

#1248

# **ENVIRONMENTAL MODELING**

**Proceedings of the International Conference  
on Water, Environment, Ecology, Socio-  
economics and Health Engineering  
(WEESHE)**

**October 18-21, 1999  
Seoul National University  
Seoul, Korea**

**Edited by**

**Vijay P. Singh**

**Department of Civil and Environmental Engineering  
Louisiana State University  
Baton Rouge, LA 70803-6405, U. S. A.**

**Il Won Seo and Jung H. Sonu**

**Department of Civil and Environmental Engineering  
Seoul National University  
Gwanak-Gu, Seoul 151-742, Korea**



---

*Water Resources Publications, LLC*

# INFORMATION SYSTEMS TECHNOLOGY FOR ASSESSMENT OF RANGELAND ECOSYSTEMS

Leonard J. Lane, Mary H. Nichols, and Lainie R. Levick  
USDA-ARS

Southwest Watershed Research Center  
2000 E. Allen Road  
Tucson, Arizona 85719, U.S.A.

**ABSTRACT:** Increased emphases on conservation, management, and sustainable use of rangeland resources in the western United States has led to the need for new technology for assessing rangeland health. Rangeland health is the degree to which rangeland ecosystems are sustainable under current and alternative land use and management practices. The assessment of rangelands based on health has replaced the traditional assessment based on range condition. The new concept requires new technology to assess soil/site stability, nutrient/energy cycling, and plant recovery mechanisms. Currently, a project is underway to improve soil/site stability assessment using a distributed soil erosion and sediment yield simulation model. Information systems technology has been used to develop an internet-based system to access data, information, knowledge, simulation models, and evaluation criteria to assess rangeland health in an integrated personal computer environment. Information systems technology is used to focus database design and development, data collection and processing, development and management of knowledge bases, simulation of soil erosion and sediment yield, interpretation of sediment yield estimates in the rangeland health context, and knowledge-based determination of rangeland health. Field sites in the Great Plains of the United States are used to illustrate applications of information systems technology in the development and application of rangeland health assessments to improve rangeland resource conservation and management programs.

## 1. Introduction

### 1.1. Background And Importance

Worldwide, rangelands make up about 40% of all land areas (Branson et al., 1981), and in the United States rangelands and pastures make up over half the land areas. In the western United States, rangelands make up over 300 million hectares or as much as 80% of the total land area. Western rangelands are widely distributed geographically and thus produce a very diverse mix of benefits and renewable products ranging from aesthetics for human enjoyment to forage for millions of domestic livestock to water and wildlife habitat. The many natural resources of rangelands, and therefore the health of rangelands, are critical to the well being of humans, wildlife, and ecosystems. If conserved, managed, used, and developed in sustainable ways, these rangelands will remain healthy, and will continue to provide products and values indefinitely.

The distribution and nature of arid and semiarid areas is determined in large part by climate. Arid and semiarid climates are characterized by extreme variability in precipitation and thus uncertainty in water availability, both throughout the year, and from one year to another. Commonly occurring droughts and infrequent periods of above average rainfall and subsequent flooding are also characteristic. Arid regions generally receive too little precipitation to support dryland cropping systems or continuous livestock grazing, although they are grazed by wildlife, and, sometimes, by domestic livestock in wetter years. With increasing precipitation, arid lands change into semiarid lands. Semiarid areas usually have sufficient moisture at some time during the year to produce forage for livestock and wildlife, and there are some years when dryland crop production may be successful. Arid and semiarid areas, meadows, and grazeable woodlands are all considered to be rangelands.

Productive uses of rangeland resources are governed by many factors. Soil is key among the dominant factors because of its influence on productivity and ability to produce forage and vegetative biomass for environmental sustainability, its ability to store water and nutrients, and its status in the continuous struggle to balance soil conservation and productivity with erosion and other degradation processes. Increasing concern for conservation of soil, water, vegetation, and other resources on vast arid and semiarid rangelands in the United States and throughout the world has led to a reconsideration of the scientific and technical basis for assessing and managing rangeland ecosystems. Recent advances in information systems technology and evolving scientific interpretations of rangeland ecosystems can be combined to develop tools for sustainable management of rangelands.

