Science Assessment for the Sierra Checkerboard Initiative - Technical Appendix

INTRODUCTION

This Technical Appendix has been prepared in support of the Science Assessment conducted for Phase I of the Sierra Checkerboard Initiative. One purpose of the Science Assessment was to identify candidate areas for developing conservation and management strategies, which will be developed in Phase II of the Sierra Checkerboard Initiative. Areas that are candidates for developing conservation strategies, or candidates for conservation action, are areas that support biodiversity, mature forest connectivity, and passive recreation values and are threatened by risk of exurban development, unnatural fire, and management incompatible with conservation of mature forests. This Technical Appendix details the technical approach used in the Phase I Science Assessment, describes in more detail the development of the conceptual model for the project, provides details on the data sets used to run the model, and presents complete model results.

KNOWLEDGE BASED ASSESSMENT

Due to the complexity of ecosystems, our relative lack of quantitative information on their dynamics and interdependencies, and our subjective determinations as to what are *desirable* ecosystem characteristics, it is extremely difficult to develop quantitative models to predict these characteristics. *Fuzzy logic* , a branch of mathematical set theory, allows imprecise information typical of natural resource science to be used in modeling (Reynolds et al. 2000). This knowledge based reasoning approach allows us to characterize an ecological system in terms of characteristics or conditions (e.g., acres of late-successional forest, numbers of special status species, levels of habitat fragmentation, etc.) and their logical relationships to one another. In consultation with the Science Advisors, we concluded that a fuzzy logic knowledge based approach would be an appropriate tool for the Science Assessment.

We employed the Ecosystem Management Decision Support (EMDS) System (Reynolds et al. 2002) to evaluate whether an area is a good candidate for conservation action. The EMDS system is a framework for knowledge based decision support of ecological assessments at any geographic scale. The system integrates geographic information system (GIS) as well as knowledge based reasoning and decision modeling technologies to provide decision support for management processes. EMDS provides a set of general solution methods for conducting ecological assessments and developing priorities for management activities. To conduct an assessment with EMDS, the user:

- Constructs a data base that includes all GIS data sets that enter into an assessment.
- Designs a knowledge base that describes how to interpret information of interest to the assessment.

• Designs a decision model for planning management activities based on results of an assessment and possibly other information pertinent to planning, such as efficacy and feasibility issues. (Management priorities were not evaluated in the Phase I Science Assessment but will be developed in Phase II of the Sierra Checkerboard Initiative.)

EMDS integrates the logic engine of NetWeaver (Rules of Thumb, Inc.) to perform landscape evaluations and the decision modeling engine of Criterium DecisionPlus (InfoHarvest, Inc.) for evaluating management priorities. The NetWeaver logic engine evaluates data against a knowledge base that provides a formal specification for the interpretation of data. A knowledge base can be thought of as a type of meta database. The logic engine allows partial evaluations of ecosystem states and processes based on available information, making it ideal for use in landscape evaluation where data are often incomplete.

Conceptual model - knowledge bases

Our conceptual model for assessing the suitability of a site as a candidate for conservation action was constructed as a fuzzy logic knowledge base. The model uses knowledge bases connected by logic operators, i.e., *and* , *or* , and *union* operators, to evaluate the relationships between and among values and threats within the study area, and the relationships and dependencies of characteristics and conditions that we identified as contributing to these values and threats. Five diagrams representing the hierarchical fuzzy logic knowledge bases developed for the project in NetWeaver—for determining candidates for conservation action in the central Sierra Nevada—are presented below. Table A-1 presents a tabular summary of the hierarchical relationship of all of the conditions and characteristics used in the knowledge base. The EMDS and NetWeaver analysis for the Science Assessment used the entire knowledge base described by these five diagrams

• Knowledge base 1 is the highest level knowledge base and contains overall analysis results .

• Knowledge base 2 contains existing terrestrial and aquatic biodiversity results as well as potential future biodiversity value results .

• Knowledge base 3 contains existing mature forest fragmentation results as well as potential future mature forest connectivity results .

• Knowledge base 4 contains recreational access results and passive recreation resources results.

• Knowledge base 5 contains risk of exurban development results, risk of unnatural fire results, and risk on incompatible mature forest management results.

Table A-1—Hierarchical summary of characteristics and conditions used in the logic model for ranking sections of land as good candidates for conservation action.

