**Volume 7: An Ecosystem Simulation
of Perturbations Applied
to Shale Oil Development**

**Western Oil Shale
Development:
A Technology Assessment**

May 1982

Prepared for the
U.S. Department of Energy
Assistant Secretary for Environmental
Protection, Safety, and Emergency
Preparedness
under Contract DE-AC06-76RLO 1830

DOE Project Manager: G. J. Rotariu

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

NTIS Price Codes
Microfiche A01

Printed Copy

Pages	Price Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A010
226-250	A011
251-275	A012
276-300	A013

Volume 7: An Ecosystem Simulation
of Perturbations Applied
to Shale Oil Development

WESTERN OIL SHALE DEVELOPMENT:
A TECHNOLOGY ASSESSMENT

May 1982

Prepared for the
U.S. Department of Energy
Assistant Secretary for Environmental
Protection, Safety, and Emergency Preparedness
under Contract DE-AC06-76RLO 1830

DOE Project Manager: G. J. Rotariu

Pacific Northwest Laboratory
Richland, Washington 99352

FOREWORD

The U.S. Department of Energy (DOE), Office of the Assistant Secretary for Environmental Protection, Safety, and Emergency Preparedness (EP), Office of Environmental Assessments, has been conducting technology assessments of the evolving energy technologies. The purpose of these is to evaluate in as quantitative a manner as possible the potential environmental, health, and socioeconomic impacts of each technology as it moves towards commercialization. The assessments identify where further information is needed, provide an analysis of potential environmental, health, and socioeconomic consequences of each technology, and define research and development (R&D) needed to ensure environmentally acceptable commercialization.

This is the final report of the Western Oil Shale Development Technology Assessment. We would like to express our appreciation to Drs. Darryl Hessel and Ira Levy of the Pacific Northwest Laboratory for their efforts in coordinating the work, to Dr. Hessel and Mr. Gabor Strasser for preparing this report, and to the entire team of participants listed in the Executive Summary and in the Appendix of Volume 1 of this report for conducting and reporting the major technical studies.

Dr. George J. Rotariu
Oil Shale Technology Assessment Project Manager
Technology Assessments Division

ABSTRACT

This report outlines progress on activities leading toward evaluation of ecological and agricultural impacts of shale oil development in the Piceance Creek Basin region of northwestern Colorado. After preliminary review of the problem, it was decided to use a model-based calculation approach in the evaluation. This report discusses the general rationale and objectives of this approach.

The structure and function of ecosystems in the Piceance Creek Basin is defined. Existing studies were examined to characterize climate, soils, vegetation, animals, and "ecosystem response units". More than 50 categories of information were tabulated from key investigations. This information provides a background set of data for eventual model verification and validation. Our analyses suggest that the major ecological and agricultural impacts generally expected from shale oil development can be accounted for by defining less than 10 terrestrial and aquatic ecological response units.

System function was methodically defined by developing a master list of variables and flows, structuring a generalized system flow diagram, constructing a flow-effects matrix, and conceptualizing interactive spatial units through spatial matrices. The process of developing individual mathematical functions representing the flow of matter and energy through the various system variables in different submodels is discussed.

The system model diagram identifies 10 subsystems which separately account for flow of soil temperatures, soil water, herbaceous plant biomass, shrubby plant biomass, tree cover, litter biomass, shrub numbers, animal biomass, animal numbers, and land area. Among these coupled subsystems there are 45 unique kinds of state variables and 150 intra-subsystem flows.

A nomenclature system is developed for the driving variables, state variables, flows, intermediate variables, and parameters in the model. These terms are characterized in a standard algebraic notation and in PASCAL computer code, and are defined by reference and measurement units. The flow-effects matrix illustrates for each individual flow the various factors which are used in the calculation. The individual flow equations for the model are then specified algebraically and discussed in the text.

The model, coded in the computer language PASCAL, now operates on a CDC CYBER 172 computer. The model is generalizeable and canonical so that it can be expanded, if required, by disaggregating some of the system state variables and allowing for multiple ecological response units. This model, in effect, integrates information on climate, surface water, ecology, land reclamation, air quality, and solid waste as it is being developed by, and when it is provided to us from, several other task groups.

The overall model output is illustrated with time-series graphs and with tabular summaries for the mean, maximum and minimum value, time of maximum and minimum value, and standard deviation of driving variables, state variables, and flows.

The report illustrates how shale oil development impacts will be used to modify flow functions. The shale oil development driving variable records to accompany any given combination of development scenario and climatic phenomena are discussed. Model limitations, data limitations, and priority information and research needs are outlined. An approach is also suggested for strategies of model usage and experimentation.

The report includes a list of references cited plus a detailed list of references examined to incorporate oil shale development effluents and impacts on flows in the base model.

Included as an appendix, the actual computer code and a brief users manual are provided for the curious.

This ecosystem model can be classified as a canonical, spatially-oriented, nonlinear difference equation simulation model that flows multiple currencies. The terrestrial component is fully coded and operable; the aquatic component is conceptualized but not coded. Shale oil development impacts influence calculations through effluent effects on critical plant growth and death processes. In addition to its utility for evaluating ecological and agricultural impacts of shale oil development, the model has potential utility (through adaptation) in examination of other energy-development and renewable resource management activities in semiarid and arid environments.

TABLE OF CONTENTS

	<u>Page</u>
Abstract	ii
Acknowledgements	iv
Table of Contents	v
List of Figures	viii
List of Tables	xii
 1. GENERAL APPROACH AND SCOPE	 1
1.1 Conceptual Framework	1
1.2 Implementation of Conceptual Framework	1
1.3 Objectives and Scope	2
1.4 Achievements	2
 2. PICEANCE CREEK BASIN CHARACTERISTICS	 4
2.1 Current (or Baseline) Conditions of Piceance Creek Basin System	 4
2.1.1 Climate and Air Quality	4
2.1.2 Soils	5
2.1.3 Flora	8
2.1.4 Fauna	12
2.1.4.1 Small Mammals	12
2.1.4.2 Large Mammals	13
2.1.4.3 Large Mammal Interrelationships	17
2.1.4.4 Mammalian Predators	18
2.1.4.5 Avifauna	19
2.1.4.6 Reptiles and Amphibians	22
2.1.4.7 Invertebrates	23
2.1.4.8 Domestic Livestock Use	25
2.1.5 Aquatic	26
2.1.6 Tabulated Literature Survey	26
2.2 Dynamics of Piceance Creek Basin Systems	49
2.2.1 Climate	49
2.2.2 Soils	51
2.2.3 Flora	51
2.2.4 Fauna	56
2.2.5 Aquatic	59
2.3 Human and Associated Activities	61
2.3.1 Agriculture	61
2.3.2 Development and Activities	62
 3. A.E.S.O.P MODEL STRUCTURE	 64
3.1 Driving Variables	64
3.1.1 Base Climate Pattern	64
3.1.2 Weather Adjustments for Ecological Response Units	64
3.1.2.1 Elevation Adjustments	64
3.1.2.2 Aspect Adjustments	65
3.1.2.3 Percent Slope - Aspect Adjustments	65
3.1.2.4 Intermediate Variables	65
3.1.3 Shale Oil Development Emissions	67
3.2 System State Variables	68
3.3 System Processes	68
3.4 Ecological Response Units	68
3.4.1 Abiotic Components	69

	<u>Page</u>
3.4.2 Floral Components	69
3.4.3 Faunal Components	70
3.4.4 Land Area/Use Components	70
3.4.5 Hydrologic Components	71
3.4.5.1 Streamflow	71
3.4.5.2 Inorganic Ions	71
3.4.5.3 Organic Compounds	71
3.4.5.4 Turbidity	72
3.4.6 Aquatic Biota Components	72
3.5 System Flow Diagrams	73
3.6 Process Effects Matrix	79
3.7 Spatial Configuration	79
3.8 Temporal Description	84
3.9 Nomenclature Master List	84
4. A.E.S.O.P. MODEL FUNCTION	97
4.1 Development of Process Functions	97
4.1.1 Selection of Process Components	97
4.1.2 Estimation of Parameters	97
4.2 Abiotic Processes	98
4.2.1 Soil Temperature	98
4.2.2 Soil Moisture	102
4.2.3 Hydrologic	125
4.2.3.1 Streamflow	125
4.2.3.2 Inorganic Ions	126
4.2.3.3 Organic Compounds	126
4.2.3.4 Turbidity	128
4.2.4 Land Area/Use	128
4.3 Biotic Processes	133
4.3.1 Terrestrial Floral Processes	133
4.3.1.1 Variable Timesteps: The Active Days Concept ..	133
4.3.1.2 Cover and Leaf Area	134
4.3.1.3 Germination and Extinction	135
4.3.1.4 Phenology	135
4.3.1.5 Tree Processes	136
4.3.1.6 Herbaceous and Shrub Processes	136
4.3.1.7 Shrub Population Processes	147
4.3.2 Litter Processes	150
4.3.3 Terrestrial Fauna Processes	150
4.3.3.1 Biomass Processes	152
4.3.3.2 Population Processes	171
4.3.4 Aquatic Biota Processes	184
4.4 Resource Management and Development	187
5. SHALE OIL DEVELOPMENT	191
5.1 Literature Review	191
5.1.1 Air Pollutants	191
5.1.1.1 Regulations	191
5.1.1.2 Abiotic Effects	194
5.1.1.3 Floral Effects	194
5.1.1.4 Faunal Effects	214

	<u>Page</u>
5.1.2 Construction and Operations	217
5.1.3 Human Related Disturbance	218
5.2 Modelling Approach	220
5.2.1 Air Pollutants	220
5.2.1.1 Abiotic Modelling Steps	220
5.2.1.2 Floral Modelling Steps	220
5.2.1.3 Faunal Modelling Steps	229
5.2.2 Construction and Human Related Disturbance	229
6. A.E.S.O.P SIMULATIONS EVALUATION	230
6.1 Scenario Descriptions	230
6.1.1 Driving Variable Records	230
6.1.2 Initial Conditions	230
6.2 Simulation Dynamics	249
6.2.1 Without Development	249
6.2.2 With Development	338
6.3 Comparison of Non-Development vs. Development	338
7. CONCLUSIONS AND GENERAL DISCUSSIONS	339
7.1 Projections of Future Conditions Without Shale Oil Development	339
7.1.2 Climate and Air Quality	339
7.1.3 Soils	340
7.1.4 Vegetation	340
7.1.5 Fauna	340
7.1.6 Agriculture	341
7.1.7 Human Related	341
7.1.8 Summary	342
7.2 Projections of Future Conditions With Shale Oil Development ...	342
7.3 Data Limitations	343
7.4 Model Limitations	343
7.5 Research Needs	348
7.5.1 Model Output as Guidance to Experimental Studies	348
7.5.2 Field Data for Validation of Model Results	349
7.6 Strategies of Model Usage	349
7.7 Some Specific Recommendations Regarding Model Development and Usage	350
8. LITERATURE CITED AND GENERAL BIBLIOGRAPHY	351

LIST OF FIGURES

	<u>Page</u>
Figure 2.1 Expected nominal dynamics during one year for climatic driving variables for an intermediate elevational zone in the oil shale development region	50
Figure 2.2 Expected nominal dynamics during one year for abiotic state variables for an intermediate elevational zone in the oil shale development region	52
Figure 2.3 Expected nominal dynamics during one year for plant state variables for an intermediate elevational zone in the oil shale development region	54
Figure 2.4 Expected nominal dynamics during one year for animal state variables for an intermediate elevational zone in the oil shale development region	57
Figure 2.5 Expected nominal dynamics during one year for aquatic state variables for an intermediate elevational zone in the oil shale development region	60
Figure 3.1 Forrester flow diagram for the soil heat and soil water submodels	74
Figure 3.2 Forrester flow diagram for tree, litter, shrub, and herbaceous submodels	75
Figure 3.3 Forrester flow diagram for fauna submodel	76
Figure 3.4 Forrester flow diagram for land area submodel	77
Figure 3.5 Forrester flow diagram for the aquatic submodels	78
Figure 3.6 Juxtaposition of six ERUs describing the Piceance Basin, with an example set of edge factors	80
Figure 3.7 Model structure for inter-township water flow	81
Figure 4.1 Major pathways of heat entering or exiting the surface soil layer	99
Figure 4.2 Effects of soil components upon heat conduction through the soil	103
Figure 4.3 (a) Snow melt as a function of ambient temperature, (b) water evaporation as a function of soil moisture content, (c) depth of snow cover as a function of precipitation	105
Figure 4.4 Rainfall intercepted by litter cover at three rain intensities	106

	<u>Page</u>
Figure 4.5 Rainfall intercepted by forb cover at three rain intensities	107
Figure 4.6 Rainfall intercepted by grass cover at three rain intensities	108
Figure 4.7 Rainfall intercepted by shrub cover at three rain intensities	109
Figure 4.8 Rainfall intercepted by tree cover at three rain intensities	110
Figure 4.9 Matric potential as a function of volumetric water content for three soil types	111
Figure 4.10 Matric potential as a function of volumetric water content for three soil types	112
Figure 4.11 Effect of flora cover on infiltration rate and hydraulic conductivity as a function of volumetric water content for six soil types	114
Figure 4.12 Maximum infiltration rates as a function of volumetric water content for six soil types at three soil thicknesses	117
Figure 4.13 Photosynthesis as a function of soil water and temperature	140
Figure 4.14 Effect of competing leaf area on net daily photosynthesis ..	140
Figure 4.15 Daily respiration as a function of translocation rate	140
Figure 4.16 Effect of daily maximum air temperature on the rate of total translocation	143
Figure 4.17 Effect of water potential for the wettest zone containing roots on the rate of total translocation	143
Figure 4.18 Nominal germination rate as a function of water potential in the top soil layer	148
Figure 4.19 Effect of daily maximum air temperature on shrub germination	148
Figure 4.20 Shrub germination multiplier as a function of competing shade	148
Figure 4.21 Basal metabolism energy requirement	153
Figure 4.22 Thermal metabolism energy requirement	153
Figure 4.23 Thermal metabolism energy requirement	153

	<u>Page</u>
Figure 4.24 Activity metabolism energy requirement	153
Figure 4.25 Animal growth rate	155
Figure 4.26 Food Relative Scarcity Index	155
Figure 4.27 Food Relative Scarcity Index	155
Figure 4.28 Food Relative Scarcity Index	155
Figure 4.29 Population proportion shift	173
Figure 4.30 Population proportion shift	173
Figure 4.31 Habitat Condition Index for snow cover	173
Figure 4.32 Habitat Condition Index for ambient temperature	173
Figure 4.33 Habitat Condition Index for ambient temperature	174
Figure 5.1 Dose-injury curve for SO ₂ damage to plants	197
Figure 5.2 Leaf growth rate response of <u>Agropyron smithii</u> for the field to fumigation with ambient levels of SO ₂	203
Figure 5.3 Measures of sensitive plant responses to relatively long- term SO ₂ exposure	205
Figure 5.4 Various plant responses to long-term ethylene exposure	213
Figure 5.5 Relative effect of NO ₂ on the apparent net photo- synthetic rate in combination with equivalent or greater concentrations of SO ₂	222
Figure 5.6 Threshold SO ₂ concentrations that will produce about 5 percent leaf necrosis in sensitive, intermediate, and resistant plants grown under sensitive conditions	223
Figure 5.7 Effluent effect on net photosynthesis. The figure illus- trates the most sensitive species at full growth rate	224
Figure 5.8 Effluent effect on daily leaf death rate	224
Figure 5.9 Simulation of general plant response to ethylene in the model for three sensitivity classes	228
Figure 6.1 Climatic driving variables used for prototype simulation ...	232
Figure 6.2 Example time series dynamics of soil temperature state variables and processes	252

	<u>Page</u>
Figure 6.3 Example time series dynamics of soil moisture state variables and processes	258
Figure 6.4 Example time series dynamics of plant state variables	269
Figure 6.5 Example time series dynamics of plant processes	276
Figure 6.6 Example time series dynamics of fauna biomass state variables and processes	317
Figure 6.7 Example time series dynamics of fauna population state variables and processes	324

LIST OF TABLES

	<u>Page</u>
Table 2.1 A summary of characteristics of ecosystems of the Piceance Creek Basin	29
Table 2.2 User area criteria	63
Table 3.1 Parameter values for driving variables	66
Table 3.2 A process-effects matrix showing the items that are used in calculating each flow in the different subsystems	82
Table 3.3 A summary of terms used in the numerically implemented model	85
Table 4.1 Parameter values for soil temperature submodel	100
Table 4.2 Parameter values for soil water submodel	123
Table 4.3 Parameter values for the hydrologic process submodel	127
Table 4.4 Parameter values for land area submodel	129
Table 4.5a Parameter values for <u>Juniperus osteosperma</u>	137
Table 4.5b Parameter values for <u>Pinus edulis</u>	138
Table 4.5c Parameter values for <u>Agropyron</u> sp.	144
Table 4.5d Parameter values for <u>Bromus tectorum</u>	145
Table 4.5e Parameter values for <u>Artemisia tridentata</u>	149
Table 4.6 Parameter values for litter	151
Table 4.7a Parameter values for fauna biomass submodel	157
Table 4.7b Parameter values for mule deer diet	160
Table 4.7c Parameter values for cottontail diet	162
Table 4.7d Parameter values for chipmunk diet	164
Table 4.7e Parameter values for coyote diet	168
Table 4.8a Parameter values for mule deer population	176
Table 4.8b Parameter values for cottontail population	178
Table 4.8c Parameter values for chipmunk population	180
Table 4.8d Parameter values for coyote population	182

	<u>Page</u>
Table 4.9	Parameter values used by aquatic processes submodel 188
Table 5.1	Federal Ambient Air Quality Standards 192
Table 5.2	Maximum allowable increase in pollutant concentrations for PSD areas 192
Table 5.3	Current Federal and Colorado Air Quality Standards for sulfur dioxide 193
Table 5.4	Types of chronic low-level plant effects and probable mechanisms involved 196
Table 5.5	Percent of the total leaf area injured by different con- centrations of SO ₂ in two-hour fumigation studies 199
Table 5.6	Yield reductions in soybeans subjected to varying concen- trations of SO ₂ in the open-air fumigation system, 1977-1978 208
Table 5.7	Summary of toxicological experiments with sulfur dioxide 215
Table 5.8	Summary of toxicological experiments with nitrogen oxides ... 216
Table 6.1	Statistical summary for climatic driving variables used for prototype simulation 231
Table 6.2	Initial conditions for simulation 235
Table 6.3	Statistical summary of simulation results for soil temperature state variables and processes 250
Table 6.4	Statistical summary of simulation results for soil moisture state variables and processes 256
Table 6.5	Statistical summary of simulation results for plant state variables and processes 265
Table 6.6	Statistical summary of simulation results for fauna state variables and processes 287

1. GENERAL APPROACH AND SCOPE

Successful shale oil development must give due consideration to engineering, ecological, economic, social, and political components of the total development activity. This report addresses ecological and agricultural impacts upon the major ecosystems, including agriculture. As such, agricultural systems are ecosystems operated by and for man. The functioning of natural and agricultural systems is not fully understood, although a great deal of separate data have been collected on various components of these systems. Previous baseline studies in the shale oil development region of northwestern Colorado, northeastern Utah, and southwestern Wyoming and related studies in these regions have provided much information on the operational characteristics of these ecological and agricultural systems.

A preliminary conceptual structure of the operation of these ecological systems was evolved in Volume V of the C-b Tract Study report (Van Dyne and Haug 1977, Haug and Van Dyne 1979). That work developed a conceptual understanding of the spatial, structural units typical of the Piceance Creek Basin area and illustrated initial concepts of structure-function interrelationships. This volume presents a modified conceptual model of system interrelationships which can be used to qualitatively track environmental impacts. This process leads to insights in planning and monitoring of the development program and of mitigation of these disturbances.

