



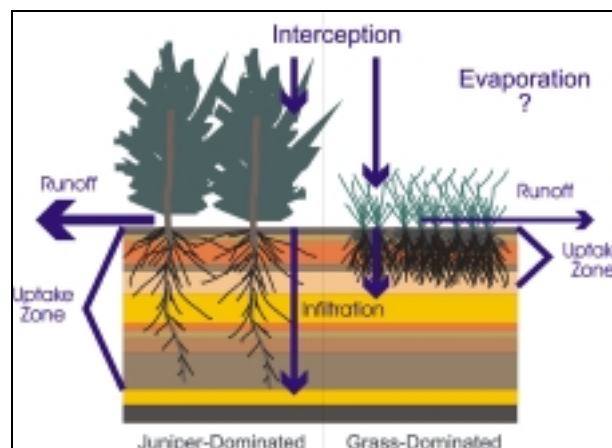
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# A Functional Description of the Ecological Dynamics Simulation (EDYS) Model, With Applications for Army and Other Federal Land Managers

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In FY95, USACERL initiated the "Land Based Carrying Capacity" capability package. The impetus behind this research and development package was the coincidence of needs from the Office of the Deputy Chief of Staff for Operations (ODCSOPS), the Office of the Directorate of Environmental Programs (ODEP) and several installations, to address the requirement of sustainable training and testing land carrying capacity. A key component of this capability package is the Ecological Dynamics Simulation (EDYS) model. The model provides the capability to predict responses of training lands to both military and non-military stressors and

facilitates linking the cost of training and testing land maintenance to the actual level of training.

We provide here a functional description of the EDYS model with applications for several Army installations, the U.S. Air Force Academy, and the National Water Management Center of the USDA Natural Resources Conservation Service. We also have included appendices that describe system implementation, and data requirements and structure. The EDYS model will be incorporated into the Land Management System (LMS) and will be available to users via the Corps' Engineer Research and Development Center web site.

## Foreword

This study was conducted for Office of the Directorate of Environmental Programs (DAIM), Assistant Chief of Staff (Installation Management) (ACS[IM]) under project 4A162720A896, "Environmental Quality Technology," Work Unit EN-TK-7, "Land-based Carrying Capacity." The technical monitor was Dr. Victor Diersing, DAIM-ED-N.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr. David L. Price. Dr. Harold E. Balbach is Chief, CECER-CN-N, and Dr. John T. Bandy is Operations Chief, CECER-CN. The technical editor was Gloria J. Wienke, Information Technology Laboratory. The Director of CERL is Dr. Michael J. O'Connor.

Drs. Terry McLendon, W. Michael Childress, and Cade L. Coldren are Vice President, Ecological System Scientist, and Ecological Modeller, respectively, of Shepherd Miller Inc., Department of Ecological Systems, Fort Collins Colorado, and developed the Army's and other applications of the Ecological Dynamics Simulation (EDYS) model under contract to CERL.

Mr. Brett Russell and Mr. Kevin Vonfinger, Directorate of Environment, Fort Bliss, Texas; Mr. Don Jones, Land Rehabilitation and Management Coordinator, Fort Hood, Texas; Mr. Craig Phillips, Land Rehabilitation and Management Coordinator, Fort Riley, Kansas; Mr. Pete Nissen, Chief of Natural Resources, Yakima Training Center, Washington; and Mr. T. Gene Gallogly, Environmental Division Manager, U. S. Air Force Academy, Colorado Springs, Colorado all provided site-specific technical expertise and data, reviews of early versions of the EDYS model, and funding to leverage the Land Based Carrying Capacity capability. In particular, Fort Bliss' internal carrying capacity research program heavily leveraged the military impacts component of the Land Based Carrying Capacity capability and provided essential databases for the EDYS model regarding tracked and wheeled vehicle impacts and impacts of wildfires.

Drs. Terry Atwood and David Moffit, staff scientists of the National Water Management Center of the USDA Natural Resources Conservation Service, provided technical expertise, reviews of the EDYS model, and funding (Military Interde-

partmental Purchase Request [MIPR] #677103712) to leverage the development of the water dynamics module of the EDYS model. This was done in conjunction with the demonstration and validation of the EDYS model at Fort Hood, Texas, that was partially funded by the U.S. Army Environmental Center (MIPR #5617). The technical monitor was Ms. Kim Michaels.

Mr. William Beavers, formerly staff scientist of the Plant Materials Center, U.S. National Park Service, provided technical expertise and data, reviews of the EDYS model, and funding for several applications of the EDYS model specific to National Park needs. These applications were a direct leverage of Army and National Park Service funds, a direct effort to share land management information, and in practice an interagency partnership.

The military impacts component of the EDYS model was partially funded by the Office of the Directorate of Environmental Programs (DAIM), Assistant Chief of Staff (Installation Management) (ACS(IM)) under Project 40162720A896, "Environmental Quality Technology," Work Unit LL-T08, "Installation Capacity Factors." The technical monitor was Dr. Victor E. Diersing, DAIM-ED-N. The principal investigator was Mr. Alan B. Anderson.

The military impacts component of the EDYS model was partially funded by the Strategic Environmental Research and Development Program (SERDP) Office under Funding Authorization Document (FAD) 0400-98-8141-08, work unit EL8, "Improved Units of Measure For Training and Testing Area Carrying Capacity Estimation." The technical monitor at the beginning of this work was Dr. Femi Ayorinde, Conservation Program Manager. The current technical monitor is Dr. Robert Holst. The principal investigator was Mr. Alan B. Anderson.

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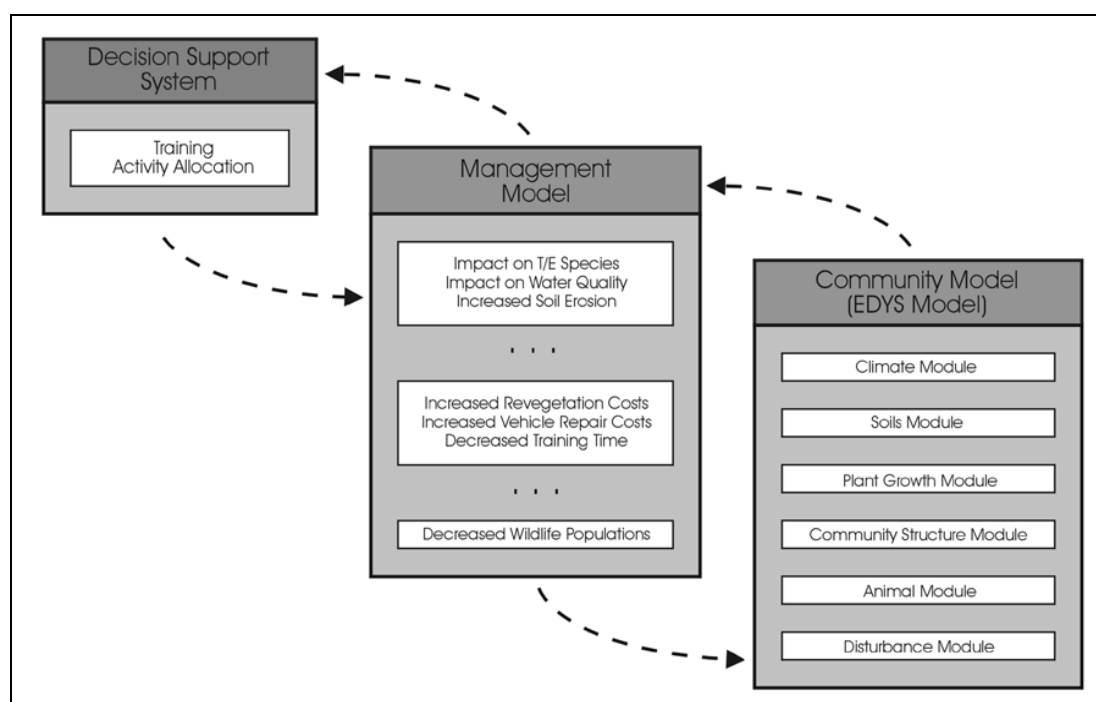
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# 1 Introduction

This report contains an understandable functional description of the Army's version of the Ecological Dynamics Simulation (EDYS) model. To accomplish this we use examples of applications specifically for Army training as a stressor, developed in conjunction with Forts Hood and Bliss, Texas, as well as examples of other applications developed for other federal land managers. We address our approach to scaling the model, provide diagrams and pseudo code for module structure, module programs, module linkages, database design and plans for Internet access. For those readers who are so inclined, we have included appendices that describe system implementation (Appendix A), and data requirements and structure (Appendix B). For a complete discussion on the theoretical background, conceptual approach (Figure 1), technical approach, and approaches for technology transfer plans for the EDYS model, see McLendon, Childress, and Price 1996; Childress, McLendon, and Price 1999; and Price et al. 1997.



**Figure 1. Army Training Decision Support System.\***

\* The Management Model produces all projections of anticipated effects of different training scenarios. EDYS provides projections of dynamics of all ecosystem components under these scenarios.

The impetus behind the research and development of the EDYS model was the coincidence of needs from the Office of the Deputy Chief of Staff for Operations and Plans (ODCSOPS), the Office of the Directorate of Environmental Programs (ODEP), and several installations, to address the requirement of sustainable training and testing land carrying capacity (U.S. Army Environmental Center 1996). We also have executed the research and development of the EDYS model within the context of the Department of Defense (DOD) guidance for implementation of an “Ecosystem Management” approach to military land management (DOD 1994 and Goodman 1996), and the DOD Instruction 4715.3, “Environmental Conservation Program” (DOD 1996). Although the term “Ecosystem Management” and the associated concepts (e.g., ecological thresholds) remain controversial, the core themes are generally well accepted by the public and professionals. The primary contact with ecosystem management for most people, including DOD land managers, is vegetation management (see Brown, Herrick, and Price 1999). In the Army’s case, vegetation management is where we strive to maintain a realistic training and testing environment on a sustained basis. The EDYS model is one of several useful tools to achieve this end.

## Background

The principal program used by the Army to manage its training lands is the Integrated Training Area Management (ITAM) program (Macia 1996). The Land Condition Trend Analysis (LCTA) component of ITAM provides an estimate of the status of the installation’s land and natural resources and trends in those resources. ODCSOPS is currently responsible for the ITAM program and has initiated actions to improve the utility of LCTA data and day-to-day management of the Army’s land assets within the context of ITAM. One of these initiatives is to develop methods to link the cost of training land maintenance to the actual level of training activity and the subsequent trend in condition of the resource (U.S. Army Concepts Analysis Agency [CAA] 1996). Over the past 15 years these efforts have enhanced the Army’s ability to be good stewards of their training lands and associated resources.

Despite these efforts, increasing public concern about the environment continues to generate new legal and regulatory restrictions on training land use. In particular, training impacts on vegetation integrity, threatened and endangered species habitat, soil stability, and water quality/quantity are of major concern. The traditional approach to addressing these types of concerns has been to acquire the necessary data to make a judgment regarding the status and trend of the resources in question. The cost of acquiring the necessary data to determine status and trend and then design and implement a restoration or rehabilitation effort is

often prohibitive until the issue becomes a regulatory or compliance problem. Therefore, in practice, training land management has become management by prioritized level of compliance problems rather than preventative.

In an effort to help training land managers deal with this situation the Deputy Under Secretary of Defense for Environmental Security has initiated an effort to develop and use modeling and simulation technologies within the context of ecosystem management (Goodman 1996). The idea is to use currently available data with knowledge of management oriented ecological thresholds (Brown, Herrick, and Price 1999) and ecological simulation modeling (McLendon, Childress, and Price 1996; Childress, McLendon, and Price 1999; Price et al. 1997) in a risk-based approach to predict outcomes of planned training land use. This approach will reduce data acquisition and its cost to only the data necessary to develop a good a priori decision or management strategy. However, until recently there has been only limited research with the specific objective of developing quantitative vegetation dynamics models that are temporally and spatially explicit enough to lend themselves to practical land management decisions (Brown, Herrick, and Price 1999).