A. Resource value

1. Biodiversity value

i. Existing biodiversity value

- Terrestrial biodiversity value
  - Landscape condition
    - High percentage of roadlessness
    - Low road density
    - Low percentage of human impact (land cover change)
  - Under-represented habitat types
    - High percentage of priority vegetation communities
  - Terrestrial special elements
    - High number of sensitive species
    - High percentage of late-seral forests
    - High percentage of rare edaphic features
- Aquatic biodiversity value
  - Watershed condition
    - Low road density on steep slopes
    - Low road density near rivers/streams
    - High percentage of roadlessness (subbasin scale)
    - Low cumulative dam influence (subbasin scale)
    - Low percentage of human impact (land cover change - subbasin scale)
  - Aquatic special elements
    - High number of sensitive habitats
    - High number of sensitive species

ii. Future biodiversity value

- Average existing biodiversity value results within a 5km^2 neighborhood
- Potential biodiversity value
  - Low development density
  - High percentage of rare edaphic features
  - High forest productivity

2. Mature forest connectivity

i. Existing mature forest connectivity

- Site mature forest fragmentation
  - High percentage of mature forest
  - Low number of mature forest patches
  - Large mean size of mature forest patches
  - Low mean nearest neighbor distance between mature forest patches
  - High total core area index
- Neighborhood (5km^2) mature forest fragmentation
  - High percentage of mature forest
  - Low number of mature forest patches
  - Large mean size of mature forest patches
  - Low mean nearest neighbor distance between mature forest patches
  - High total core area index

ii. Future mature forest connectivity
- Neighborhood (5km^2) mature forest fragmentation
  - o High percentage of mature forest
  - o Low number of mature forest patches
  - o Large mean size of mature forest patches
  - o Low mean nearest neighbor distance between mature forest patches
  - o High total core area index
- Potential forest growth
  - o Low development density
  - o High forest productivity

3. Passive recreation value

i. Access to recreational resources
- o Adequate trail density
- o Adequate road density

ii. Recreational resources
- o High percentage of lakes
- o High river density
- o High percentage of meadows
- o High percentage of Wild & Scenic Rivers
- o High percentage of late-seral forests
- o High percentage of recreation acquisition areas identified by recreation authorities
- o High percentage of wilderness

B. Threat to resource value

1. Risk of exurban development

i. Site contains privately owned parcels
- o High percentage of site privately owned

ii. Development infrastructure available
- o Short distance to existing development
- o High road density

iii. Site is environmentally unconstrained
- o Low percentage of wet vegetation types

iv. Degree of parcel subdivision
- o Low average parcel size

2. Risk of unnatural fire
- o High average FRAP condition class

3. Risk of management incompatible with conservation of mature forests
- o High percentage of mature forest outside of protected and roadless areas

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o = data sets used to assess characteristics and conditions

For example, Knowledge Base 1 can be interpreted as follows:

A site is a good candidate for conservation action to the degree that it has both a *threat to resource value* ***and*** *a high resource value* . A site has a *high resource value* to the degree that it has either *high biodiversity value* ***or*** *high mature forest connectivity* ***or*** *high passive recreation value* . A site has a *high threat to resource value* to the degree that it has either *high risk of exurban development* ***or*** *high risk of unnatural fire* ***or*** *high risk of incompatible mature forest management.*

At the terminus of the logic knowledge base (shown in Knowledge Bases 2, 3, 4, and 5) are links to data (identified as rectangles in the logic knowledge base diagrams) that evaluate the degree to which specific characteristics or conditions postulated in the model are met. For example, the condition *low development density* (Knowledge Base 2) is evaluated in EMDS using a data set created by FRAP that describes residential and commercial development within the study area. Each data link box provides the name and the range of values for that data set. A description of the data set can be accessed by clicking on the name of the data within each data link box in the knowledge base diagrams. Links to metadata for all data sets used in the analysis (where available) can be accessed from the data descriptions or here .

EMDS uses these data to evaluate the strength of evidence for the postulated condition for each analytical unit. The strength of evidence is referred to as *truth values* , which range from +1 to -1, as follows:

• The strength of the evidence is highest (+1).

• The strength of the evidence is lowest (-1).

The relationship between data values and truth values is assigned via fuzzy curves in NetWeaver. The shape of fuzzy curves can be varied to establish different thresholds in individual data sets for assigning truth values between +1 and -1. Examples of fuzzy curves used in the assessment are given in Figure A-1. For the majority of data, fuzzy curves were set with a -1 truth value for the minimum data value and a +1 truth value for the maximum data value. However, there were several data sets (e.g., Figures A-1a, A-1b, A-1d) where the fuzzy curves were modified for the analysis.

