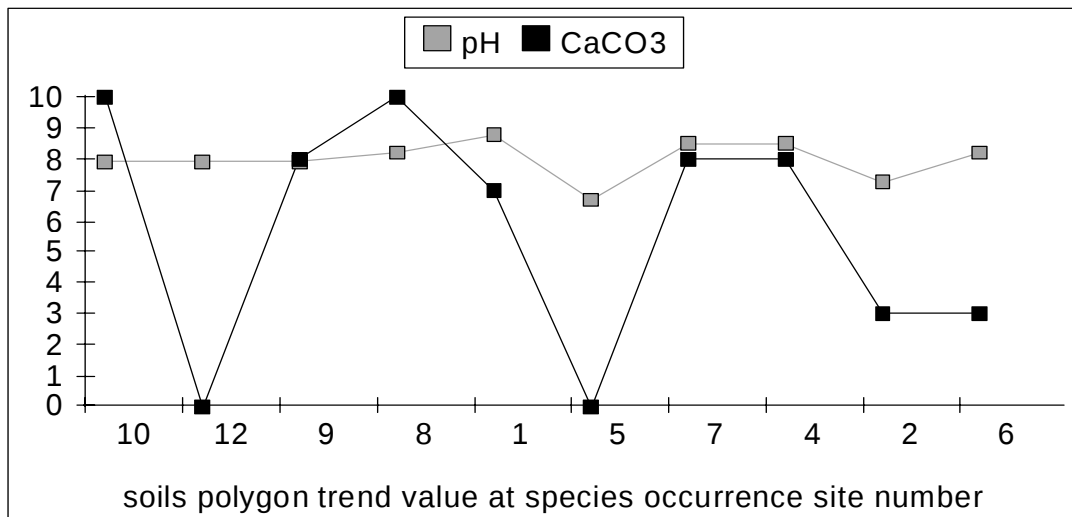


Figure 31. pH (1:1 water) / CaCO<sub>3</sub> (%weight).  
A mean trend value relationship may be interpreted from the graph; as one component fluctuates, so does the other. But again, due to the large CaCO<sub>3</sub> variance, a linear codependency can not be established.

A review of the soils component covariant graphics reveal that few internal relationships, if any, create unique habitat indicators. The exceptions are the high  $\text{CaCO}_3/\text{EC}$  relationship and the dependency of the available water supply on organic matter relationship. It was determined, after examining the covariant graphics, that with the qualitative descriptions followed by the soils component trend limit values, the hierarchical logic is developed by which the suitable habitat prediction criterion is created.

### Hierarchical Grouping

The habitat component hierarchical order is summarized by grouping the attributes into three indicator categories; dominate, moderate or marginal. Evaluating their mean trend variance limit relationships determined the weighted order-of-importance in each category. The categories, based on similar habitat descriptions and the independent statistical trend value limits, are summarized below:

First order, or dominate indicators with a  $< 1$  standard deviation

- Soil Type Name (descriptive evaluation)
- Available Water Supply
- pH

Second order, or moderate indicators with a  $> 1 < 2$  standard deviation

- Organic Matter

Third order or marginal indicators with a  $> 3$  standard deviation

- $\text{CaCO}_3$
- Electrical Conductivity

The Value Index is the hierarchical order-of-importance component sets generated from the statistical trend data analysis. The order-of-importance and value limits create the query data to map the spatial predictions. The polygons are queried in cumulative layers of importance where only those polygons containing the previous query sets are represented in the next hierarchical display. Table 5 illustrates the hierarchical ordered of suitable habitat prediction criterion. Suitable habitats are predicted and delineated in the study area by the ordered value sets presented in the table.

| Indicator Category | Soils Component         | First Order layer limit values - 1s.d. | Second Order layer limit values - 2 s.d.                             | Third Order layer limit values -3 s.d.           |
|--------------------|-------------------------|----------------------------------------|----------------------------------------------------------------------|--------------------------------------------------|
| Dominate           | Soil type name          | Fairway-Threeriv-Rivra complex         | Ryell-Rivra-Fairway and Meadowcreek, Slightly Saline-Rivra complexes | Threeriv, Rivra, Loam wetland complex variations |
|                    | AWS                     | 2.92 – 4.30                            | 2.23 – 4.99                                                          | 1.54 – 5.68                                      |
|                    | pH                      | 7.37 – 8.61                            | 6.75 – 9.23                                                          | 6.13 – 9.85                                      |
| Moderate           | Organic Matter          | 1.43 – 4.47                            | 0.00 – 5.99                                                          | 0.00 – 7.51                                      |
| Marginal           | CaCO <sub>3</sub>       | 1.84 – 9.56                            | 0.00 – 13.42                                                         | 0.00 – 17.28                                     |
|                    | Electrical Conductivity | 0.63 – 9.97                            | 0.00 – 14.64                                                         | 0.00 – 19.31                                     |
|                    | Flooding Frequency      | rare                                   | occasional                                                           | none                                             |

Table 5. Order-of-Importance Value Index (based on statistical summary trend analysis). Quantitative components are grouped in hierarchical indicator category sets by order-of importance limit value layers.

### Discriminate Analysis by GIS Mapping

The discriminate analysis, delineating suitable-habitats in Missouri Headwaters State Park, is created by two mapping processes:

1. A proximity map is created of soils polygons delineating the quantitative component values.
2. A series of suitable-habitat prediction maps are queried from the Value Index data sets.

The prediction maps delineating suitable species habitats were developed from quantitative soils properties. The ordered prediction criterion is translated to the proximity polygons by their relationships with the predicted values. Results from the covariant evaluations (see page 63) indicate that species habitats are not influenced by component dependencies. Thus, the suitable habitat discriminate analysis, for this study, is predicted on the statistical trend summary values of the independent components.

The regional evaluations of geologic features (Figure 9), land cover (Figures 10, 11) and land use (Figure 12) maps, showed similar habitat characteristics of the occurrence sites with the proximity map. These data provided the initial spatial relationship analysis to suggest that Missouri Headwaters State Park was suitable *Spiranthes deluvialis* habitat. While the regional feature maps identify general habitat relationships developed from grid discretions over continuous space, the statistical classification process creates a discrete polygon dispersion of the measured values for delineating species-specific habitats. It should be understood then, that while the quantitative predictions are

practical for this study, the paradigm ignores the spatial variation in the process as well as the resulting soil.

The Map Unit Soils Type Name proximity display (Figure 32) illustrates the twenty-six soil survey polygons represented in the proximity display. The histogram illustrates the 30m x 30m pixel area value for each soil type. Although the soils type name attribute does not employ numeric values, an order-of-importance is processed by the degree of similarities to occurrence polygon soil type name identifications.

The following set of displays (Figures 33-38) examines the proximity polygon component values. These distribution data create the relationships of proximity components to the value index data. The proximity data are processed and displayed by five equal-interval classifications (same as the occurrence site data). The maps delineate the polygon component values from which the suitable habitats are predicted. The histograms are created, as visual aids, to illustrate the spatial quantity of dispersion. The polygons are numbered (1-26) for convenient identification.

Trend charts were not illustrated for the proximity components (Table 6). Values were queried from the site trend data. Evaluating covariant relationships were not necessary because codependent relationships could not be established from the site data.

|                    | AWS<br>Cm3  | Organic<br>Weight % | pH<br>1:1 water | CaCO3<br>Weight % | EC<br>mmhos/cm |
|--------------------|-------------|---------------------|-----------------|-------------------|----------------|
| Sum                | 83.82       | 216.25              | 189.90          | 57.00             | 21.00          |
| Count              | 25          | 25                  | 25              | 22                | 19             |
| <b>Mean</b>        | <b>3.31</b> | <b>8.65</b>         | <b>7.59</b>     | <b>2.59</b>       | <b>1.10</b>    |
| Maximum            | 4.49        | 70.00               | 8.20            | 10.00             | 6.00           |
| Minimum            | 2.65        | 0.75                | 6.50            | 0.00              | 0.00           |
| Range              | 1.84        | 69.25               | 1.70            | 10.00             | 6.00           |
| Variance           | 0.23        | 380.88              | 0.24            | 17.20             | 2.76           |
| Standard Deviation | 0.47        | 19.51               | 0.49            | 4.14              | 1.66           |

Table 6. Proximity Polygon Soils Component Statistical Summary Table.