1.1 CONCEPTUAL FRAMEWORK

Intuitive planning has a short term view. Difficulties of using intuitive decision-making practices arise because of the large number of complex interactions among system components. In dealing with complex systems, a long-term approach may be required to isolate the cause-and-effect relationships and to understand the interactions that can minimize or mitigate environmental disturbances. A potential working solution to this problem can be accomplished using a systems approach to develop a conceptual framework.

A conceptual model in diagrammatic form serves to organize, summarize, classify, integrate, and synthesize information about the real world. It is an expression of the relationships between the biotic and abiotic components of an ecological system. A diagrammatic model is useful for various types of environmental analysis, such as tracing potential impacts through the ecosystem, planning monitoring, and developing mitigation measures (Haug and Van Dyne 1979). The conceptual model may then be implemented in mathematical form and solved analytically or via a simulation.

1.2 IMPLEMENTATION OF CONCEPTUAL FRAMEWORK

Cause-and-effect reasoning can be applied to changes in several individual ecosystem components, alone or in combination. Feedbacks and interactions are represented so that many variables must be considered simultaneously. Because of the large number of combinations, there is considerable need for computer implementation of the conceptual model so that the interrelationships may be traced automatically, simultaneously, and quantitatively rather than just qualitatively.

Generally, in making predictions about man's technological impacts on the environment, not only are qualitative descriptions of impacts required, but also quantitative data. To make quantitative estimates of potential impacts on the natural and agricultural ecological systems requires a great deal of evaluation and calculation, following through all the various direct and indirect pathways within the systems. Therefore, the conceptual model is translated into a system of equations. Calculations are driven or forced with a series of external or driving variables. The model described in this report uses a system of nonlinear difference equations plus logical relations to describe the behavior of the system.

In a systems approach there should be continued analysis of the concepts, the data base, the relationships and the factors related to an understanding of the system. This is an evolutionary process. The framework, or model structure, will undergo successive refinements. Such refinements may condense or expand the lists of variables and the number of processes considered.

1.3 OBJECTIVES AND SCOPE

With quantitative outputs as a long-term goal, the efforts have been (i) to define a qualitative structure, i.e., a conceptual picture of relationships within natural and agriculture ecosystems, (ii) to implement this structure into a difference equation simulation model, (iii) to simulate baseline ecological conditions, and (iv) to simulate ecological conditions modified by development and management policies. Finally, the results of (iii) and (iv) will be compared to estimate potential effects in terrestrial, aquatic, and agricultural systems.

1.4 ACHIEVEMENTS

This report documents in detail the achievements and work completed to date. Two years of effort by various individuals has produced a computer model which fulfills objectives (i) and (ii). Objectives (iii) and (iv) have been near completion for the last nine months, however, several confounding problems in meeting the second two objectives have required modifications of the first two objectives. Although most of the model operates properly, due to the interdependencies of the model operations, any one error can invalidate the results from the rest of the model. Thus, as it is with most computer programs, there is no middle ground, they either work or they do not. All of the computer code required to meet the objectives has been programmed into the computer. The remaining work represents debugging to eliminate a few technical and conceptual problems. The primary problem is that the model works well for a one-year simulation, but is not stable for longer periods. Thus, a final analysis for objectives (iii) and (iv) is not possible at this time.

The following list describes the capabilities of the A.E.S.O.P model as it stands now:

- allows user definition of climatic conditions
 - allows user selection of resolution
 - allows user definition of ecological initial conditions
 - allows user definition of spatial relationships
 - allows user definition of climatic conditions
-
- simulates microclimatic conditions
 - simulates soil temperature and soil moisture dynamics
 - simulates tree cover dynamics
 - simulates shrub population dynamics
 - simulates shrub phenological dynamics
 - simulates herbaceous plant phenological dynamics
 - simulates animal population dynamics
 - simulates animal metabolic dynamics
 - simulates decomposition dynamics
-
- allows user selection of output from submodels
 - calculates summary statistics of selected output
 - creates line printer graphical time series plots of selected output
 - contains facilities for implementing a user query system which would be suitable for workshop gaming sessions.

2. PICEANCE CREEK BASIN CHARACTERISTICS

The Piceance Creek Basin of northwestern Colorado is delimited by the outcropping of the Green River formation and includes two separate drainage systems, the Piceance Creek drainage and the Yellow Creek drainage. This basin is one of the important subtypes of the Uinta Basin section, which is in turn, one of the major physiographic sections of the Colorado Plateau Province.

2.1 CURRENT (OR BASELINE) CONDITIONS OF PICEANCE CREEK BASIN SYSTEM

Some fifty million years ago, a large body of water covered what is now the area occupied by the upper Colorado River Valley in the Rocky Mountains of the United States. During the time the lake, called Lake Uinta, was in existence, large amounts of organic material were deposited on the bottom. Over time, these deposits solidified into what may be the richest deposit of shale oil in the world (CDO 1974). Subsequent plate tectonic activity over geologic time has caused the disappearance of the large lake, the upthrust of the Rocky Mountains, and vast changes in the climate of the area. These changes have produced a series of ecosystem formations typical of xeric environments at moderate to high elevations.

These ecosystems are vegetatively characterized by pinyon pine (Pinus edulis)-juniper (Juniperus osteosperma) associations in mountain and hillside locals, sagebrush (Artemisia tridentata)-grass (typically Hilaria jamesii and Sitanion hystrix) associations in the desert grassland type, blackbrush communities (Coleogyne ramosissima), greasewood communities (Sarcobatus vermiculatus) and saltbush (Atriplex nuttallii) associations.

Fauna commonly associated with the above vegetation types include (on a migratory or resident basis) the black-tailed jackrabbit (Lepus californicus), yellow-bellied marmot (Marmota flaviventris), Colorado chipmunk (Eutamias quadrivittatus), deer mouse (Peromyscus maniculatus), desertwood rat (Neotoma lepida), coyote (Canis latrans), raccoon (Procyon lotor), elk (Cervus canadensis), mountain sheep (Ovis canadensis), mule deer (Odocoileus hemionus), and pronghorn antelope (Antilocapra americana). In addition, more than 250 species of birds, reptiles, and some amphibians have been reported in the area (McKean and Burkhard 1978).

2.1.1 Climate and Air Quality

The climate of the area is characterized by abundant sunshine with generally low precipitation and relative humidity. Strong outgoing terrestrial radiation creates cool nights. In midwinter, daytime temperatures are often low, but strong solar radiation and dry air combine to produce usually pleasant weather.

The climate of any local area within the region is strongly influenced by slope, aspect, elevation, and vegetation. As such, local surface wind patterns and vertical temperature profiles are almost entirely dependent on topography.

Temperatures of the region are moderate during spring, summer, and fall. Maximum temperatures at the lower elevations may exceed 38°C (100°F) during midsummer while winter temperatures may drop to -40°C (-40°F). The number of frost free days per year varies from 50 in the high elevations to 180 in the lower elevations. Any given site may experience wide variation in the growing season from one year to the next.

Predominant prevailing wind direction aloft over the region is from the southwest. However, surface air movement patterns are more variable because of topographic effects. Strong thermal convection winds, or updrafts, are common during warm summer days. Thunder storms, often the consequence of the thermal convection winds are accompanied by strong, turbulent downdrafts.

The average annual precipitation over the area varies from about 203 mm (8 in) on the lower desert elevations to 508 mm (20 in) on top of the Roan Plateau.

The influence of the solar regime on frequency and duration of inversions is all important. More numerous inversions of shorter duration occur during the summer months, and longer lasting inversions occur during the winter. In summer, surface heating and convection are greater and effectively disperse the stable layers, creating inversions of shorter duration that are not as well defined as those occurring in winter. Inversions in the summer most frequently originate after sunset or nearer midnight as radiation cooling becomes effective in the formation of stable layers (CDO 1974). In winter, inversions usually begin between the late afternoon and early morning hours. Inversion dissipation is generally related to the time of sunrise. Inversion conditions may exist over 50% of the time in the fall and winter seasons. A severe episode may be expected to occur at least once a year and may last from three to six days (BPNL 1972). Perhaps, the most notable air pollution is dust generated by traffic on unpaved roads.

2.1.2 Soils

Soil pH in the vicinity ranges from neutral (7.3) to highly alkaline (9.8) for surface soils and from 8.0 to 9.0 for subsurface soils. Soil pH is particularly important to plants because it influences the availability of nutrients for plant absorption and concentration of toxic ions. In general, soil is acid where precipitation is high enough to leach appreciable amounts of exchangeable bases (sodium, calcium, magnesium) from the soil and soil is alkaline where precipitation is generally insufficient for leaching.

Soil pH in the area increases with depth, a trait common to many soils. As organic matter decomposes, various acids are produced and released to the soil. Decomposition is most intense in surface soil and decreases sharply with depth. In addition, leaching removes carbonates from the surface and deposits them lower in the soil profile. Such processes develop gradients in soil pH.

Electrical conductivity of surface soils in the region ranges from less than $1.0 \text{ mmhos cm}^{-1}$ to a high of 59 mmhos cm^{-1} . When electrical conductivity exceeds about $15.0 \text{ mmhos cm}^{-1}$, few plant species can survive, and those that do may be restricted in their yield (Barth 1976). In the area,

only a few highly saline zones have been identified. They occur between 50 to 150 cm in depth. The general absence of highly saline material at or near the surface apparently mitigates detrimental effects of salts on plant growth since the sites where high saline subsurface soils exist support vegetation similar to areas lacking saline zones. When a highly saline interval is at or near the surface, plant species composition reflects the presence of salts. Those sites are generally dominated by shadscale or basin wild-rye, both salt tolerant species of plants.

Electrical conductivity in the region's soils increases from 2.2 mmhos cm^{-1} at the soil surface to 7.7 mmhos cm^{-1} at 100 to 150 cm depth. This increase in salinity with depth is due, in part, to leaching of water soluble salts from surface to subsurface; other factors may also be involved. In many areas of the region, aeolian material has been deposited on the original surface. This material may have contained less soluble salts than the original surface. Hence, surface and near surface soils are apparently of one geologic origin while the deeper soils are of another geologic origin. Mean electrical conductivity of subsurface soils (1.49 mmhos) is higher than that for surface soils (0.86 mmhos), but well within the tolerance range for most plants of the region.

Cation exchange capacity is the sum total of exchangeable cations that a soil can absorb (Brady 1974). Clay minerals and humus account for essentially all of a soil's exchange capacity. When average cation exchange capacity of the study area is related to the percentage clay, the exchange capacity is approximately 250 meq 100 g^{-1} . This relatively high exchange capacity indicates that montmorillonite is the dominant clay mineral, a mineral most commonly found in semi-arid regions. Little difference exists between cation exchange capacities of surface and sub-surface soils of the region.

Exchangeable sodium percentage (ESP) expresses the percentage of sodium ions in the soil exchange complex. When this percentage exceeds 15.0 the soil is termed sodic or alkaline (Lunt 1966). A given level of ESP is more detrimental to plant growth in a soil with a higher percentage of clay than with a lower percentage of clay. This is thought to be due to the greater degree of particle dispersion in clayey soil than in sandy soil (Pearson and Bernstein 1958, Pearson 1960). Water penetration into a dispersed soil is very slow, thus increasing erosion potential and reducing the amount of soil water available for plant use.

Mean ESP for surface soils in the region is about 5.1. Sodic intervals in the soil occur in several areas, but are rare in the 0 to 15 cm soil depth interval. This is probably indicative of a deposition of salts in solution to the maximum wetting front depth. Sodium that may have been in or near the surface probably leached out or was replaced by other salts. As a consequence, the ESP was not restrictive of plant growth and water infiltration.

Subsurface sodic intervals appear to have little effect on vegetation. Pinyon-juniper or sagebrush dominate sites where sodic intervals are found. Vegetation on these sites is similar to vegetation found on sites where sodic intervals are not present. Dominant vegetation in areas where sodic intervals are at or near the surface is composed of greasewood or shadscale.

Reference is made to RBOSP (1977) for a discussion of the status of plant macronutrients (nitrogen, phosphorus, potassium, magnesium, calcium, and sulfur) and plant micronutrients (baron, molybdenum, copper, iron, zinc, chloride, and manganese) in the soils of the region.

Water holding capacity is a measurement of the amount of water retained by a soil at a given level of suction. When measured at 0.33 bar (4.85 psi) suction pressure, the water holding capacity approximates the amount of water retained by a soil after free drainage has ceased. The capacity at 15 bars (220 psi) suction pressure is the upper limit at which most plants are able to absorb water from the soil. The amount of water retained between those two extremes is termed the plant-available moisture capacity, and serves as an index to the amount of water available for plant absorption. Nishimura (1974) suggests that soil used in reclamation should have a minimum plant-available moisture capacity of approximately 7% to insure that the soil has the potential to retain sufficient water for normal plant growth. Soil texture, structure, and organic matter content are the main determining factors of soil water holding capacity. Soils in the shale oil developmenet region have sufficient water-holding capacity to adequately support active plant growth.

Soil texture is an important physical trait in that it influences the nutrient-supplying ability of soil as well as the supply of air and water to plant roots. Optimum soil texture varies with climatic conditions. In semi-arid regions, the production of native vegetation is greater on sandy soils than on medium to fine textured soils. In sandy soils the infiltration rate is rapid so there is little water lost through surface runoff. Additionally, less moisture is held per unit depth in sandy soils so less moisture is lost to surface evaporation. However, sufficient fine-textured material must be present to retain adequate amounts of water (Berg and Barrau 1973). Soils in the region are generally in the loam category and range from loamy sand to clay loam. Most subsurface soils are in the coarse to medium texture categories. These soils contain sufficient boundaries to retain adequate amounts of water.

Vegetation plays an important role in the redistribution of soil constituents. Plants absorb soil constituents from a large area and concentrate them in a relatively small area thereby contributing to the vertical gradients in the soil. Certain types of vegetation will impart different traits to the soil. Rooting pattern, life span, phenology, elemental composition and other factors differ between plant species and can significantly influence many soil traits. However, differences in parent material, relief, microclimate, and time also influence soil traits and may mask the influence of vegetation.

Big sagebrush, a very common species in the region, is found on moderately alkaline, nonsaline, and nonsodic soils. The concentration of water soluble nutrients is generally lower for sagebrush soils than for other vegetation types in the region.

The nonsaline, nonsodic, and moderately alkaline soils of the pinyon-juniper vegetation type show no unusual traits relative to surface and near-surface soils of the area. These soils are very similar in chemical traits to those associated with sagebrush. It seems that both pinyon and juniper plants have a competitive advantage on sandy and rocky soils.

Soils of the shadscale vegetation type in the area are nonsaline and nonsodic but do have slightly higher ESP and soluble salt electrical conductivity than other vegetation types. Sharma and Tongway (1973) and Fireman and Hayward (1952) found that soils under shadscale are higher in ESP and in electrical conductivity than soils outside the influence of this shrub. These findings imply that shadscale redistributes sodium and other salts. Also, shadscale soils are unusually high in magnesium, calcium, and sulfate in the study area. Areas dominated by shadscale are generally located on steep canyon slopes where soils are poorly developed and very shallow.

Mixed brush soils in the region typically have the lowest pH, electrical conductivity, ESP, magnesium, and sulfate. This suggests that leaching is more intense in this vegetation type than in other types of the area. Mixed brush is generally found on north-facing slopes in the higher elevations of the region. Such areas tend to be relatively moist and presumably more intensively leached than other soils. Manganese, zinc, and iron are in relatively high concentrations as is organic matter. This latter may be related to the deciduous nature of many shrubs of the mixed brush type. The annual shedding of leaves may also increase the soil organic matter over that found in areas dominated by vegetation that retains leaves. Mixed brush soils tend to have little sand and large amounts of clay which suggests a slightly more intense chemical and physical weathering of soil.

The degree of influence of rabbitbrush on soil traits appears to be of the same low magnitude as indicated as that for sagebrush and pinyon-juniper. Extractable phosphorus and potassium are very high for these soils. Rabbitbrush generally dominates bottomland soils where sagebrush has been eliminated by burning. Such burning can increase soil concentrations of phosphorus and potassium (Uggla 1959).

Greasewood appears to occur on a distinct soil type. Soils where greasewood dominates are saline, sodic, and strongly alkaline. Fireman and Hayward (1952) found that pH, electrical conductivity, and ESP are higher under greasewood plants than in open areas free from the influence of the plants. They also found that greasewood leaves contain a high proportion of anions in the form of organic acids. When the leaves decompose and the various products are released to the soil, calcium and magnesium are displaced on the soil exchange complex and replaced with sodium, thereby increasing pH and ESP. Nitrate and sulfate are two macronutrients that are unusually high for the area dominated by greasewood. It is possible that greasewood influences the distribution of these macronutrients. Greasewood dominated soils tend to have the least amount of clay of the soil types in the region.

2.1.3 Flora

Eight vegetation types have been identified in the shale oil development region. These are aspen, Douglas-fir, pinyon-juniper, mixed brush, sagebrush, bald, shadscale, and riparian. The pinyon-juniper type may be further divided into three associations. These are pinyon-juniper/woodland, pinyon-juniper/mixed brush, and pinyon-juniper/sagebrush associations. The sagebrush type may be further divided into four associations. These are upland sagebrush, bottomland sagebrush, greasewood, and rabbitbrush.

The distribution of vegetation types in the region is strongly influenced by topography and soil development. The Douglas-fir and aspen types are generally restricted to cool north-facing exposures at the highest elevations. The mixed brush type dominated primarily by serviceberry shrubs, is widely distributed at high elevations between 2100 and 2500 m (7000 to 8000 ft) and reaches maximum cover and density on north-facing slopes. The pinyon-juniper types, so called because of the dominance of pinyon pine and Utah juniper, is found at low and intermediate elevations between 1950 and 2250 m (6500 to 7500 ft) on areas of shallow soils. The sagebrush types, dominated by big sagebrush shrubs, are found at all elevations within the area, but predominantly on gently sloping uplands with deeper soils and on alluvial soils along drainages. The rabbitbrush association represents a seral stage in the sagebrush type while the greasewood association appears to be an edaphic variant of the sagebrush type. The shadscale shrub type is restricted to shale outcroppings on steep slopes along major drainages. The bald type consists primarily of herbaceous species and is restricted to windy ridgetops with shallow soils. The riparian type is limited to areas below the outflow of perennial springs and major drainages. It consists mainly of introduced forbs and pasture grass species.

The plant communities present consist of a stable mosaic and are segregated from each other on the basis of the adaptation of the dominant species to different environmental gradients imposed by the diverse topography and climatic variability found within the region. Probably the chief controlling factor for plant distribution within the region is topography (slope, aspect, elevation) which influences moisture availability to the soil. Physical and chemical characteristics of the soil in the study area as well as soil depth also have very important effects on the distribution and abundance of different plant species. Another factor is the interaction between components of different strata within each vegetation type (tree, shrub, ground-cover). This interaction is especially important in the pinyon-juniper and sagebrush types where the dominant overstory stratum exerts a major influence on the development of the understory strata. An additional factor is the effect of destruction of different members of the plant community by fire, disease, and mechanical means by man. Disturbances such as these indicate the successional process within the plant community during recovery. Plant communities within the shale oil development area are generally stable in their distribution and composition, but short-term changes in herbaceous cover and diversity which are responses to yearly climatic variability and differential consumption by herbivores has been observed.