Using the specific logic operators assigned in the model, the results for each condition (ovals in the knowledge base diagram) are assessed and combined with the results for all other conditions within the logic knowledge base model to assess whether a site is a good candidate for conservation action. Each of the knowledge base diagrams (Knowledge Bases 1, 2, 3, 4, and 5) provides links to maps of all of the EMDS and NetWeaver analysis results, as well as to the data sets used in the analysis. The analysis unit used to summarize results on maps is individual sections from the township and range public land survey system. Some results in the watershed analysis are initially summarized by Hydrologic Unit Code (HUC) level 6 watersheds, then assigned to individual sections (indicated in the appropriate data links in Knowledge Base 2). Results are displayed in map form, showing the support for the postulated characteristics or conditions (e.g., the site is a good candidate for implementing a conservation action) of each analytical unit (i.e., sections of land) in a series of colors ranging from dark green (relatively supported or high) to red or brown (relatively unsupported or low). All of the map legends of

analysis results were created using Jenk's natural breaks classification for seven classes. This means that the range of values depicted by any single color in a legend is not the same from map to map. For example, the range for best results in one map could be 0.4 to 0.6, while in another map it could be 0.8 to 1.0.

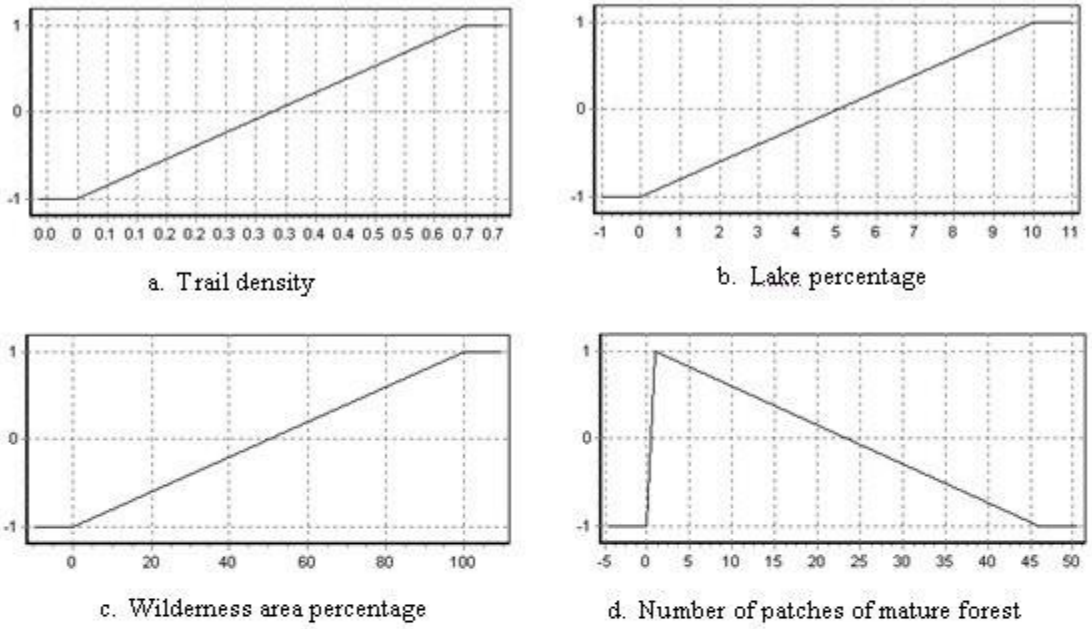

Figure A-1. Examples of fuzzy curves used in the EMDS analysis, showing relationship of truth values (vertical axis) to values of four data sets (horizontal axis).

a. Trail density—used in the passive recreation value assessment with maximum truth value set at a threshold of 0.65 km/km^2 and minimum value set at 0 km/km^2. The maximum truth value was arbitrarily set at 0.65 km/km^2 to reflect that a relatively low density of trails is considered to provide adequate recreational access.

b. Lake percentage—used in the passive recreation value assessment with a maximum truth value set at 10% and minimum set at 0%. The maximum truth value was arbitrarily set at 10% to reflect the high recreational attraction of mountain lakes, even if they are small in area.

c. Wilderness area percentage—used in the passive recreation value assessment with a maximum truth value set at 100% and minimum set at 0%.

d. Number of patches of mature forest per section—used in the mature forest connectivity assessment with a maximum truth value set at 1 patch/section and minimum values set for 0 patch/section and 45 patches/section (the maximum number in the data set).