## 1.2. Scope And Purpose

This paper describes the use of integrated information systems for addressing rangeland resource problems. A prototype system is under development at the USDA-ARS Southwest Watershed Research Center in Tucson, Arizona (Figure 1). The conceptual framework for the system, which will contain databases, knowledge bases, an expert system, simulation models, and interpreted output, is described. Currently, the prototype system contains operational databases and knowledge bases linked with a simulation model for evaluating soil and site stability. The system operates within a website. Work is underway to develop an expert system to facilitate populating databases and interpreting simulation model output.

The simulation model embodied in the prototype system was used to quantify sediment yield within a semi-arid ecosystem in the western U.S. Results of the modeling effort were evaluated with respect to rangeland health assessments based on field observations and the judgement of experienced personnel. The results of this analysis are presented, and will ultimately be used in the development of the expert system component of the prototype system. Gaps in knowledge and research needs that were identified through this comparison are described.

## 1.3. Context And Definitions

Much of the science and technology associated with computers, data, and automation evolved within the operations research, computer science, business and business management arenas. While the definitions we use are consistent with, to the extent practical, the standards arising in these subject areas, the present context of agriculture, natural resources, and environmental concern require specificity. In Section 7., a glossary is presented with selected definitions in this context with the specificity essential to the discussions herein.

## 2. Information Systems And Natural Resources

### 2.1. Introduction

Natural resources monitoring, assessment, and management can be conducted on the basis of watersheds, ecological sites and major land resource areas, or political subdivisions. Regardless of the scale of delineation, simulation modeling and application of expert knowledge are required. Not all watersheds, ecological sites, or political subdivisions can be monitored and characterized, so methodologies are needed by which results from monitored sites with measured data can be generalized across the landscape to unmeasured sites. Simulation modeling and application of experienced, expert judgment are used to meet this need. Knowledge based systems incorporating the power of simulation modeling with the judgment of expertise appear to offer more than do modeling or judgment alone. However, simulation models are difficult to use and require

simplification and interpretation (NRC, 1999). Expert judgment has severe limitations due to its lack of transferability and its basis in experience. Clearly, research and technology developments are needed to integrate the power of simulation modeling with the education and experience inherent in expert judgment.

## 2.2. Integrated Information Systems

Integrated (linked components and subsystems) information systems provide a framework for developing computer systems that assist resource managers in efficiently using the information at their disposal. These systems combine the power of simulation modeling with the information from databases, the expert judgement from knowledge bases, and visualization technology. The USDA-ARS is developing an integrated information system with the goal of providing an efficient assessment and management tool for rangelands. The major operational components of the system are a database and a simulation model, which contains a knowledge base. As a mechanism for data storage and retrieval, the database is the foundation of the information contained within an integrated information system. Collected field data, information, expert knowledge, and simulation model input and output can all be stored in a structured format that allows for efficient access. Components under development include additional knowledge bases and an expert system to interpret model output. These components are described below, and will be illustrated through an example application in subsequent sections.

Expert systems have been developed for a wide range of applications including pest management (Berry et al., 1991; Travis et al., 1992), simulation model parameterization (Ritchie, 1989), natural resource planning (Schmoldt and Rauscher, 1996), and regulation and compliance (Greathouse and Decker, 1991). These systems have been built to emulate the decision-making ability of human experts. The particular application that is the focus of this paper can be used to interactively determine a quantitative assessment of the soil stability component of the rangeland health assessment. The quantitative assessment is based on simulated hillslope sediment yield. Output from the hillslope sediment yield model will be interpreted using an expert system that is currently under development. The expert system will apply logic to evaluate and quantitatively rate the impacts of cover, topographic and climate changes on rangeland health. The considerable knowledge and expertise of several scientists and researchers working in the areas of rangeland erosion, hydrology, and ecology are being embodied in the expert system.

## 2.3. Internet-Based Technology Development And Transfer

The best land management tools are significantly enhanced if they are easily accessible. The Internet provides a convenient and far-reaching forum for technology development and transfer. The information system to assess rangeland health is being developed to run within a website currently maintained by personnel at the USDA-ARS Southwest Watershed Research Center. Technology development and transfer will be facilitated through convenient access to the expert system, documentation, scientific publications, and contact with scientists and system developers.