The general scarcity of large trees indicates that the climatic conditions for optimum tree growth are most often not met within this region. However, the pinyon-juniper type represents a stable adaptation to this climatic regime, and represents a complex of critical importance to animals living within the study area by providing shelter and a major food source in the form of foliage, juniper berries, and pinyon nuts.

The shrub form is the predominant life form in the area and is best represented by big sagebrush, a ubiquitous plant species in the region. Shrub species on the area form an interactive group with nearly all sites containing more than one species. The reproductive strategy of the shrub species is divided between those which reproduce primarily by seeds, such as big sagebrush, greasewood, and rabbitbrush, and those which reproduce primarily by

vegetative means (and secondarily by seeds) such as serviceberry, chokecherry, and Gambel oak. Shrubs provide shelter and nesting sites for birds and small mammals and provide a major portion of the diet for mule deer. The herbaceous stratum over the study area is predominantly composed of perennial species, some of which are widely distributed throughout the study area at all elevations. Such widely distributed species are bladderpod (Physaria floribunda), Sandberg bluegrass, and slender wheatgrass. In general, there is little change in herbaceous cover over the growing season due to the slow growth of most species. Exceptions occur within the aspen and Douglas-fir types which contain species that sprout from dormant crowns each spring, and in greasewood and riparian areas where higher soil moisture levels permit more rapid plant growth. Maximum herbaceous stratum diversity appears to occur primarily in open areas such as balds.

The aspen and Douglas-fir types occur at the highest elevations, and are a minor component of the Basin vegetation because of their limited areal extent and distribution. These types are more structurally diverse, are most productive, and provide the greatest standing crop among the vegetation types in the study area.

The high productivity of these sites appears to be the result of favorable growth conditions which comes from sustained periods of high soil moisture. These favorable soil moisture conditions within aspen and Douglas-fir stands appear to be derived from deep winter snow, from reduced solar radiation because these stands are bound on north-facing slopes, and from generally deep loamy soils. The aspen and Douglas-fir types are segregated from each other on the basis of shallower soils in the Douglas-fir stands. The relatively moist, cool conditions sustain several species of plants and animals not found elsewhere in the region. The structural diversity and abundant food resources within these types contribute to the high summer diversity of birds and the frequent utilization of these areas by mule deer and elk. Large animal utilization of these areas in winter is limited because of deep snow.

There is little human disturbance in the Douglas-fir or aspen stands. This is probably due to the inaccessibility and small size of these stands which limit their economic importance.

The sagebrush, mixed brush, and pinyon-juniper types form an interactive mosaic over the entire region, and are the dominant vegetation types based on areal extent. These three types are segregated from each other on the basis of climatic, edaphic, and biotic factors. The mixed brush type is found primarily at higher elevations, above 2100 m (7000 ft); the pinyon-juniper type is found at intermediate and lower elevations below 2250 m (7500 ft); the sagebrush type is found at all elevations but is most common at lower elevations, below 2100 m (7000 ft). The three types intergrade extensively at intermediate elevations within the pinyon-juniper type, and form broad ecotonal areas with compositional and structural characteristics of all three types. Sagebrush predominates on areas with relatively deep soils, particularly along the tops of ridges and the bottom of drainages. Pinyon-juniper and mixed brush predominate on shallow soils at intermediate elevations in the region and tall mixed brush species (serviceberry and Gambel oak) increase in importance on deeper soils at higher elevations where precipitation is higher and overall temperatures are cooler.

The sagebrush type may be divided into four associations based on edaphic, physionomic, and serial criteria. Upland sagebrush is segregated from bottomland sagebrush on the basis of differences in height and density and occurrence on different soil types (bottomland on alluvial, upland on residual soils). The greasewood association is designated as an edaphic variant of the bottomland sagebrush association based on its occurrence on soils with high salinity or alkalinity. The rabbitbrush association is considered a seral variant of the bottomland sagebrush association because of its secondary successional status on disturbed bottomland sagebrush sites.

Production within the three types is primarily controlled by available soil moisture. Since production appears to increase with elevation over the area there appears to be a gradient of greater precipitation with elevation. Upland sagebrush and mixed brush stands above 2100 m (7000 ft) appear to be more productive than pinyon-juniper and sagebrush stands below this elevation. However, relatively high production can occur in low elevation bottomland sagebrush, greasewood, and rabbitbrush stands where perennial surface moisture contributes to rapid growth. In the pinyon-juniper type, the three strata contribute the majority of annual production because of the capability of pinyon pine and Utah juniper to out-compete other plant species for available water. Actual production in the pinyon-juniper type is rather low because of generally shallow soils with limited water-holding capacity.

The physiognomy and species composition of the different types influence the kind of animal usage. An extensive herbaceous component exists in both the sagebrush and the mixed brush type and large herbivores are most frequent there. Shrub species occurring in these two types are also important browse species for mule deer. The pinyon-juniper type is most important in terms of the utilization of these dominant tree species in the form of nuts and juniper berries for birds and rodents, and as browse and shelter for large mammals. Differences in species composition among the upland, bottomland, rabbitbrush, sagebrush, and greasewood associations affect the types of animals which occur within the different associations. The herbaceous stratum of the greasewood, rabbitbrush, and bottomland sagebrush association consists of a number of annual species which, because of their high seed production, favor the occurrence of seed eating small mammals and birds. The greater cover afforded by the shrub stratum in these associations also favors large populations of small mammals, making these bottomland habitats especially important to the overall ecosystem. The upland sagebrush stands consist of a larger component of grass species and there, shrub cover is less. Small mammals and birds are less abundant in these sites, but these areas are heavily utilized by livestock and wild horses.

The shadscale type is an edaphically and topographically determined type which occurs in local areas along the face of steep south-facing slopes in the major drainages. It occurs in transitional areas between bottomland sagebrush stands and pinyon-juniper woodlands and has species common to both these communities. The areal extent of the shadscale type is very small and the production and biomass of the dominant species, shadscale and big sagebrush, is low. The importance of this type to the ecosystem is minor because of its low productivity.

The bald type is also edaphically and topographically determined, occurring on tops of ridges where strong winds and shallow soils are

prevalent. Composition of these areas is restricted primarily to mat-forming herbaceous species. Shrubs and trees are unable to become established in these areas, but despite severe conditions, herbaceous productivity is similar to nearby sagebrush stands. The balds are critical winter habitat for wild horses, providing forage during that time of year. Because of low cover and low food availability, utilization of balds by small mammals and birds is low.

The riparian type occurs in isolated areas in the bottom of major drainages with perennial water flow. These areas have been extensively developed as livestock pastures, and species composition consists largely of introduced grasses and forbs. These sites are unusual because of the general lack of shrub and tree species (willows and cottonwood) characteristic of riparian habitats in western Colorado. (One spring area, Cottonwood Spring, on Duck Creek, is relatively undisturbed and contains several plant species which are unusual within the Piceance Basin.) Riparian areas are highly productive because of abundant moisture and are heavily utilized by livestock.

2.1.4 Fauna

2.1.4.1 Small Mammals.

The kind of vegetation is the most important factor controlling the distribution and abundance of small mammal populations in the Basin. For some species, elevation is also important. Within habitats below 2430 m (8000 ft), the amount of shrub cover appears to be the most important factor regulating the abundance of small mammals, although other factors such as plant species composition, substrate condition, slope, and aspect may play a role. The largest number of small mammals per unit area occurs in the rabbitbrush, pinyon-juniper/mixed brush and mixed brush types and associations. Below 2430 m the habitat with the fewest animals is bottomland meadow which also has the lowest shrub cover.

Aspen and Douglas-fir contain fewer small mammals than all other habitats except bottomland meadow even though they exhibit the highest shrub cover of any of the habitats. The harsher environmental conditions and the accompanying lower productivity caused by a shorter growing season characteristic of communities at these elevations are probably the major limiting factors to small mammal abundance. Vegetation species composition and kinds of food available may also influence small mammal abundance in these types.

With the exception of the bald vegetation type, the habitats above 2430 m (8000 ft) (aspen, Douglas-fir, and mixed brush) show the same general trend as evident at lower elevations, with more small mammals being encountered in habitats with a higher shrub cover.

Species diversity, as measured by the Shannon-Weiner index (c.f. Krebs 1978) which accounts for both the number of species and the relative number of individuals of each species, is closely tied to the presence or absence of trees (pinyon pine and juniper) in habitats below 2430 m. Pinyon and juniper trees provide food for many small mammal species that eat the highly nutritious pinyon nuts and juniper berries. The latter are more consistently available than pinyon nuts because they remain on tree a large part of the

year and are not as completely destroyed by insects as are pinyon nuts. The cambium of pinyon may also be eaten by some species of small mammals and the bark of juniper is often used in nest building (Frischknecht 1975).

If abundance is used as the criterion as an indicator of species importance, then the deer mouse and the least chipmunk are by far the most important small mammals in the area. They are well represented in all habitat types except the aspen and Douglas-fir types where the red-backed vole predominates. As a result of their high population levels and similar distribution patterns the potential for competition between the least chipmunk and deer mouse is great, especially since they exhibit almost identical food preferences. Competitive interaction may be avoided, however, since the species utilize different activity periods, the deer mouse being nocturnal and the least chipmunk, diurnal. These species may also utilize different parts of the same habitat. The deer mouse is most common in habitats with high shrub cover while high population levels of the least chipmunk are more closely associated with pinyon-juniper habitat.

The golden-mantled ground squirrel and the Colorado chipmunk are the third most abundant small mammals in the area. Both species show a definite preference for pinyon-juniper woodlands as do two other species, the pinyon mouse and the bushy-tailed woodrat.

Of the four vole species in the region, the red-backed vole is the most abundant. It is adapted for living at elevations above 2430 m (8000 ft) (Lechleitner 1969) and is the predominant small mammal in both Douglas-fir and aspen vegetation. The montane vole shows a definite affinity for bottomland meadow while its congener, the long-tailed vole, shows an affinity for bottomland sagebrush. The sagebrush vole, as its name indicates, prefers upland sagebrush as well as mixed brush vegetation.

Studies of the food habits of the deer mouse, least chipmunk, and long-tailed vole (RBOSP 1977) characterized all three species as omnivorous, opportunistic feeders. The deer mouse and least chipmunk utilize seeds to a great extent while the long-tailed vole prefers succulent vegetation. All species can switch to other food sources when these become more abundant.

Other small mammals present in the area include the northern pocket gopher, the wandering shrew, cottontail rabbit, white-tailed jackrabbit, black-tailed jackrabbit, and porcupine.

Five species of bat frequent the area. These are the California myotis, long-eared myotis, big brown bat, hoary bat, and the silver-haired bat.

2.1.4.2 Large Mammals

Non-domestic large mammals in the area include mule deer (Odocoileus hemionus), elk (Cervus canadensis), and feral or wild horses (Equus caballus).

Mule Deer. Mule deer activity in the region varies seasonally. Summer is generally the season in which the lowest mule deer densities are found. Mule

deer during the summer months are found at higher elevations in the aspen, Douglas-fir, sagebrush, and mixed brush vegetation types.

Mule deer do not exhibit a preference for any particular aspect or slope during summer. It is possible that mule deer seek a variety of macro-environments in response to everchanging environmental conditions throughout the summer. Kufeld et al. (1973) have reported that average summer mule deer diets consist of 49% browse, 46% forbs, and 3% grasses and grasslike plants. The vegetation types occurring at higher elevations are generally more diverse and productive than the types on the lower elevations of the Basin. Accordingly, mule deer on the study area in the summer occupy such higher elevations where they are able to take advantage of the more desirable conditions in terms of quantity and diversity of forage. These higher elevations are probably also attractive during summer owing to their relatively cool temperatures. Water is also available there at springs, streams, and stock watering ponds in the bottoms of gulches.

In October, mule deer start to move into and through the lower elevations to winter ranges. The environmental, physiological, and psychological factors initiating their behavior are not clearly understood. However, movements are often positively correlated with a drop in temperature, snowfall, or a combination of the two (Loveless 1967, Richens 1966, Russell 1932). Some mule deer move into the lowlands before snow at the higher elevations is deep enough to hamper activity, while others remain at the highest elevations possible and only move enough to avoid snow depths which hamper activity. A snow depth of 30.5 cm (12 in) does hamper mule deer use of most areas (Loveless 1967, Gilbert et al. 1970). Mule deer move in response to a change of as little as 5°F during winter and fall periods (VTN 1976). Whatever the cause of the movement a change in range occurs with the change in seasons.

Mule deer movements continue during the entire winter as animal density and areas of activity change. Movements continue into the spring when the animals then move to summer range. Mule deer occur on all vegetation types, but as winter progresses, most move from mixed brush types to sagebrush and pinyon-juniper covered areas where the animals range until returning to higher elevations in the spring. An area used at one time may not be used at another for a number of reasons. Variables include forage palatability, wind speed, temperature, slope, aspect, cover availability, etc.

A very small portion of the Basin is composed of steep cliffs that could present a barrier to mule deer movement. However, most sections can be easily traversed by mule deer, thereby precluding a migration route dictated by topographical characteristics. Mule deer appear to use most portions of the area during at least part of their seasonal movements but take advantage of topographic and man-made features present. Deer tracks, for example, are often seen along roads and cleared pipeline zones where gates are left open or old fences are down.

A continuous change in mule deer density and distribution occurs throughout the winter. Density and distribution changes may be gradual or rapid and appear to be related to weather and snow accumulation patterns. A heavy snowfall in a short period of time has been shown to cause rapid change also.

Mule deer apparently do not concentrate in winter until deep snow forces them into more limited areas of lesser snow depth. Some animals stay in the higher elevations where forage is more abundant as long as possible, then move to areas where their movements are not hindered by deep snow. These are usually south-facing slopes at the higher elevations as well as north-facing slopes and other slopes at the lower elevations. Deer use thick brush or pinyon-juniper stands as cover from cold winds but on still, cloudless winter days they have been seen to be bedded in direct sunlight in more open areas. Mule deer use the eastern, lower, more-open portions of the area more than the western sections during winter periods.

Mule deer rely mainly on browse for forage during the winter, but their diets are quite variable throughout the Rocky Mountain Area (Kufeld et al. 1973). Hansen and Dearden (1975) studied the diets of mule deer under stress in the Piceance Basin and found that pinyon pine (Pinus edulis), Utah juniper (Juniperus osteosperma), big sagebrush (Artemisia tridentata), Utah serviceberry (Amelanchier utahensis) together made up 96 to 98% of the forage consumed. Pinyon and juniper comprised about four-fifths of the mule deer foods but reasons for this high percentage are unknown. The above authors suggest that there may be a relationship between extremely cold winter temperatures and high percentages of pinyon and juniper in the diet.

Elk. A relatively small number of elk occur in the Piceance Basin throughout the year. Elk are generally located in mixed brush or aspen and Douglas-fir sites along the Cathedral Bluffs, but they have also been seen in pinyon-juniper types and sagebrush types during spring mule deer migration.

Elk diets generally contain a relatively lower percentage of shrubs (browse) and a greater percentage of grass than mule deer diets. Kufeld (1973) reviewed food habit studies of Rocky Mountain elk throughout the western United States and Canada and Boyd (1970) conducted food habit studies on elk of the White River Plateau in Colorado. These two papers were used for the following summary of elk food habits. Winter use is concentrated on either grass or shrubs depending on forage availability. Browse of all types represented 57% of the plants consumed from December through April in the White River study. Browse species used were oakbrush, aspen, serviceberry, big sagebrush, and snowberry. Most of the other winter forage were grasses.

Spring, summer, and fall diets are comprised primarily of grasses with relatively smaller amounts of forbs and browse. Grass averaged 78% of the diet over the summer months and 92% of the diet from September through November in the Colorado study. Forbs were taken mainly during mid-summer and late fall. Overall, the one-year study in Colorado reported 65% grasses, 27% woody species, and 8% forbs on a frequency-of-occurrence basis for the summer samples.

Elk are not hampered by snow as much as are deer so they can remain at higher elevations during the winter. Since snow covers most of the grasses in this area during mid-winter, elk are forced to rely on browse to meet forage requirements. Elk occurring in the study area during summer share water sources with mule deer, wild horses, and domestic livestock.

Wild and Feral Horses. Wild horses range over the region. In contrast to the variable seasonal distribution of mule deer, wild horses are present

throughout the year. Wild horse herds range in all vegetation types, though long range seasonal movements by the various herds are probably limited by barbwire fence.

Feral horses demonstrate great mobility and during most seasons easily travel through the area until encountering fences. While deer and elk easily jump most fences, horse movements appear to be restricted by fences. They will cross a fence only if it is down or if they are harassed. Consequently, most of the vegetation types described earlier exhibit evidence of horse activity.

During the winter, many horses forage along wind-swept ridge tops where plants are not covered by snow. Horses move to dense brush, ravines or the lee side of ridges during inclement weather. Horse size and strength permit them to maneuver through all but the deepest drifts. They probably obtain sufficient water during the winter by eating snow.

During the summer, horses forage in mixed brush, sagebrush, bottomland meadow and bald vegetation types. They are at ease during mid-day near these same areas or under large solitary trees. Many animals appear to seek shade in pinyon-juniper stands during the hottest period of the summer day. Horses are able to graze many more miles from water than can domestic sheep, cattle or most wildlife species (USDI 1973). Horses have also been observed in bottomlands near water sources during summer periods. At times, both wild and domestic horses lie down and roll over on their back, to scratch otherwise inaccessible parts of their bodies and to dust ectoparasites. Places where horses roll in the dust are evident on many roadbeds throughout the area.

Hubbard and Hansen (1976) report the principle year-round foods of wild horses in the Piceance Basin are sedges (Carex sp.), needle-and-thread (Stipa comata), wheatgrass (Agropyron sp.), prairie junegrass (Koeleria cristata), bromes (Bromus sp.), Indian ricegrass (Oryzopsis hymenoides), bluegrass (Poa sp.), and common winterfat (Eurotia lanata) for mountain shrub, ecotone and pinyon-juniper vegetation zones. Utah serviceberry (Amelanchier utahensis) is a principle food of wild horses in the mountain shrub zone. Horses probably browse the serviceberry most during winter when grasses are covered by snow in all but the windswept areas. In contrast to the seasonal consumption of forage by mule deer and cattle, horses consume forage during all seasons and have therefore the potential to affect range resources at all times during the year.

New-born foals begin appearing by mid-April. The peak foaling period is May and continues throughout the summer. Relatively young foals have been observed as late as September, but these animals probably have little chance to survive the harsh winter conditions.

Dead horses and skeletons have been seen in the region, but the cause of mortality is not generally evident. Foals probably suffer high mortality during winter when forage is covered by snow and they must compete with stronger adult horses for food. Deep snows may trap even adult animals causing starvation. Predators probably have limited influence on horse mortality.

2.1.4.3 Large Mammal Interrelationships

Competition for forage is one obvious important potential interaction of the large herbivorous mammal species. Cattle are mainly grazers, eating grass and forbs. They will, however, at time browse shrubs throughout the summer and will consume large amounts of browse in late fall. Mule deer consume mainly browse plant species, but at certain times (spring) graze on the initial growth of grasses and forbs. Elk prefer grass and forbs throughout the year, but consume browse during the winter. Wild horses rely mainly on grass but browse serviceberry at higher elevations (Hubbard and Hansen 1976). Competition for food occurs to the extent that the various species consume the same forage. Conversely, a complementary food relationship can exist when various herbivores consume different forage species, provided that the total consumed by all species is not excessive to the point of range deterioration. Cattle consumption of grass can reduce competition for moisture and nutrients in favor of browse plants used by mule deer.