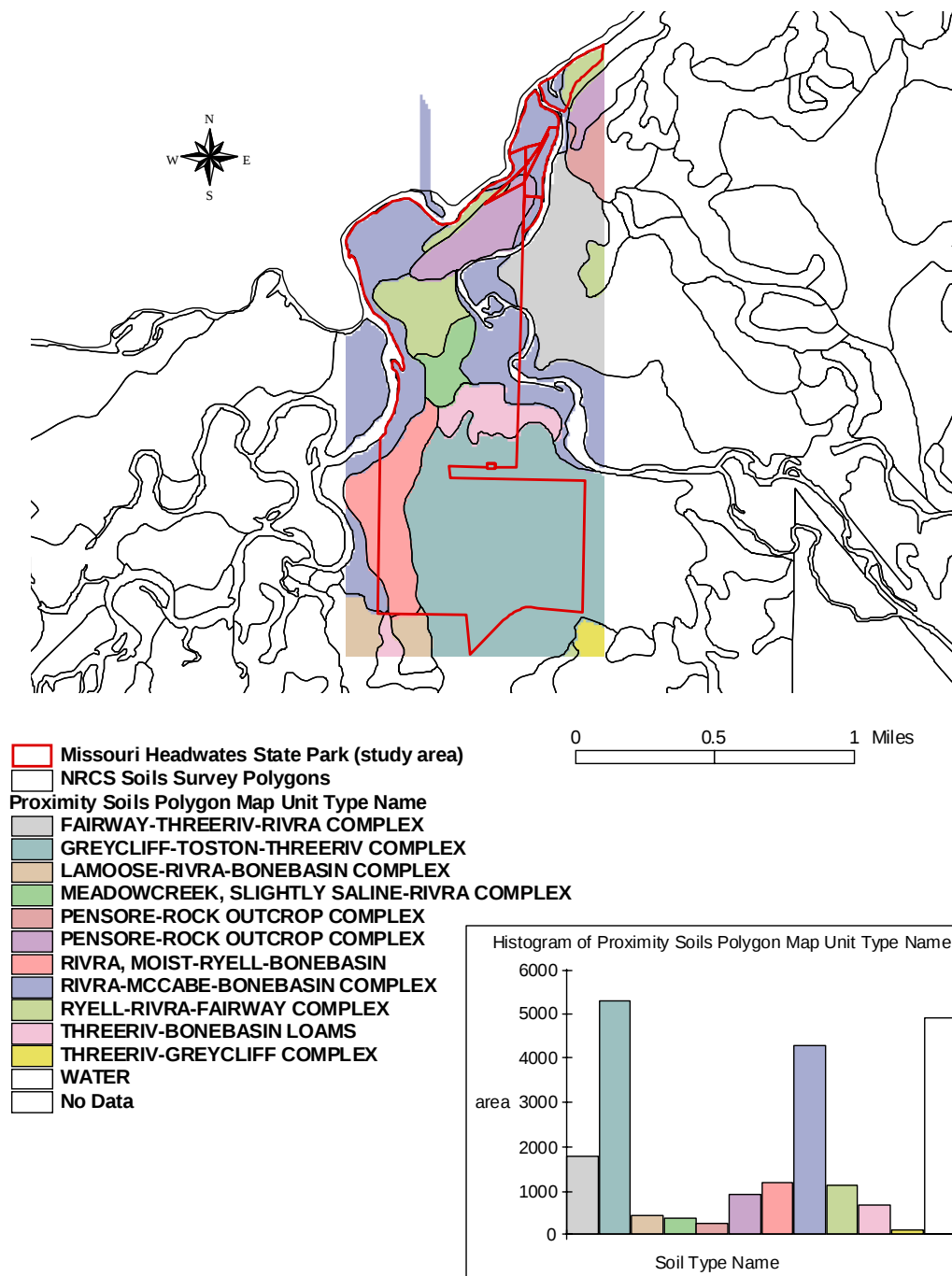


Figure 32. Proximity Soils Polygon Map Unit Type Name. 1:39,543(Soil Data Viewer, 2001). The map identifies each of the twenty-six proximity polygons by heir unique soil type name. The histogram illustrates the area, in 30x30 meter pixels, of the map unit soils types.

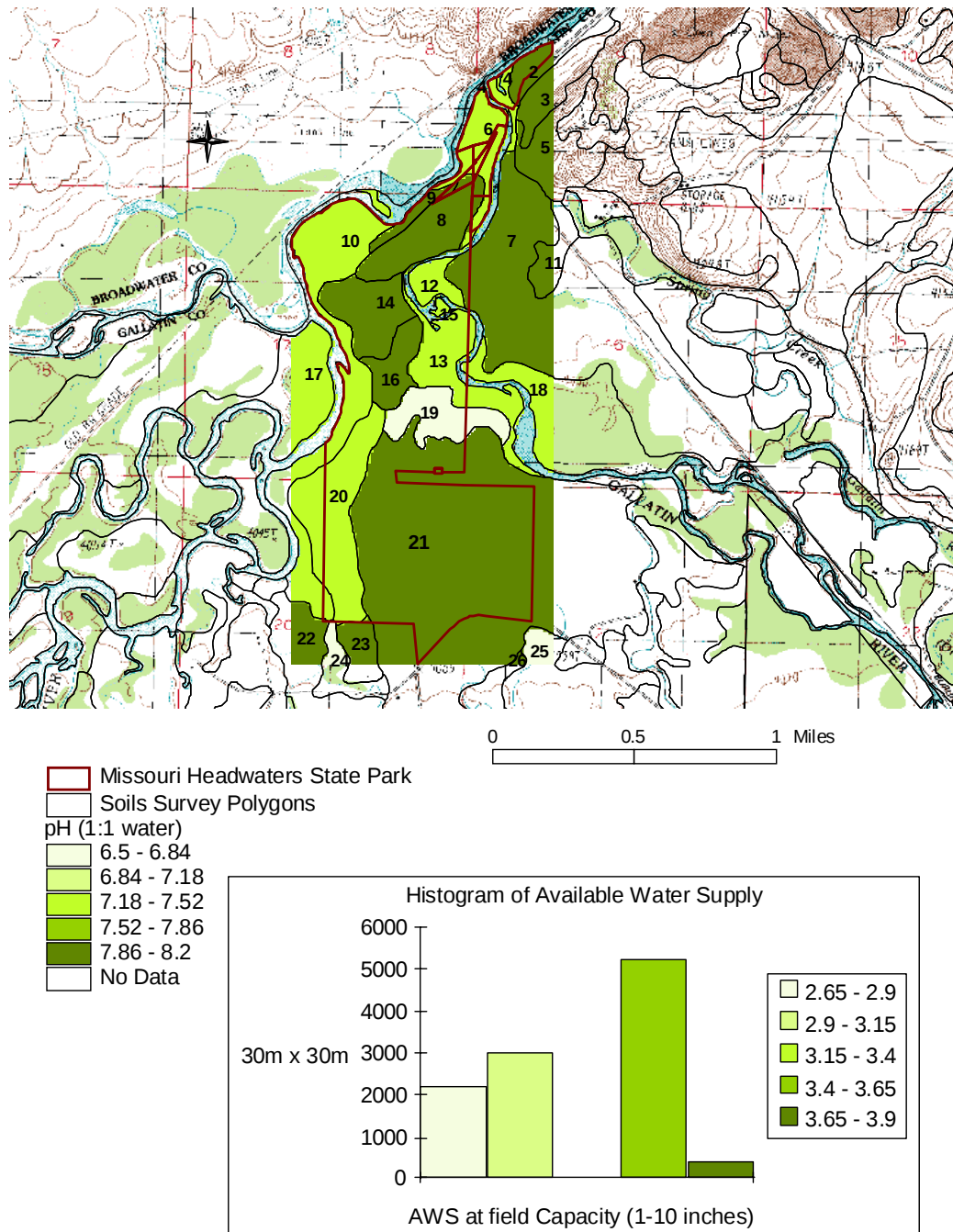


Figure 33. Available Water Supply. 1:39,500 (Soil Data Viewer, 2001). Most polygons indicate available water supply, at 1-10 inches soil depth, suitable for species habitat (2.92 - 5.68). This evaluation may be dependent on several other habitat features.

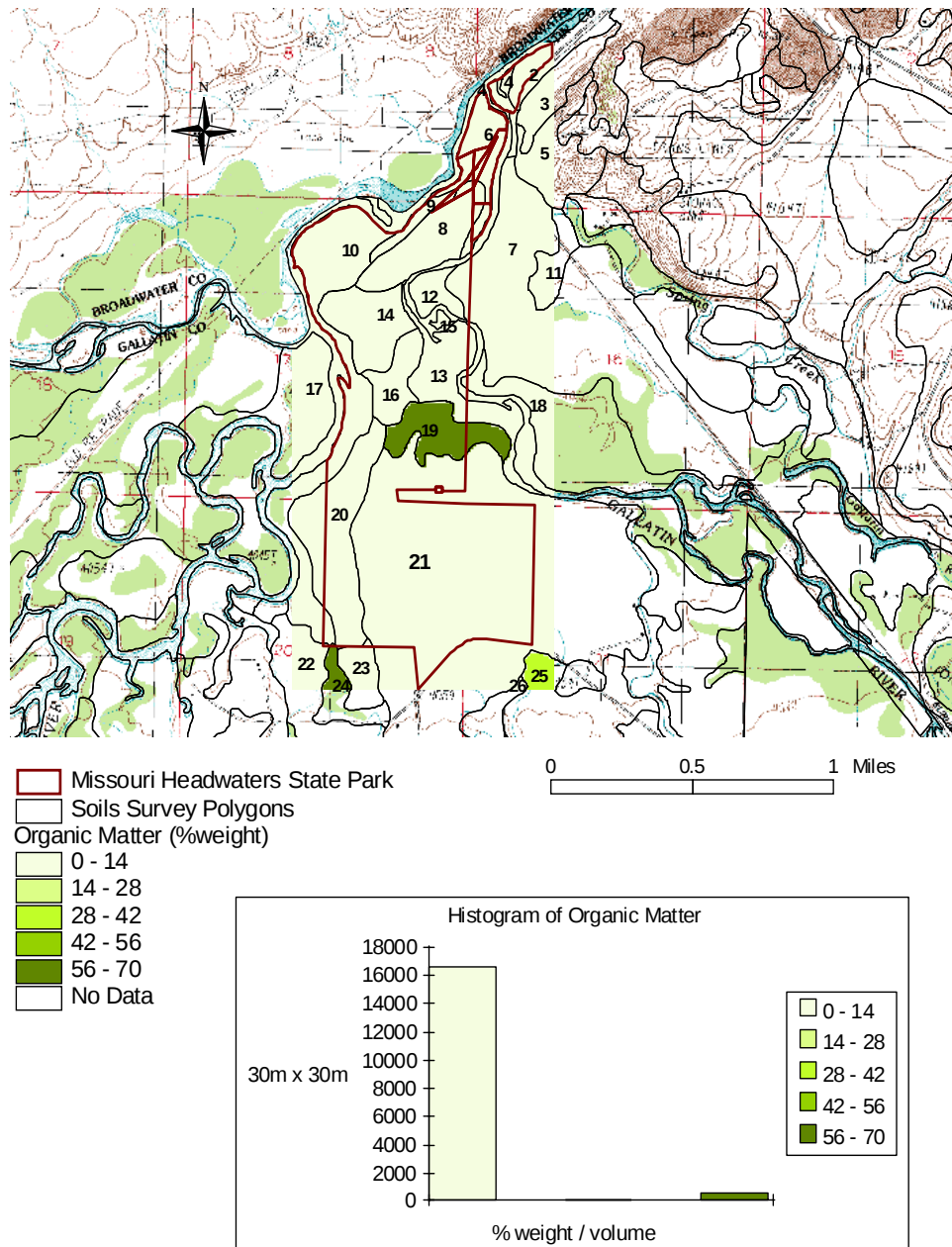


Figure 34. Percent Organic Matter. 1:39,500 (Soil Data Viewer, 2001).  
Most of the study area polygon values, with the exception of polygons #19 and #24, are within the target range for suitable habitat (1.43 – 9.92 %).