In Fiscal Year 1995, the U.S. Army Construction Engineering Laboratory (CERL) initiated an applied research project to develop a mechanistic-based ecological dynamics simulation model. We planned to incorporate into the model, current knowledge of military impacts and management scenarios on training lands to predict carrying capacity for training lands and facilitate linking the cost of training to land and resource maintenance. An initial evaluation of simulation models then in the public domain for land management resulted in the following conclusions. The models suffer from one or more of the following shortcomings: (1) overly general and of little practical value in evaluation of specific management scenarios, (2) overly specific and therefore, limited to only one or a few sites, (3) very complex and require extensive calibration with site-specific data that are not available, and (4) the endpoints they evaluate, such as soil erosion, are important but the endpoint is only one of several important aspects of ecological dynamics (McLendon, Childress, and Price 1996). However, as a result of this evaluation we found in the private sector an existing simulation model that did not suffer from the above constraints (Childress, McLendon, and Price 1999 and Price et al. 1997). Therefore, CERL determined that it would be most cost effective to partner with the private sector and several key installations to develop applications of this existing ecological simulation model. The core model is generally applicable Army-wide but can easily be made applicable to any installation with only minimum site-specific data requirements.

## Objectives

The first objective of this research was to develop military applications of an ecological dynamics simulation model that are applicable to most terrestrial ecosystems but easily calibrated for site-specific applications with only data from the literature and currently available field data from installations. A second objective was to develop the simulation model so that it would stand alone as a PC-based system. The next phase will be to link EDYS with GIS and GIS-based landscape process models such as CASC2D.

## Approach

Our approach has been to develop a general hierarchical model, EDYS, in a modular design to quantitatively simulate small- to large-scale ecological dynamics. Modules with linkages at the quadrat (1x1 m), community (1 ha), and landscape-level (thousands ha) have been developed. We present here the design for each module, the functional linkages, results from preliminary simulation runs, code for each module and link, and results thus far from field studies designed to provide calibration, testing, and validation of EDYS. We have also explicitly incorporated the mechanistic approach and ecological processes into the EDYS model. The purpose is to increase the predictive capability and realism and allow consideration of a broad cross section of stressors, including the complex interaction between natural stressors and management actions. Current thinking and application support this approach of simulating the underlying mechanisms that drive ecological processes to more accurately predict ecological dynamics or trajectories, based on management-specified requirements (see Childress et al. 1999 and Brown et al. 1999).

## Mode of Technology Transfer

The EDYS model described in this report is or can be linked with other appropriate simulation technologies and decision environments being developed for the Army, DOD, and other Federal and private land managers. EDYS is also being developed as a stand-alone PC-based program for other applications leveraged by other Federal agencies. This report is available in color on the CERL web site at [www.ccer.army.mil](http://www.ccer.army.mil).

## 2 Model Design

The EDYS model is a PC-based, mechanistic simulation model developed by Drs. Terry McLendon and W. Michael Childress. EDYS simulates changes in all components of ecological systems resulting from natural and anthropogenic ecological stressors. It can be applied to a wide variety of ecosystems and numerous disturbance and management scenarios.

EDYS consists of Climate, Water, Nutrient, Contaminant, Soil, Plant, Animal, Spatial, Stressor, and Management Units. Climatic inputs can be historical or stochastically generated, or a combination of these. The Water, Nutrient, and Contaminant Units simulate transport, fates, and effects of these materials in all parts of the ecosystem. The Soil Unit is subdivided into layers (horizons, sub-horizons, or artificial layers), the characteristics of which are specified for each site. The Plant Unit includes above- and below-ground components for each individual species within a user-defined suite. Plant growth is dynamic in relation to plant components (roots, trunk, stems, leaves, seeds, and standing dead material), season, resource availability, and stressors. The Animal Unit consists of basic population parameters and diets for each species (e.g., insects, small mammals, large mammals, livestock). The Stressor Unit includes drought, nutrient availability, competition, herbivory, fire, trampling (foot and vehicle), contaminants, and control activities. The Spatial Unit implements processes ranging across multiple ecological scales: fine scale (1 m<sup>2</sup> or smaller), patches (e.g., 100 m<sup>2</sup>), communities (e.g., 1 to 10 hectares), and landscape and watersheds (1-km<sup>2</sup> and larger). Time intervals vary from day (e.g., precipitation events, plant water demand, fire, herbivory) to month (e.g., plant growth, species composition) to year and longer (e.g., climatic cycles).

The EDYS core model is parameterized with data for each application. For a first approximation, these data can consist entirely of literature or other currently existing values. A large database incorporating ecological data for a great variety of plant and animal species and sites is currently being developed to facilitate fast initial parameterization and testing. However, increased accuracy in EDYS projects can be achieved, if desired, by collection and use of site-specific data.

EDYS is currently being used to simulate responses to 17 ecological and management stressors in 33 different ecological communities at 14 sites. The stressors include contaminants (metals), cultivation, drought, erosion, fire, herbivory (insects, rodents, deer, elk, bison, cattle), hunting, logging, military training, mining, non-native plant invasion, nutrient availability, revegetation, road construction and abandonment, secondary succession, trampling, and weed control (biological, chemical, fire, mechanical). The sites include: Fort Bliss, Texas; Fort Carson, Colorado; Fort Hood, Texas; Fort Riley, Kansas; Yakima Training Center, Washington; U.S. Air Force Academy, Colorado; Acadia National Park (NP), Maine; Big Bend NP, Texas; Glacier NP, Montana; Grand Tetons NP, Wyoming; Lake Mead National Recreation Area (NRA), Nevada; Rocky Mountain NP, Colorado; Yellowstone NP, Wyoming; and Midnite Mine, Washington. Ecological communities at these sites include freshwater wetlands, riparian shrublands, creosote bush desert, sagebrush shrubland, desert grassland, shortgrass plains, bluestem prairie, fescue prairie, ponderosa pine forest, lodgepole pine forest, and subalpine fir/alpine tundra.

EDYS applications for three US military installations are now well underway. The Fort Hood project involves modeling the impacts of military training, fire, grazing, and juniper control on the vegetation dynamics, soil erosion, and water yield of a 3-community landscape/ecotone in central Texas. The Fort Bliss application addresses similar impacts in a black grama grassland in the Chihuahuan Desert. The U.S. Air Force Academy project addresses the impacts of 10 management scenarios (e.g., cadet training, grazing, hunting, weed control) on a 7-community landscape in the 3000-acre Jack's Valley Training Area. Other EDYS applications consider: (1) revegetation of abandoned roadways in Grand Tetons NP and Lake Mead NRA, (2) purple loosestrife invasion of wetlands in Acadia NP, (3) ecological effects of fire in pinyon-juniper-oak woodlands in Big Bend NP, (4) impacts of fire and grazing by bison and elk on sagebrush shrubland in Yellowstone NP, (5) road cut erosion control and revegetation in Big Bend NP, and (6) rangeland recovery following cultivation in blue grama grassland in Colorado.

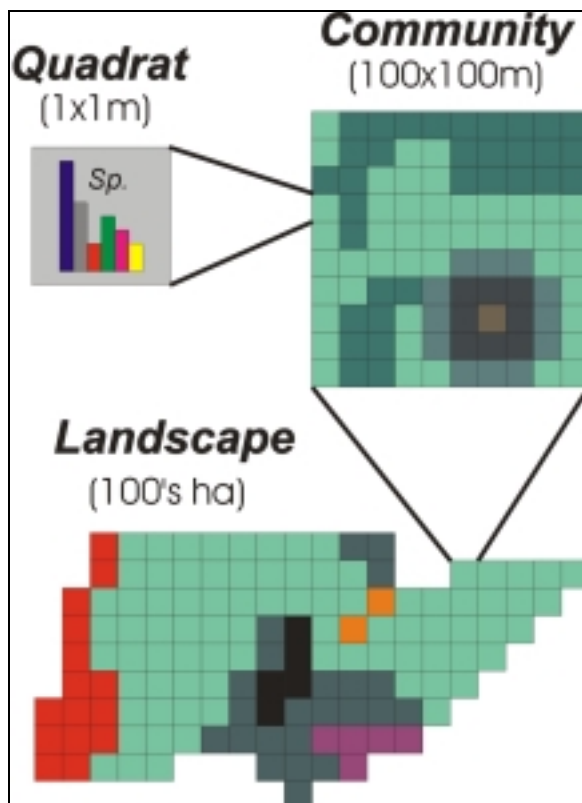
Because EDYS uses explicit representations of all components of terrestrial ecosystems and all important ecological processes in these systems, it can be adapted for almost any terrestrial system, ranging from small plots to an entire landscape. Because processes are simulated mechanistically, indirect effects, long-term cumulative effects, and ecological thresholds can be evaluated to fully assess impacts of stressors and management strategies.

## Multiple Scales

EDYS contains three major modules that correspond to three major scales in ecosystems: Quadrat, Community, and Landscape. The Quadrat Module is the basic unit in the Community Module, and the Community Module is the basic unit in the Landscape Module (Figure 2).

The Quadrat Module simulates ecological mechanisms and dynamics at the small scale ( $1 \text{ m}^2$  to  $100 \text{ m}^2$ ). Most of the mechanisms in the EDYS model related to plants (growth, water and nutrient uptake, and competition) and soils (water and nutrient transport through the profile, decomposition) are implemented in this module.

The Community Module focuses on spatial patterns and dynamic from the patch ( $100 \text{ m}^2$ ) to the community (1 to 10 hectares) scales. These include spatial heterogeneity in soils, plants, and stressors among quadrats within the community, stressors such as fire propagation, grazing, and lateral flow of surface and sub-surface water and materials, and important spatial patterns such as vegetation cover, habitats, and topography.



**Figure 2. Quadrat-Community-Landscape Module linkages in EDYS.\***

\* Multiple Quadrats are included within each community to represent small-scale ecological heterogeneity. Similarly, multiple communities are included in the landscape to represent medium-scale ecological heterogeneity.

The Landscape Module focuses on ecological processes operating at large spatial scales (1 km<sup>2</sup> and larger). These include fire initiation regimes, climatic regimes, watershed-level water movement and transport of materials, and management practices such as training scheduling, grazing operations, and weed control.