Hubbard and Hansen (1976) report high dietary overlaps between wild horses and cattle, and suggest that competitive food relationships can develop if stocking rates of horses and cattle are not balanced with production of sedges and grasses in the Piceance Basin. Although wild horses and mule deer consume high percentages of Utah serviceberry in the mountain shrub zones, the diets of mule deer are generally quite different from the wild horses and cattle, suggesting complementary rather than competitive potential food relationships. McKean and Bartman (1971) indicate that cattle and mule deer on pinyon-juniper ranges can be grazed in combinations if kept at moderate rates (2 acres per deer per month and 20 acres per cow per month) without serious competition and range deterioration. Elk diets overlap with the diets of mule deer, wild horses and cattle. Since elk can winter at higher elevations, they are able to browse food unavailable to mule deer during part of the winter, though the mule deer do consume browse on their migration through the area. The small number of elk present in the study area limits the extent of their interaction with other species. Certainly overstocking of any one large mammal species would cause increased competition for forage, not only with other species in the area, but between individuals of the same species.

Interactions other than those dealing with forage also occur between the large mammals. Horses traveling and pawing through snow for their own food often uncover forage for deer. They may also open trails through deep snow to areas which otherwise would be inaccessible to mule deer. Competition for water between individuals of one species as well as individuals of different species can occur during summer months. This competition probably occurs only if the animals use the same water source at the same time. Protective cover suitable for use during the winter is another potential competition area in severe cases where food sources may be depleted near good cover.

In addition to the large mammal species interrelationships with each other, they also interact directly and indirectly with other animals. Herbivorous animals such as sage grouse, chipmunks, and phytophagous insects can have either competitive or complementary interrelationships with the large mammals in a manner similar to the interactions between large mammal species, depending on the foods they eat. Oakbrush resprouts, which are deer and elk winter forage, may be stimulated after porcupines have killed the mature

aboveground plant by eating the bark during the previous winter. Insect pests such as mosquitos and bot flies cause undesirable conditions for large mammals. Other insect activities, such as plant pollination or predation of undesirable insect species, benefit the large mammals. Insectivorous birds and mammals benefit the large mammals by reducing insect pests, but they also reduce the number of beneficial insects. Large mammals provide food sources for coyotes and other predator/scavenger animals such as ravens, magpies, and golden eagles. Coyotes have been observed preying on mule deer, the carcasses of which also provide food and shelter for various insects.

Browsing by animals often stimulates growth of plants such as serviceberry, oakbrush, mountain mahogany, and bitterbrush. Severe browsing of various plants on the lower elevations of the study area, may retard plant growth. Browse plants on lower elevations have assumed growth forms characteristic of plants under moderate to heavy utilization, while the same species of plants at the higher elevations generally exhibit little or no hedging. Some shrubs on the higher elevations have grown to the extent that most production is unavailable to deer, while plants on the lower elevations have been browsed sufficiently each year to keep most of the new growth within reach of mule deer. Also, seeds of various plants may be dispersed by clinging to animal hair or by being ingested and deposited elsewhere in feces.

2.1.4.4 Mammalian Predators

The coyote and long-tailed weasel are the two most abundant mammalian predators in the region. Others present include ermine, bobcat, badger, skunk, mountain lion, black bear, pine marten, grey fox, and ringtail. Other mammalian predators occurring in western Colorado, such as the mink, raccoon, shunk, and red fox prefer riparian or agricultural vegetation types.

Coyotes are active all year in all habitat types. Coyotes probably shift their activities to lower elevations during mid-winter and spring when carrion from winter kill provides an abundant food source.

Coyotes are primarily nocturnal although they may be active at any time of day. They consume a variety of plants and animals, taking generally whatever is available. Most information on their food habits suggests that rodents and rabbits are the main item of diet, but they may depend on fruits or carrion and under some circumstances may kill and consume big game animals (Lechleitner 1969). Seasonal rodent abundance probably plays an important role in coyote diet habits and may dictate the habitat types the predator uses. Serviceberry and juniper berries are probably also important during summer. During the winter period when many rodents are inactive and fruits are unavailable, coyotes probably resort to more intensive hunting of lagomorphs and winter active mice and voles and feed heavily on carrion. During harsh winter conditions they may prey upon mule deer.

Rasmussen (1941) examined coyote scat collected during mid-winter from a pinyon-juniper ecosystem in northern Arizona. He found scat consisted mainly of deer hair and bones, rabbit fur and the remains of deer mice. He found both mule deer carrion that had been fed upon by coyotes and fresh mule deer that had been killed and eaten by coyotes. He also found that coyote scat

collected from the same area during summer months consisted primarily of rodents, serviceberries, juniper berries, pricklypear cactus, and grass.

The long-tailed weasel has the broadest ecological and geographical range of any mustelid in Colorado. It is always dominant to the smaller ermine or short-tailed weasel which is not common anywhere in the State (Armstrong 1972). Quicks (1951) found population densities of 0.8 long-tailed weasel km^{-2} (2.0 mi^{-2}) in Gunnison County, Colorado. Population densities in the Piceance Basin may be somewhat lower than this figure because of the sparser vegetation.

Burrowing activity of badgers may be seen throughout the region. Badgers feed primarily on small mammals such as the golden-mantled ground squirrel, northern pocket gopher, and the least chipmunk, which they excavate from their burrows (Lechleitner 1969). For this reason, badgers prefer habitats with loamy soil and probably use ridgetops and valley bottoms more often than side slopes.

Bobcats occur much less frequently than the coyote. Bobcats prefer rough, broken terrain and are probably most common along the rims of gulches and ravines.

The skunk is a common resident of some environs because of its preference for agricultural and riparian habitats.

Black bear and mountain lion occur in the region. The black bear are most common along Cathedral Bluffs. Mountain lion distribution is more closely associated with mule deer distribution. Mountain lion range down to the lower gulches and draws, where they prey on the mule deer.

The marten occurs throughout Colorado in mountainous areas of dense forest. Suitable habitat exists within the Basin, but patches of Douglas-fir (its preferred habitat) are probably too isolated to support this species successfully.

The ringtail is another possible predator of the area. Habitat there is not ideal because this species prefers cliffs and rocky outcrops especially in conjunction with large trees. This animal is secretive and nocturnal and difficult to detect even in areas where it is common (Lechleiter 1969). Ringtail sightings have been recorded approximately 25 miles south of Tract C-a in the Parachute Creek drainages (ECI 1975). The grey fox is also an occasional resident.

Other carnivorous mammals of western Colorado such as the red fox, raccoon, and mink prefer agricultural or riparian vegetation types. It is likely that individuals may occasionally travel upstream to various drainages.

2.1.4.5 Avifauna

More than 140 species of birds have been observed within the region (McKean and Burkhard 1978). There are certainly other birds which are of minor transient importance in the area. Other species are waterfowl and

upland gamebirds having extremely limited recreational importance in the study area, and migratory songbird and raptor species having limited ecological importance due to their scarcity in the Basin.

Songbirds. The greatest number of species during the fall is encountered within the rabbitbrush, bottomland sagebrush, and Douglas-fir vegetation types. Large flocks of birds may be observed in the mixed brush (upland), pinyon-juniper, and riparian types. For all seasons combined the following important songbird species according to habitat type are: agricultural, robin and red-winged blackbird; upland sagebrush, horned lark and sage sparrow; rabbitbrush, mountain bluebird and Brewer's sparrow; pinyon-juniper mixed brush, mountain bluebird and dark-eyed junco; mixed brush, green-tailed towhee and dark-eyed junco; pinyon-juniper sagebrush, scrubjay and mountain bluebird; bald, horned lark and vesper sparrow; bottomland sagebrush, dark-eyed junco, grey-headed junco, and Brewer's sparrow; pinyon-juniper, scrubjay, mountain bluebird, and mountain chickadee; upland sagebrush, mountain bluebird and vesper sparrow; Douglas-fir, black-capped chickadee and mountain chickadee; aspen, black-capped chickadee and mountain chickadee; riparian, red-winged blackbird and song sparrow.

Flocking species of birds are common to temperate areas where seasonal fluctuations in food availability exist (Welty 1975). These flocks are an adaptive mechanism that aid wintering birds in finding food, heat conservation and protection from predators. In addition, flocking behavior probably satisfies gregarious tendencies.

The abundant non-flocking species are year-round residents and include the black-billed magpie, the pinyon jay, and shrubjay. Members of the family Corvidae are abundant during the winter due to their ability to exploit a wide variety of food resources.

Species diversity, species composition, and density of winter avian communities can vary annually. These are regulated by winter weather conditions, the abundance of seeds produced during the previous summer and the abundance of overwintering insects and their larvae.

The habitats supporting the largest number of birds and the highest species diversity during the spring are the riparian, Douglas-fir, bottomland sagebrush, and pinyon-juniper/sagebrush types. During spring migratory periods, songbird species do not exhibit the well defined habitat preferences and attachments to specific locations shown during the breeding season. Bird distribution during periods of migration is often highly clumped or aggregated and large areas of seemingly appropriate habitat support no birds at a given time while relatively small areas may contain extremely high densities of birds.

Wintering species such as the northern shrike and dark-eyed junco begin northward migration in April. The scrubjay, pinyon jay, mountain chickadee, mountain bluebird, yellow-rumped warbler, red-winged blackbird, dark-eyed junco, grey headed junco, vesper sparrow, and chipping sparrow are the most frequently seen species during the early spring. Of these, the mountain bluebird, dark-eyed junco, and grey-headed junco exploit a wider range of vegetation types than other species.

Overall, avian utilization of the region is greatest during the summer periods. The largest number of birds and the greatest species diversity are encountered within the riparian, agriculture, Douglas-fir, and all pinyon-juniper vegetation types. The rabbitbrush, sagebrush, mixed brush, and bald vegetation types support fewer species and lower total number of birds in comparison with the aforementioned types. Avian utilization of habitat types is generally greater in those habitats that exhibit greater foliage height diversity and plant species diversity.

Gamebirds. Three gamebird species are known to inhabit the region; the sage grouse, blue grouse, and mourning dove.

The sage grouse is a common year-round resident within areas of upland sagebrush and mixed brush habitats. It also winters in the lower elevations of the region. Throughout its range, the sage grouse is intimately associated with sagebrush all year. Sagebrush provides winter escape cover and is a dominant part of its diet. The distribution of sage grouse populations within the sagebrush and mixed brush habitats are regulated by sagebrush height and density and topography. Breeding sage grouse populations fluctuate annually, the main controlling factors being the severity of winter kill and the abundance of herbaceous material during spring and summer.

Blue grouse are common year-round residents along Cathedral Bluffs. In this area, the bird primarily inhabits bald, mixed brush, aspen/mixed brush, and Douglas-fir/mixed brush ecotonal areas. Throughout its range in the Basin, it is always in proximity to Douglas-fir stands. Douglas-fir needles, buds, twigs, and cones are major winter food items for blue grouse. As winter ends, the birds migrate from the Douglas-fir stands to areas of more open cover such as the forest-edge ecotones. Females generally nest in habitats that provide opportunities for the young to forage on insects and berries.

Relative abundance of summer blue grouse populations in the region can vary. This is associated with variations in winter mortality and natural variability in blue grouse breeding populations. The population of blue grouse residing in the Basin is probably small in relation to other areas of northwestern Colorado due to the limited amount of preferred blue grouse habitat. The importance of the blue grouse in the region is related to its economic and recreational value as a gamebird.

The mourning dove is the most widely distributed game bird within the Basin during the breeding and migration periods. During these seasons, it may be observed in a variety of habitats, but the most likely are the pinyon-juniper and upland sagebrush vegetation types. The mourning dove is herbivorous in its food requirements and feeds on a variety of plant species. Some interspecific competition for food may exist between the mourning dove and other ground-feeding herbivorous passerines during the breeding season.

Waterfowl and Shorebirds. A few surface ponds and intermittent streams create isolated islands of habitat for waterfowl and shorebirds. Since surface water is restricted in distribution in northwestern Colorado, such habitat types have an unusually high ecological value in the region. Although usage of the area by waterfowl and shorebirds is greater during late spring and summer than during the fall, the overall waterbird population within the region is small. The paucity of open water is undoubtedly a major limiting

factor on the size of the resident migratory waterfowl populations. The mallard, green-winged teal, blue-winged teal, and killdeer are the most common waterfowl and shorebirds utilizing surface waters of the area.

There are two migrant shorebird species of note which are present at times in the area. These are the greater sandhill crane and the whooping crane. The population of greater sandhill cranes that nest in Colorado has been recognized as "endangered" by the Colorado Department of Wildlife. This designation does not apply to populations which stop temporarily within the state during migration.

Raptorial Birds. Raptorial birds include the vulture, hawk, eagle, falcon, and owl. Also included in this category because of a similar ecological role is the common raven (Craighead and Craighead 1969).

Fourteen diurnal hawk, vulture, eagle, and falcon species, six nocturnal owl species, and the common raven are the raptor species that have been recorded in the Piceance Basin. The year-round residents are the golden eagle, red-tailed hawk, American kestrel, great horned owl, and the common raven.

Raptors are distributed over the entire area, but the majority of species and species numbers are associated with drainages in the lower elevations. The pinyon-juniper woodland and rimrock areas on the slopes adjacent to the drainages provide numerous potential nest and perch sites for many species. The bottomland sagebrush and agricultural bottoms support abundant small mammal populations, the predominant prey of most raptor species.

The major limiting factor for the wintering and breeding populations of the various raptor species in the region is the availability of food items, particularly deer mice, microtines, lagomorphs, and deer carrion. Minimum territory size requirements exhibited by many species (such as the great horned owl) also regulates the abundance of raptor populations.

Some interactions between raptor and other bird groups in the Basin exist. Songbirds, upland gamebirds, and waterfowl species probably constitute a portion of the diet of some raptor species. The golden eagle, bald eagle, common raven, and turkey vulture probably compete with other members of the Carvidae family for scavengeable prey, especially during the winter.

2.1.4.6 Reptiles and Amphibians

The most abundant and widespread reptile species in the region is the sagebrush lizard. It utilizes south-facing slopes with ledges and rock piles for basking and shelter with a few scattered bushes and deadfall for additional refugia. The limited amount of this habitat in the region results in a fairly low reptile population density and low diversity as well.

Three species of amphibian reside in the Basin. These are the chorus frog, the Great Basin spadefoot frog, and the tiger salamander. Amphibian populations fluctuate annually and seasonally and are limited by the amounts of standing water and suitable habitat.

Neither reptiles or amphibians occur in sufficient numbers of have a significant effect on their prey species. This low abundance also prevents reptiles and amphibians from serving as a primary or obligate food source of predator species. The western terrestrial garter snake probably comes closest to relying on other herpetofauna for an important proportion of its food. However, this snake preys on several invertebrate groups, fish, small mammals, and some birds as well as amphibians and other reptiles.

2.1.4.7 Invertebrates

Invertebrate population sizes in the Basin are closely tied to moisture and temperature regimes. Insects emerge in early summer when moisture and temperature conditions are usually best for reproduction and development of immature organisms which require high moisture levels. Rain and snow in late winter and early spring along with increased closed cover and generally moderate temperatures mean high invertebrate population densities, usually in June and July.

Greatest densities in the region occur on the pinyon-juniper/south slope vegetation types, bottomland sagebrush and mixed brush vegetation types. Most common of the invertebrates are springtails, harvester ants, chironomids, fungus gnats, dark-winged fungus gnats, and stiletto flies.

Activity of ground stratum invertebrates is closely tied to changes in the physical environment. Night-time temperatures are generally cooler in the valleys of the region resulting in higher absolute and relative humidities compared to slopes and ridgetops. The higher humidities and the intermittent presence of flowing water in the bottomland sagebrush areas make more moisture available on the surface for longer portions of the season relative to other habitat types. The dense vegetation and deep litter in bottomland sagebrush types also contributes to moisture retention for long periods into the summer. This results in continued activity of numerically dominant groups such as Lipocelis liparus, L. formicarius, and Entomobrya griseo-olivata. When daily relative humidity is high, the extremely desiccation intolerant harvestman (Homolophus biceps) is also active.

Surface and litter moisture is readily available only in the early summer on the pinyon-juniper/south slopes and upland sagebrush types. These two types are warmed to levels conducive to insect development much earlier in the season than other vegetation types because of this exposure and relative lack of vegetation. By July, however, increased temperatures and decreased moisture availability cause the litter and soil surface to be too hot and dry to sustain activity of desiccation-intolerant soft-bodied invertebrates common to the ground stratum of the pinyon-juniper/south slope and upland sagebrush vegetation types. As a result, Isotoma cinerea and Xenylla grisea are very abundant on the surface and subsurface respectively in early summer in these types. By July, I. cinerea is found only in deep pinyon pine litter where several species concentrate to avoid extremes in temperatures and moisture loss. Hypogastrura armata is an abundant springtail in the upland sagebrush habitat ground stratum in early spring but is generally not seen in the litter in July. It is prevalent again in September when temperatures drop and moisture levels increase.

Mites are also an important group of invertebrates found consistently in the ground stratum of all vegetation types. Mites usually increase in density during the summer, suggesting an ability to withstand desiccation.

The primary importance of springtails, mites, booklice, and other less abundant litter and surface dwelling microarthropods is their role in detritus breakdown and nutrient recycling. The saprophytic feeding groups break down detritus to components directly useable by the primary producer trophic level. They also increase fungal breakdown of detritus by cropping hyphae, thereby keeping the fungi at maximum levels of new growth production and detritus breakdown. Saprophytic invertebrates also breakdown detritus to components useable by microorganisms which ultimately return the mineral and organic products back to the soil for plant usage. Seasonal fluctuations in the density and activity of saprophytic invertebrates suggest that detritus reduction at the invertebrate level is also seasonal.

Invertebrate feeding in the vegetation stratum affects only a few plant species in the Basin. Rabbitbrush, a dominant on bottomland sagebrush habitat is fed upon by a variety of herbivorous insects. Foliage can be attacked by Anthonomus tenuis, Epimechus modicus, Leptothrips sp., and Haplothrips sp., while roots are fed upon by the larvae of A. tenuis and E. modicus.

Leptothrips speices may also be found on sagebrush and ryegrass at bottomland sagebrush sites. There it may cause reduction of optimum biomass accumulation by plants due to sap removal and plant cell destruction.

Sagebrush is also affected by invertebrates feeding at the pinyon-juniper north slope and upland sagebrush habitats, as well as the bottomland sagebrush vegetation type. Visable damage is due primarily to galls produced by gall midges (Diarthronomyia artemisiae and others). Sagebrush flowering buds are attacked by Frankliniella occidentalis which burrows into the forming buds and feed upon developing pistils and stamens. Roots of sagebrush may be affected by the feeding of several invertebrate groups including Orthezia artemisiae and several broad-nosed weevils. The cumulative effect of these groups is to destroy flower and root tissues resulting in a reduction of growth and vigor.

Ryegrass is affected by seed bugs and chloropid flies in the bottomland sagebrush habitat. Both families inhibit seed formation by feeding on developing seeds (Lygaeidae) or in the culms of flowering heads (Chloropidas). Aelothrip auicestus is also found in ryegrass. The combined feeding effect of the three above-mentioned insect groups coupled with sometimes heavy cattle grazing can result in very low seed production and growth of new ryegrass seedlings in the sagebrush bottomland habitat.

Few trees in the area are damaged or killed by insects. The most visible signs of insect attack on pinyon pine is from needle miners (Recurvaria sp.) and pine needle scale, the latter below the density needed to cause extensive damage (Little 1943, Felt 1965).

Herbivorous activity on serviceberry and snowberry in the mixed brush habitat is generally low. Serviceberry seed production can be reduced through bud feeding by western flower thrips (E. occidentalis) and the foliage affected by gall species (e.g., Trisharmomyia canadensis). The two shrub species may, at times, be attacked by aggregations of Hemilueca sp. and

Malacosoma cisstria caterpillars. These insects may completely defoliate a plant, but permanent damage rarely occurs because the same plant is not attacked in successive years.