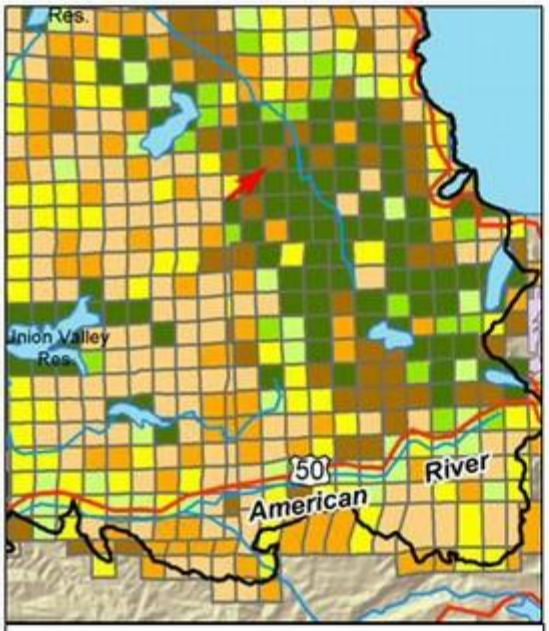

Figure A-2. EMDS recreation value results with example section indicated by red arrow.

In all of the NetWeaver knowledge base diagrams, *bright red* indicates no support for a tested statement, *black* indicates the support is intermediate, while *bright green* indicates there is high support for a tested statement. The left panel of Figure A-3 depicts the two major conditions (*user access* and *resources of recreational interest*) used to determine if a section has high passive recreation value. Based on the conceptual model for the Science Assessment, there must be both adequate user access and desirable passive recreation features for a section to have high passive recreation value. The use of the *AND* in the knowledge base means that a section must satisfy both conditions to have high passive recreation value. EMDS takes the minimum value of the two truth values when an *AND* operator is used. For our example section, passive recreation value is considered low because user access is low, even though resources of high recreational interest are present.

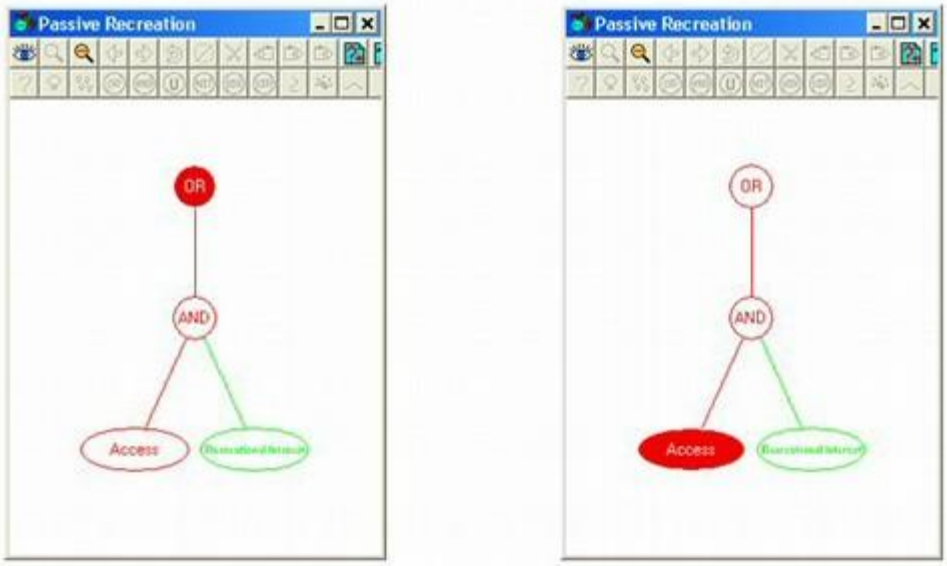

Figure A-3. Knowledge bases for determining passive recreational value. The left panel shows the support for the two conditions of the tested statement: *user access* (access) and resources of *recreational interest* (recreational interest). The right panel shows how the underlying conditions for the *user access* condition can be obtained by clicking on the *access* condition, which leads to the results in Figure A-4.