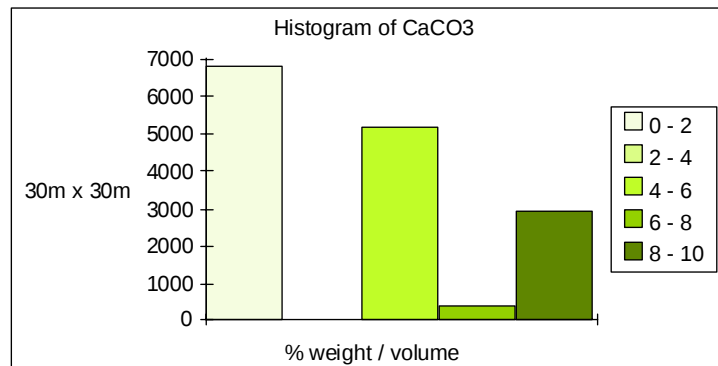
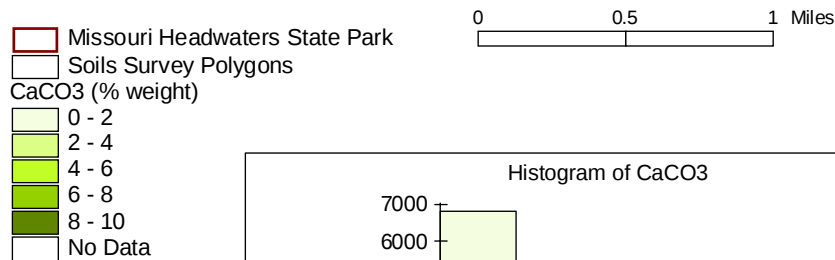
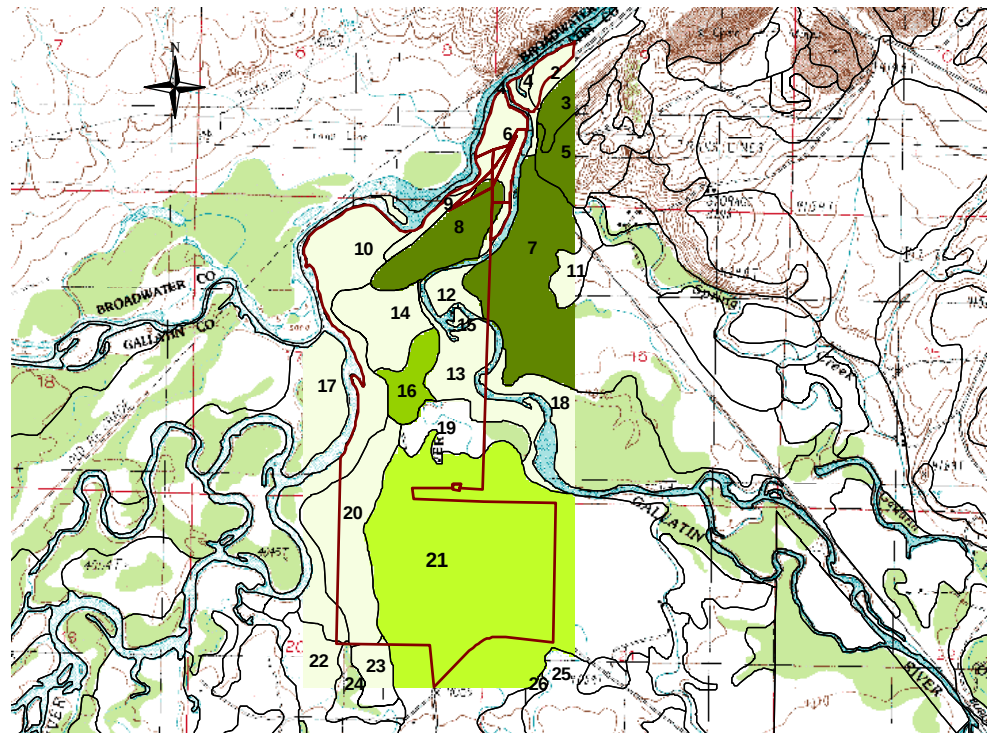


Figure 35. CaCO<sub>3</sub>. 1:39,500 (Soil Data Viewer, 2001).

All of the polygons are within the prediction range of values (1.84 – 9.56 %). Polygons represented at the 7.5–10.0 % classification are specifically suitable for species habitat due to the high values discussed in the literature.

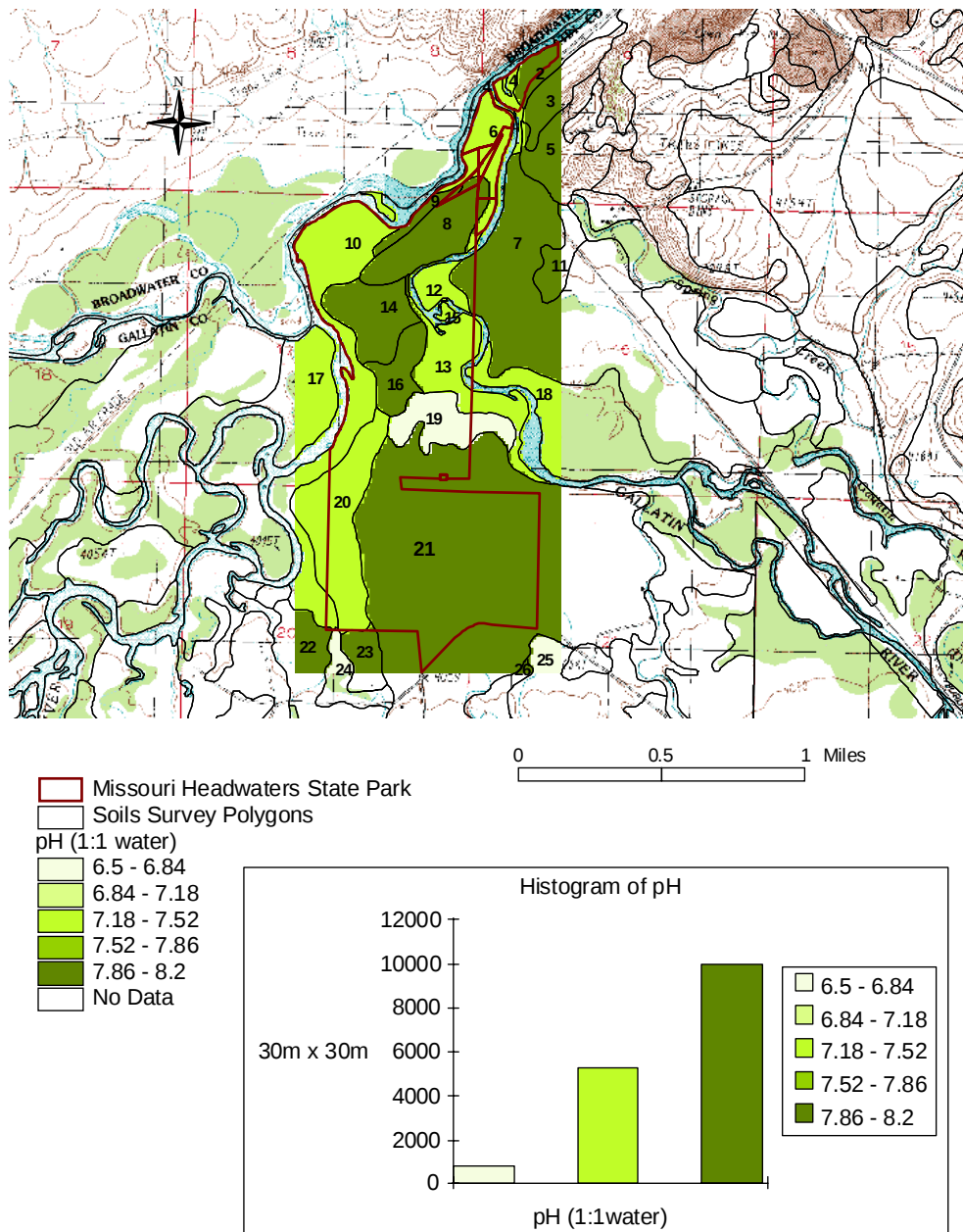


Figure 36. pH. 1:39,500 (Soil Data Viewer, 2001).  
With the exception of polygon #19, all polygons display the targeted values, of slightly alkaline soils (>7.00), for suitable habitats.