## Quadrat Module

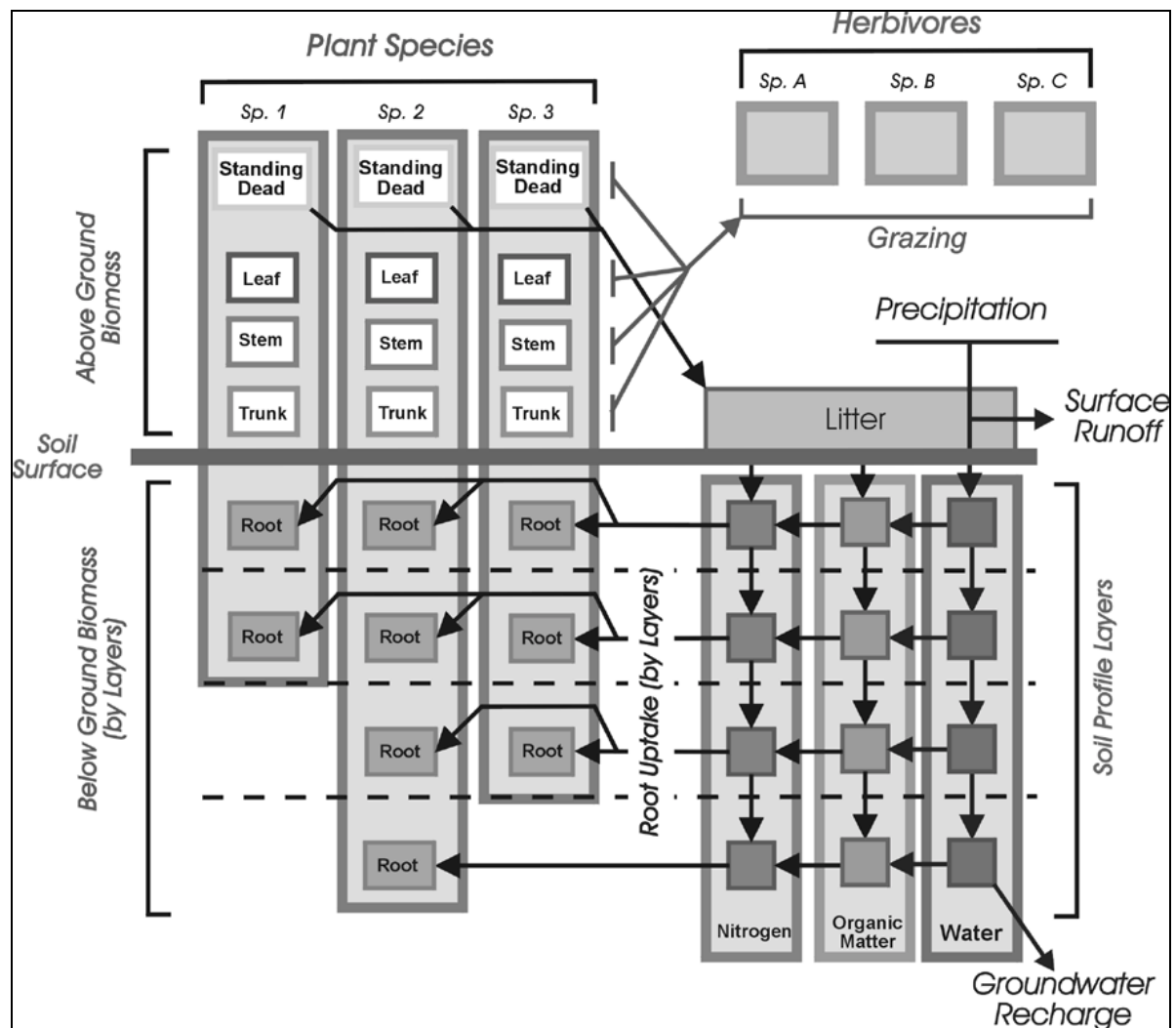
The Quadrat Module comprises the core of the EDYS Model. All the small-scale components of terrestrial ecosystems are explicitly represented by state variables in this module (Figure 3). The spatial extent of each Quadrat is set to be the smallest unit that contains reasonably uniform vegetation and soil profile. Most EDYS applications to date have set the Quadrat scale at 1 m<sup>2</sup>, although in one application Quadrats of 150 x 150 m were used to correspond with available ecological data. The Soil Unit in the Quadrat Module represents the vertical depth, water content and holding capacity, nitrogen content, organic matter content, contaminant content, microbial activity, and decomposition rates in each horizon of the soil profile. Precipitation events cause movement of water through the profile and transport of nitrogen, organic matter, and contaminants between horizons. The Plant Unit implements the structural components of all selected plant species, including root biomasses in each of the soil horizons. Plant production algorithms in this unit calculate uptake of water, nitrogen, and contaminants from each horizon, and allocation of new growth among the different structural components. The Animal Unit incorporates important herbivore, omnivore, and predator species in the model. Diet preferences of all animal species are used to simulate herbivory losses of all plant species and transport of contaminants in the food web. Trophic energetics and habitat availability and preferences are used as bases for projecting population dynamics.

Different processes implemented in the Quadrat Module operate at different time scales, and are therefore incorporated into different calculation loops corresponding to different time steps (Figure 4). For example, most of the hydrological, soil profile, and herbivory operations are conducted on a daily basis, and are included in the Daily Loop. Plant growth operations are conducted in the Monthly Loop, using as inputs the cumulative daily uptake of water and nutrients in the Daily Loop.

These different time loops provide great flexibility in adapting EDYS to different management and stressor scenarios. For example, calculations for consumption of plant parts by animals is conducted daily; however, the herbivore population response to plant consumption is conducted monthly. Effects of human disturbances such as military training activities or park visitation activities can be



simulated on daily or monthly bases, depending on the time interval and intensity of these stressors as well as on characteristics of available data. Because EDYS uses essentially all ecosystem components and processes at multiple spatial and temporal scales, complex ecological effects of almost any type of stressor can be addressed with suitable definition of parameters and calibration.



**Figure 3. Ecosystem representation in the EDYS Quadrat Module.\***

\* The dynamics of all depicted elements in the ecosystem are calculated in various EDYS Units to provide a mechanism-based projection of overall ecosystem dynamics.

## Community Module

Although the Quadrat Module provides detailed simulations of small-scale ecological dynamics, there can be considerable heterogeneity in small-scale soil profiles and vegetation within a plant community. This heterogeneity is explicitly represented in the EDYS Community Module in a grid-based representation of this spatial variability (Figure 5). The dynamics of Quadrats with similar vegetation and soils are simulated by a single version (a “Quadrat Type”) of the Quadrat Module. Quadrats with different vegetation or soils are simulated by different Quadrat Types. The spatial pattern of where these different Types occur within the Community is then represented by a grid of Quadrat cells arrayed within the Community. In this manner, EDYS is able to implement important small-scale processes such as soil hydrology and plant growth within each Quadrat Type, without the computational intractability of independently simulating every cell in the Community grid. Instead of simulating potentially several hundred Quadrats independently in the Quadrat Module, typically 2 to 10 representative Quadrat Types are simulated and their results applied to corresponding cells in the grid.

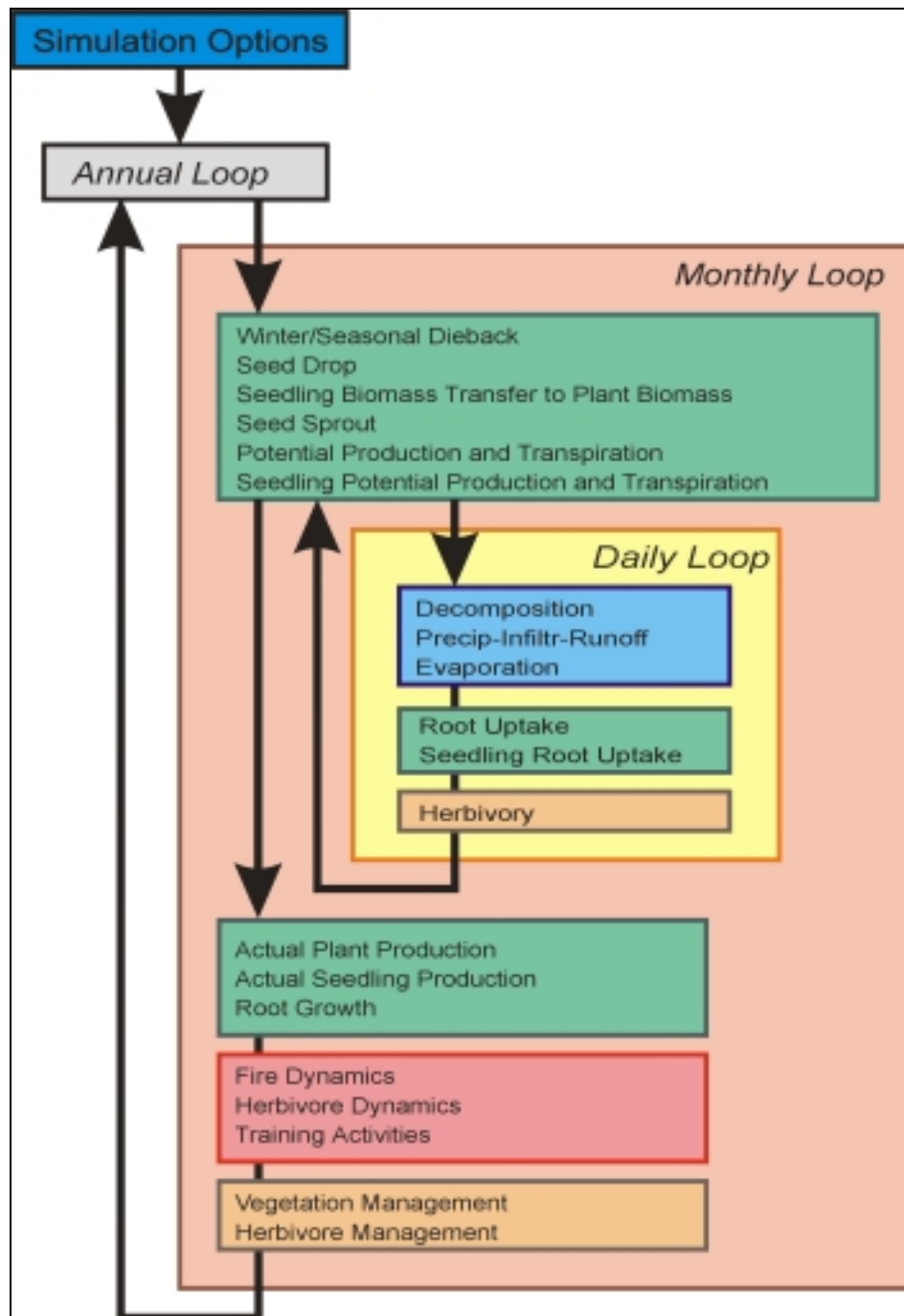
The Community Module coordinates the dynamics of the Quadrat Types, represents their locations in the Community Grid, and simulates community-level processes such as fire propagation, grazing, surface and subsurface lateral flow of water and materials, and small-scale disturbances such as trails and roads.

Certain disturbances such as fire can cause changes in the vegetation composition of affected Quadrats, therefore requiring new Quadrat Types in the EDYS model to reflect the effects of such stressors. The Community Module coordinates the creation of new Quadrat Types to reflect the impacts of quadrat to community-scale disturbance, and the merging of Quadrat Types when their structural components become sufficiently similar again, such as when vegetation fully recovers after fire.

## Landscape Module

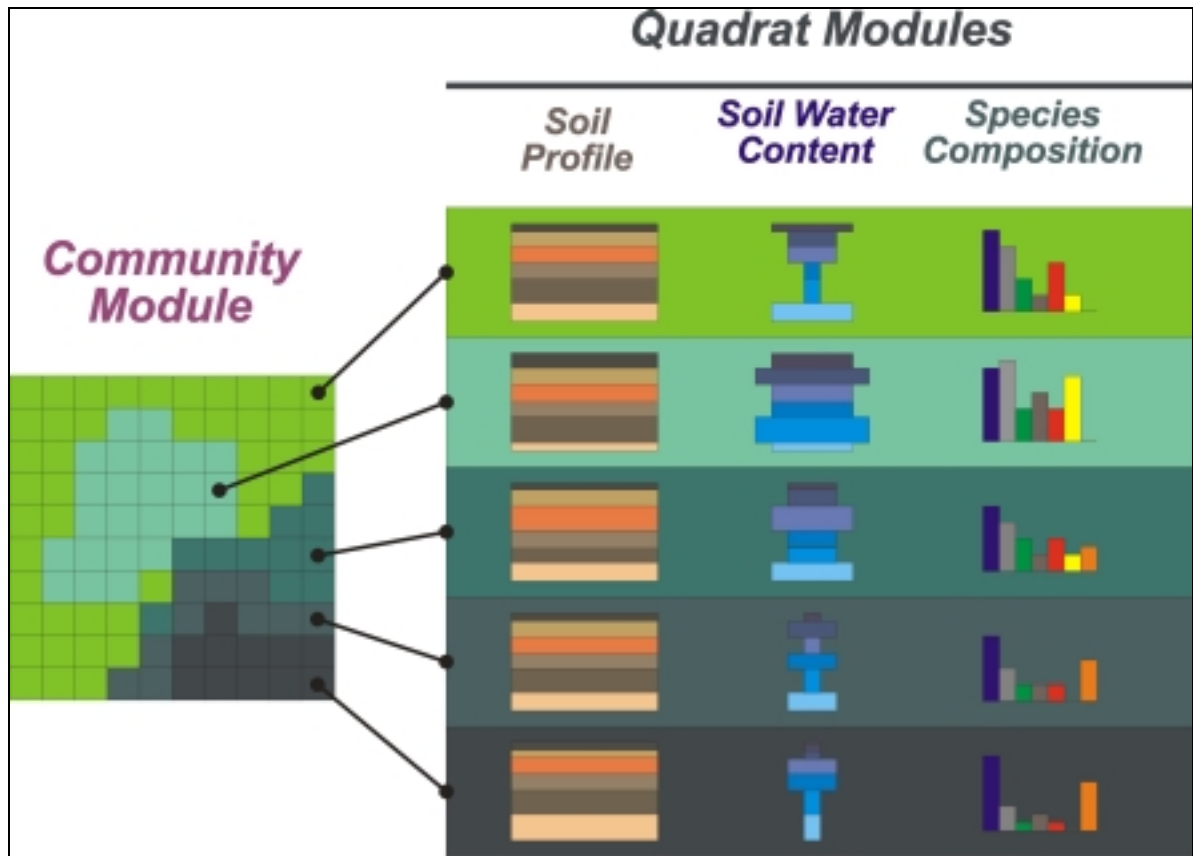
Land management usually involves larger spatial scales than Quadrats or Communities. For example, land management objectives, planning, and activities at U.S. military installations typically focus on training areas on the order of 1000's of acres in spatial extent. Certain ecological and hydrological processes, such as animal population dynamics, natural fire regimes, and surface runoff can only be adequately considered at this same scale. The Landscape Module in

EDYS is specifically designed to represent these processes and to accommodate addressing management issues at the same scale considered by land managers.