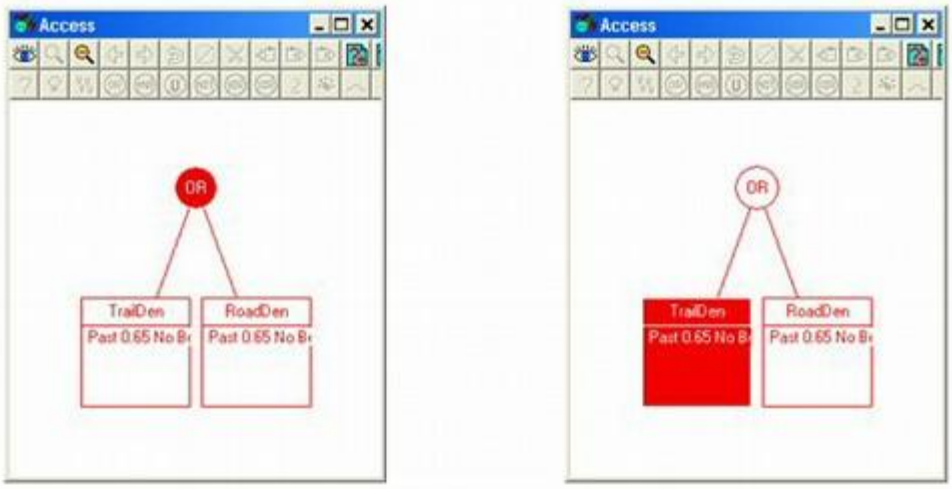

Figure A-4. Knowledge bases for determining user access. The left panel shows the support for the two conditions of the tested statement: *trail density* (TrailDen) and *road density* (RoadDen). The right panel shows the underlying value for the trail density data, which leads to the result in Figure A-5.

Figure A-5. Trail density datum for the example section shown in Figure A-2.

NetWeaver allows the user to see the results of the analysis at different levels of the hierarchical knowledge base. For example, we want to see why the *user access* condition of the knowledge base shown in Figure A-3 is not supported. In the right panel in Figure A-3, the *user access* condition is selected, and the results can be seen in Figure A-4. Access to a section was measured using *road density* (RoadDen) or *trail density* (TrailDen) calculated for each section. The use of *OR* in the knowledge base means that a section is considered to have adequate user access if either road *or* trail density is high, which for this analysis was assumed to be a density of 0.65 km of road or trail per square kilometer of section. This is about the same density as a single, slightly curvy, trail or road running all the way across a section. In the analysis, EMDS takes the maximum value of the two truth values when an *OR* operator is used.

We can see the actual data values for each section of land. For example, in the right panel of Figure A-4, the *trail density* data link is selected and the result is shown in Figure A-5. The actual density of trails for this section was 0.01579 km/km^2, which was substantially less than the threshold density of 0.65 km/km^2 that was considered to support good user access (e.g., Figure A-1). As there are no roads within the example section, the *road density* condition received no support. Figure A-6 depicts trails (black lines) in the vicinity of Desolation Wilderness; the only trail in the area just barely enters the example section at the northeast

corner. EMDS assigns a truth value for this section based on the *trail density* datum for this section and the fuzzy curve for *trail density* (Figure A-1a).

The discussion above shows why there was low support for the *user access* condition within the *passive recreation value*. The other condition used to determine a section's passive recreation value was *features of recreational interest*. Figure A-7 shows the *passive recreation value* knowledge base with the *features of recreational interest* selected. Note that *features of recreational interest* is colored green, indicating high support for this condition for the example.

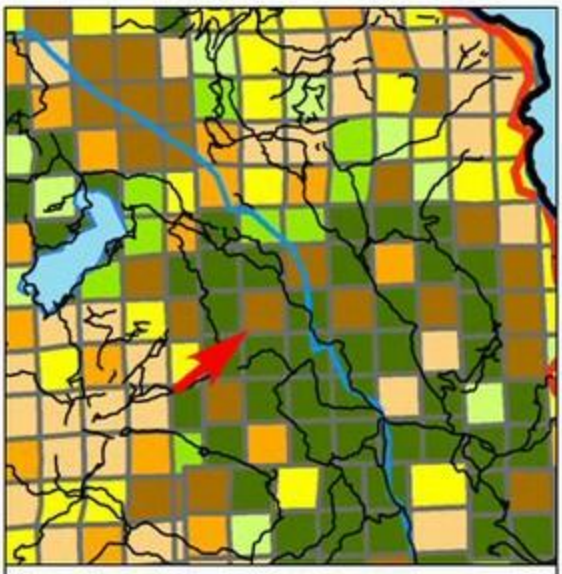

Figure A-6. Trails mapped in the vicinity of Desolation Wilderness. The section discussed in this example is indicated with the red arrow.