The invertebrate groups most important to the dynamics of the ecosystem function in the region are those involved in pollination or associated with population control of other invertebrate groups. Many dipteran families are abundant in all vegetation types. These include chironomids, fungus gnats, and gall midges. They may play roles in plant reproduction but are generally poor pollinators. Other families including syrphid flies, anthomyid flies, bee flies, and butterflies and moths, which are nectar feeders, are common on all vegetation types and act as pollinators. The most efficient pollinators present in the region are members of the bee superfamily Apoidea, the families Apidae and Halictidae. These are found in all vegetation types, but are most abundant in the upland sagebrush habitat in the early summer where a great variety of insect pollinated flowering plants exist. Braconioidea and Chalcidoidea wasp families are the parasitic groups found most often in the area. The most visible parasitic wasp-host relationship is the platygasterid wasp which preys on gall midges, which are most common on habitats with sagebrush associations.

Western harvester ant (Pogonomyrmex occidentalis) are associated primarily with sagebrush dominated vegetation types. Highest densities (colonies per unit area) are found in upland sagebrush habitat, ridgetop upland sagebrush habitat, and bottomland sagebrush types. Methods of calculating seed consumption by ants (Lavigne and Fisser 1961) show that about one pound of seed per acre is taken by harvester ants on upland sagebrush vegetation types (RBOSP 1976a). Harvester ants thereby are important agents of seed dispersion and removal.

2.1.4.8 Domestic Livestock Use

Cattle (Bos taurus) and domestic horses (Equus caballus) are the primary livestock occurring in the Basin. The very limited number of domestic horses in the area are used primarily for recreation and herding cattle. Usually they are confined to corrals near ranching operations. Cattle, which range throughout the region, account for most of the domestic livestock use. Cattle stocking rates are variable and depend on year to year range conditions.

During the winter period, cattle are located at lower elevations, usually bottomland meadows. Animals start to disperse from their winter ranges in May. Cattle graze at the higher elevations throughout the summer, and move to lower elevations in October.

During the summer, cattle concentrate and graze within range of water sources or near rancher supplied salt-licks. Forage can be quickly depleted near these water and salt sources as the grazing season progresses causing uneven range utilization (Stoddard et al. 1975).

Relative preferences of herbivores for various plant associations may be indicated by diet composition. Bald and mixed brush vegetation types receive the highest utilization while pinyon-juniper and sagebrush receive lower utilization. Cattle are frequent grazers of the bald and mixed brush types

during the summer. Hubbard and Hansen (1976) report that the principle forage species of cattle in the Piceance Basin are sedges (Carex sp.), needle-and-thread (Stipa comata), wheatgrasses (Agropyron sp.), prairie junegrass (Koeleria cristata), brome grasses (Bromus sp.), Indian ricegrass (Oryzopsis hymenoides), bluegrasses (Poa sp.), and winterfat (Euratia lanata). Domestic cattle receive supplemental feed during portions of the winter.

2.1.5 Aquatic

Studies of the aquatic biotia of the Piceance Basin (RBOSP 1976b) revealed that phytoplankton, zooplankton, and macrophytes play relatively unimportant roles in the aquatic ecosystems. Periphyton are the major primary producers, giving rise to significant portions of the free-floating planktonic organisms present. In the absence of fish, benthic organisms are the primary aquatic consumers. Fish occur only in Yellow Creek, the White River, the Colorado River, and the Piceance Creek because of the ephemeral nature of most surface water. Distribution of macrophytes is limited to a few pond habitats.

Species composition of phytoplankton is similar among spring brook, pond, creek, and river habitats but the dominant taxa can vary.

Rotifers are the most abundant zooplankton organisms and are most numerous in pond habitats. Protozoans, whose highest concentrations occur in rivers, are the second most numerous organisms. Protozoans increase as water velocity increases, while rotifers, which tend to be destroyed by heavy water turbulence, are found in predominantly calm water.

Periphyton communities in the pond habitats are more diverse than in the spring brook habitats, are similar to the creek habitats, and are less diverse than in river habitats.

High numbers of benthic taxa are found in river and creek drainages. Substrate characteristics appear to be of major importance in determining species diversity. The number of taxa is generally lower in creek habitats than in other aquatic habitats. The heterogeneous substrate of the river habitats tends to increase benthic diversity while physiochemical variations appear to influence benthic populations in the various aquatic habitat types. Many of the benthic organisms possess special food-gathering adaptations which allow them to survive in the adverse conditions of the area.

Perhaps only 15 species of bony (teleost) fishes reside in the Basin, and these only in the nonephemeral portions of the creeks and rivers. Speckled dace is the most abundant.

Overall, there are few aquatic habitats in the Basin, and those that do occur are so limited in variety and extent that their biological resources are virtually unused by man.

2.1.6 Tabulated Literature Survey

Within the Piceance Creek Basin there is considerable variation in land form, hydrology, vegetation, and wildlife. To be able to derive parameters and functional relationships for the model, it was necessary to review and

organize available information concerning the Piceance Creek Basin. Table 2.1 presents a summary of climatic, topographic, edaphic, hydrologic, and vegetational characteristics reported in major works related to shale oil development. More than 50 categories of information are tabulated. A variety of vegetational measurements are reported, including cover, density, annual herbage yield (i.e., peak standing crop biomass), height, basal area, and litter biomass. The lists of vegetative communities are aligned with the soils or elevational zones. Along with the standard soil classifications and descriptions are included soil types; soil series; depths; infiltration rates; permeability; water holding capacity including wilting point and field capacity; organic matter; rooting depth; specific density; and texture. To varying degrees of detail, the studies reviewed identify the vegetation on the various soils.

Data from each reference reviewed is tabulated in a separate table (Table 2.1A-2.1D). Each reference has a unique approach to its study of the characteristics of the C-b tract or Piceance Creek Basin.

The reference for Table 2.1A, C-b Oil Shale Venture (1978), contains statistical analyses of data collected and of correlations between soil series and vegetation. Table 2.1A is the major summary of the C-b Tract environmental data which focuses on ecological implications. Information from the C-b Environmental Baseline Program study shows that a variety of plant communities may exist on any given soil series. Similarly, the soil series may occur at different geographic sites.

The reference for Table 2.1B has a much stronger overall emphasis on the soil-plant associations. That topic of study is the basis for the Tiedeman and Terwilliger (1978) research, which contributed to an understanding of the potential ecological response units in the Piceance Creek Basin. Table 2.1B distinguishes successional stages of plant communities as opposed to the mature, stable vegetation common to specific environmental conditions. The focus of Table 2.1B is on land management.

The Table 2.1C reference, Vories (1974), is the most recent complete vegetation description of the Piceance Creek Basin as a whole and was used extensively by Tiedeman and Terwilliger (1978). Vories identified 11 tree species, 53 shrub species, and 349 herbaceous species. Five major climax zones and 35 associations were classified for the study area. Since Vories lacked any soil-plant-climate-topographic-hydrologic correlations, Tiedeman and Terwilliger supplied much of that type of information. Table 2.1C is the foundation of plant community data upon which succeeding studies have been based.

The Table 2.1D reference (Heil 1976) focuses on soil characteristics with respect to hydrologic dynamics, climate, physiognomy, chemical content, engineering specification standards, vegetation, and many other soil-specific parameters. It is currently the most recent and complete soil study in the Piceance Creek Basin. Dr. Berg has continued the soil studies with emphasis on soil moisture potentials, but his data is as yet unpublished. A discussion with him revealed that soil moisture potential is a major limiting factor with respect to rehabilitation potentials of the Piceance Creek Basin.

This side of page intended to be blank; Table 1 begins on opposite side of this page.

Table 2.1. A summary of characteristics of ecosystems of the Piceance Creek Basin. Data are synthesized from various reports for topographic, climatic, edaphic, hydrologic, vegetational, and animal components: A. Ecological information

TOPOGRAPHIC DATA				CLIMATE AND RELATED DATA					SOILS DATA										SOIL-WATER AND PLANT-WATER DATA									
Study Unit	Elevation (m)	Slope (%)	Aspect	Geographic Description <i>p. 73-86a</i>	Ann. Mean Air Temp (°C) <i>p. 73-86</i>	Ann. Mean Precip (cm) <i>p. 73-86</i>	Interception (cm/yr)	Evaporation (cm/yr)	Transpiration (cm/yr)	Soil Classification <i>p. 79</i>	Soil Series <i>p. 79-84</i>	Total Soil Series Area (ha) ^b	Standard Soil Descriptions <i>p. 73-86B</i>	Soil Layer Depth (cm) ^c	Approx. Specific Density (g cm ⁻³)	Approx. Specific Heat (cal g ⁻¹ °C)	General Surface Albedo	α			Field Capacity (%) ^d	Wilt Point (%), Permanent Wilting Coef <i>p. 85</i>	Available Water Capacity (%) <i>p. 85</i>	Infiltration	Permeability ^e <i>p. 74-84</i>	Runoff ^f <i>p. 79-84</i>	Effective Rooting Depth (cm) ^e <i>p. 79-84</i>	Organic Matter in Surface (%) <i>p. 85</i>
																		Sand	Silt	Clay								
Refer to "Soil Series" Column	1800-2050	0- 5		Floodplains Alluvium	7	41				Entisol; Fluvent (Torri); Typic; Fine, Loamy; Mixed, Frigid	#9 Hagga Loam	Minor	A1-Light Gray (10 yr 7/2) Loam A12-Light Gray (10 yr 7/2) Loam A13gb-Dark Gray (10 yr 4/1) Loam	0- 13 13- 30 30- 43										Mod-Low	Very Slow	152 +		
	1800-2300	2-15		Valleys--Alluvial Material	6	36-46				Entisol; Fluvent; Torri; Ustic; Coarse, Loamy; Mixed; Frigid	#41 Glendive Fine Sandy Loam	53	A1-Pale Brown (10 yr 6/3) Fine Sandy Loam C1-Pale Brown (10 yr 6/3) Stratified Loam & Sandy Loam C2-Highly stratified loam, Sandy Loam & Loamy Sand	0- 31 31- 99 99-198						11-25 16	10-18 11	1-13 6		Mod ↓	Slow ↓	152 ↓	2-4 2	
	1800-1980	2- 9		Narrow Stream Bottom	7	41				Entisol; Fluvent (Torri); Ustic, Sandy, Mixed, Frigid	#75 Rivra Loam	Minor	A1-Pale Brown (10 yr 7/3) Channery Loam Fine Sand C1-Light Yellowish Brown (10 yr 6/4) Channery Sand C2-Light Yellowish Brown (10 yr 6/4) Channery Sand	0- 15						9	7	2		High ↓	Slow ↓	152 ↓	3	
	2000-2300	5-15		Upland Slopes and Ridges	6	38-43				Aridisol; Orthid (Camb); Boralllic; Fine, Loamy Mixed	#70 Piceance Fine Sandy Loam	64	Brown Fine Sandy Loam Light Yellowish Brown Loam Very Pale Brown, Very Channery Sandy Loam	0- 25 25- 56 56- 94						33	25	7		Mod ↓	Slow-Med +	51-102 ↓	2	
	1828-2200	3- 8		Upland and Terrace Slopes	5	36-46				Aridisol; Argid (Hap); Boralllic; Fine, Sandy, Loam	#71C Forelle Loam	87	A1-Brown (10 yr 5/3) Loam B2t-Brown (10 yr 5/3) Light Clay Loam B3c4-Pale Brown (10 yr 6/3) Loam	0- 10 10- 40 40- 48						25-31	14-25	6-11		Mod ↓	Slow ↓	152 ↓	2-4	
	1800-2300	5-50		Foothills and Ridgetops	7	41				Entisol; Orthent (Torri); Lithic; Ustic; Loamy, Skeletal, Frigid	#63 Rentsac Channery	1202	A11-Pale Brown Sandy Loam (10 yr 6/3) A12-Pale Brown Sandy Loam (10 yr 6/3) C-Very Pale Brown (10 yr 7/3) Fine Channery Sandy Loam	0- 5 5- 15 15- 28						23-28 23 11 20 10-14	16-17 11 9 15 9-10	6-12 12 2 6 2- 5		High ↓	Med ↓	25- 51 ↓	2-5 3 4 1	
	1800-2300	5-30		Mountain Slopes and Ridges	7	41				Entisol; Orthent (Torri); Lithic-Ustic; Loamy, Frigid	#66 Reedcreek Rentsac Complex	659	A1-Brown (10 yr 4/3) Fine Sandy Loam B1-Brown (10 yr 5/3) Very Fine Sandy Loam B2-Light Yellowish Brown (10 yr 6/4) Loam	6- 10 10- 25 25- 56						24-33 22-27 30 11	18 10-20 23 9	6-15 6-12 7 2		Mod-High ↓	Slow ↓	25- 51 ↓	2-6 2-5 2 3	

^aPage numbers referenced in the column headings apply to the *C-b Final Environmental Baseline Report*, Vol. 4; a page number followed by "A" or "B" is a reference to Vol. 4, Appendices A or B. Where page references are not given, the

^bThe areas listed were supplied by the Soil Conservation Service office in Meeker, Colorado. They are not a result of data from the *C-b Environmental Baseline Study*.

^cSoil depth values for the soil layers apply to the soil layers in the "Standard Soil Descriptions" column.

^dAll values listed from this column to the end of the table to the right relate to specific vegetative communities. Follow the values horizontally across the table to the "Vegetative Community" column to find the appropriate community.

^eData for "Permeability", "Runoff", and "Effective Rooting Depth" are not quantitative; the qualitative information listed pertains to all communities found on the "Soil Series" study unit.

^fAcreages are not listed in the *C-b Final Environmental Baseline Report*. Areas available pertain strictly to the totals for each of the different community categories listed below. Such acreage figures were made available by Erik R.

^gValues for grass density are given in number of individual plants per square meter. It would be a misrepresentation to proportionally generalize the values to represent density per hectare.

from C-b Final Environmental Baseline Report (1974-1976), Volume 4 and Appendices A & B.

VEGETATIVE DATA																								
Vegetative Community	Total Community Area (ha) f	Avg Bare Ground (%), Soil and Rock p 141B & 164B	Vegetative Cover (%)						Vegetative Density (#/ha)						Basal Area (m ² ha ⁻¹) p 134B	Shrub Biomass--Live (g m ⁻²) p 195 & 197	Forb Biomass--Live (g m ⁻²)	Grass Biomass--Live (g m ⁻²)	Woody (trees and shrubs) Biomass (g m ⁻²)	Herbaceous (forbs and grasses) Biomass (g m ⁻²)	Litter Biomass (g m ⁻²) p 193	Total Live Standing Biomass--1975 (g m ⁻²) p 182	Avg Shrub Height (cm)	% Shrub Height <15 cm
			Tree p 134 App B, 140-167	Shrub p 153-155B	Forb	Grass	Woody (trees and shrubs)	Herbaceous (forbs and grasses) p 141 & 164B	Litter p 141 & 164B	Tree p 134B	Shrub p 135-155B	Forb	Major Grasses (#/m ²) g p 179-187B	Woody (trees and shrubs)	Herbaceous (forbs and grasses)									
Agricultural Meadows Riparian Communities																								
Bottomland Sagebrush Rabbitbrush Great Basin Wildrye Agricultural Meadows Riparian Annual Weed		18-20 14		45-41 43			3-4 2	14-27 51	77-82 80		17843-18076 11362		109-246				908-2182				7-12	8-31		
Bottomland Sagebrush Greasewood Agricultural Meadows		21		31			2	43	76		6671													
P-J Woodland Chained P-J Rangeland Upland Sagebrush		20		18			1	63	81		14293													
P-J Woodland Chained P-J Rangeland Upland Sagebrush		32-51		25			4	30-43	26-66		24934		121-205				142- 251				9-13	30-53		
P-J Woodland Chained P-J Rangeland Upland Sagebrush Mixed Mountain Shrubland Douglas Fir Forest Bunchgrass		24-51 28-34 55	<1 37 17 6	7-24 37 17 6			0-<1 29	22-26 15-23 29	48-72 35	160-214 259	3642-25661 72417 16999 2636		1- 10 20- 41 46- 87 15-26			13-20 7	29- 55 223-385 47- 75				6-21 9-15 9-13	7-23 14-61 12-30		
P-J Woodland Chained P-J Rangeland Upland Sagebrush Mixed Mountain Shrubland Bunchgrass		23-29 27 55	2 37 6	8 9-15 37 6			<1 0-2 29	20 36-42 21-23 29	81 57-72 64-69 35	259 259	2636- 9522 6169- 9092 72417 2636		46- 87 15-26 46- 87 15-26			7 7	47- 75 47- 75				9-13 9-13	12-30 12-30		

reference is to the "Plant Communities" section on p. 139-169.

Olgerson, but are not listed here because most of the communities are subdivided in this table.