**Figure 4. Computational structure in the EDYS Quadrat Module.\***

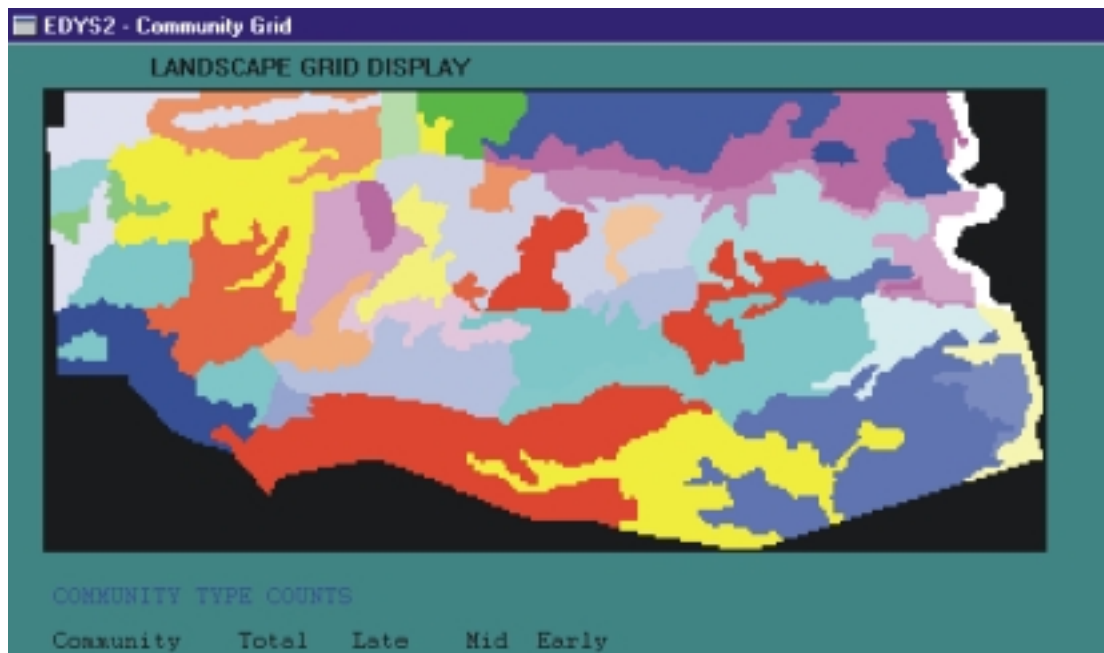
\* The various ecological processes simulated in EDYS are computed at different time scales to more realistically reflect the appropriate rate of change for each process.



**Figure 5. Quadrat-Community Module linkages in EDYS.\***

\* Each Quadrat type is simulated independently in the Quadrat Module, and the results then applied to those cells in the community grid with corresponding soil profiles and plant species composition.

The Landscape Module centers on three grid-based representations of the entire area of concern for the particular EDYS application: Quadrats and Communities (Figure 6), elevations, and disturbance and management units. This grid is designed to incorporate the entire area of concern for the particular EDYS application. The grid mapping of vegetation is important in representing fuel loads for fire events, habitats for different wildlife species, and pathways for surface runoff and transport of sediments during heavy precipitation events. An example of Landscape grids and dynamics is presented in the following chapter for Jack's Valley Training Area at the U.S. Air Force Academy.



**Figure 6. Landscape Vegetation Grid in the EDYS Landscape Module for Jack's Valley Training Area.\***

\* In this example, each cell in the Landscape Grid corresponds to a single 20m x 20m quadrat. Quadrats are further organized into Community Type as indicated by different shades of gray. Spatial Vegetation Patterns are derived from available vegetation maps and aerial photography.

## Hydrological Dynamics

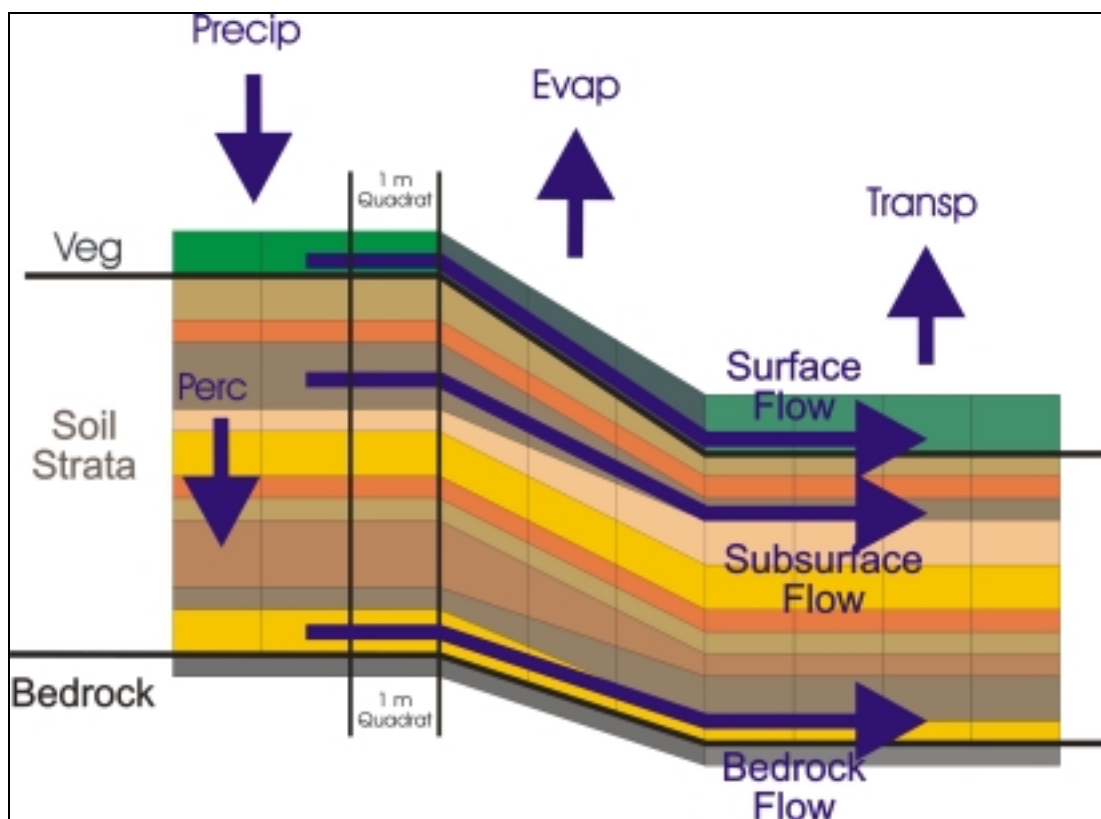
Water dynamics are major components in the Quadrat, Community, and Landscape Modules. EDYS explicitly represents water and materials transport vertically within each Quadrat, among Quadrats in the Community, and among Communities in the Landscape. Effects of stressors and disturbance on vegetation directly influences water dynamics at all scales, and is therefore usually of concern to land managers.

The Quadrat Module focuses primarily on 1-dimensional movement of water up and down in the soil profile (Figure 7). Precipitation events deliver water to each Quadrat; the water then percolates down into different horizons in the profile. Evaporation removes water from the top horizons, and uptake by plant roots in each horizon is then transpired as plants grow.

The Community Module allows excess precipitation water to move along the soil surface among different Quadrats in the Community (Figure 7). These flows are influenced by vegetation and litter cover within each Quadrat and by slope and topology within the Community. Similarly, water in excess of the wetting capacity of each horizon can move down in the profile as groundwater recharge, or

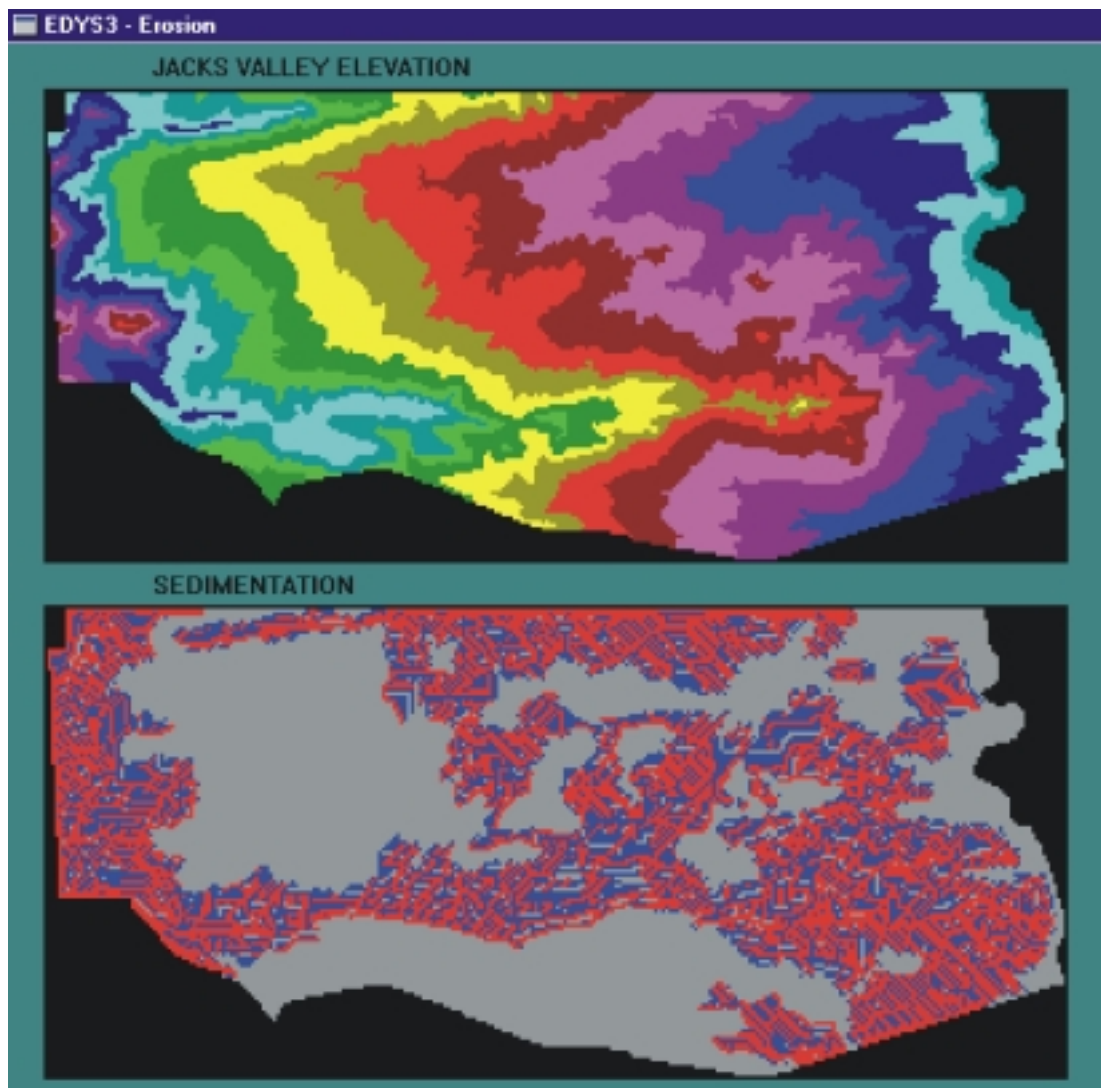
horizontally to adjacent Quadrats as Subsurface Flow downslope, depending on permeability of the different soil horizons.