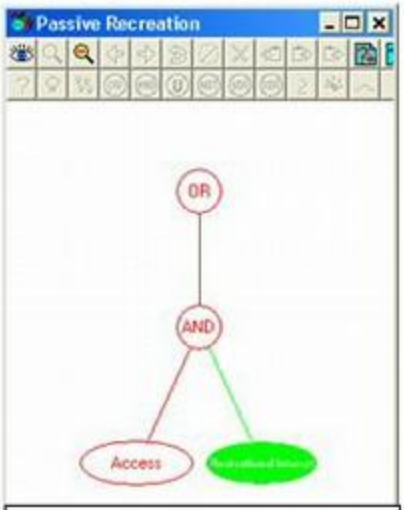

Figure A-7. NetWeaver knowledge bases for determining passive recreational value. The panel shows the support for the two conditions of the tested statement: *user access* (access) and *resources of recreational interest* (recreational interest). *Recreational interest* is selected and the underlying conditions shown in Figure A-8.

In our conceptual model for the Science Assessment, there were seven different types of resources considered to be of recreational interest: rivers, lakes, meadows, late seral forests, wild and scenic rivers, wilderness areas, and areas identified as recreation acquisition priorities by land management agencies (Figure A-8). For this example, we will show results for the *lakes* and *wilderness* conditions. Because of the *OR* operator, a section must have support for only a single recreation feature for the entire section to have high support for the *resources of recreational interest* condition.

The presence of lakes is measured as the percentage of a section covered by lakes. For the example section, the percent coverage by lakes is relatively low (Figure A-9). By selecting the *lakes* data link, we see the data value for the example section (0.190788%), shown in Figure A-10. EMDS assigns a truth value for this section based on the *lake* percentage datum for this section and the fuzzy curve for *lake* percentage (Figure A-1b). Figure A-11 depicts the lakes (blue polygons) for the region around the example section, showing only one small lake in it.

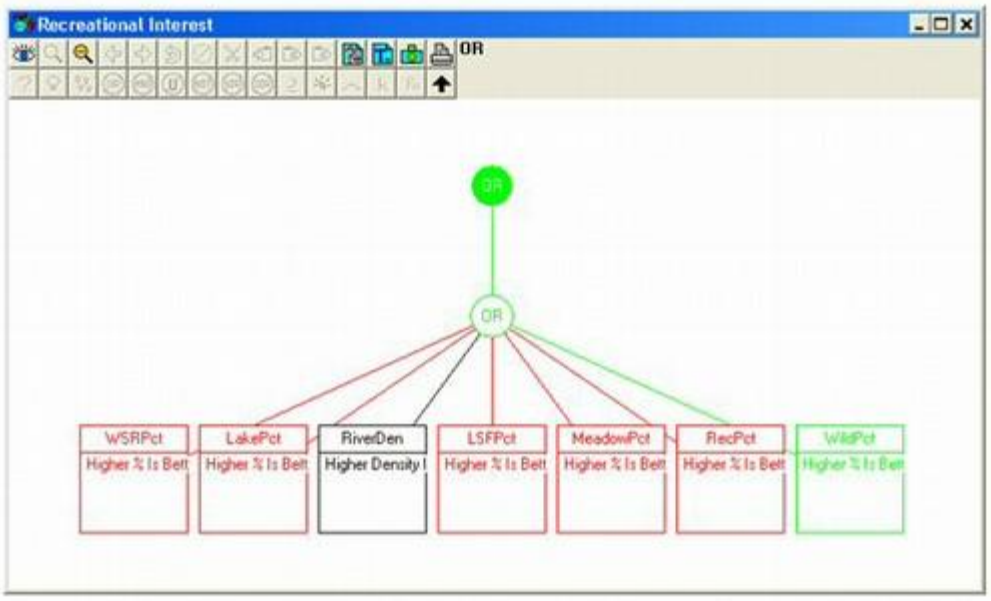

Figure A-8. Conditions used to determine areas of recreational interest. These include: *wild and scenic rivers* (WSRPct), *lakes* (LakePct), *rivers* (RiverDen), *late seral forests* (LSFPct), *meadows* (MeadowPct), *recreation acquisition priorities* by land management agencies (RecPct), and *wilderness areas* (WildPct).