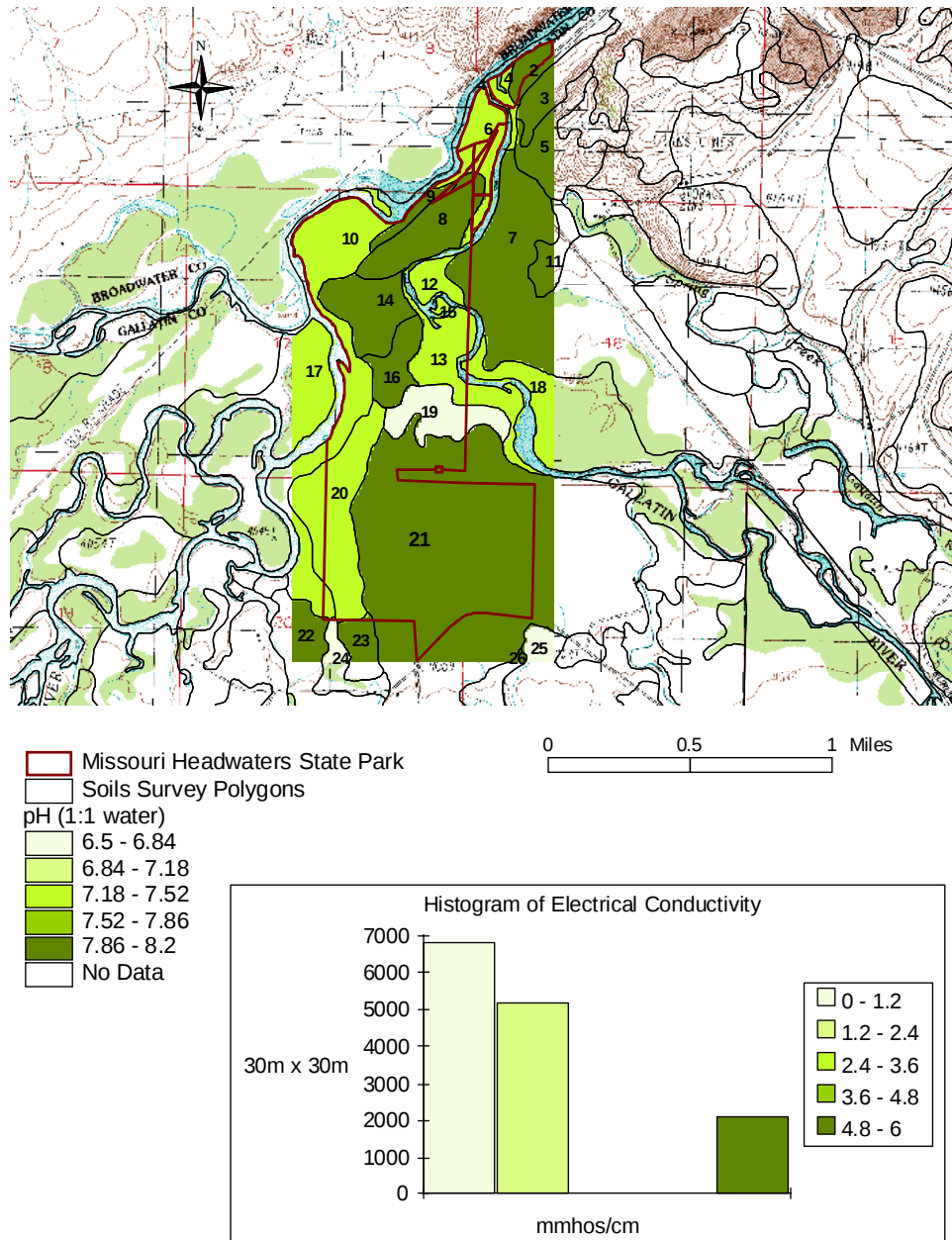


Figure 37. Electrical Conductivity. 1:39,500 (Soil Data Viewer, 2001).  
 Electrical conductivity values are too varied for an average value prediction (0.72). However, the literature suggests that the high values indicated for polygons # 7, # 14 and # 21 equate to  $\text{CaCO}_3$  high values.

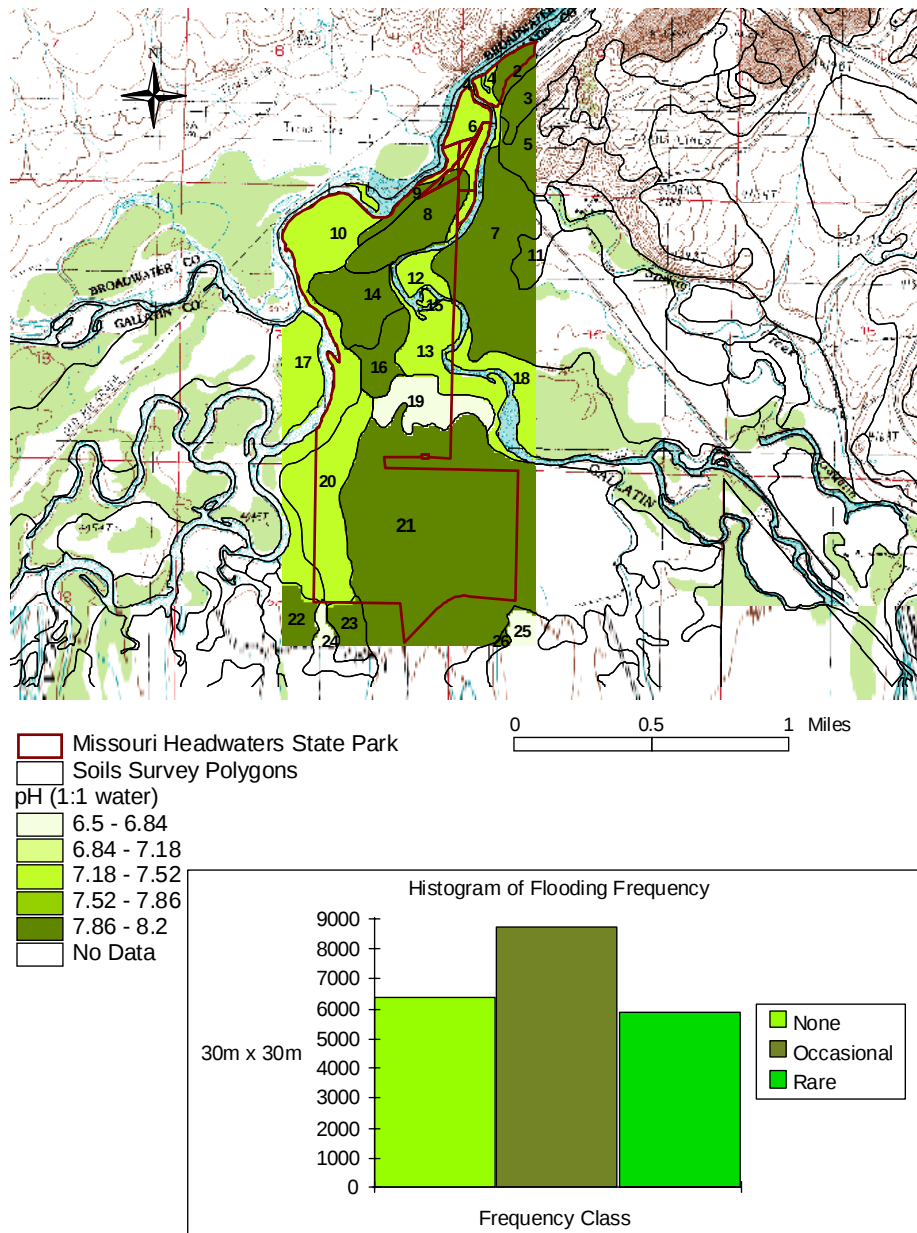


Figure 38. Flooding Frequency. 1:39,500 (Soil Data Viewer, 2001).

Data resources conflict with species-specific flood occurrence frequency. The Natural Heritage Program suggests occasional flooding for species habitats while the soils survey polygon data display rare flooding frequency at the occurrence sites. The survey data was used in this study for data continuity. Discrepancies may be caused by error or external impacts.

### Prediction Displays of Suitable Habitat Distribution

The suitable habitat predictions are generated from indirect indicator values. The results of these processes delineate species-specific habitats in the proximity map. The statistical component distribution maps assist in developing a conservation strategy in three ways:

- 1) The data processed with GIS technology extrapolates quantitative habitat characteristics over geologic space. With the GIS analysis application, trend values can be manipulated and new data can easily be added to the prediction process.
- 2) The suitable-habitat maps created in the GIS provide the spatial delineations from which to conduct the associated feature field surveys reducing redundant field efforts.
- 3) The statistical data provide a means for testing the assumptions reviewed from the literature research.

The spatial predictions are displayed in two sets of three maps. The first set (Figures 39-41) delineates suitable habitats based on the characteristic values generated by trend summary analysis (see table 5, Value Index). The spatial predictions are mapped by first order, second order and third order trend values depending on the species-specific component value similarities. The second set (Figures 42-44), display permutations of the 'Value Index' displays. The permutations illustrate the trend value distribution excluding the qualitative characteristics from the query expression. The soil type name component was excluded (all twenty-six polygons are represented as wetland soil types)

because the descriptive properties may affect the prediction. And the flooding frequency component was excluded due to discrepancies in the initial data. The permutations produced the same results as the original prediction sets. The prediction displays indicated three of the twenty-six proximity polygons support species-specific habitats.