All water movement has the potential for transporting nutrients, sediments, and contaminants within and among Communities. The EDYS model can therefore explicitly represent fate and effects of contaminants as well as plant community response to nutrient and contaminant additions in a variety of temporal and spatial patterns. Because spatial patterns and elevations of Quadrats and Communities are explicitly represented in the Landscape Module, small to large-scale locations of water movement and material transport is simulated for all precipitation events producing surface runoff (Figure 8).



**Figure 7. Hydrological dynamics in the EDYS Community Module.\***

\* Water dynamics at Quadrat, Community, and Landscape scales are crucial in EDYS simulations, so all relevant above and below-ground processes are explicitly represented (Precip - precipitation; Evap - evaporation; Transp - transpiration; Perc - percolation; Veg - vegetation).



**Figure 8. Simulated sediment transport resulting from surface runoff in the EDYS Landscape Module for Jack's Valley Training Area.\***

\* Gray areas indicate quadrats with no net change in the soil profile, red indicates quadrats with a net loss of soil sediment, and blue indicates quadrats with a net gain of sediments from surface runoff.

The hydrological calculations for surface runoff implemented in EDYS are simplified to ensure computation tractability and reasonably short computation time for long-term simulations. For certain management situations, detailed runoff projections are crucial for management planning and decision-making. A special version of EDYS has been developed specifically for linking with a new grid-based rainfall-runoff modelling system, CASC2D (Dr. Fred Ogden, University of Connecticut) (Figure 9). This linkage is facilitated by the Watershed Management System (WMS) software (U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi), which transfers parameters between EDYS and CASC2D, sends simulation control parameters to each, and provides graphical displays for results from both simulations. This combined package has great potential for use by land managers because it combines strengths of all three pack-

ages: multiple-scale ecological dynamics from EDYS, large-scale hydrological dynamics from CASC2D, and GIS compatibility and visualization tools in WMS. This package comprises the initial component of a larger Land Management System (LMS) which will link a wide variety of software packages via Internet to assist in decision-making procedures for land managers at Army installations.

## Current Status

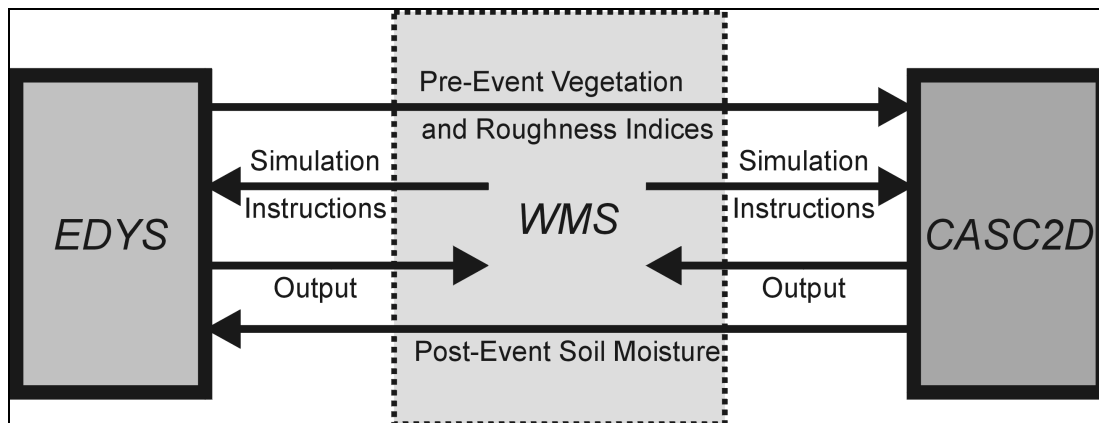
EDYS has been developed in a sequence of versions for major enhancements and specific applications (Table 1). The most current version is EDYS - 3, which incorporates a complete Landscape Module and all the associated spatial representations required to simulate ecological and hydrological dynamics at multiple spatial and temporal scales. This version is now being applied at Jack's Valley Training Area at the U.S. Air Force Academy to assist environmental and training managers in making ecologically-sound decisions about training and other human activities and management practices in this area. Version 4 is currently under development for Jack's Valley, and will incorporate a graphical user interface so that EDYS can be readily used by land managers. This version is scheduled for delivery in April 1999.

EDYS Versions 1 through 3 have been developed in Pascal for Windows (Inprise Corporation) for PC computers using any Microsoft Windows operating system. Version 4 will be implemented in Delphi 4 (Inprise Corporation), an advanced version of Pascal with full 32-bit processing capabilities (i.e., much faster processing and larger data set capabilities) and rapid application development tools for user interface design (i.e., menus and high-resolution graphics). This version will be constrained to PCs with Pentium-equivalent or more advanced processors. It is anticipated that Version 2a will be implemented in the C programming language to facilitate linkages with CASC2D and WMS, and should therefore be applicable for essentially any Windows or Unix systems.

EDYS is also undergoing validation testing at two Army installations: Forts Bliss and Hood, Texas. These projects involve testing projected vegetation dynamics in a number of field plots against field data gathered in 1998 and 1999 from these plots (McLendon, Childress, and Coldren 1999). Results for the black grama grassland at Fort Bliss indicate that projected total aboveground biomass over one growing season is within 4.4% of field-measured biomass (Table 2). Further validation testing involves EDYS projections using literature data for initial vegetation communities (specifically LCTA field plots), precipitation records from nearby long-term monitoring stations, and experimental manipulations of water and nitrogen availability in the field plots. Validation testing will



continue for a second year at both Forts Bliss and Hood to provide additional time for vegetation responses to experimental manipulations.



**Figure 9. Linkages among EDYS, CAS2D, and the Watershed Management System (WMS).\***

\* CAS2D is a grid-based rainfall-runoff simulation model. WMS mediates transfer of spatial data between EDYS and CAS2D, sends simulation control commands to each model, and provides graphical displays for output from each model.

**Table 1. EDYS Model versions, key features, and current DOD applications.**

Version	Features and Major Enhancements
EDYS - 1	- Core Quadrat Module
EDYS - 2	- Multiple Community Module - Quadrat-Community Module Linkages - Simple Runoff Procedure - Simple Landscape Module <i>Applications:</i> Ft. Bliss and Ft. Hood Dem-Val Validation Testing
EDYS - 2a	- LMS/WMS/CASC2D Data Transfer Interface - Simplified Input/Output Procedures <i>Applications:</i> Land Management System (LMS)
EDYS - 3	- Complete Landscape Module - Revised Runoff and Sediment Transport Procedures - Management Endpoint Procedures <i>Applications:</i> U.S. Air Force Academy Jack's Valley Training Area
EDYS - 4 (under development)	- Conversion to Windows Environment - Initial End-User Interface <i>Applications:</i> U.S. Air Force Academy Jack's Valley Training Area

**Table 2. Summary of EDYS validation testing results for a Black Grama desert community at Fort Bliss, Texas.**

Input Data		Simulation Accuracy*			
Vegetation	Precipitation	Total Above-ground	Shrubs	Perennial Grasses	Species Weighted Average
Feb 98 Site Samples	1998 Site	1.044	0.223	1.184	0.674
Feb 98 Site Samples	1998 El Paso	0.697	0.138	0.797	0.693
Feb 98 Site Samples	1948 El Paso	0.687	0.185	0.762	0.660
1989 LCTA 7 Plots	1998 Site	1.010	0.682	1.065	0.769
1989 LCTA 7 Plots	1998 El Paso	0.680	0.524	0.723	0.606
1989 LCTA 7 Plots	1948 El Paso	0.661	0.579	0.686	0.582
1989 LCTA 34 Plots	1998 Site	0.594	0.867	0.503	0.083
1989 LCTA 34 Plots	1998 El Paso	0.373	0.558	0.329	0.240
1989 LCTA 34 Plots	1948 El Paso	0.472	0.545	0.319	0.135

\* The accuracy measures are based on October 1998 aboveground biomass. Different vegetation inputs reflect initial simulation biomasses obtained from 48 sample sites, from 7 nearby LCTA plots, and from all 34 Black Grama LCTA plots on Fort Bliss. Different precipitation inputs reflect different monitoring locations and dates. Perfect accuracy of the simulation results is indicated by 1.0.

### 3 Applications

The EDYS Model is designed to make accurate, long-term ecological projections for different disturbance and management scenarios to assist land managers in making ecologically sound decisions. The Model and its projections must therefore fit into a management context for each specific application. The following sections present an overall strategy for land management that makes use of simulation models such as EDYS, and also presents examples of EDYS applications at three DOD installations. In addition, we describe two areas for future development of EDYS to increase its broader utility to both public and private land managers.

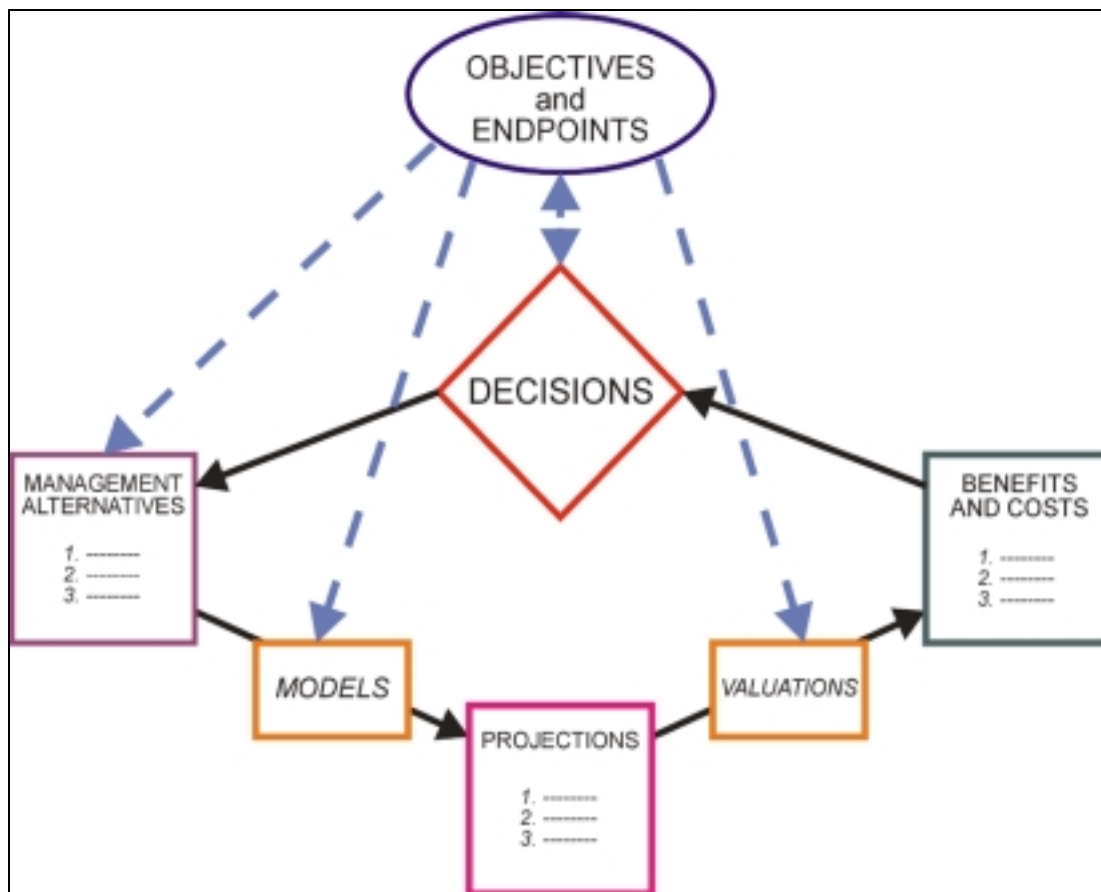
#### Strategy for Land Management

Sustainable land management must take into account the multiple uses and values of the multiple aspects of ecological systems. This requires explicit specification of these different values and uses so that management objectives can be assigned to each. Alternative management practices can only be assessed in terms of how they meet the specified management objectives. Successful assessments require some means of expressing both the objectives and the anticipated effects of alternative practices in quantitative, measurable terms so unambiguous results can be derived.