## 2.4. Rangeland Ecosystem Assessment

Rangeland health represents concepts that are complex and difficult to quantify. For the purposes of this paper we adopt the generally accepted definition of rangeland health as defined by the U.S. National Academy of Science/National Research Council (NRC, 1994, p. 4): "rangeland health should be defined as the degree to which the integrity of the soil and the ecological processes of rangeland ecosystems are sustained." A primary determination of rangeland health using this definition is via the degree of soil stability and watershed function in the context of the previously mentioned balance of soil

Recently, gullying and stream sedimentation have been identified as problems on the FCMR, and DECAM has used erosion control dams and other physical means to address the problem. For long-term control and sustainable land use, however, predictive tools are required. Although a 10-year database exists for vegetation and ground cover (Land Condition-Trend Analysis data), DECAM is seeking a methodology that fully uses these data for the evaluation of training impacts with respect to soil erosion and sedimentation. The application of information systems technology for assessment of rangeland ecosystems at FCMR would greatly aid DECAM in using existing data for determining sustainable land use and management.

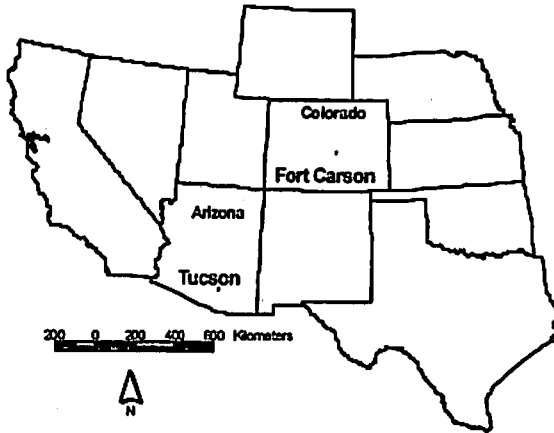


Figure 1. Map of the southwestern United States showing the locations of Tucson, Arizona and Ft. Carson, Colorado.

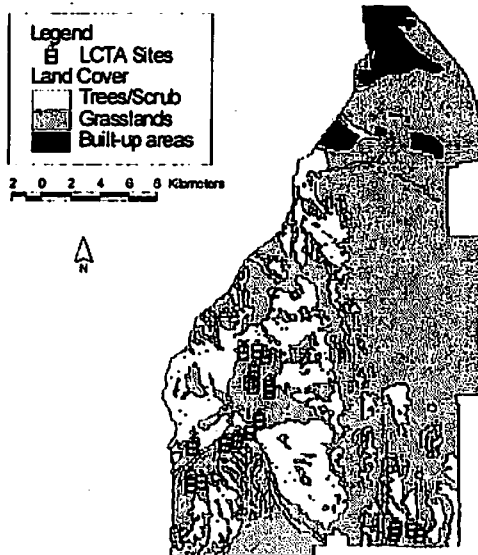


Figure 2. Map of Ft. Carson with Land Condition Trend Analysis sites on generalized vegetation cover.

### 3.2. Assessment Of Rangeland Health At Ft. Carson

During the summer of 1998, twenty (20) field plots were identified at FCMR. Their locations were based on existing land condition trend analysis (LCTA) study sites (Figure 2). All 20 plots were located on trainable land, and occurred mainly in the grassland areas. The ecological sites are loamy foothills, loamy plains, limestone breaks, saline overflow or shaly plains. Plots were approximately 100 square meters in area, and detailed site surveys were conducted on each plot for soil erosion modeling and rangeland health assessments. Most of the plots showed moderate to severe evidence of training activities, such as disturbances from tank tracks.

Rangeland Health assessments were performed on all plots using the Rangeland Health Worksheet from the NRCS National Range and Pasture Handbook, Chapter 4, Rangeland Health (NRCS, 1997) as a guideline. In this chapter (and in the Worksheet), seventeen ecological attributes are described for interpretation of the three critical site ecological processes of soil/site stability, watershed and hydrologic cycle, and soil and plant community integrity. Each of the 17 ecological attributes are field evaluated based on the ecological site description (potential plant community, soil series, and MLRA) and rated from 1 to 5 (1 being the worst, 5 the best). Professional knowledge, expertise, and a preponderance of evidence about the site are used in addition to the 17 Worksheet attributes and ecological site descriptions for final overall rangeland health ratings of *healthy*, *at risk of degradation*, or *unhealthy*. The rangeland health assessments for the 20 sites at Ft. Carson indicated that 30%, or 6, of the sites were *at risk*, and 70%, or 14, were *healthy*.