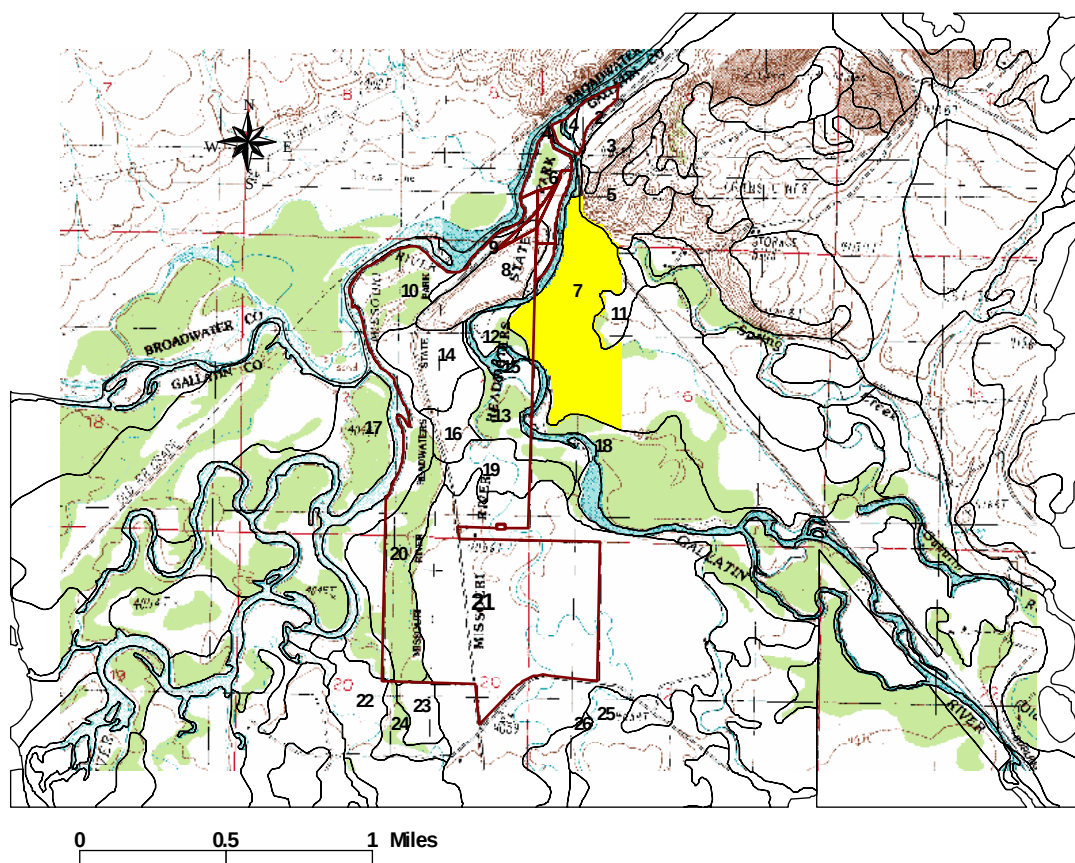


Figure 39. First Order Suitable Habitat Prediction Query Expression Display.  
Yellow shaded polygon represents spatial query results 1:39,500

Dominant Indicator query script:

Soil Type Name = Fairway-ThreeRiver-Rivra complex *and* Available Water Supply > 2.91  
*and* Available Water Supply < 4.31 *and* pH > 7.36 *and* pH < 8.62 *and*

Moderate Indicator query script:

Organic Matter > 1.43 *and* Organic Matter < 4.48 *and*

Marginal Indicator query script:

CaCO<sub>3</sub> > 1.83 *and* CaCO<sub>3</sub> < 9.57 *and* Electrical Conductivity > 0.62 *and* Electrical  
Conductivity < 9.98 *and* Flooding Frequency = rare

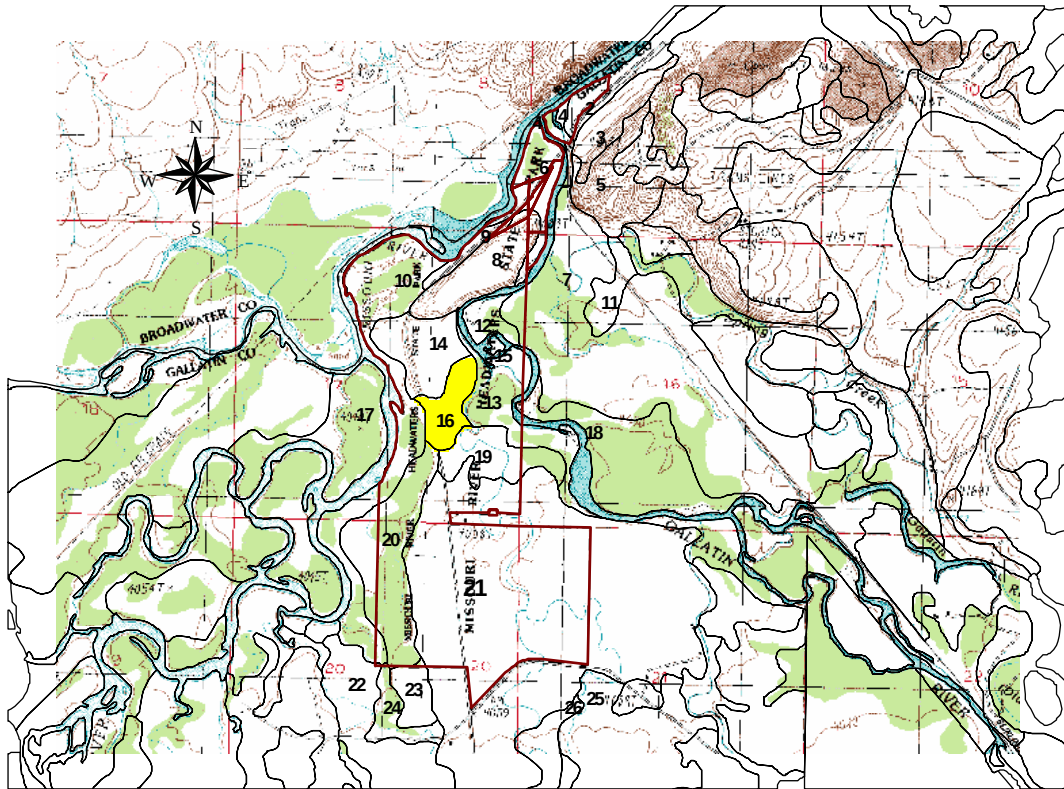


Figure 40. Second Order Suitable Habitat Prediction Query Expression Display. Yellow shaded polygon represents spatial query results 1:39,500.

Dominate Indicator query script:

Soil Type Name = Meadowcreek, Slightly Saline-Rivra complex or Soil Type Name = Ryell-Rivra-Fairway complex and Available Water Supply > 2.22 and Available Water Supply < 5.00 and pH > 6.74 and pH < 9.24

Moderate Indicator query script:

Organic Matter < 6.00 and

Marginal Indicator query script:

CaCO<sub>3</sub> < 13.42 and Electrical Conductivity < 14.64 and Flooding Frequency = occasional

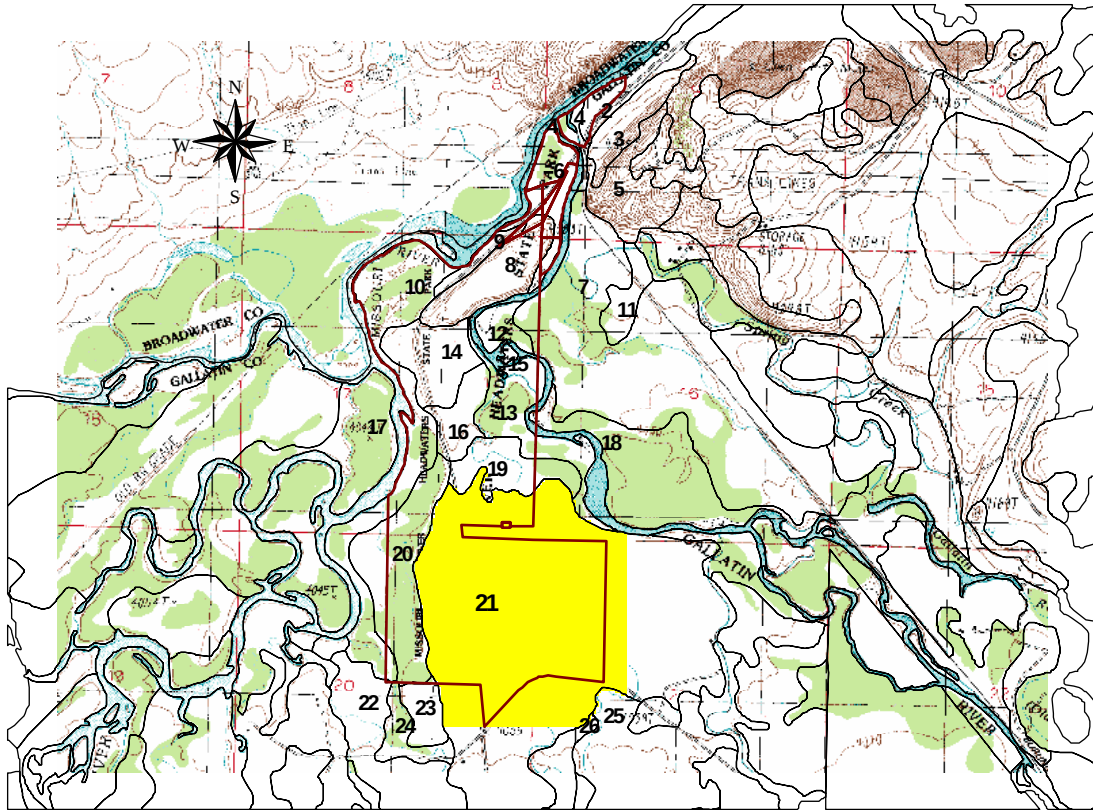


Figure 41. Third Order Suitable Habitat Prediction Query Expression Display. Yellow shaded polygon represents spatial query results 1:39,500.