We propose a strategy for land management that focuses on management objectives and selecting management practices that best advance these objectives (Childress and McLendon 1998). This strategy involves a process for specifying objectives, projecting effects of management alternatives using simulation models, quantitatively assessing these effects specifically in light of the objectives, and thereby facilitating the decision-making process (Figure 10). This strategy involves two major steps. First, Management Objectives are specified by all stakeholders and managers. These Objectives determine criteria against which all formally described Management Alternatives will be judged. Second, the Alternatives are assessed in a Decision-Making Process in which the effects of each Alternative are projected using simulation models. The effects are then assigned relative benefits and costs in terms of the Management Objectives. This second

step is repeated iteratively with revised Management Alternatives and under different environmental scenarios until a satisfactory Alternative is selected.

Management Objectives must first be established before any management schemes can be adequately assessed. For land units with multiple users and uses, it is important to develop a consensus among all stakeholders for uses and values for which the unit will be managed. Priorities can be assigned to different Objectives in the event that there are conflicting uses and Objectives.



**Figure 10. Iterative decision-making strategy for land management.\***

\* This strategy allows identification of cost-effective management alternatives which meet all specified management objectives and endpoints. EDYS is used specifically to make projections of anticipated ecological and environmental effects of each alternative for subsequent evaluation.

The second Step is a Decision-Making Process for selecting Management Alternatives that best meet Management Objectives and Endpoints. There are a number of steps in this process, some of which are performed with the assistance of computer tools. Management Alternatives are first specified for consideration in the Process. Each Alternative will include a suite of practices that are considered potentially useful in meeting one or more Objectives. EDYS would then be used to project ecological effects of each Management Alternative. These projections would include a series of runs in which various environmental inputs, such as precipitation, are varied to give a more complete picture of possible outcomes for each Alternative. The various Alternatives would then be assigned valuations based on how well the projections for each Alternative meet specified Management Endpoints. The Alternatives are then ranked according to each of the Endpoints to indicate total Benefits and Costs anticipated if the Alternative was implemented.

Finally, a decision is made by the land unit managers about which, if any, of the Management Alternatives adequately conform to the Endpoints. All of the Alternatives that do conform to the Endpoints are then deemed “Green Light” Alternatives, and can be implemented with confidence that the Management Objectives will be met. Those that only partially conform to the Endpoints are considered “Yellow Light” Alternatives. These would not ordinarily be implemented without further study or revisions. Finally, those that fail to conform to Endpoints are labeled “Red Light” Alternatives, and would not be adapted without major revision. If none of the Alternatives is rated as “Green Light” then some or all of the Alternatives can be revised and run through the process repeatedly until an acceptable Alternative is found. This iterative process can also be used to compare a number of “Green Light” Alternatives to select the best one, or to iteratively revise and improve a single Alternative to find the best overall suite of management practices.

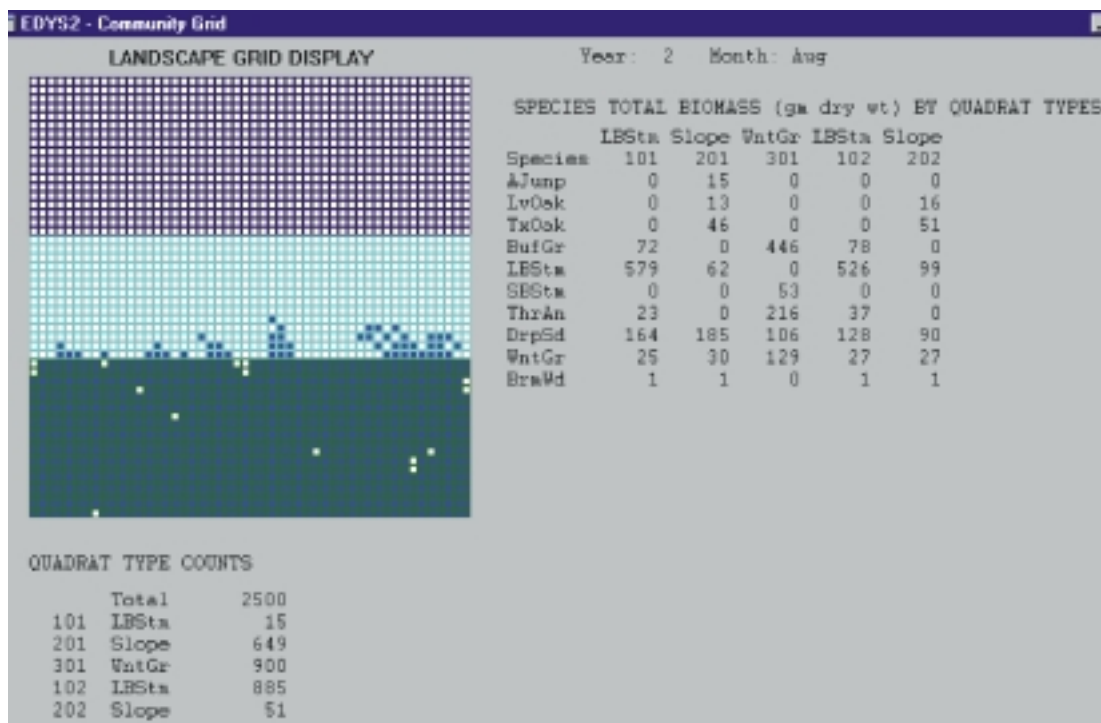
Successful management of larger land units such as landscapes, watersheds, and installations, is best approached using a formal strategy such as the one proposed here. As a rule, such areas will have multiple uses and concerns, multiple stakeholders, multiple Management Objectives at multiple spatial scales, and a wide variety of possible management practices. The strategy we propose should greatly assist land managers in objectively assessing all the considerations in such complex scenarios to more successfully achieve Management Objectives.

## Fort Hood, Texas

Land management at Fort Hood in central Texas is complicated by a variety of uses (e.g., training by armored units and cattle grazing) and environmental concerns (e.g., endangered species, water quality in the watershed, and fire hazards). The application of EDYS to land management at this installation has proceeded in an incremental fashion, with parameterization (definition of parameters) and validation testing for 48 research plots located at 3 little bluestem sites to be completed in Spring 1999.

An initial proof-of-concept adaptation of EDYS has been completed for a simple landscape incorporating three grass-dominated communities: a higher-elevation, shallower-soil community dominated by Texas wintergrass; a high-slope, thin-soil community dominated by woody plants; and a lower-elevation, deeper-soil community dominated by little bluestem. These communities are arranged in a 50 x 50 m grid of 1 x 1 m quadrats, with an elevation gradient from top to bottom. Figure 11 is a typical monthly display from the EDYS simulation. This figure depicts location and counts of each Community and Quadrat Type in this simple landscape, along with a table listing biomass of each major plant species in each Quadrat Type. This particular example depicts the aftermath of a simulated natural burn that in the previous year consumed most of the little bluestem community and some of the slope community. Wherever the fire burned, the vegetation in the quadrats was largely consumed, so EDYS automatically created a new Quadrat Type for those cells. In this example, Quadrat Type "101 LBStm" indicates the little bluestem community quadrats that were not burned, and "102 LBStm" those that burned. The differences in the plant biomasses in these quadrats is also evident in the Total Biomass table.

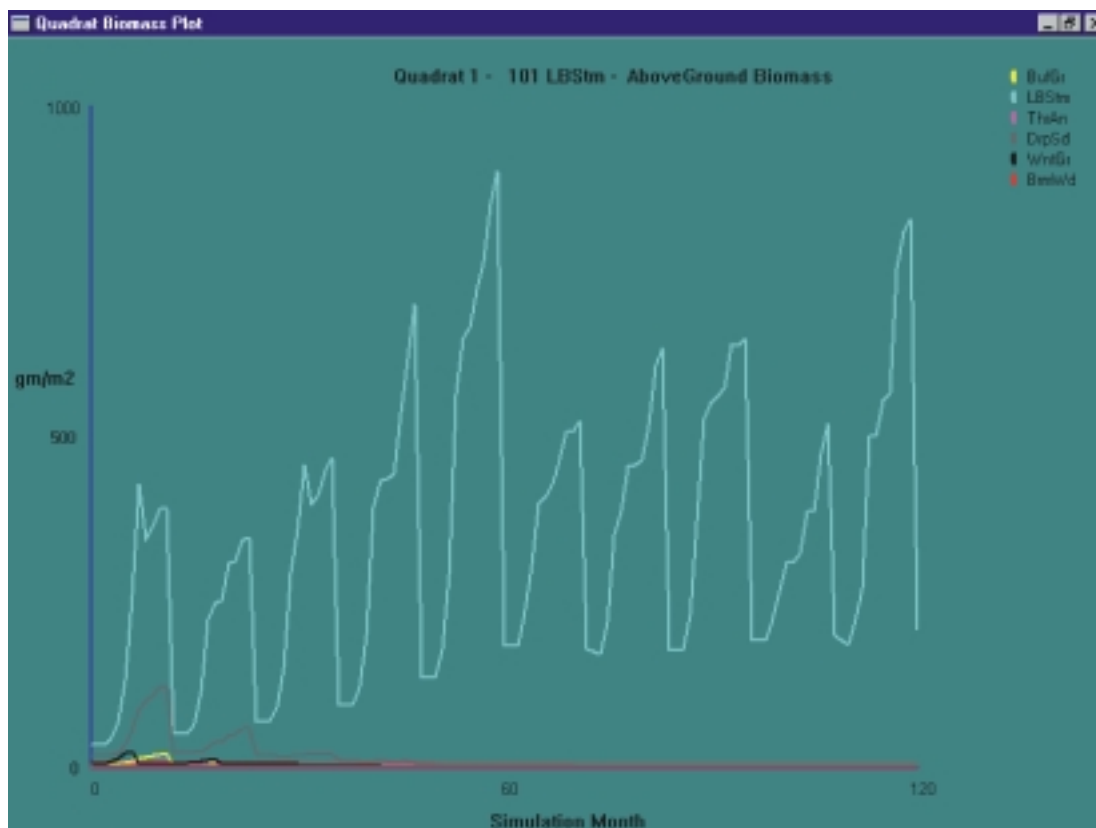
EDYS records vegetation biomasses for each Quadrat Type each month throughout the simulation for later display and printouts. Figure 12 is a graphical display for the aboveground biomass of each major plant species in one of the little bluestem community Quadrat Types. In this particular simulation run, disturbances such as fire, herbivory, and training activities did not occur within this Quadrat Type, resulting in rapid dominance of little bluestem (LBStm) and decline of all other species.