In an effort to quantify the soil/site stability component of the assessment, field data were collected on all 20 sites to characterize vegetative and surface ground cover, as well as topography. These data are stored in a database and were used as input for modeling soil erosion and sediment yield on each site. The modeling effort addresses 5 of the 17 ecological attributes upon which the qualitative rangeland health assessments are based.

### 3.3. Brief Description Of Hillslope Erosion/Sediment Yield Model.

To estimate sediment yield for analysis of soil/site stability in the rangeland health context, a simple, robust sediment yield model was selected (Lane et al., 1995). This model is a time-averaged solution of the coupled kinematic wave equations for overland flow and the sediment continuity equation. Thus, the solution emphasizes spatially distributed soil erosion and sediment yield processes averaged over a specified time period. The model was developed specifically for hillslopes and tested, evaluated and parameterized primarily for rangeland applications. The sediment-yield model for hillslopes was used to simulate erosion and sediment yield as a function of position on the hillslope and to simulate the influence of spatial variability in hillslope properties (topography, vegetative canopy cover and surface ground cover) on sediment yield and mean sediment concentration. While the simple model may be less powerful than more complex models, the single-event model used has an analytic solution, simplified input, relatively few parameters, and an internal knowledge base to relate slope steepness, soil erodibility, vegetative canopy cover, and surface ground cover to the model parameters.

An important component of the sediment yield simulation model is the knowledge base it contains. Model calibration results, corresponding relationships from the literature, and expert judgment were used to build a knowledge base relating soil properties, slope length and steepness, vegetative canopy cover and ground surface cover with the model parameters. The knowledge base was incorporated as a subroutine (expert system) within the computer program to simulate sediment yield. The entire hillslope sediment yield program is called the Hillslope Model.

The Hillslope Model was used to simulate erosion and sedimentation processes at each of the sites. However, because the knowledge bases relating erosion and

sedimentation processes to rangeland health and soil/site stability are currently under development and testing, only relative sediment yield (sediment yield at each site normalized by the average sediment yield from all 20 sites) was used as a soil/site stability index to compare with the Rangeland Health Worksheet evaluations. A comparison of the results of the rangeland health assessment and erosion modeling is included in Table 1.

**Table 1. Comparison of Erosion Modeling and Rangeland Health Assessment Results Using the Rangeland Health Critical Attributes Worksheet**

Site No.	RH rating	Reason	Erosion rank	Agree?	Reason for disagreement
62	at risk	1 cat.I s/pc-I, 2 cat.II s/ss	3	yes	--
64	at risk	1 cat.I s/pc-I, 2 cat.II s/pc-I	18	no	low slopes (1-2.5%), avg. vc, high gc
76	at risk	1 cat.I s/pc-I, 3 cat.II s/ss	2	yes	--
77	at risk	1 cat.I s/pc-I, 2 cat.II s/ss	17	no	low slope (0.5-2.5%), high vc & gc
137	at risk	2 cat.II s/pc-I, 1 cat.II s/ss	19	no	mild slope (2-3.5%), heavy vc & gc
166	at risk	2 cat.II s/ss	7	yes	--
63	healthy	1 cat.I s/ss, 2 cat.II s/pc-I	20	yes	--
65	healthy	1 cat.I s/pc-I, 1 cat.II s/pc-I	13	yes	--
73	healthy	1 cat.I s/pc-I, 1 cat.II s/pc-I	8	yes	--
79	healthy	1 cat.II s/pc-I, 1 cat.II s/ss	9	yes	--
101	healthy	1 cat.I s/pc-I	6	no	1 crit.attrib. less than cat.III (crypto.crust)
102	healthy	1 cat.I s/pc-I	11	yes	--
135	healthy	2 cat.II s/pc-I	15	yes	--
136	healthy	1 cat.II s/pc-I	12	yes	--
147	healthy	1 cat.I s/pc-I, 1 cat.II s/ss	14	yes	--
165	healthy	1 cat.I s/pc-I	1	no	1 crit.attrib. less than cat.III (crypto.crust)
167	healthy	2 cat.II s/pc-I	16	yes	--
168	healthy	1 cat.I s/pc-I	4	no	1 crit.attrib. less than cat.III (invasive plants)
181	healthy	1 cat.I s/pc-I	10	yes	--
186	healthy	0 less than cat. III	5	no	no crit.attrib. less than cat. III