Dominate Indicator query script:

Soil Type Name = Greycliff-Toston-Trreerivcomplex or Soil Type Name = Lomoose-Rivra-Bonebasin complex or Soil Type Name = Rivra, Moist-Ryell-Bonebasin or Soil Type Name = Rivra-Mccabe-Bonebasin complex or Soil Type Name = Threeriv-Bonebasin Loams or Soil Type Name = Threeriver-Greycliff complex and Available Water Supply > 1.53 and Available Water Supply < 5.69 and pH > 6.12 and pH < 9.86

Moderate Indicator query script:

Organic Matter < 7.51

Marginal Indicator query script:

CaCO<sub>3</sub> < 17.28 and Electrical Conductivity < 19.31 and Flooding Frequency = none

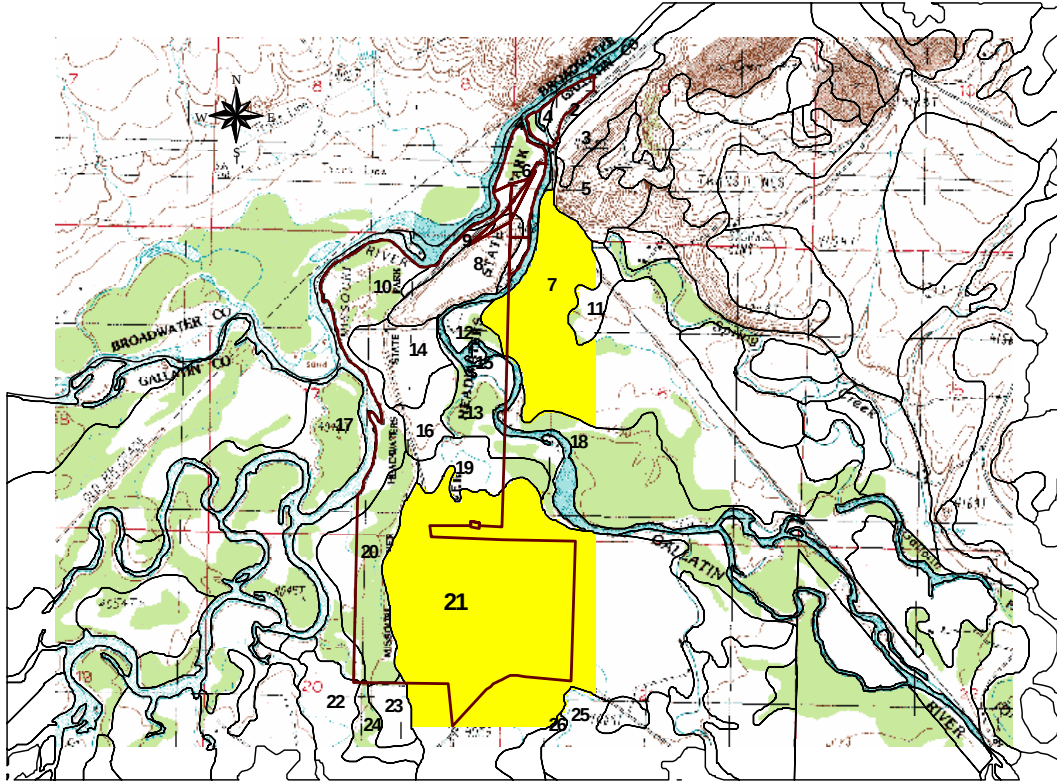


Figure 42. First Order Suitable Habitat Permutation Prediction.  
Yellow shaded polygon represents spatial query results 1:39,500.

Dominate Indicator query script:

*Available Water Supply > 2.91 and Available Water Supply < 4.31 and pH > 7.36  
and pH < 8.62 and*

Moderate Indicator query script:

*Organic Matter > 1.43 and Organic Matter < 4.48 and*

Marginal Indicator query script:

*CaCO<sub>3</sub> > 1.83 and CaCO<sub>3</sub> < 9.57 and Electrical Conductivity > 0.62 and Electrical  
Conductivity < 9.98*

Query expression excludes descriptive components (soil type name and flooding frequency). First and third Value Index order-of-importance prediction polygons are represented in this display.

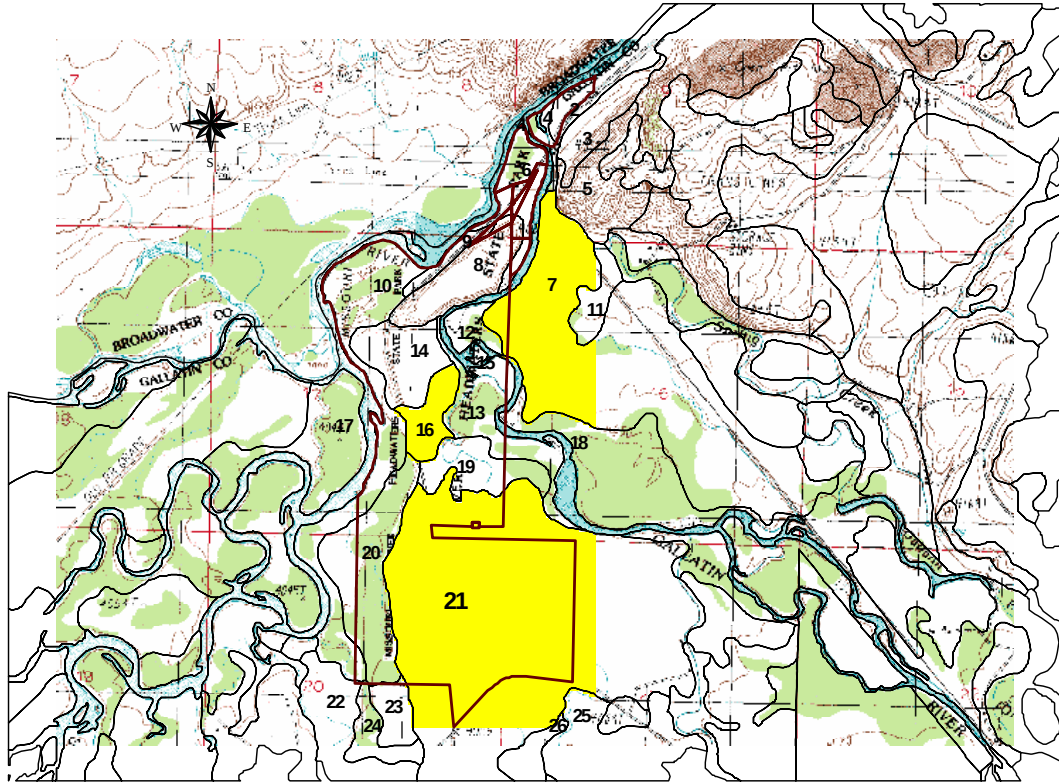


Figure 43. Second Order Habitat Permutation Prediction.  
Yellow shaded polygon represents spatial query results 1:39,500.

Dominate Indicator query script:

Available Water Supply > 2.22 and Available Water Supply < 5.00 and pH > 6.74 and pH < 9.24

Moderate Indicator query script:

Organic Matter < 6.00 and

Marginal Indicator query script:

CaCO<sub>3</sub> < 13.42 and Electrical Conductivity < 14.64

Query expression excludes descriptive components (soil type name and flooding frequency). Note all three of the Value Index order-of-importance prediction polygons are represented in this display.

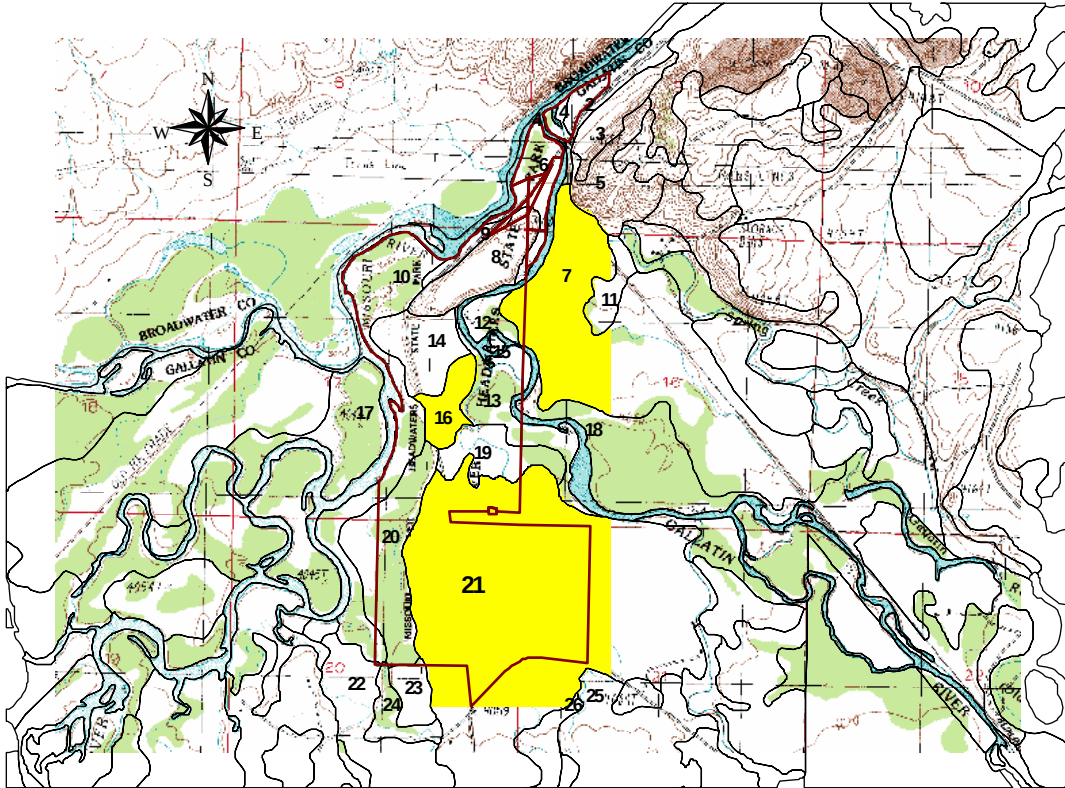


Figure 44. Third Order Habitat Permutation Prediction.  
Yellow shaded polygon represents spatial query results 1:39,500.