**Figure 11. Monthly graphical display during the EDYS simulation of a simple Little Bluestem landscape at Fort Hood.\***

\* The landscape is a 50m x 50m grid of 1m x 1m Quadrats organized into three communities (WnGr - hilltop wintergrass community; Slope - slope community dominated by shrubs; LBStm - lower Little Bluestem community) along an elevational gradient. Biomasses of each dominant plant species in each community are displayed in one table, with number of Quadrats in each Community displayed in another.

Further development of the EDYS application for Fort Hood will proceed in several directions. Data are now available describing timing, location, and local effects of training activities across the installation; these will be used to revise the training disturbance calculations in the Stressor Unit. A second year of validation testing in the field plots will facilitate further calibration of ecological processes in all Units in EDYS. Two endangered birds species found on the installation have been studied in detail by a variety of ecological researchers. Adding population dynamics and habitat preference and use modules for these species will provide another validation test for the Animal Unit in EDYS. Of particular interest will be a planned demonstration application of the EDYS-CASC2D-WMS package to the Henson Creek watershed at Fort Hood. This demonstration should provide impetus to develop an installation-wide EDYS-CASC2D-WMS system for projecting effects of various land management plans on total watershed water quality and quantity.



**Figure 12. Simulated aboveground biomass of dominant plant species in one Quadrat Type in a little Bluestem community at Fort Hood.\***

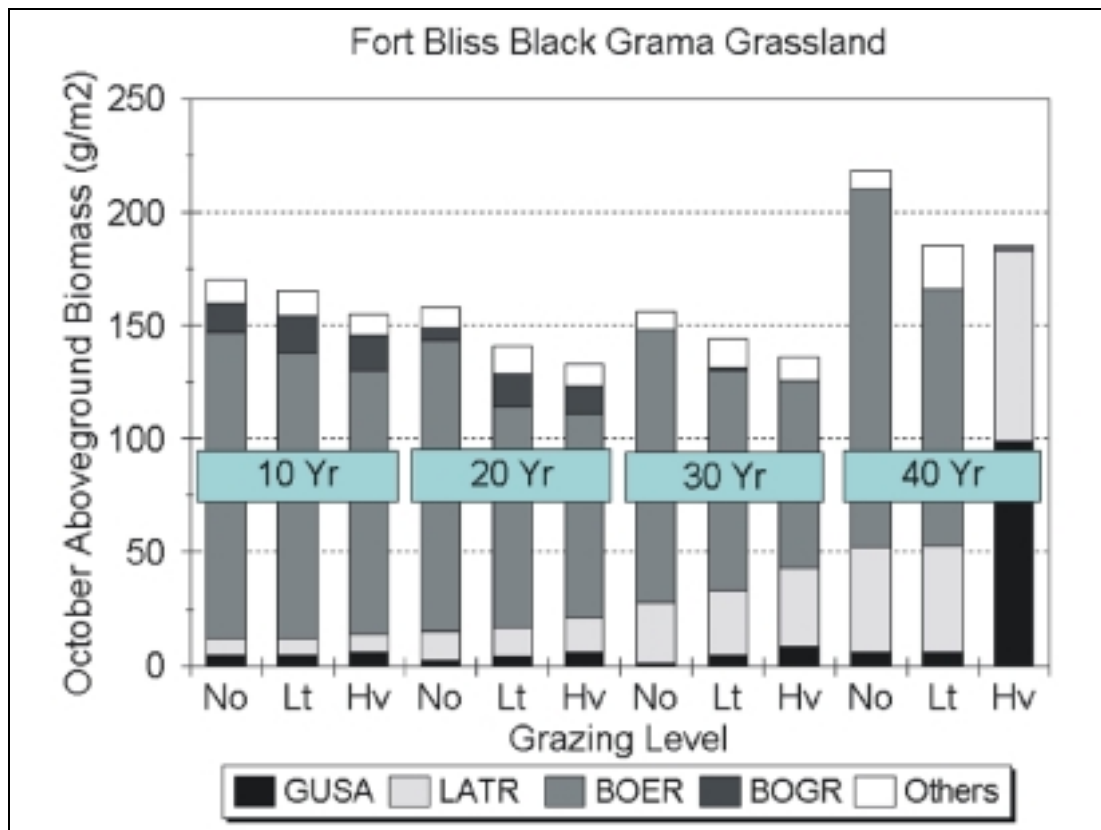
\* In this simulation natural fires, herbivory, and other disturbances were excluded so that little bluestem quickly dominates the Quadrat and the community.

## Fort Bliss, Texas

Application of EDYS to land management at Fort Bliss in far West Texas has also proceeded incrementally. The first year of validation testing of EDYS projections for 48 field plots in a black grama desert grassland have been recently completed (McLendon et al. 1999). Results of this first year indicate that, on average, EDYS predicts total plant biomass in each plot within 4.4% of the actual end-of-year biomass (Table 2). EDYS was also run using precipitation data from another nearby site and a different year, and using data from other LCTA black grama sites to provide a measure of the benefit of site-specific data for projection accuracy. The site-specific data for biomass and precipitation produced better accuracy than the alternative data sets, but at a significantly higher cost because of the expense of field surveys. Validation testing will continue at these same plots for a second year in 1999, along with experimental manipulations of soil moisture and nitrogen in selected field plots for further EDYS calibration in this community.



Validation data was then used to recalibrate the EDYS model for the black grama grassland at Fort Bliss and was then used to make some preliminary projections of the effects of different intensities of cattle grazing in this community (Figure 13). Results of 40-yr alternative simulations with no, light, and heavy grazing indicated only incremental shifts in plant species composition over the first 30 years, but a collapse in blue grama by year 40 under the heavy grazing alternative. This preliminary example indicates a primary utility of well-calibrated, mechanistic simulation models: projections of long-term cumulative effects of stressors and management activities on ecosystem structure and function. Field studies over such a long time frame (40 years) are not feasible, nor cost-effective, in evaluating a variety of management alternatives, and short-term studies may not adequately indicate long-term cumulative effects nor thresholds leading to ecological collapse.



**Figure 13. Simulated aboveground biomass of dominant plant species in Black Grama grassland community at Fort Bliss.\***

\* Results of three different simulations under different intensities of cattle grazing (No - none, Lt - light, Hv - heavy) are plotted at 10-year intervals. After 40 years of heavy grazing, black grama (BOER) collapses and is replaced by snakeweed (GUSA) and creosote bush (LATR).

## U.S. Air Force Academy, Colorado

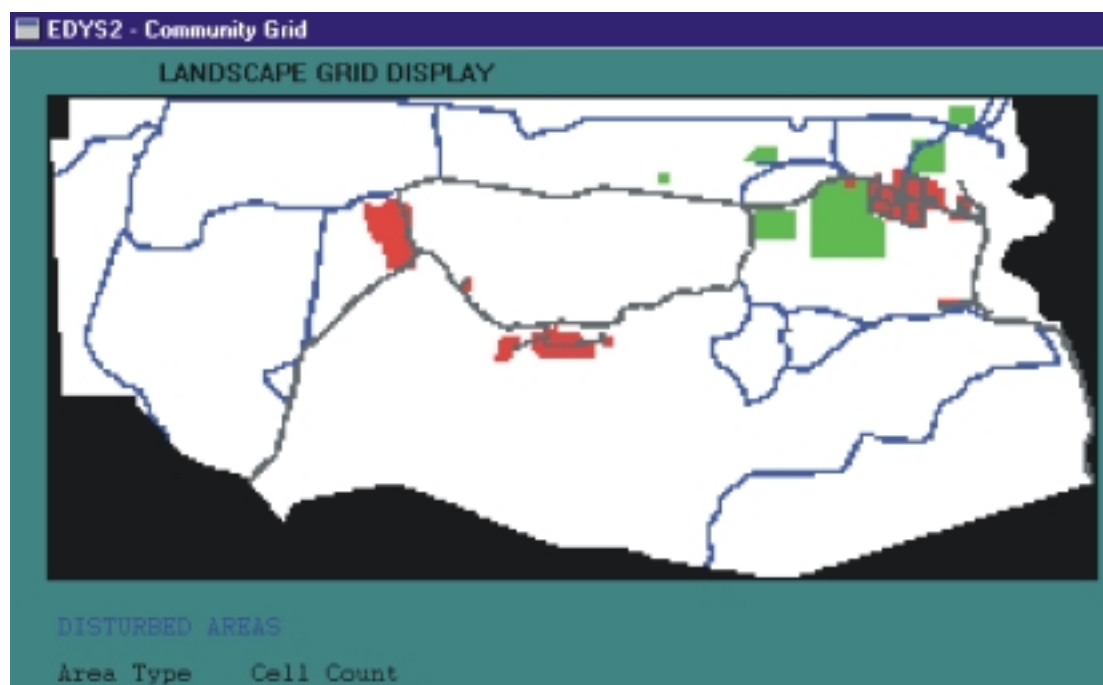
A recent application of EDYS has been in development of a management system for Jack's Valley Training Area at the U.S. Air Force Academy in central Colorado. This 3000-acre area, located at the junction between the Great Plains and the Rocky Mountains, is used for a variety of training activities, including basic cadet training each summer for incoming Academy freshmen. The specifications for the EDYS application for Jack's Valley include 8 community types, 6 different ecological stressors, 10 alternative management activities, and 18 different management end points to be used as indicators of environmental/ecological quality in Jack's Valley (Table 3). The initial outcome of this application in Spring 1999 will be a software package delivered to land managers at the Academy to be used in assessing outcomes of different management scenarios planned for 1999 training activities in Jack's Valley.

**Table 3. EDYS application specifications for U.S. Air Force Academy Jack's Valley Training Area.**

Eight Community Types	Six Ecological Stressors
1. Ponderosa pine woodland 2. Pine-oak woodland 3. Gambel oak woodland 4. Bluestem grassland 5. Stipa grassland 6. Brome grassland 7. Riparian shrubland 8. Roads and buildings	1. Foot traffic 2. Vehicle traffic 3. Drought 4. Fire 5. Nitrogen availability 6. Herbivory
Ten Management Activities	Eighteen Management End Points
1. Training 2. Fire control and fuel reduction 3. Chemical and weed control 4. Timber thinning and harvesting 5. Rehabilitation and revegetation 6. Wildlife watering facilities 7. Reforestation 8. Boundary line maintenance 9. Road and trail closures 10. Deer hunting	1. No increase in soil erosion overall 2. No increase in soil erosion in BCTA 3. No successional decline in BCTA 4. No change in habitat proportions in BCTA 5. No change in habitat proportions overall 6. No bareground except in road/building areas 7. Maintain or improve successional status overall 8. Maintain habitat types and diversity 9. Reduce abundance of exotic plant species 10. Maintain riparian community structure 11. Shift from smooth brome to native grasses 12. Maintain western areas in best habitat 13. Maintain 200 m buffer strips around boundaries 14. Maintain hunting habitat for peregrine falcon 15. Protect spotted owl habitat 16. Maintain deer population 17. Maintain elk population 18. Maintain wild turkey population