**Notes:**

cat. I = worst condition, cat. V = best condition

s/ss = soil/site stability attributes group (water flow pattern, infiltration and runoff, cryptobiotic crusts)

s/pc = soil/plant community integrity attributes group (invasive plants, production)

Relative Erosion Rank: 1 = highest, 20 = lowest

vc = vegetative cover

gc = surface ground cover

The rationale behind the rangeland health rating for the *at risk* sites is shown in column labeled "Reason". The Hillslope Model results were ranked by relative erosion rate with "1" indicating the highest relative sediment yield and "20" indicating low. Three of the six sites rated *at risk* showed low erosion rates and relative sediment yield according to the model. The reasons for the three disagreements were due to characteristics, which are indicated in the column labeled "Reason for disagreement".

Assuming the Worksheet/expert based rangeland health ratings are correct, comparing the rangeland health assessment ratings with the relative sediment yield ratings, three of the six *at risk* sites and 10 of the 14 *healthy* sites were identified correctly using the sediment yield ratings. Thus, 13 out of 20 sites (or 65%) were rated correctly using the single sediment yield variable. Analysis with the binomial probability distribution suggests that the probability of this level of success, given no relations between sediment yield and Worksheet assessed ratings, is about 13%. Thus, it is likely at the  $p=0.13$  level that sediment yield alone can predict assessment ratings based on application of the Worksheet. Clearly, additional predictor variables from the Hillslope Model are needed to lower the  $p$  value down to below the 10% or 5% levels.

This comparison demonstrates that expert assessment based on extensive field data and experience provides more information regarding erosion potential or site stability than can be obtained from information on model simulated sediment yield alone. As sediment yield at the bottom of the hillslope is an integrated value from erosion processes occurring all along the hillslope profile, it remains significant in assessing soil/site stability. However, field observations and expert application of the rangeland health assessment methodology incorporate a qualitative evaluation of the entire hillslope. To provide comparable distributed assessment information, distributed output from the Hillslope Model will need to be used in addition to hillslope sediment yield.

Research is now underway to incorporate distributed mean sediment concentration, spatial statistics of distributed sediment yield, and statistics relating soil erosion rates to the depth and properties of the soil profile within the knowledge bases of the expert system. Recently a multi-attribute decision support system was used to assess the physical scale at which rangeland health assessments are performed (Frasier et al., 1999). Information from this type of research can provide guidance on selection of distributed hillslope model information for use in the rangeland health assessments. Additional research is needed, however, to develop relative importance or weighting factors for each of the 17 attributes used in rangeland health assessments.

#### 4. Discussion Of Gaps In Knowledge And Research Needs

There is an immediate need to specify relative weighting factors for the attributes used in the qualitative, worksheet approach to rangeland health assessment and to relate the weighting factors to quantitative, distributed sediment yield information from the Hillslope Model. This step is necessary to develop the knowledge bases required to transform Worksheet tabulations and distributed sediment yield estimates into rangeland health assessments. However, as discussed below, there are additional long-term research needs.

##### 4.1. Distributed Quality Factors For Soil & Site Stability

Currently, the principal soil quality factor used to assess erosion and its impact on soil productivity is the soil loss tolerance. Soil loss tolerance,  $T$  (t/ha/yr), is conceptualized and tied to the Universal Soil Loss Equation (USLE) as described by Wischmeier and Smith (1978). The long-term average annual soil loss rate (t/ha) from eroding portions of the landscape where the USLE is applicable (i.e. on uniform slopes in the absence of sediment deposition areas and in the absence of concentrated flow areas larger than rills)



calculated. The calculated, spatially averaged soil loss rate is then compared to a soil loss rate (T) which can be "tolerated indefinitely" without reducing the productivity of the soil. For most agricultural soils, the recommended T values are 1, 3, or 5 t/ac/yr or 2.24, 6.73, or 11.2 t/ha/y respectively. Depending on soil depth and properties, each soil is assigned a single T value. Rangeland soils tend to be relatively shallow and are often assigned the lower values of T in the range of 2.24 to 6.73 t/ha/y.

However, it is obvious that "tolerated indefinitely" is an ill-defined term that depends upon a variety of soil properties and that spatial averaging underestimates erosion on critical positions in the landscape. Hillslope erosion and sediment yield processes are distributed in time and space and should be compared with attributes or criteria that are also distributed. Comparing sediment yield resulting from distributed processes with a spatially averaged criterion such as soil loss tolerance presents a logical inconsistency. A major gap in our understanding of the role of soil/site stability in rangeland health involves the lack of distributed criteria or attributes to replace the soil loss tolerance concept.