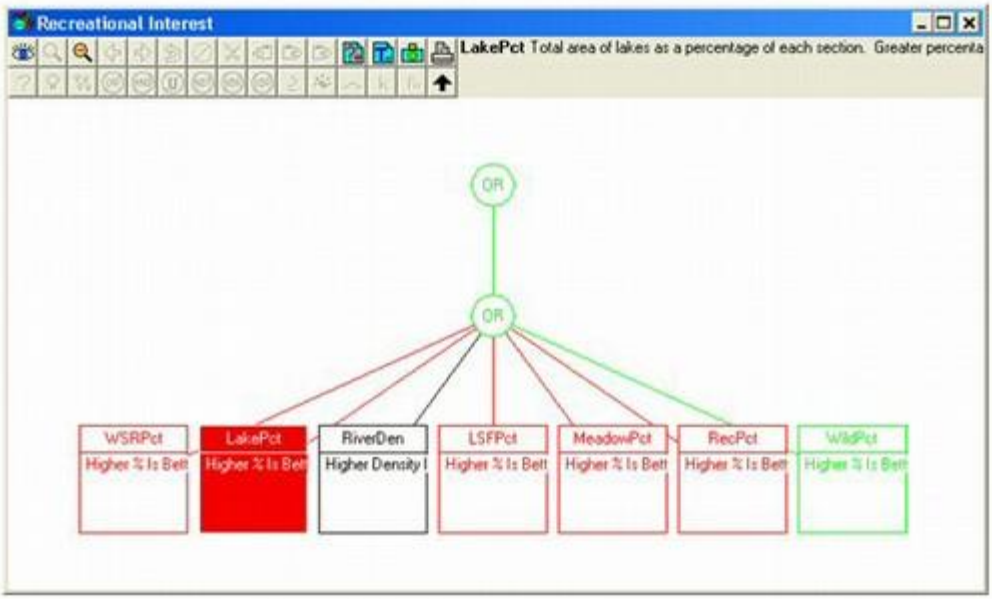

Figure A-9. Conditions used to determine areas of recreational interest for the example section. The presence of *lakes* (Lake Pct) datum is selected, and the underlying datum is shown in Figure A-10.

Figure A-10. *Lake* percentage datum for the example section shown in Figure A-2.

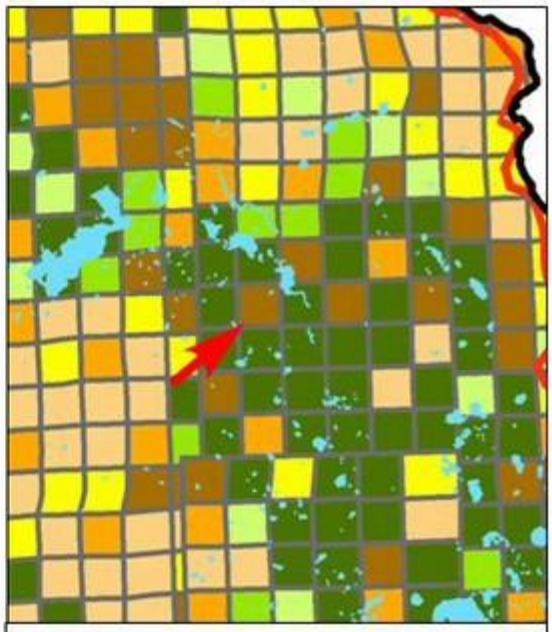

Figure A-11. Lake mapped in the vicinity of Desolation Wilderness. The example section is indicated with a red arrow.

Wilderness recreational features were measured as the percentage of a section encompassed by wilderness. For the example section, the percent coverage by wilderness was very high (Figure A-12). EMDS assigns a truth value for this section based on the *wilderness* percentage datum for this section and the fuzzy curve for *wilderness* percentage (Figure A-1c). Figure A-14 depicts the wilderness boundaries (purple line) within the region around the example section, showing that the section lies completely within the wilderness area.