Table 2.1. -Continued: B. Ecological information from *Physo-Edaphic Classification of the Piceance Basin* (1978)

TOPOGRAPHIC DATA				CLIMATE AND RELATED DATA					SOILS DATA										SOIL-WATER AND PLANT-WATER DATA									
Study Unit	Elevation (m)	Slope (%)	Aspect	Geographic Description	Ann Mean Air Temp (°C)	Ann Mean Precip (cm)	Interception (cm/yr)	Evaporation (cm/yr)	Transpiration (cm/yr)	Soil Classification	Soil Series	Total Soil Series Area (ha)	Standard Soil Descriptions ^a	Soil Layer Depth (cm)	Approx Specific Density (g cm ⁻³)	Approx Specific Heat (cal g ⁻¹ °C)	General Surface Albedo	%			Field Capacity (%)	Wilt Point (%), Permanent Wilting Coef	Available Water Capacity (%)	Infiltration	Permeability (cm/ha)	Runoff	Effective Rooting Depth (cm)	Organic Matter in Surface (%)
PEU 2 42-46b	1946-2736	30-70	N	NE 1/4, SW 1/4 Sec 11, T25 R95W	4-7	38-56				Dark Brown Gravelly Loams--Typic Cryoboroll			All-Very dark greyish brown (10 yr 3/2) sandy loam, slightly hard, very friable, 10% gravel, 5-15% >2 mm ^c A12-Sandy loam, slightly hard, friable, 10% gravel, 5-15% >2 mm Cr-Very gravelly and cobbly sandy loam, slightly hard, friable, 60% gravel, 30% cobbles, 85-95% >2 mm	0- 8 8- 28 28- 63				58 57 62	29 31 31	13 12 7			13-18 3- 6	Mod 2- 5	Slow with Cover Rapid when Clear	25-51	High 9 7 6	
PEU 3 52-57	1824-2128	Up to 30	All	SE 1/4, SE 1/4 Sec 7, T35 R98W	6-8	33-41				Shallow Sandy Loams--Lithic Ustorthent	Redcreek		A-1-Dark yellowish brown (10 yr 4/4) sandy loam, soft, very friable, 5-15% >2 mm AC-Sandy loam, slightly hard, very friable, 15% gravel, 5-15% >2 mm Cr-Very gravelly loamy sand, hard, firm, 10% cobbles, 50% gravel, 40-75% >2 mm	0- 10 10- 23 23- 41				75 71 81	17 18 13	8 11 6			11-15 7-12	Rapid 5-15	Mod 5-15	Mod 20-46	High 4 Med 1 Low 1	
PEU 4 62-72	1824-2219			NW 1/4, NW 1/4 Sec 20, T15 R97W	6-8	33-41				Shallow Very Gravelly Sandy Loams--Lithic Ustic Torriorthents	Rentsac		A1-Brown (10 yr 5/3) very gravelly sandy loam, soft, friable, 35% gravel, 30-40% >2 mm AC-Very gravelly sandy loam, soft, friable, 5% gravel, 40% gravel, 30-40% >2 mm Cr-Very gravelly sandy loam, soft, friable, 5% cobbles, 40% gravel, 35-55% >2 mm	0- 10 10- 25 25- 41				62 65 59	33 32 34	5 3 7			10-14 4-10	Rapid 5-51	Mod 2- 5	Mod-Rapid 15-46	High 3 Med 3 Med 2	
PEU 5 72-82	1824-2280			NE 1/4, NE 1/4 Sec 11, T35 R97W	6-8	33-41				Rockland--Lithic Ustorthent			A1-Pale brown (10 yr 10/3) gravelly sand, loose, very friable, 30% gravel, 10% cobbles, 10% stones Cr-Partly decomposed sandstone, loose, very friable, 30% gravel, 50% cobbles, 10% stones R-Hard layered sandstone	0- 11 11- 19 19+				91 87	6 10	3 3			0-10	Mod Mod-Slow	Rapid 0-25	Med 2 High 6		
PEU 7 83-86	1829-2134	0- 8		Sec 19, T28N R13F	4-7	33-41				Farmland--Fluventic Haplaquept	Hagga		A1-Very dark grey (10 yr 3/1) hard, very friable, 0% >2 mm Cg1-Very fine sandy loam, slightly hard, very friable, 0% >2 mm Cg2-Light clay loam, hard to very hard, friable, 0% >2 mm	0- 8 8- 48 48- 90									16-18	Mod	Mod	Very Slow		

[illegible]

Table 2.1.B. --Continued

TOPOGRAPHIC DATA					CLIMATE AND RELATED DATA					SOILS DATA										SOIL-WATER AND PLANT-WATER DATA									
Study Unit	Elevation (m)	Slope (%)	Aspect	Geographic Description	Ann Mean Air Temp (°C)	Ann Mean Precip (cm)	Interception (cm/yr)	Evaporation (cm/yr)	Transpiration (cm/yr)	Soil Classification	Soil Series	Total Soil Series Area (ha)	Standard Soil Descriptions ^a	Soil Layer Depth (cm)	Approx Specific Density (g cm ⁻³)	Approx Specific Heat (cal g ⁻¹ °C)	General Surface Albedo	%			Field Capacity (%)	Wilt Point (%), Permanent Wilting Coef	Available Water Capacity (%)	Infiltration	Permeability (cm/ha)	Runoff	Effective Rooting Depth (cm)	Organic Matter in Surface (%)	
																		Sand	Silt	Clay									
PEU 8 p 289-289	1829-2134	0-10		NW 1/4, SE 1/4 Sec 30, T2N R98W	6-7	36-46				Deep Sandy Loams-- Ustic Torrifluvents	Hanly Piora Glendive Daure		Al-Pale brown (10 yr 6/3) gravelly sandy loam, loose, 30% gravel, 0-10% >2 mm C1-Sandy loam, soft, loose, 0-10% >2 mm C2-Gravelly sandy loam, soft, loose, 30% gravel, 10-30% >2 mm	0- 15 6- 48 48- 81					70 50 60	26 46 35	4 4 5			8-13 4- 8	Rapid	Rapid 2-15 15-51	Slow	>152	Med 2 Med 2 Med 2
PEU 11 p 330-344	1829-2347	0-20	All	NE Corner, SW 1/4, Sec 2, T2S, R99W	5-7	33-46				Moderately Deep Loams-- Borollic Camborthid	Yamak Forelle Piceance		Al-Brown (10 yr 5/3) loam, slightly hard, friable, 3% gravel, 0-3% >2 mm B2-Loam, slightly hard, friable, 0-3% >2mm C1ca-Loam, slightly hard, friable, 0-3% >2 mm	0- 13 13- 25 25- 59					49 48 37	43 42 45	8 10 18			15-17 4- 7	Mod	Mod-Slow 2-15 5-15	Mod	76-102	Med 2 Med 2 Low 1
PEU 12 p 345-358	1829-2134	0-15	S and W	NW 1/4, SE 1/4 SW 1/4, Sec 19 T1S, R98W	6-8	28-41				Moderately Deep Loams-- Borollic Camborthid	Piceance		Al-Yellowish brown sandy loam (10 yr 4/3), loose, very friable, 5% gravel, 5% >2 mm B2-Fine sandy loam, slightly hard, friable, 5% gravel, 5% >2 mm Cca-Clay loam, slightly hard, friable, 0% >2mm	0- 8 8- 28 28- 58					66 53 21	29 38 41	5 9 38			13-15 19-21	Mod	Mod Slow 5-15 1- 2	Slow	38- 63	Med 3 Med 2 Lbw 1
PEU 13 p 369-377	1737-2042	0-50	S and W	NE 1/4, NW 1/4 Sec 1, T1S R98W	6-8	25-38				Shallow Gravelly Soils-- Typic Ustorthent	Rentsac		Al-Yellowish brown (10 yr 5/4) gravelly sandy loam, slightly hard, very friable, 20% gravel, 2% cobbles, 20-25% >2 mm Cca-Very gravelly and cobbly loamy sand, loose, very friable, 45% gravel, 25% cobbles, 5% stones, 70-80% >2 mm Cr-Sandstone gravel, very hard, loose, 30% gravel, 40% cobbles, 20% stones	0- 13 13- 28 28- 99					68 72 80	26 26 17	6 2 3			7- 9 4- 8	Rapid	Mod-Rapid 5-15 15-51	Mod-Rapid	20- 38	Med 2 Med 3 Low 1
PEU 14 p 378-388	1920-2438	10-60		NW 1/4, SW 1/4 Sec 19, T1N R99W	4-7	36-56				Dark Brown Loams-- Calcic Cryoboroll	Parachute		Al-Very dark greyish brown 10 yr 3/2) fine sandy loam, soft, friable, 10% gravel, 5-15% >2 mm Cca-Very cobbly sandy loam, soft, friable, 30% cobbles, 40% gravel, 60-80% >2 mm Cr-Very cobbly sandy loam, soft, friable, 10% stones, 45% cobbles, 10% gravel, 85-95% >2 mm	0- 33 33- 66 66- 91					60 62 69	35 33 26	5 5 5			16-18 3- 6 3- 6	Rapid	Mod 2- 5 5-15 5-15	Mod	76-102	High 6 Med 3 Med 3

VEGETATIVE DATA																								
Vegetative Community	Total Community Area (ha)	Avg Bare Ground (%), Soil and Rock	Vegetative Cover (%)						Vegetative Density (#/ha)						Basal Area (m ² ha ⁻¹)	Shrub Biomass--Live (g m ⁻²)	Forb Biomass--Live (g m ⁻²)	Grass Biomass--Live (g m ⁻²)	Woody (trees and shrubs) Biomass (g m ⁻²)	Herbaceous (forbs and grasses) Biomass (g m ⁻²)	Litter Biomass (g m ⁻²)	Total Live Standing Biomass--1975 (g m ⁻²)	Avg Shrub Height (cm)	% Shrub Height <15 cm
			Tree	Shrub	Forb	Grass	Woody (trees and shrubs)	Herbaceous (forbs and grasses)	Litter	Tree	Shrub	Forb	Major Grasses (#/m ²)	Woody (trees and shrubs)										
Big Sagebrush, Greasewood Bottomlands: Sagebrush, greasewood, wheatgrass, cheatgrass, lambquarter		30-60														7	48	287	55		368			
Mid Elevation Big Sagebrush: Sagebrush, Douglas rabbit- brush, western wheatgrass, flowery phlox, needle-and- thread, mutton bluegrass		40														16	49	140	65		233			
Low Elevation Big Sagebrush: Sparse vegetation--big sagebrush, greasewood, saltbrush, some juniper, winterfat, flowery phlox, Indian ricegrass		40														6	28	107	33		145			
Low Elevation Big Sagebrush: Sagebrush, rabbitbrush, saltbush, phlox, cheat- grass, ricegrass, wheat- grass, needle-and-thread		15-65														22	28	92	50		148			
Mixed Mountain Shrub: Serviceberry, snowberry, aspen, Douglas fir, rabbitbrush, sagebrush, wheatgrass, sedges, lupine																101	24	255	126		405			

Table 2.1.B. --Continued

TOPOGRAPHIC DATA					CLIMATE AND RELATED DATA					SOILS DATA										SOIL-WATER AND PLANT-WATER DATA								
Study Unit	Elevation (m)	Slope (%)	Aspect	Geographic Description	Ann Mean Air Temp (°C)	Ann Mean Precip (cm)	Interception (cm/yr)	Evaporation (cm/yr)	Transpiration (cm/yr)	Soil Classification	Soil Series	Total Soil Series Area (ha)	Standard Soil Descriptions ^a	Soil Layer Depth (cm)	Approx Specific Density (g cm ⁻³)	Approx Specific Heat (cal g ⁻¹ °C)	General Surface Albedo	ae			Field Capacity (%)	Wilt Point (%), Permanent Wilting Coef	Available Water Capacity (%)	Infiltration	Permeability (cm/ha)	Runoff	Effective Rooting Depth (cm)	Organic Matter in Surface (%)
																		Sand	Silt	Clay								
PEU 15 p 239-239	1829-2743	0-50		NE Corner, NW 1/4, Sec 27 T4S, R97W	4-6	38-69				Pacic Dark Brown Loams-- Pachic Cryoboroll	Rhone		All-Very dark greyish brown (10 yr 3/2) fine sandy loam, slightly hard, friable, 10% gravel, 10-20% >2 mm A12-Fine sandy loam, slightly hard, friable, 14% gravel, 10-20% >2 mm B-Gravelly loam, slightly hard, friable, 5% stones, 10% cobbles, 20% gravel, 30-45% >2 mm	0- 18 18- 58 58- 76				57 54 51	37 39 37	6 7 2			16-21 13-18 3- 5	Mod 2-15	Mod 2- 5 2- 5 2-15	Slow-Mod	76-102	High 7 High 6 Med 2
PEU 18 p 239-239	1829-2286	35-70	SE to W	1500' W, 300' S of NE Corner Sec 28, T1S R97W	6-8	25-41				Shallow Stony Loams-- Ustic Torriorthent			A1-Pale brown (10 yr 6/3) very gravelly fine sandy loam, soft, friable, 5% stones, 10% cobbles, 40% gravel, 50-60% >2 mm C1-Very stony and gravelly sandy loam, soft, friable, 25% stones, 30% cobbles, 35% gravel, 90-95% >2 mm C2-Very stone sandy loam, soft, friable, 35% stones, 40% cobbles, 20% gravel, 90-95% >2 mm	0- 18 18- 56 56-142				62 64 65	34 29 27	4 7 8			6- 8 4- 8	Rapid 15+	Rapid 15+ 15+	Mod	20- 51	Med 2 Low 1 Low <1

^aThe data listed in the columns starting with "Standard Soil Description" to the left, up to and including the "Organic Matter" column, are data pertinent to each soil layer described in the first of these columns. All other data in

^bSpecific page references are not given in this table because almost each datum has a unique page reference. Page references given in Column 1 are chapter pages.

^cParticle size data in "Standard Soil Description" column: % by weight of soil in soil layer.

VEGETATIVE DATA																										
Vegetative Community	Total Community Area (ha)	Avg Bare Ground (%), Soil and Rock	Vegetative Cover (%)							Vegetative Density (#/ha)					Basal Area (m ² ha ⁻¹)	Shrub Biomass--Live (g m ⁻²)	Forb Biomass--Live (g m ⁻²)	Grass Biomass--Live (g m ⁻²)	Woody (trees and shrubs) Biomass (g m ⁻²)	Herbaceous (forbs and grasses) Biomass (g m ⁻²)	Litter Biomass (g m ⁻²)	Total Live Standing Biomass-1975 (g m ⁻²)	Avg Shrub Height (cm)	% Shrub Height <15 cm		
			Tree	Shrub	Forb	Grass	Woody (trees and shrubs)	Herbaceous (forbs and grasses)	Litter	Tree	Shrub	Forb	Major Grasses (#/m ²)	Woody (trees and shrubs)											Herbaceous (forbs and grasses)	
Mixed Mountain Shrub Oak: Gambel oak, snowberry, serviceberry, Wood's rose, elk sedge, bedstraw, American vetch, Colorado columbine																										
Shrub-Grass Rockland: Big and fringed sage, shadscale, saltbush, wheatgrass, Indian rice- grass																										

the table relate to the PEU In toto specified in each row of data.

[illegible]

VEGETATIVE DATA																									
Vegetative Community	Total Community Area (ha)	Avg Bare Ground (%), Soil and Rock	Vegetative Cover (%)							Vegetative Density (#/ha)						Basal Area (m ² ha ⁻¹)	Shrub Biomass--Live (g m ⁻²)	Forb Biomass--Live (g m ⁻²)	Grass Biomass--Live (g m ⁻²)	Woody (trees and shrubs) Biomass (g m ⁻²)	Herbaceous (forbs and grasses) Biomass (g m ⁻²)	Litter Biomass (g m ⁻²)	Total Live Standing Biomass--1975 (g m ⁻²)	Avg Shrub Height (cm)	% Shrub Height <15 cm
			Tree	Shrub	Forb	Grass	Woody (trees and shrubs)	Herbaceous (forbs and grasses)	Litter	Tree	Shrub	Forb	Major Grasses (#/m ²)	Woody (trees and shrubs)	Herbaceous (forbs and grasses)										
<u>Bunchgrass</u> Tree General Shrub General Herb <i>Agropyron</i> spp. <i>Oxyzopsis hymenoides</i> <i>Bromus</i> <i>Agropyron</i> <i>Artemisia</i> General			< 1	7				2 < 1 < 1 11 < 1	< 1	7				33 4 1 9 < 1									250 34 45 28 33 15		
<u>Greasewood</u> Tree General Shrub <i>Sarcobatus</i> <i>vermiculatus</i> General Herb <i>Bromus tectorum</i> <i>Lappula redoubkii</i> <i>Agropyron</i> General			--	6 6				3 6 3		4 10				29 76 24									80 31 15 12 21		

Table 2.1. --Continued: D. Ecological information from Characterization Studies of Major Soils Found in Proposed Oil Shale and Coal Development Areas of Northwest Colorado (Heil, 1976).

TOPOGRAPHIC DATA				CLIMATE AND RELATED DATA					SOILS DATA										SOIL-WATER AND PLANT-WATER DATA									
Study Unit	Elevation (m)	Slope (%)	Aspect	Geographic Description	Ann Mean Air Temp (°C)	Ann Mean Precip (cm)	Interception (cm/yr)	Evaporation (cm/yr)	Transpiration	Soil Classification	Soil Series	Total Soil Series Area (ha)	Standard Soil Descriptions	Soil Layer Depth (cm)	Approx Specific Density (g cm ⁻³)	Approx Specific Heat (cal g ⁻¹ °C)	General Surface Albedo	%			Field Capacity (%)	Wilt Point (%), Permanent Wilting Coef	Available Water Capacity (%)	Infiltration	Permeability (cm/ha)	Runoff	Effective Rooting Depth (cm)	Organic Matter in Surface (%)
																		Sand	Silt	Clay								
Site 3	1987	3	NE	Upland, Undulating to Rolling Sec 16, T4N R93W		30-36				Borollic Haplargid Loam	Forelle		A1-7.5 yr 5/4 dry, very friable moist, soft dry, 95-100% particles <2 mm	0-12				46	37	18	18	8	10		2- 5			1
													B1-7.5 yr 5/2 dry, slightly hard dry, firm moist, 80-90% particles <2mm	12-28				36	32	31	23	14	9		1- 2			1
													B2t-7.5 yr 5/3 dry, hard dry, firm moist, 80-90% particles <2 mm	28-58				26	42	32	27	16	11		2- 5			1
Site 5	1939	6	SW	Upland, Rolling Sec 36, T5N R54W		30-36				Borollic Natrargid Clay Loam			A21-10 yr 7/2 dry, soft dry, very friable, moist, 90-95% particles <2 mm	0-10				24	49	27	25	14	11		1- 2			3
													A22-10 yr 6/3 dry, soft dry, very friable moist, 90-95% particles <2 mm	10-23				20	55	25	23	13	10		2- 5			1
													B21t-2.5 y 6/2 dry, very hard dry, very firm moist, 85-95% particles <2 mm	23-43				18	48	34	24	15	9		1- 2			1
Site 6	1999	5	S	Upland, Rolling Sec 34, T5N R94W		30-36				Borollic Camborthid Silty Loam			A11-2.5 y 6/2 dry, very friable moist, slightly hard dry, 95-100% particles <2 mm	0- 5				20	54	27	24	13	11		2- 5			4
													A12-2.5 y dry, firm moist, hard dry, 85-95% particles <2 mm	5-15				17	47	36	25	15	10		1- 2			2
													B21-5 y 5/3 dry, very firm moist, very hard dry, 85-95% particles <2 mm	15-25				14	50	36	26	15	11		1- 2			2
Site 3	1945	4	SW	Bench Upland, Undulating Sec 32, T6N R91W		30-33				Aridic Argiboroll Loam			Ap-10 yr 5/3 dry, slightly hard dry, friable moist, 75-85% particles <2 mm	0-25				26	47	27	21	12	9		2- 5			3
													B21t-7.5 yr 4/2 dry, hard dry, firm moist, 90-95% particles <2 mm	25-46				25	40	35	25	15	10		1- 2			1
													11B22tb-7.5 yr 5/4 dry, very hard dry, very firm moist, 90-95% particles <2 mm	46-65				39	24	28	25	15	10		1- 2			1
Site 11	2073	20	NE	Mountain Slope, Sloping Sec 33, T6N R90W		41				Aridic Argiboroll Sandy Loam			A11-10 yr 4/2 dry, soft dry, very friable moist, 95-100% particles <2 mm	0-18				65	22	14	15	9	6		5-15			2
													A12-10 yr 5/2 dry, soft dry, very friable moist, 95-100% particles <2 mm	18-36				70	20	10	13	8	5		5-15			1
													B1-10 yr 6/3 dry, soft dry, very friable moist, 95-100% particles <2 mm	36-68				68	19	14	15	8	7		5- 5			4

[illegible]