A second need is to develop on-site, distributed soil quality criteria to relate hillslope erosion processes and rates with rangeland health as expressed by soil/site stability and sustainability. Major impacts of soil erosion on upland areas occur off-site and downstream. Evaluating these off-site impacts and developing quality criteria for the upland areas that affect the off-site impacts are critical needs in assessing rangeland health.

#### 4.2. Scale Factors In Assessment Of Rangeland Ecosystem Health

The rangeland health assessment technology described herein applies to processes at the hillslope scale. Management decisions and land use practices are implemented at larger scales, i.e. at the ecological site scale, the pasture or ranch scale, the watershed scale, or at administrative/political subdivision scales. Critical gaps in our understanding of scale effects on hydrological and ecological processes, soil/site stability, biological community factors and their interactions affecting rangeland health limit our ability to scale up rangeland health assessments from hillslopes to broader areas of the landscape.

### 5. Summary Discussion

Productive and sustainable uses of rangeland resources are governed by many factors. Key among the dominant factors is the soil and its productivity and ability to produce vegetative biomass for environmental sustainability. Increasing concern for conservation of soil, water, vegetation, and other resources on vast arid and semiarid rangelands in the United States and throughout the world has led to a reconsideration of the scientific and technical basis for assessing and managing rangeland ecosystems. Recent advances in information systems technology and evolving scientific interpretations of rangeland ecosystems can be combined to develop tools for sustainable management of rangelands.

Integrated information systems provide a framework and new technology to integrate the power of simulation modeling with the education and experience inherent in expert judgement for addressing rangeland resource problems. Currently, efforts are focused on quantifying the soil/site stability component of the rangeland health assessment. Incorporating quantitative measures into the current qualitative methods will significantly strengthen the scientific defensibility of rangeland health assessments. Fortunately, the system will accommodate scientific advances in the quantification of additional rangeland health assessment components such as nutrient and energy cycling and plant recovery mechanisms. Information systems provide a framework for including quantitative methods, as a compliment to the knowledge and experience of field personnel that can be embodied in an expert system. A prototype system under development will provide a tool, accessible via the Internet, for assessing rangeland health. The Internet

provides a convenient and far-reaching forum for technology development and transfer. As a whole, the integrated information system will provide land managers with a broad ecosystem-based tool that has the potential to facilitate better decision making.

## 6. Acknowledgments

We gratefully acknowledge DECAM at the Ft. Carson Military Reservation for their financial support and their continuing efforts to build and maintain long term semi-arid grassland ecosystem databases. We also gratefully acknowledge the support and cooperation of NRCS employees in both Arizona and Colorado in assisting with Rangeland Health Assessments. Finally, the financial support of the USDA-ARS and cooperation of employees at the Southwest Watershed Research Center in Tucson, Arizona have ensured continuing research and advancements in the development of an integrated information system for addressing rangeland resource problems.

## 7. Glossary For Selected Terms

### *Data*

Symbols, numbers, words, graphics or otherwise from observations and measurements that may be organized for analysis.

### *Database Management System (DBMS)*

A specialized set or system of computer programs that store, modify, and extract information from an electronic database.

### *Electronic Database*

A computerized and systematized collection of data grouped together and organized to enable search and retrieval.

### *Electronic Knowledge-Base*

An electronic database that stores knowledge used to solve problems in a particular problem area or a specific domain.

### *Electronic Knowledge Based System (or Knowledge Based System)*

A set or system of computer programs that solve problems requiring specialized knowledge. This knowledge need not necessarily be acquired from human experts, a major difference from expert systems. Although the terms "knowledge based system" and "expert system" are often used interchangeably, the distinction is necessary to identify system performance comparable to human experts.

### *Expert System*

A set or system of computer programs, which embodies organized data, organized knowledge, and sometimes simulation models in an area of expertise to perform as a skilled, effective consultant. The term "expert system" is used to signify that knowledge was acquired from human experts.

### *Information*

A collection of data that has been organized by the meanings that human beings assign to the data using known conventions. The conventions may be as simple as grouping or as complex as conceptual and mathematical relationships describing the data. "Information" as used here connotes organized data and meaningful relationships. In contrast to knowledge, it does not imply a truthful or factual basis.