Dominate Indicator query script:

Available Water Supply > 1.53 and Available Water Supply < 5.69 and pH > 6.12  
and pH < 9.86

Moderate Indicator query script:

Organic Matter < 7.51

Marginal Indicator query script:

$\text{CaCO}_3$  < 17.28 and Electrical Conductivity < 19.31

Query expression excludes descriptive components (soil type name / flooding frequency).  
Note all three of the Value Index order-of-importance prediction polygons are represented in this display.

### Associated Features Field Survey

The final prediction process in this study was the associated features field survey. Field surveys were conducted in the three predicted suitable habitat polygons. Identifying habitat feature similarities in the select polygons address two useful conservation strategy criteria:

- The field survey explores the feature/trend relationships compiled from the literature research (i.e., associated flora, topographic features, impacts and pollination vectors).
- The field survey identifies species populations and/or suitable habitats within the predicted polygons.

Polygon 7 (Figure 39), the first-order prediction polygon, is wetland grasses and brush with dense trees along waterways. No exotic or introduced plant species were sighted. Topographic features showed water channels with several areas of drier, open meadow habitat. The site is water-channeled on three sides with wetlands (much of it riparian) on the remaining side. Private agricultural development borders the site and species populations could be affected by pollutants transmitted from agricultural production. Only a small portion of the polygon is state managed but, due to its remote location and limited access, recreational impacts are minimal. Species propagation may be influenced by honey-producing bee hives near the site although it is not known if the species can pollinate *Spiranthes diluvialis*. However, bumblebees (*Bombus* spp.), the dominate pollen vector (Sipes & Tepedino, 1994), have been sighted in the park.

Polygon 16 (Figure 40), the second-order prediction polygon, is a large open meadow between two rivers (Gallatin and Madison rivers) with a paved state highway skirting along the eastern side. East of the highway is not suitable habitat, vegetation is dense brush and trees with limited open grasses. West of the highway are wide, open meadows of grasses, sedges, sparse trees and brush as well as the unfortunate abundance of exotic noxious weeds associated with species habitats; spotted knapweed (*Centaurea biebersteinii*) and Canada thistle (*Cirsium arvense*). Flooding is rare, but in some areas soil remains saturated into late August. Slight undulations produce swales that can hold moisture late into the season. Old drainage ditches and soil disturbance from past agricultural development and practices may impact habitat conditions. Bi-annual herbicide spraying for noxious weeds may influence species populations as well. Recreational impacts are minimal due to primitive habitat status park protection. Local honey production hives may be a beneficial pollinator, but the research is not conclusive. Bumblebees have been sighted in the area, the open meadows providing excellent habitat.

Polygon 21 (Figure 41), the third-order suitable-habitat polygon, encompasses a large area with varied land covers and several first and second-order suitable component conditions. The vegetation is predominantly open, grassy meadow with sedges, spotted knapweed and Canada thistle throughout. Riparian habitats occur along the rivers and braided channels. Topographic features include open meadow swales susceptible to moisture saturation into late summer. External impacts may have a greater influence on the habitat suitability for this polygon. Old irrigation channels produce unnatural drainages. Highway construction has diverted the natural water runoff, which may inhibit species dispersion and promote noxious weed introductions. Light impact

recreational trails are present that may influence propagation and/or the spread of noxious weeds. Much of this polygon is impacted by frequent herbicide spraying for noxious weeds. Livestock grazing (four horses) impacts are associated with a large section of the polygon, but may, in fact, benefit species populations by keeping grasses low, promoting *Spiranthes deluvialis* growth (MNHP, 1998). Honeybee hives are present in this polygon and may provide a pollination vector.

## CONSERVATION STRATEGY

### Management strategies

The field surveys conducted in the three predicted suitable-habitat proximity polygons did not identify species populations but selected areas support species-specific-habitat features. These selected areas are small, accessible, and benefit by state lands protection. It is prudent therefore, to suggest a site monitoring protocol be implemented for each of the suitable sites as a conservation strategy.

Site monitoring protocol is the field survey process identifying species populations and/or influences on habitat characteristics. The objectives achieved by site monitoring are:

1. to determine *Spiranthes deluvialis* populations and/or suitable habitats.
2. to determine environmental changes that indicates secure populations/ habitats.
3. to provide data for future prediction modeling.
4. to determine the effects of terminating populations/habitats.

It should be noted, when and if site monitoring identifies species populations, a revived management strategy should be drafted focusing on conservation and propagation of the species while continuing with a monitoring protocol.

### Site Recommendations

Polygon 7 conservation recommendations are based on the following analysis results:

1. The habitat quantifies as a first-order trend value prediction (Figure 39).

2. The site is very similar in feature characteristics to the species occurrence site polygon nearest to the study area (Figure 13).
3. A management strategy is benefited by site accessibility, small area coverage and state lands protection.

Recommendations for this site suggest a detailed field evaluation for species populations and the associated habitat feature characteristics. A bi-annual field monitoring protocol is recommended. Where, and if, species populations are identified at this site, it is recommended that a revived management strategy be drafted, focusing on species protection and propagation, and an upgrade to a bi-annual monitoring protocol should be started.

Polygon 16 conservation recommendations are based on the following analysis results:

1. The habitat quantifies as a second-order trend value prediction (Figure 40).
2. The field survey identified select areas exhibiting first-order feature characteristics.
3. A management strategy is benefited by site accessibility, small area coverage and state lands protection.

Recommendations for this site suggest an annual monitoring protocol, with no other strategies recommended at this time.

Polygon 21 conservation recommendations are based on the following analysis results:

1. The habitat quantifies as a third-order trend value prediction (Figure 41).

2. The field survey identified select areas exhibiting first-order and second-order feature characteristics.
3. A management strategy is benefited by site accessibility, small area coverage and state lands protection.

Recommendations for this site suggest restricting management strategy to an occasional monitoring protocol with no other strategies recommended at this time.

## CONCLUSION

The goal of this study was to propose conservation management recommendations for *Spiranthes diluvialis* (a threatened plant species), based on the quality of species-specific habitats. The purpose for the methodology used in the project was to demonstrate the utility of a GIS in: 1) formulating suitable habitat value-indices and, 2) translating those indices as suitable habitat delineations in a prediction model display.

The suitable habitat delineation criterion was developed from the compilation of historical review, regional characteristic similarities and species-specific quantitative soils component values. The habitat suitability was formulated from a four-step compilation process of habitat evaluations:

1. Regional land-cover/use maps were evaluated to determine general habitat similarities of the species occurrence sites within the study site.
2. Occurrence site-specific quantitative properties were statistically summarized into tabular data, creating the suitable habitat value-index.
3. The indexed values are delineated, as suitable habitats, in the proximity prediction model.
4. Field surveys were conducted of the prediction sites for species-specific associated features and to confirm the results of the index value predictions.

Regional evaluations suggested that the study site (Missouri Headwaters State Park) to be suitable species habitat. However, the variations in the five-state range characteristics prompted the statistical analysis be developed exclusively from the southwest Montana occurrence sites. These data created the species-specific habitat

indicator value limits (Value Indices) for the study. The field surveys were restricted to those proximity polygons where suitable habitats were delineated, evaluating the trend value predictions and the species-specific associated features.

Results from the quantitative indicator query and the associated features field survey showed that suitable species habitats were limited to three of the twenty-six polygons represented in the proximity display. Although *Spiranthes diluvialis* populations were not identified in the prediction sites, all three of the prediction polygons supported sufficient habitat characteristics. The select areas within the three predicted polygons that support species-specific habitats are relatively small, they are protected, and they have easy access. Therefore, it was prudent for this project to recommend that a monitoring protocol be developed for each of the three suitable habitat sites as the conservation management strategy. The protocol was established by the quality of species-specific similarities based on the following criteria:

1. Sites supporting first-order suitable habitat qualities and substantiated by associated features indicate a high probability of species occurrence. Even if populations are not identified, the quality of species-specific similarities suggests that a bi-annual monitoring protocol be recommended. And if sparse populations are present at these sites, a propagation protocol may also be recommended.
2. For the prediction sites supporting moderate indicator values and associated features, or second-order habitat suitability, an annual monitoring protocol would be developed as the conservation strategy.

3. For the prediction sites supporting marginal indicator values and limited associated features, or third-order habitat suitability, occasional site monitoring is recommended but no particular management strategies would be proposed.
4. And finally, in those areas not supporting sufficient indicator values or associated features, developing a management protocol for these sites would have little effect on species propagation or distribution. Therefore, a conservation strategy is not necessary.