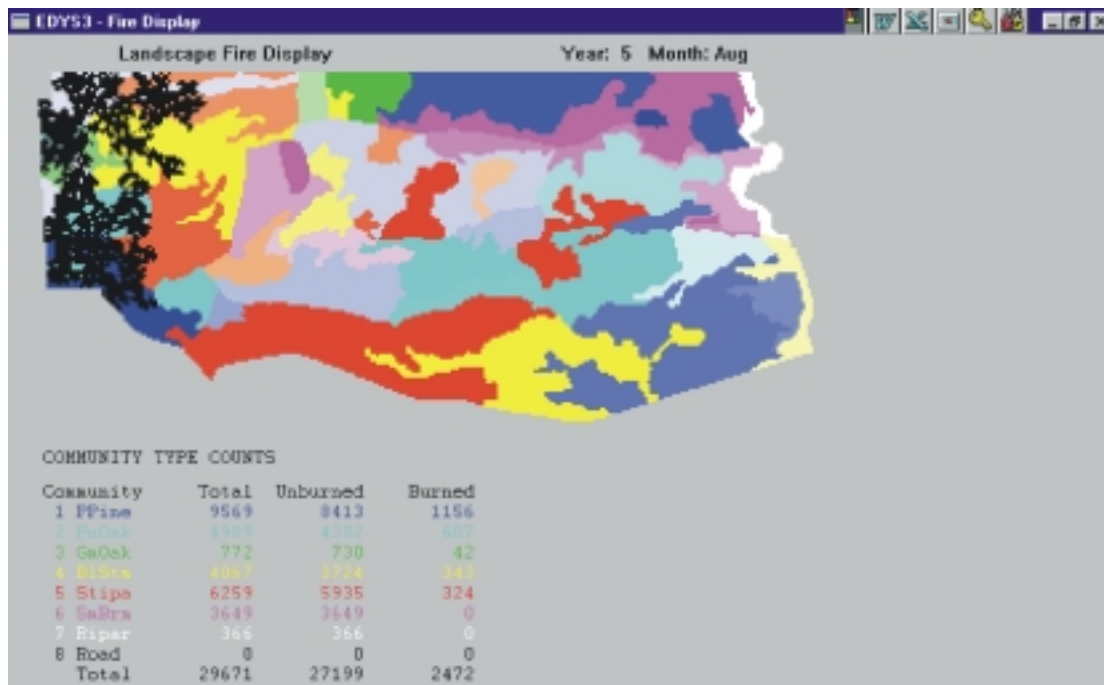
This application requires landscape-level spatial information about community types (Figure 6), elevations (see Figure 8), soil types, waterways and watersheds (see Figure 8), and human use areas (Figure 14). These data have been incorporated into a grid-based representation system with resolution down to 20 x 20 m quadrats. Forty field plots have been established in different communities across Jack's Valley to provide parameterization data for plant biomasses and soil profiles and for ground-truthing of existing vegetation maps for the Academy. These plots will be surveyed through 1999 to provide validation tests of small-scale ecological dynamics in the various ecosystems.

Preliminary EDYS simulation runs concur with Academy land managers that natural fires present a significant risk to management of habitats in the Valley. Simulated burns can propagate rapidly across different community types in the landscape (Figure 15), especially under dry fuel conditions, making fuel management to protect training facilities a high priority. However, most of the Valley is relatively undisturbed by human activities, so that potential habitat is available for a wide variety of wildlife, including threatened and endangered species such as the spotted owl, peregrine falcon, and Preble's meadow jumping mouse.



**Figure 14. Human use disturbed areas grid for the EDYS adaptation for Jack's Valley Training Area.**

\* These areas include roads (gray lines), permanent use areas and structures (dark gray/orange areas), and seasonal training areas (light gray/green areas).



**Figure 15. Simulated natural fire in the EDYS Landscape Vegetation Grid for Jack's Valley Training Area.\***

\* Burned Quadrats are indicated by black. Simulated natural fires propagate across the EDYS Landscape using a stochastic process which considers vegetation type, fuel load, and moisture content in calculating probabilities of spread into each Quadrat from adjacent burning Quatrats. New Quadrat Types are automatically created in EDYS for each burned Quadrat type to reflect change in vegetation structure in those cells.

Even though these species may not be present in the Valley, maintenance of appropriate habitat for them ensures compliance with regulatory environmental constraints (e.g., National Environmental Policy Act [NEPA] and Endangered Species Act [ESA]), another high priority for Academy land managers. For example, song birds in the Valley provide a potential prey base for peregrine falcon, so the dynamics of different guilds are explicitly simulated in the EDYS application for Jack's Valley as an indicator (i.e., a management "endpoint") for falcon habitat quality (Figure 16). It is by including appropriate endpoints for all areas of concern listed in the application specifications (Table 3) that EDYS will have maximum utility for land managers in deriving an appropriate land management strategy.

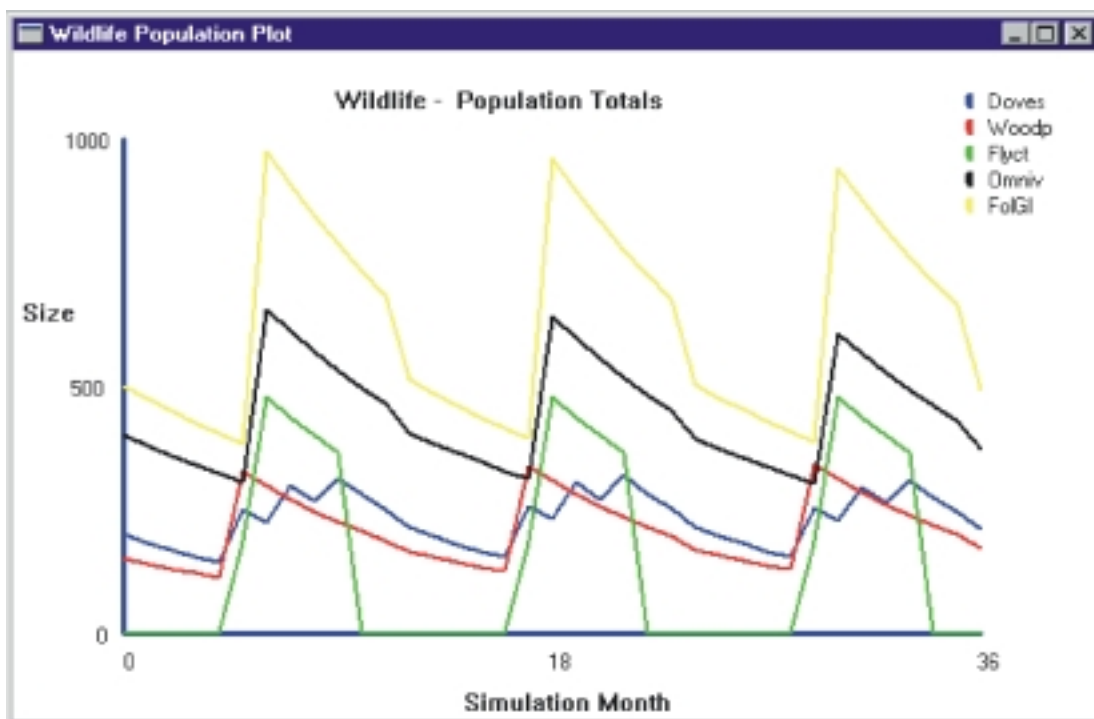
Because an EDYS simulation package will be delivered to the Academy for specific use by land managers, a graphical user interface is now under development. This interface makes use of menus and graphical displays to assist users in selecting simulation options for different management scenarios, and for designating outputs (graphical or tabular) for monitoring different components of the landscape and communities for each scenario (Figure 17). EDYS developers will provide training and user manuals to Academy managers, and will monitor use of this application and the new interface to identify areas for improvement and

further development. It is anticipated that a successful outcome for this EDYS application will result in expansion to the entire Academy, and eventual application for other installations, as well as for a wide variety of public and private land managers in the United States and elsewhere.

## Hydrological Applications

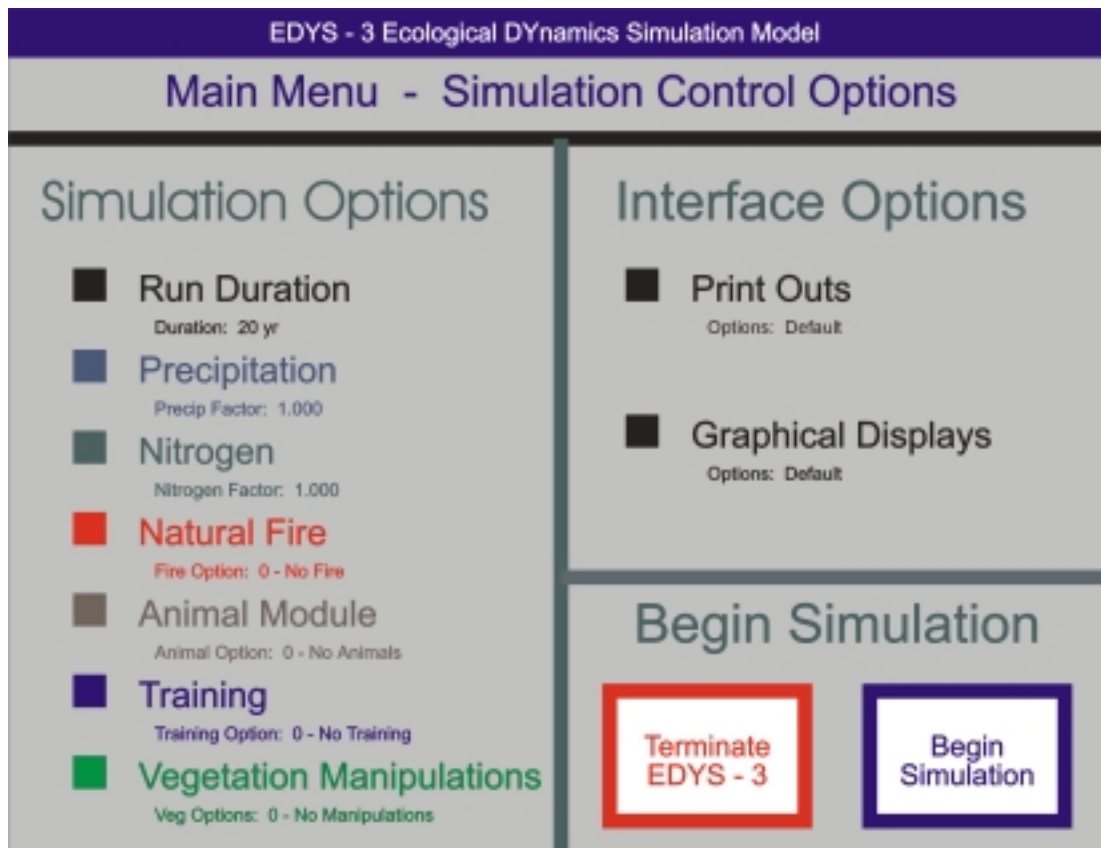
As noted earlier, EDYS has great potential utility in assessing linkages between ecological dynamics and water quantity and quality in small- to large-scale systems. EDYS can be used alone to make these projections, or in conjunction with CASC2D and WMS to make highly accurate runoff quantity and quality projections for landscapes and watersheds.

A recent application of EDYS as a stand-alone simulation model is investigating the effects of invasion of junipers in grasslands of the western United States on water resource quality and quantity. These effects are likely to be complex and highly site-specific (Figure 18).



**Figure 16. Simulated bird guild dynamics for the EDYS implementation at Jack's Valley Training Area.\***

\* Each guild represents several species with similar feeding habits. (Doves - granivores such as mourning dove and rock dove; Woodp - bark-foraging insectivores such as woodpeckers, sapsuckers, and flickers; Flyct - aerial insectivores such as swallows, wood peewees, and flycatchers; Omniv - omnivores such as magpies, robins, and tanagers; FolGI - foliage-gleaning insectivores such as vireos, chickadees, and warblers.)



**Figure 17. Menu-based user interface design for the EDYS implementation at Jack's Valley Training Area.\***

\* The management user specifies simulation duration, details of disturbance and management options, and graphical and printed output options for each simulation run using a series of menus for each EDYS Module.

Junipers have dense canopies and secondary compounds in roots and leaf litter that effectively exclude all other plant species. Juniper canopies have substantially greater interception of precipitation than grasses, resulting in a significant decrease in the amount of water that reaches the soil surface. Evaporation of water from the surface is highly site specific, depending on amount of bare ground, height and density of vegetation, and water-holding capacity of the top soil layers. Because the ground is essentially bare under the junipers, there is little biomass to slow surface runoff of water and allow it to enter the soil profile. This high energy flow picks up substantial quantities of sediment, resulting in considerable erosion. In dense grasslands, however, the dense plant material litter substantially slow any sheet flow, allowing the water time to infiltrate, thereby reducing erosive power and sediment-carrying capacity of remaining runoff.