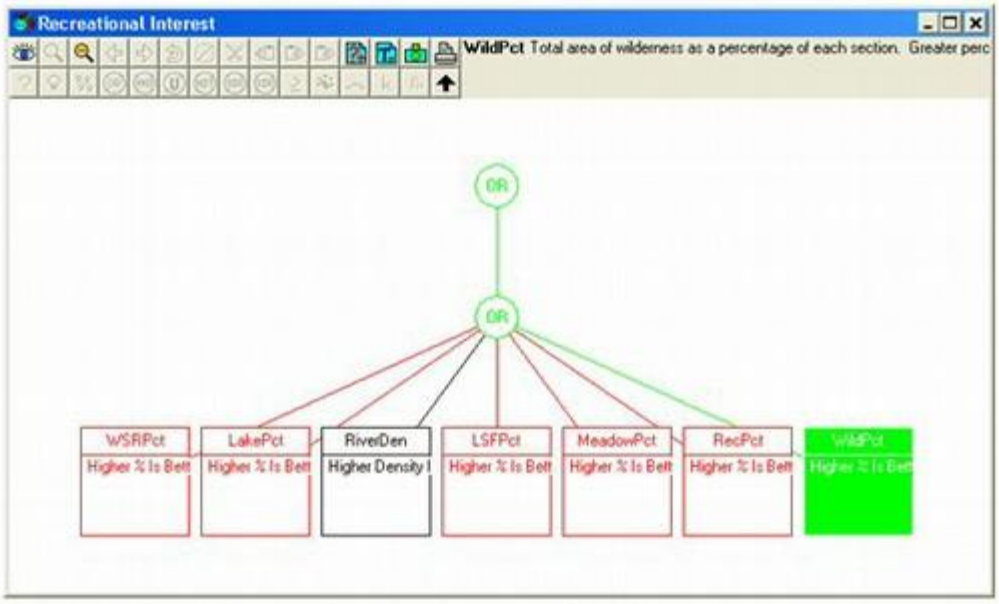

Figure A-12. Conditions used to determine areas of recreational interest for the example section. The *wilderness areas* (WildPct) datum is selected, and the underlying datum is shown in Figure A-13.

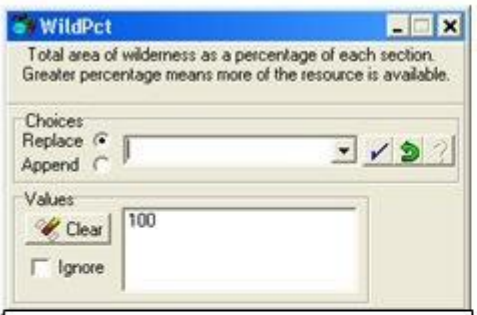

Figure A-13. Wilderness percentage datum for the example section shown in Figure A-2.

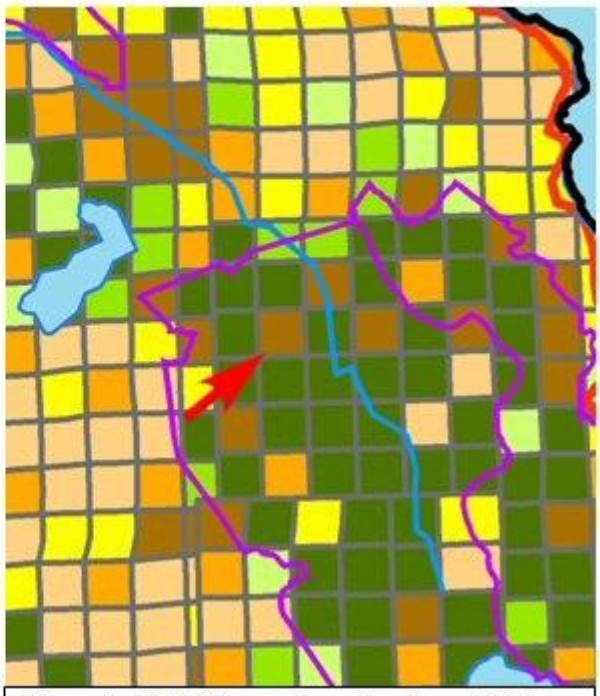

Figure A-14. Wilderness boundary (purple line) mapped in the vicinity of Desolation Wilderness. The example section is indicated with a red arrow and lies completely within the wilderness area.

Literature Cited

Reynolds, K.M., M. Jensen, J. Andreasen, and I. Goodman. 2000. Knowledge-based assessment of watershed condition. Computers and Electronics in Agriculture 27:315-333.

Reynolds, K.M., S. Rodriguez, and K. Bevans. 2002. Ecosystem Management Decision Support 3.0 User Guide. USDA Forest Service.