Two other important habitat conditions were considered in the suitability assessment when processing a conservation management strategy; 1) the effects of human impacts and, 2) the presence of a pollination vector. Impacts may significantly alter habitat suitability even though analysis suggests polygon compatibility. Past or present developments may alter associated plant survival, soil properties and/or hydrologic variables. And even when a suitable habitat is validated, the pollination vector may influence *Spiranthe deluvialis* propagation and distribution. It should be noted then, that the analytically determined suitable habitat conservation strategies are also predicated on the degree of external impacts regardless of characteristic similarities.

This project demonstrated that the spatial habitat predictions processed in a GIS, utilizing available public digital data, produced effective results from which to develop comprehensive conservation strategies. Thus, the processes employed in this project will assist land managers in satisfying the threatened plant species conservation philosophy adopted by state and federal resource agencies.

## Bibliography

- Arft, A. M. 1995. *The genetics, demography, and conservation management of the rare orchid *Spiranthes diluvialis** (Doctoral dissertation, University of Colorado, Boulder, 1995).
- Boast, R. R. and R. G. Shelito 1989. *Soil survey of Madison county area, Montana*. Bozeman, MT: USDA Soil Conservation Service.
- Brown, T. C., & T. C. Daniel 1990. *Scaling of Ratings: Concepts and Methods*. Res. Pap. RM-293. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain and Range Experiment Station. 24 p.
- Burrough, P. A., and R. A. McDonnell 1998. *Principles of Geographical Information Systems*. New York: Oxford Press.
- Carson, R. 1963. *Silent Spring*. Publisher: Hamish Hamilton.
- Colorado State University Department of Rangeland Ecosystem Science 2001. *Models for Inventory, Monitoring, and Management of Threatened and Endangered Plant Species*. Available from <http://www.cnr.colostate.edu>.
- Coyner, J. 1990. Report for population study: *Spiranthes diluvialis*. Mutual project between the Bureau of Land Management and Red Butte Gardens. University of Utah, Salt Lake City.
- 1991. The Ute-ladies' tresses, *Spiranthes diluvialis*. Survey report prepared for the Bureau of Land Management and Red Butte Gardens. University of Utah, Salt Lake City.
- Dent, B. D. 1999. *Cartography: Thematic Map Design*. 5<sup>th</sup> ed. Boston: McGraw-Hill.
- Ebdon, D. 1985. *Statistics in Geography*. 2<sup>nd</sup>. ed. Massachusetts: Blackwell
- Environmental Systems Research Institute Inc. 1996. *ArcView GIS: The Geographic Information System for Everyone*. Redlands CA: Author.
- 1996. *ArcView Spatial Analyst: Advance Spatial Analysis Using Raster and Vector Data*. Redlands CA: Author.
- Heidel, B. L. 1996a. New additions to the Montana flora. *Madroño* 43(3):436-440.

- Heidel, B. L. 1996b. *Spiranthes diluvialis* – A Threatened orchid in Montana. *Kelseya* 9(3) – Newsletter of Montana Native Plant Society.
- 1998. Conservation Status of *Spiranthes diluvialis* Sheviak in Montana. Unpublished report to U.S. Fish & Wildlife Service. Montana Natural Heritage Program, Helena. 55pp. + app.
- Hildebrand, T. 1998. 1997 Inventory for *Spiranthes diluvialis* Sheviak in western Nebraska. Unpublished report to the U. S. Fish and Wildlife Service. Nebraska Game & Parks Commission, Lincoln. 25 pp. + app.
- Jankowski, P. 1995. Integrating geographical information systems and multiple criteria decision-making methods. *International Journal of Geographic Information Systems*, vol. 9, no. 3. 251-273.
- Jennings, W. F. 1989. Species studies: *Eustoma grandiflorum*, *Spiranthes diluvialis*, *Malaxis brachypoda*, *Hypoxis hirsute*, *Physaria bellii*, *Aletes humilis*. Unpublished report to Colorado Office of The Nature Conservancy. Boulder. 48 pp.
- 1990. *Spiranthes diluvialis* and *Sisyrinchium pallinum*. Final report, Colorado natural history small grants program. Prepared for the Nature Conservancy.
- Lesica, P. 1991. Sensitive, threatened and endangered vascular plants of Montana. Helena: Montana Natural Heritage Program. 88 pp.
- Microsoft Corporation 2001. Access 2002 (computer software). Redmond WA: Microsoft Corporation.
- Montana Natural Heritage Program. 1998. Ute Ladies' tresses (*Spiranthes diluvialis* Sheviak): Guidebook Information on Species, Habitat, Distribution and References. Helena: Author. <http://www.orion2.nris.state.mt.us/pguide.html>. (accessed August 18, 1998).
- Montana State Library GIS Data Dictionary, 2001. Metadata for Montana Fish, Wildlife and Parks lands. Helena: Author. <http://www.nris.state.mt.us> (accessed January 3, 2001)
- Murphy, C. 2000. Ute Ladies' -Tresses (*Spiranthes diluvialis*) in Idaho: 2001 Status Report Technical Bulletin no. 02–2. Idaho Bureau of Land Management.
- Sheviak, C. J. 1984. *Spiranthes diluvialis* (Orchidaceae), a New Species from the Western United States. *Brittonia* 36(1): 8 -14.
- Sipes, S. D. and V. J. Tepedino. 1995. *Reproductive Biology of the Rare*

Orchid, *Spiranthes diluvialis*: Breeding System, Pollination, and Implications for Conservation. Conservation Biology 9(4): 929-938.

USDA, Natural Resources Conservation Service 2001. Soil Data Viewer (SDV) Version 3.0 (computer software). Fort Collins: USDA, Natural Resources Conservation Service Information Technology Center.

[http://nasis.state.mt.us/nrcs/soils/mt\\_sdvtemplate.html](http://nasis.state.mt.us/nrcs/soils/mt_sdvtemplate.html) (accessed January 16, 2003)

---

—2001. Soils Survey Geographic Data Library (SURRGO) (computer shape files). Fort Collins: USDA, Natural Resources Conservation Service Information Technology Center.

<http://nasis.nrcs.usda.gov/products/nasisexport50.shtml> (accessed February 17, 2003)

---

—2001. Plants Profile. (computer data). Fort Collins: USDA, Natural Resources Conservation Service Information Technology Center. [http://plants.usda.gov/cgi\\_bin/plant\\_search.cgi](http://plants.usda.gov/cgi_bin/plant_search.cgi) (accessed January 28, 2003)

U. S. Fish and Wildlife Service. 1992. Endangered and Threatened wildlife and plants; final rule to list the plant *Spiranthes diluvialis* (Ute Ladies'-tresses) as a threatened species. Federal Register 57: 2048-2053.

---

—1995. Ute ladies' tresses (*Spiranthes diluvialis*) Draft Recovery Plan. Denver, CO. 46pp

Wells, T. C. E. 1981. Population ecology of terrestrial orchids. *The Biological Aspects of Rare Plant Conservation*, 1981. H. Synge, ed. London: John Wiley & Sons, Ltd.

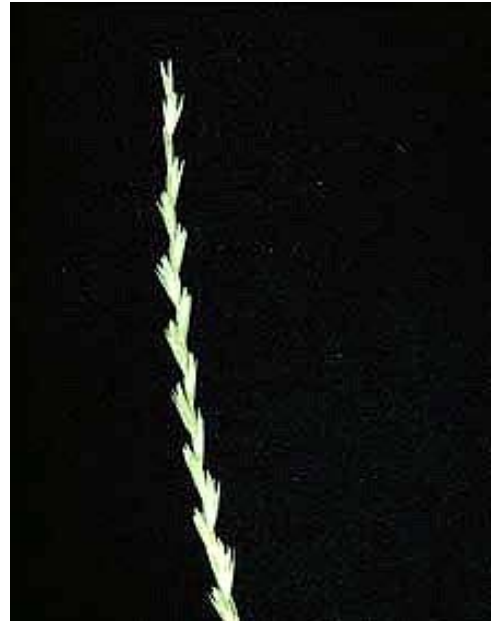
APPENDIX A:

ASSOCIATED PLANT SPECIES

*Agrostis stolonifera*  
Creeping bentgrass



*Elymus trachycaulus*  
slender wheatgrass



*Carex simulate Mackenzie*  
Analogue sedge



*Juncus balticus* Wild  
Baltic rush



Common associated species with >10% cover at all Montana sites.  
(Photos provided by USDA plants gallery, 2003).

*Juncus longistylis*  
Longstyle rush



*Muhlenbergia asperifolia*  
Scratchgrass



Common associated species with >10% cover at all Montana sites  
(Photos provided by USDA plants gallery, 2003).

## Montana Only

*Carex simulate Mackenzie*  
Analogue sedge



## Montana Wetlands

*Carex aquatilis Wahlenb*  
Water sedge



*Eleocharis quinqueflora*  
Fewflower spikerush



*Carex praegracilis*  
Clustered field sedge



Associated species exclusive to Montana / Montana wetlands (photos provided by USDA plants gallery, 2003).

## Gallatin County wetlands

*Carex scirpoidea* Mischx.  
Northern singlespike sedge



*Deschampsia caespitosa*  
Tufted hairgrass



Associated species exclusive to Gallatin County wetlands (Photos provided by USDA plants gallery, 2003).

*Agrostis stolonifera*  
Creeping bentgrass



*Lolium arundinaceum*  
Tall fescue



*Poa pratensis*  
Kentucky bluegrass



*Cirsium arvense*  
Canada thistle



Exotic associated species (photos provided by USDA plants gallery, 2003).

*Centaurea biebersteinii*  
Spotted knapweed



*Trifolium repens*  
White clover



Exotic associated species (photos provided by USDA plants gallery, 2003).

*Eleocharis rostellata*  
Beaked spikerush



*Primula incana*  
Silvery primrose



Endangered associated species (photos provided by  
USDA plants gallery, 2003).