Table 2.1:D.--Continued

TOPOGRAPHIC DATA					CLIMATE AND RELATED DATA					SOILS DATA										SOIL-WATER AND PLANT-WATER DATA								
Study Unit	Elevation (m)	Slope (%)	Aspect	Geographic Description	Ann Mean Air Temp (°C)	Ann Mean Precip (cm)	Interception (cm/yr)	Evaporation (cm/yr)	Transpiration	Soil Classification	Soil Series	Total Soil Series Area (ha)	Standard Soil Descriptions	Soil Layer Depth (cm)	Approx Specific Density (g cm ⁻³)	Approx Specific Heat (cal g ⁻¹ °C)	General Surface Albedo	%			Field Capacity (%)	Wilt Point (%), Permanent Wilting Coef	Available Water Capacity (%)	Infiltration	Permeability (cm/ha)	Runoff	Effective Rooting Depth (cm)	Organic Matter in Surface (%)
																		Sand	Silt	Clay								
C-b Site 19	2039	3	NE	Upland Slope and Bench, Undulating Sec 18, T3S R96W		41				Borollic Haplargid Loam	Forelle		A1-10 yr 6/4 dry, slightly hard dry, very friable moist, 95-100% particles <2 mm	0-13				32	42	26	23	14	9		2- 5			1
										Clay Loam			B2t-10yr 6/3 dry, slightly hard dry, friable moist, 75-85% particles <2 mm	13-28				24	48	28	25	16	9		1- 2			1
										Silt Loam			B3ca-10 yr 6/3 dry, slightly hard dry, friable moist, 75-85% particles <2 mm	28-61				25	51	25	27	17	10		2- 5			1
C-b Site 20	2103	6	NW	Upland Ridges, Rolling to Moderately Steep		43				Lithic Ustic Torriorthent Loam			A1-10 yr 4/3 dry, soft dry, very friable moist, 99-100% particles <2 mm	0-10				49	32	18	23	13	10		2- 5			3
										Loam			AC-7.5 yr 5/2 dry, soft dry, friable moist, 90-100% particles <2 mm	10-27				42	39	19	26	17	9		2- 5			2
										Very Channery Loam			Cr-10 yr 7/3 dry, slightly hard dry, friable moist, 25-30% particles <2 mm	27-40				36	42	23	33	18	15		5-15			2
Site 22 Piceance Basin	1939	2	NE	Alluvium, Narrow Valley Bottom, Gently Sloping Sec 12, T2S R98W		41				Ustic Torrifluvent Silt Loam			A1-10 yr 6/3 dry, soft dry, very friable dry, very friable moist, 95-100% particles <2 mm	0-30				37	56	7	22	11	11		2- 5			2
										Silt Loam			A1b-10 yr 7/3 dry, slightly hard dry, very friable moist, 95-100% particles <2 mm	30-46				34	51	15	25	12	13		2- 5			3
										Silt Loam			11C1-10 yr 6/3 dry, slightly hard dry, very friable moist, 95-100% particles <2 mm	46-99				33	53	15	25	13	12		2- 5			1
Site 23 Piceance Basin	2039	3	NE	Rolling Upland Sec 19, T1S R97W		41				Borollic Natrargid Loam			A2-10 yr 7/2 dry, slightly hard dry, very friable moist, 95-100% particles <2 mm	0- 8				45	43	12	18	8	10		1- 2			1
										Silt Clay			B2t-7.5 yr 5/4 dry, hard dry, firm moist, 95-100% particles <2 mm	8-21				18	41	41	35	26	9		1- 2			1
										Silt Clay Loam			B3ca-10 yr 5/3 dry, hard dry, firm moist, 95-100% particles <2 mm	21-41				19	50	31	32	20	12		1- 2			1
Site 24 Piceance Basin	2039	1	NE	Rolling Upland, Undulating, Somewhat Concave Sec 19, T1S R97W		41				Borollic Camborthid Loam			A1-10 yr 5/3 dry, soft dry, very friable moist, 95-100% particles <2 mm	0-10				42	36	22	20	12	8		2- 5			1
										Clay Loam			B2-10 yr 5/4 dry, slightly hard dry, friable moist, 95-100% particles <2 mm	10-26				21	49	30	28	18	10		1- 2			1
										Silt Clay Loam			133ca-10 yr 7/3 dry, slightly hard dry, friable moist, 95-100% particles <2 mm	26-39				20	53	27	28	17	11		1- 2			1

[illegible]

Table 2.1:D. --Continued

TOPOGRAPHIC DATA					CLIMATE AND RELATED DATA					SOILS DATA										SOIL-WATER AND PLANT-WATER DATA								
Study Unit	Elevation (m)	Slope (%)	Aspect	Geographic Description	Ann Mean Air Temp (°C)	Ann Mean Precip (cm)	Interception (cm/yr)	Evaporation (cm/yr)	Transpiration	Soil Classification	Soil Series	Total Soil Series Area (ha)	Standard Soil Descriptions	Soil Layer Depth (cm)	Approx Specific Density (g cm ⁻³)	Approx Specific Heat (cal g ⁻¹ °C)	General Surface Albedo	α _s			Field Capacity (%)	Wilt Point (%), Permanent Wilting Coef	Available Water Capacity (%)	Infiltration	Permeability (cm/ha)	Runoff	Effective Rooting Depth (cm)	Organic Matter in Surface (%)
																		Sand	Silt	Clay								
Site 28	2146	5-7	NE	Upland Ridge Top Sec 31, T4N R86W		43				Borollic Camborthid Silt Clay Loam	Abor		A1-10 yr 6/2 dry, friable moist, slightly hard dry, 90-100% particles <2 mm	0- 8				16	49	35	32	19	13		1- 2			6
													Clay	B21-2.5 yr 4/3 dry, firm moist, very hard dry, 85-95% particles <2 mm	8-15				8	34	58	30	21	9	<1- 1		3	
													Clay	B22-10 yr 5/3 dry, firm moist, very hard dry, 85-95% particles <2 mm	15-46				9	38	54	26	17	10	<1- 1		1	
Site 31	1995	5	NE	Upland, Rolling Sec 30, T6N R88W		41				Borollic Vertic Camborthid Silt Clay			A1-10 yr 6/3 dry, hard dry, firm moist, 90-100% particles <2 mm	0- 8				5	41	54	35	23	12		1- 2			2
										Clay			B21-10 yr 5/2 dry, very hard dry, firm moist, 80-90% particles <2 mm															
										Clay			B22-10 yr 6/4 dry, very hard dry, firm moist, 80-90% particles <2 mm															

[illegible]

The five main sections of data consider topography, climate, soils data, soil-water and plant-water, and vegetation.

Under TOPOGRAPHIC DATA, STUDY UNIT describes the way the data was grouped. No two references had identical study units or study sites. ELEVATION gives the elevation mean or interval of the study unit. SLOPE and ASPECT are generalized over the study unit. The GEOGRAPHIC DESCRIPTION is supplemental information.

Under CLIMATE AND RELATED DATA is primarily rainfall information: ANNUAL MEAN AIR TEMPERATURE, ANNUAL MEAN PRECIPITATION, INTERCEPTION, EVAPORATION, and TRANSPIRATION.

Under SOILS DATA is the fundamental soil information. SOIL CLASSIFICATION and SOIL SERIES are useful in correlating environmental conditions to vegetation. The soil names often reflect important soil-plant relations. For example, "Torri" indicates the soil is dry in all layers during most of the growing season. "Bor" indicates a soil which is cold and thus implies the type of environment preferred by the plants on that soil.

The SOIL CLASSIFICATION column also contains morphological terms which are described more quantitatively in the STANDARD SOIL DESCRIPTION column. The morphological descriptions reflect variability in thickness, kind, and arrangement of soil layers. The topmost three horizons and their depths are listed in the SOIL LAYER DEPTH column. Soil color, texture, and structure vary within a given soil as well as between soil types.

The columns SAND, SILT, and CLAY contain particle size data, which is also found in the STANDARD SOIL DESCRIPTION column. Particle size data is fundamental to soil classification. "Soil" is made up of particles less than 2mm in diameter. Otherwise, the material is considered "gravel" or "coarse fragments." The "soil" is divided into three size categories: sand, silt, and clay. The soils studied reflect a wide variety of soil textures and subsequently, wide variations can be expected with respect to infiltration, permeability, water holding capacity, structural stability, and workability. The particle size analysis also showed that in the areas where shale predominates, subsoils are generally fine textured, thus creating problems associated with infiltration, compaction, and erosion if these soils were ever used as top soil during rehabilitation.

Under SOIL-WATER AND PLANT-WATER DATA are the combined climatological, physiognomic, and soil conditions. Heil (1976) indicated the influence of the environment on soils and the influence of soil morphology on water and plant dynamics. Wymore (1974) related soil profiles, elevation zones, and water-holding capacity of soil and vegetation.

AVAILABLE WATER CAPACITY should be roughly the difference between FIELD CAPACITY and WILT POINT. The critical level standardized for agricultural plants may be higher than the critical level for native plants of arid and semiarid lands. INFILTRATION refers to the amount of water penetrating the surface of the soil and PERMEABILITY refers to water and air movement through a soil layer. RUNOFF is that portion of precipitation that does not infiltrate or evaporate but runs over the soil surface.

EFFECTIVE ROOTING DEPTH refers to the soil depth to which roots can grow. SOIL ORGANIC MATTER is associated with inherent nitrogen fertility of the soil, soil structure stability, water holding capacity, and overall general fertility. Evaluation of organic matter levels are made based on the following classes: 0 to 1.0%, low; 1.1 to 3.0%, medium; 3.1 to 10%, high; > 10%, very high.

Under VEGETATION DATA is vegetation summaries. The COMMUNITY descriptions vary among studies and ACREAGE per community was rarely found in the references. BARE GROUND proportions reflect to some degree the areas not covered by vegetation. However, this column and the VEGETATIVE COVER columns do not total 100%. VEGETATION DENSITY permits comparison of plant species or plant-type dominance and abundance. BASAL AREA refers to trees only. SHRUB HEIGHT data reflects the delineation between herbs, shrubs, and trees. Many studies classify tree and shrub seedlings as herbs and tree sapplings as shrubs, based upon their heights. In this study, trees are differentiated from herbaceous plants if they exceed a set height.

2.2 DYNAMICS OF PICEANCE CREEK BASIN SYSTEMS

The dynamics of the ecological and agricultural systems include climatic driving variable trends, system state variable fluctuations and system process activity. Most of the climatic driving variables and system state variable dynamics are essentially continuous. They are summarized on a uniform time scale. Where more than one set of data were available (e.g., several stations recorded annual precipitation) the general annual curve was drawn by tracing each separate graph on the same sheet of paper to form a composite graph. For each variable, a single curve was then visually estimated from this composite.

Time series dynamics of system components provide qualitative validation records of system performance. Such records are most readily developed for the "natural" system, in which the system variables do not involve development or management effects. The curves in the following figures are based on data and estimates from observation and experience. The example dynamics have been extracted from Ashland Oil, Inc. (1977).

The prototype graphs shown in the following sections represent the hypothesized average year. For most variables indicated, the peaks and troughs could be 50% larger or smaller than noted in other years. Furthermore, the locations in time of the peaks and troughs may vary by a few months. Therefore, the "average dynamics" shown apply only to the "average year". However, these "average year" dynamics serve to qualitatively describe the type of system behavior expected. For example, the graphs show that the basin has a seasonal climate, with a summer dry spell, and other characteristics which distinguish this area from other regions.

2.2.1 Climate

Most of the precipitation occurs during the first two-thirds of the year (Fig. 2.1A). Maximum precipitation may be in June or July. At intermediate

Figure 2.1. Expected nominal dynamics during one year for climatic driving variables for an intermediate elevational zone in the oil shale development region. A. Precipitation (cm), B. Air temperature (°C), C. Wind (km/hr), D. Solar radiation (langleys), E. Relative humidity (%).

elevations, this may be in the order of 4 cm per month. Minimum precipitation appears to be in September and October and may be less than 1 cm per month.

Snow may occur over much of the Piceance Creek Basin, but appreciable snow depths occur only at intervals in the late fall and early winter on most elevations (Fig. 2.2C).

Air temperature values peak in July (Fig. 2.1B). Minimal values are in December or January. Increase and decrease of air temperature before and after the peak air temperature appears approximately symmetrical.

High wind velocity occurs during two peak periods in April and in the October-to-November interval (Fig. 2.1C). Minimum wind velocities occur in July.

Solar radiation data show a peak in the June-to-July interval with maximum values about five times greater than the minimum values (Fig. 2.1D). Minimal values are in December to January.

Relative humidity averages as low as 30% in the month of July and as high as about 75% in late winter to early spring (Fig. 2.1E).

2.2.2 Soils

Soil temperature measurements for upper soil layers and lower soil layers suggest that highest values are found in July or August for both layers (Fig. 2.2A). The upper soil layer shows much greater dynamics in temperature than the lower soil layer (Fig. 2.2B).

Soil water levels for lower layers in the soil lag behind the peaks and troughs and have maximum values lower than in the upper layer (Fig. 2.2D-2.2E). The hypothesized levels of soil water, particularly for upper soil layer water, could vary greatly from day to day so that the figure shows only broad averages.

2.2.3 Flora

The four major regional landscape units, in approximate order of aerial extent, are ridgeland and upland plateaus, slopes, bottomland flood plains, and stream courses. Within each of the landscape units are found one or more major plant communities. These include sagebrush grassland, pinyon-juniper, mountain shrub, ponderosa pine-Douglas fir, and spruce-fir zones. Some of these plant communities can grow only in specific landscape units, while others can grow in a variety of landscape units. Studies reviewed have shown some sensitivity to the elevations at which various plant communities are found. Aspect and slope are the other major elements of the landscape units which are considered influential as to plant community location. Within the ponderosa pine-Douglas fir and the spruce-fir zones important sub-zones exist. These sub-zones are generally stratified by elevation, but may be intermixed because of differences in north and south exposures or in soil types. The pinyon-juniper zone generally exists below the ponderosa pine-Douglas fir zone and may blend into desert types at the lower limits. The upper edge of the

Figure 2.2. Expected nominal dynamics during one year for abiotic state variables for an intermediate elevational zone in the oil shale development region. A. Upper soil layer temperature (°C), B. Lower soil layer temperature (°C), C. Snow depth (cm), D. Upper soil layer water (%), E. Lower soil layer water (%), and F. Groundwater water (m³).

zone frequently contacts the mountain shrub community. Mountain shrub zones are dominant in the transition between pinyon-juniper woodland and conifer forest in some regions. Generally, these mountain shrub zones are on steep slopes, and in northwestern Colorado the lower contact may be with the sagebrush zone while the upper border frequently touches the aspen and lodgepole pine zones (Costello 1954).

An example of further subdivision of vegetation zones is illustrated by the mapping of the C-b Tract in which 14 plant communities were identified (Ashland Oil, Inc. 1977). These included:

pinyon-juniper woodland	riparian communities
chained pinyon-juniper rangeland	Great Basin wildrye communities
upland big sagebrush communities	rabbitbrush communities
bottomland big sagebrush communities	greasewood communities
Douglas-fir forests	agricultural meadows
mixed mountain shrublands	annual weed communities
bunchgrass communities	aquatic plant communities
marshlands	

Other vegetation studies have described as few as 3 and as many as 28 plant communities based on varying criteria.

Live shoots of annual plants are prominent only in the spring; there is only small growth of winter annuals in the fall (Fig. 2.3A). Perennial herbaceous plants have their peak growing periods at different times of the year. Many can be expected to reach their peak biomass in July, but some have regrowth later in the year (Fig. 2.3B). The main period of growth of the woody plants is later in the year than for the herbaceous plants. Field measurements of the shrubs show peak standing crops in July or August. Standing crop of live shrub material in August is almost twice as high as in middle to late winter. Note, however, that the data represented may include not only current twig growth but also old twig material (Fig. 2.3C). Conifers are the dominant trees in the Piceance Creek Basin. These trees maintain considerable amounts of live foliage throughout the year but it is assumed there is slightly higher current year's foliage biomass in the summer than at other seasons (Fig. 2.3D).

Dead plant biomass will peak after the decline of live biomass for annuals, perennial herbaceous plants, or shrubs (Fig. 2.3E-2.3H). For annual plants, this peak will be in May or June. For herbaceous plants it may be September. For shrubs it may be later yet, and it is assumed to occur in October.

Few data are available on the seasonal dynamics of the root biomass of plants in the basin. Thus, the curves (Fig. 2.3I-2.3M) are hypothesized for middle elevations in the Piceance Creek Basin; they are derived from information from other locations. Live annual root biomass can be expected to increase at times similar to those when the shoots are increasing. For perennial herbaceous plants, however, a great deal of root reserve material is depleted in the early stages of growth of the shoots. At a point midway in shoot growth, root biomass begins to increase, and it peaks at a date after the live shoot biomass.

Figure 2.3. Expected nominal dynamics during one year for plant state variables for an intermediate elevational zone in the oil shale development region. A. Annual shoot biomass (g/m²), B. Perennial shoot biomass (g/m²), C. Live shrub biomass (g/m²), D. Live tree biomass (g/m²), E. Dead annual biomass (g/m²), F. Dead perennial biomass (g/m²), G. Dead shrub biomass (g/m²), H. Dead tree biomass (g/m²), I. Live annual root biomass (g/m²), J. Live perennial grass root biomass (g/m²), K. Live perennial forb root biomass (g/m²), L. Live shrub root biomass (g/m²), M. Live tree root biomass (g/m²), and N. Aboveground litter biomass (g/m²).

Figure 2.3. (Continued)

Dead plant and animal material on the ground is herein termed litter (Fig. 2.3N). Aboveground litter values are relatively uniform throughout the year with slightly higher values in the fall than in other seasons. Little is known about the seasonal dynamics of the belowground litter biomass representing dead roots and other organic material. Animal biomass contributions to litter are considered but are less important by an order of magnitude.

2.2.4 Fauna

Since communities are naturally occurring assemblages of plants and animals living in the same environment, plant communities must also be considered as animal habitats. Some animal species are resident and some transitory with respect to any plant community. Many species occupy a large territory or have a large zone of activity and encompass a broad spectrum of community types, while other species are restricted to specific habitat types. Several species remain in a given community type during the entire season, but migrate completely out of the region at a given time in the year, only to return again the next spring.

Deer and cattle numbers build to a peak and then drop off each spring and fall. There are approximately equal maximum numbers present in the spring and fall for cattle. Both deer and cattle migrate to the higher elevations in late spring or early summer, and return to lower elevations during midwinter. Deer population numbers are reduced in the fall due to hunting (Fig. 2.4A-2.4B).

Cottontail numbers are fairly high throughout many elevational zones (Fig. 2.4C). They begin reproducing in the spring and reach peak numbers in middle to late summer. Predation and natural mortality from various causes reduce the population. Low numbers are probably reached in late winter and early spring.

Other small mammal numbers fluctuate seasonally (Fig. 2.4D). Some small rodents may hibernate and thus numbers will remain relatively stable during much of the late fall through early spring interval.

Arthropod numbers show a wide fluctuation in the numbers of individuals measured depending upon particular taxonomic groups (Fig. 2.4E). Overall, arthropod numbers peak in middle summer and are at their lowest level in early spring. In the early spring and middle summer arthropod numbers increase relatively rapidly in a shorter time interval than for other animal populations.

Insectivore, omnivore, and carnivore bird numbers may follow quite different patterns (Fig. 2.4F-2.4H). Insectivorous birds are most abundant in the late spring and early summer.

In order to have a reasonably mechanistic prediction of changes in numbers of animals it is necessary to account for an average individual's weight. However, relatively few data are available for predicted weights of individuals during the year.

Figure 2.4. Expected nominal dynamics during one year for animal state variables for an intermediate elevational zone in the oil shale development region. A. Cattle numbers, B. Deer numbers, C. Rabbit numbers, D. Rodent numbers, E. Arthropod numbers, F. Insectivore bird numbers, G. Omnivore bird numbers, H. Carnivore bird numbers, I. Cattle weight (g), J. Deer weight (g), K. Rabbit weight (g), L. Rodent weight (g), M. Omnivore bird weight (g), N. Insectivore bird weight (g), and O. Carnivore bird weight (g).

Figure 2.4. (Continued)

Cattle weight increases in the spring of the year (Fig. 2.4I). Autumn weights for the adults are greater than the spring weights; however, because of calves, autumn weight for the average individual in the population may be lower.

Deer weight dynamics during the year for this region have been studied intensively by the Colorado Division of Wildlife (Fig. 2.4J).

Hypothesized curves are shown for the seasonal dynamics of rodent and rabbit weight (Fig. 2.4K-2.4L).

Likewise, the seasonal dynamics of bird weights are hypothesized (Fig. 2.4M-2.4O).