### *Information System*

A discrete set of information resources and processes organized for the collection, processing, maintenance, use, sharing, and dissemination of information.

### *Information Technology*

The computers, software, telecommunications, knowledge and services applied to the processing of information.

### *Integrated Information System*

An automated information system supporting one or more major system functions that enables subsystems to share data and eliminate redundant data, operations, and processes. Linkages between components and subsystems are essential to integration.

#### *Knowledge*

A body or representation of data, information, facts, and complex relationships including an awareness and understanding of what is known as true from them and their application in problem solving.

#### *Rangelands*

Lands that have historically been used for livestock grazing, wildlife habitat, watersheds, and open spaces. Arid and semiarid areas, meadows, and grazeable woodlands are all considered as rangelands.

#### *Rangeland Health*

Rangeland health is defined herein as the degree to which the integrity of the soil and the ecological processes of rangeland ecosystems are sustained. Rangelands are classified as *healthy, at risk of degradation, or unhealthy*. A primary determination of rangeland health using this definition is via the degree of soil stability and watershed function in the context of the balance of soil conservation and production with erosion and other degradation processes.

## 8. References

- Berry, J. S., W. P. Kemp, and J. A. Onsager.(1991), Integration of simulation models and an expert system for management of rangeland grasshoppers, *AI Applications*, Vol.5 No.1, pp 1-13
- Branson, F. A., G. F. Gifford, K. G. Renard, and R. F. Hadley. (1981), "Rangeland Hydrology", *Range Science*, Series No. 1, Society Range Management. Denver, CO.
- Frasier, G., M. R. Kidwell, M.A. Weltz, D. Yakowitz, and H. D. Fox. (1998), "Assessing scale issues on semi-arid watersheds with a multi-attribute decision support system", Abstract in *Proc. Rangeland Management and Water Resources*, AWRA Specialty Conference, D.F. Potts (Ed.), May 27-29, 1998, Reno, Nevada, American Water Resources Association, Herndon, Virginia 20170-5531, p.99.
- Greathouse, D. and J. Decker. (1991), "AI And The Environment: Knowledge-Based Tools For Environmental Decision Makers", *PC AI*, 5(6), pp.29.
- "Land Condition-Trend Analysis Installation Report". (1989), Fort Carson Military Reservation, Fort Carson, Colorado.
- Lane, L. J., Nichols, M. H., and Simanton, J. R. (1995), "Spatial variability of cover affecting erosion and sediment yield in overland flow", In. *Effects of Scale on Interpretation and Management of Sediment and Water Quality*, Proc. of a Boulder Symposium, July 1995, W. R. Osterkamp (Ed), IAHS Pub. No. 226, pp.147-152.
- National Research Council (NRC). (1994), "Rangeland health: New methods to classify, inventory, and monitor rangelands", Committee on Rangeland Classification, Board on Agric., National Research Council, National Academy Press, Wash., D.C., 180 pp.
- National Research Council (NRC). (1999), *New Strategies For America's Watersheds*. National Academy Press, Wash., D.C.

- Natural Resource Conservation Service (NRCS). (1997), National range and pasture handbook, Chapter 4, Inventorying and monitoring grazing land resources. (190-NRPH, Sept. 1997).
- Polzin, Charles, (1998), *Plant Community Associations of Fort Carson, Colorado*, (draft) Directorate of Environmental Compliance and Management, Fort Carson, Colorado.
- Ritchie, J. R. (1989), "An expert system for a rangeland simulation model", *Ecological Modelling*, 46, pp.91-105.
- Schmoldt, D. L. and H. M. Rauscher. (1996), *Building knowledge-based systems for natural resource management*. Chapman & Hall, New York, 386 pp.
- Travis, J. W., E. G. Rajotte, R. Bankert, K. D. Hickey, L. A. Hull, V. Eby, P. Heinemann, R. M. Crassweller, and J. McClure. (1992), "A working description of the Penn State Apple Orchard Consultant, and expert system", *Plant Disease* Vol. 76, No. 6, pp.545-554.
- Wischmeier, W. H., and Smith, D. D. (1978), *Predicting rainfall erosion losses*. Agriculture Handbook No. 537, USDA Sci. and Educ. Admin., Washington. DC.