2.2.5 Aquatic

Abiotic variables in the aquatic system include water temperature, volume of water and flow rate, surface area of aquatic systems and light intensity. The only variable of this set which was measured in field baseline studies (Ashland Oil, Inc. 1976) was water temperature (Fig. 2.5G). High water temperatures are reached in early summer, according to an evaluation of the field data. This seems somewhat counter-intuitive, but it is based on a relatively large number of measurements. Water temperatures vary by about a factor of two from middle winter to early summer. During winter a significant fraction of the water in the aquatic systems is in the form of ice, but no data are available on ice volume or temperature.

The entry of inorganic ions and organic compounds into aquatic ecosystems and their consequent effect on those ecosystems is a major concern when considering shale oil development and exploitation. Road building and use and vegetation removal also affect aquatic ecosystems by increasing soil erosion and soil deposition in streams. For these reasons, a preliminary aquatic ecosystem model is described here. The processes and flows for the aquatic model are presented in Section 4.3.4.

Significant chemical factors in aquatic systems include concentrations of oxygen (O_2), carbon dioxide (CO_2), nitrogen (N_2) and phosphorus (P). At present, none of these elements is being measured in baseline studies of the study area streams.

The plant material in the aquatic subsystem is represented largely by the categories of rooted plants, nonrooted plants, and detritus. Field measurements were made only on the aquatic, nonrooted plant biomass, and this category of biomass in the system changes relatively little during the year. Probably, highest values occur in early spring to early summer, and lowest values occur in late fall and winter (Fig. 2.5E). Values for aquatic rooted plant biomass (both shoots and roots) and for the aquatic detritus compartment are hypothesized (Fig. 2.5D). It is expected that most of the rooted aquatic plants will make their peak growth during late spring and early summer at which time there is adequate water in the aquatic system and relatively warm temperatures. Later in the summer, although temperatures are sufficient for plant growth, many of the streams, springs, and seeps in the areas become dry, thus decreasing the live plant biomass. This is reflected also in the time-

Figure 2.5. Expected nominal dynamics during one year for aquatic state variables for an intermediate elevational zone in the oil shale development region. A. Invertebrate numbers, B. Vertebrate weight (g), C. Invertebrate weight (g), D. Rooted plant biomass (g/m²), E. Nonrooted plant biomass (g/m²), F. Detritus biomass (g/m²), G. Stream temperature (°F), and H. Vertebrate numbers.

series curve for the aquatic detritus biomass (Fig. 2.5F). With the death of plant material in middle to late summer there would be an increase in detritus in late summer or autumn. These detritus levels remain fairly high, because decomposition rates are relatively low during fall and winter. When temperature begins to increase the following spring and while water levels are high, decomposition would be rapid, accounting for a decline in aquatic detritus biomass in late spring.

Measurements were made of the numbers of aquatic vertebrates and invertebrates (Fig. 2.5A and 2.5H). Peak numbers of invertebrates showed highest average values in July with very low values from middle October until middle April. High values for invertebrates occurred earlier in the year, i.e., in late spring and early summer, and the relative dynamics throughout the year were not as great for invertebrates as for vertebrates. Few data were available for the weights of the vertebrates or invertebrates, consequently Fig. 2.5B and 2.5C represent hypothesized values.

2.3 HUMAN AND ASSOCIATED ACTIVITIES

Of human activities in the region, this report is concerned only with those which impact ecological systems. The pre-mining activities are such that the air quality falls into Federal Ambient Air Quality PSD Class II (see 5.1.1.1). The area of Rio Blanco, Garfield, and Mesa Counties is expected to grow at about 2% per year without mining-induced growth (Ashland Oil, Inc. 1976a). At the current population level, this increase would result in eventual significant deterioration of air quality, unless air quality standards are strictly enforced.

2.3.1 Agriculture

Agriculture is on the decline in the region (Ashland Oil, Inc. 1976a). It has not yet been determined what percent of this decline is ranching vs. farming. Changes in these two areas will impact wildlife and vegetation significantly.

Most fields and pastures are developed along the bottom of major drainages within the bottomland sagebrush association. The pasture areas are maintained for livestock, resulting in continued disturbance of the plant community in the vicinity of perennial water sources. Some of these fields are abandoned and are undergoing secondary succession.

Agricultural lands in the area are located in the Colorado River flood plain, along Parachute Creek in the Parachute Creek canyon, along the White River and along Piceance Creek. Hayfields and pasture constitute the greatest amount of agricultural lands. The primary hay crop is irrigated alfalfa and native grasses, which in good years, can be cut several times during the growing season. Crested wheat is grown in areas without irrigation. Soils in these areas are generally silty clay loams which would be covered with greasewood associations if not cultivated (CDO 1974).

The most common form of irrigation is flood irrigation, which has had drastic effects, such as silting of the nearby water courses.

2.3.2 Development and Activities

Another major source of human impact is use related disturbance and urbanization. In 1970 urban settlement occupied about 16% of the three-county region. This has no doubt grown since then. These urban areas take land away from natural habitats and disturb or drive away wildlife. Roads are also a disturbing factor and cause significant wildlife mortality.

Roads and other areas with significant human use may be classified by use level. This information may be used in predicting road kills and wildlife avoidance behavior. The following paragraphs on user areas in the region surrounding the C-b tract are taken from Ashland Oil (1976b).

User areas such as roads, trails, overlooks, camp sites, ranch headquarters, cow camps, ponds and streams are rated as being of primary or secondary importance based on size, volume of use, duration of use, recreational use and local importance. In this study user importance was considered only in terms of use factors within the Piceance Creek Basin. These factors are shown in the Table 2.2. User volume, duration of use, and size were the criteria used to differentiate user areas.

Table 2.2 User Area Criteria (Ashland Oil 1976b)

	Primary Importance	Secondary Importance
Travel Routes:		
Roads	High use volume	Low use volume
Trails	Major access road	Project road
	Long use duration	Short use duration
Use Areas:		
Overlooks	Large size	Small size
Camp areas	Long use duration	Short use duration
Ranch headquarters	High use volume	Low use volume
Cow camps		
Water Bodies:		
Ponds	High recreational	Low recreational
Streams	use	use

3. A.E.S.O.P MODEL STRUCTURE

3.1 DRIVING VARIABLES

Driving variables are components of the simulation whose values are calculated outside of the model's "environment" and are not affected by system responses.

3.1.1 Base Climate Pattern

The fundamental driving force of the model is climatic patterns of a selected set of nine climatic variables. These variables are input as daily values. This set includes:

Z(C,1)	Julian date
Z(C,2)	Maximum air temperature (°C)
Z(C,3)	Minimum air temperature (°C)
Z(C,4)	Mean air temperature (°C)
Z(C,5)	Relative humidity (%)
Z(C,6)	Average daily wind velocity (km hr ⁻¹)
Z(C,7)	Total daily precipitation (cm)
Z(C,8)	Shortwave radiation entering the upper atmosphere (ly)
Z(C,9)	Hours of daylight

In addition, three climatic intermediate variables are calculated from the driving variables. These three variables are:

I(C,1)	Saturation vapor pressure (mm Hg)
I(C,2)	Potential evaporation (mm)
I(C,5)	Potential transpiration (mm)

Topographic characteristics are associated with each set of climatic driving variables. These characteristics are elevation and general aspect and slope of a site expected to experience such a climatic pattern. Each land-block (Sec. 3.7) may have a separate climate record and associated characteristics.

3.1.2 Weather Adjustments for Ecological Response Units

Within each region, adjusted "mini-climates" are calculated for each ecological response unit. These adjustments are based upon the differences between the three topographic characteristics associated with the base climate record and those associated with the ecological response unit.

3.1.2.1 Elevation Adjustments

Wymore (1974) gives regression equations for mean monthly precipitation as a function of elevation in northwestern Colorado. His monthly equations were combined into a single dimensionless equation which would adjust predicted rain at a point for elevation differences at adjacent points. A base

elevation of 5000 feet was used. For each month, rain at higher elevations was converted to a percent of that at the base elevation. The elevation was then treated as the independent variable, percent change as the dependent variable, and months as the replicates. The resulting equation:

$$I_{(C,4)} = -1.76 + 0.000553 \cdot P_{(10,6)}$$

$$R^2 = 0.88$$

combined the information for an entire year with only a minor loss of information. After the elevation for a particular location is entered into this equation, the precipitation from the input data is multiplied by $I_{(C,4)}$ to calculate the precipitation for the location.

Temperature was adjusted in an identical manner to rain, also using Wymore's (1974) data. The resulting equation

$$I_{(C,3)} = 1.47 - 0.000094 \cdot P_{(10,6)}$$

$$R^2 = 0.85$$

is used to adjust daily maximum, minimum and mean temperatures (Table 3.1).

3.1.2.2 Aspect Adjustments

Wymore (1974) determined the daily mean difference in air temperature for a slope versus a horizontal plane. These differences are given for eight compass directions (Table 3.1). Maximum, mean, and minimum air temperatures are adjusted for the difference in aspect between the base record and the ecological response unit.

3.1.2.3 Percent Slope - Aspect Adjustments

Wymore (1974) has also calculated percent adjustments of incoming solar radiation for slope and aspect combinations. These adjustments reflect differences from a horizontal plane for combinations of eight compass directions and then percent-slope intervals. These adjustments also differ between spring and summer seasons and autumn and winter seasons (Table 3.1).

Incoming solar radiation is multiplied by the appropriate values of $P_{(C,6)}$

3.1.2.4 Intermediate Variables

The three climatic intermediate variables associated with each ecological response unit are calculated after adjusting the driving variables record.

Table 3.1. Parameter values for driving variables.

STANDARD NOTATION		VALUE	REFERENCE					
P(C,1)		1.47	Wymore (1974)					
P(C,2)		-0.000094	Wymore (1974)					
P(C,3)		-1.76	Wymore (1974)					
P(C,4)		0.000553	Wymore (1974)					
P(C,5)			Wymore (1974)					
		-0.67	-north					
		-0.78	-northeast					
		-0.67	-east					
		-0.33	-southeast					
		0.39	-south					
		0.78	-southwest					
		0.39	-west					
		-0.33	-northwest					
P(C,6)			Wymore (1974)					
			-Spring, Summer					
	N	NE	E	SE	S	SW	W	NW
0%	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
5%	0.979	0.985	0.999	1.011	1.016	1.011	0.999	0.985
10%	0.959	0.971	0.998	1.023	1.031	1.023	0.998	0.971
15%	0.934	0.953	0.996	1.031	1.042	1.031	0.996	0.953
20%	0.909	0.936	0.994	1.040	1.052	1.040	0.994	0.936
25%	0.882	0.916	0.990	1.045	1.061	1.045	0.900	0.916
30%	0.855	0.895	0.986	1.050	1.066	1.050	0.986	0.895
35%	0.826	0.875	0.981	1.053	1.068	1.053	0.981	0.875
40%	0.797	0.854	0.977	1.055	1.070	1.055	0.977	0.854
45%	0.766	0.833	0.971	1.055	1.069	1.055	0.971	0.833
50%	0.736	0.812	0.965	1.054	1.068	1.054	0.965	0.812
			-Autumn, Winter					
0%	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
5%	0.912	0.939	1.001	1.059	1.084	1.059	1.001	0.939
10%	0.824	0.879	1.001	1.119	1.168	1.119	1.001	0.879
15%	0.735	0.822	1.002	1.173	1.245	1.173	1.002	0.822
20%	0.647	0.765	1.004	1.226	1.322	1.226	1.004	0.765
25%	0.571	0.713	1.004	1.226	1.379	1.226	1.004	0.713
30%	0.494	0.662	1.005	1.305	1.435	1.305	1.005	0.662
35%	0.415	0.618	1.007	1.353	1.505	1.353	1.007	0.618
40%	0.335	0.574	1.009	1.402	1.575	1.402	1.009	0.574
45%	0.274	0.529	1.010	1.433	1.624	1.433	1.010	0.529
50%	0.212	0.500	1.012	1.466	1.673	1.466	1.012	0.500

3.1.3 Shale Oil Development Emissions

By reviewing the detailed reports for the shale oil tract, a long list of effluents can be generated. These effluents include: SO_2 , H_2S , NO_x , ozone, oxidants, fluorine, CO , CH_4 , NMHC, THC, particulates, aerosols, trace metals (e.g., arsenic, mercury, selenium), water vapor, steam, fog, ice, fugitive dust, and odor.

Although there is a wide range of possible types of emissions from shale oil development, a set of four emission variables was selected based upon their projected levels and toxicity to plants and animals. The emission records are monthly mean concentrations of the following:

- $Z(D,1)$ Sulfur dioxide concentration (mg m^{-3})
- $Z(D,2)$ Nitrogen dioxide concentration (mg m^{-3})
- $Z(D,3)$ Hydrocarbons concentration (mg m^{-3})
- $Z(D,4)$ Particulates (mg m^{-3})

The present set of emission records is based upon nine sources in the Piceance Basin, with an effective stack height of 50 meters.

The monthly concentrations are converted to daily concentrations (in ppm) based upon local, daily climatic conditions. These daily concentrations are used to affect biotic processes in other submodels. The conversion equations and constants are taken from the Handbook of Chemistry and Physics (Weast 1968).

$$I(D,1) = (1.293 + (1 + 0.00367 \cdot Z(C,4))) \cdot (697.959 + 760)$$

$$I(D,2) = (1.293 \cdot (273.13 + (Z(C,4) + 273))) \cdot (697.959 - (0.3783 \cdot Z(C,5) \cdot I(C,1)) + 760)$$

$$I(D,2) = (I(D,2) - I(D,1)) \cdot 1000$$

$$I(D,1) = I(D,1) \cdot 1000$$

$I(D,1)$ represents the density of dry air per cubic meter and likewise, $I(D,2)$ represents the density of water vapor in the air. The number of molecules in the volume are calculated from molecular weights and an assumed constant dry air composition. This composition assumes that dry air is 78% nitrogen, 21% oxygen, and 1% argon.

$$I(D,3) = ((0.78 \cdot I(D,1)) + 14.0067) \cdot (6.02 \cdot 10^{23})$$

$$I(D,4) = ((0.21 \cdot I(D,1)) + 15.9994) \cdot (6.02 \cdot 10^{23})$$

$$I(D,5) = ((0.01 \cdot I(D,1)) + 39.9480) \cdot (6.02 \cdot 10^{23})$$

$$I(D,6) = (I(D,2) + 18.0074) \cdot (6.02 \cdot 10^{23})$$

$$I(D,7) = I(D,3) + I(D,4) + I(D,5) + I(D,6)$$

$$I(D,8) = ((Z(D,1) \cdot 0.000001) + 64.0628) \cdot (6.02 \cdot 10^{23})$$

$$I(D,9) = ((Z(D,2) \cdot 0.000001) \div 42.0055) \cdot (6.02 \cdot 10^{23})$$

$$I(D,10) = ((Z(D,3) \cdot 0.000001) \div 13.0191) \cdot (6.02 \cdot 10^{23})$$

$$I(D,11) = I(D,8) + I(D,9) + I(D,10)$$

$$I(D,12) = (I(D,8) \div (I(D,7) + I(D,11))) \cdot 1000000$$

$$I(D,13) = (I(D,9) \div (I(D,7) + I(D,11))) \cdot 1000000$$

$$I(D,14) = (I(D,10) \div (I(D,7) + I(D,11))) \cdot 1000000$$

$$I(D,15) = (Z(D,4) \cdot 0.000001) \div (I(D,1) + I(D,2)) \div (100000 \div I(D,7))$$

The intermediate variables $I(D,12)$, $I(D,13)$, $I(D,14)$, and $I(D,15)$ represent the daily concentrations of $Z(D,1)$, $Z(D,2)$, $Z(D,3)$ and $Z(D,4)$, respectively.

Although emission records are regarded as driving variables, their activation in the model is through the event structure (Sec. 4.4).

3.2 SYSTEM STATE VARIABLES

The ecosystem is modeled using a state variable approach which entails the representation of parts of the ecosystem by discrete measurable quantities, such as biomass or energy. This approach contrasts with partial differential equation models in which quantities are distributed, with models of the topology of the multi-population phase space, and with set-theoretic models.

The state variable approach was chosen because it allows close representation of the logical relations between components of the ecosystem.

3.3 SYSTEM PROCESSES

The complement of the state variables in this approach is the transfer process by which quantities are moved between state variables. All changes of state variables are accomplished via these transfers, referred to as processes, rates, or flows, and measured as units of quantity per unit of time.

While quantities within the model are not conservative, the sum of inputs to the model equals the sum of losses plus changes within the system.

3.4 ECOLOGICAL RESPONSE UNITS

Selection of spatial units of reasonable size requires a compromise between too much and not enough detail. An ecological response unit is defined as a composite spatial unit of combined physiognomic, climatic, soil, vegetative and animal features which make that type of area a noticeably unique system in terms of its response to varying conditions.

The conversion of a conceptual model into a numerical model requires the use of a "canonical" approach to defining ecological response units and classes of state variables within response units. Thus, from the potentially large number of ecological response units, less than 10 units are selected as a starting point for numerical calculations. Within any ecological response unit, whole groups of organisms may be aggregated into one typical form, e.g., herbaceous plants.

For example, there may be defined two types of upland systems, two types of bottomland systems and an aquatic system. The upland areas can be subdivided into the forested and non-forested categories. The bottomland areas can be subdivided into brush and meadow types. Meadows are treated separately because they are important units in agricultural ecosystems. Similarly, streams, ponds, and marshes generally make up only a small portion of the surface acreage, but are important habitats.

Definition of a system of ecological response units must take into consideration the future of the region and the potential of the units for adapting to change resulting from natural resource management. The study units are designed so that they will be as meaningful 20 to 30 years from now as they are today. It is important, therefore, to evaluate a potential study unit in terms of its highly dynamic components compared to its minimally dynamic or static components. For example, in the absence of a natural catastrophe, it is probable that the elevation, slope, and aspect of a unit will not change over 20 to 30 years. Soil characteristics will change very slowly over time, while erosion and surface hydrology can be highly dynamic. Plant growth is highly dynamic while plant succession is not.

With development and management considered, additional ecological response units may be needed to represent disturbed areas, including industrial plant sites, rehabilitated sites, and grazing allotments.

3.4.1 Abiotic Components

Variables such as precipitation, air temperature, wind, and solar radiation influence all the ecological response units, yet these climatic variables remain independent of interactions within those units and are therefore considered driving variables.

Abiotic variables such as soil temperature, soil water levels, and stream temperature are considered system state variables. These variables are not independent from interactions and are characteristic components of the system. Additional resolution of some of these state variables is required. Thus, for soil heat flow, the soil may be divided into layers.

3.4.2 Floral Components

Several hundred plant species occur in the major vegetation zones. This results in too many floral units for consideration in either a conceptual or numerical treatment. As a first step, the plants are grouped according to growth forms such as trees, shrubs, annual grasses, perennial forbs, and cool-

season and warm-season perennial graminoids. Even so, considering the limited information available, further aggregation may be desirable.

It is important to note that there is no foolproof technique for delineating vegetation types or plant groups. Some schools of thought base types on dominant species, while others are based on species lists. Even statistical methods, such as principal components analysis and cluster analysis, may yield different communities depending on data quality and the objectives of the investigator. However, the level of resolution in this study dictates general community types such as sagebrush-grassland and Pinyon-Juniper forest which are distinct enough that no statistical delineation of types is needed.

The plant groups are then subdivided into structural compartments. Thus, within herbaceous plants, a live green component, a storage component, roots in each soil layer, and a standing dead component are identified.

3.4.3 Faunal Components

Animal species are grouped as mammals, birds, arthropods, reptiles and amphibians, and fish. As a second step, they may be disaggregated into subgroups such as small mammals, medium-sized mammals, and large mammals, and for birds, into groups of omnivores, insectivores, and carnivores. Within each of these major groups of animals there are various species which are considered representative of the group.

Within any given animal category, changes in number and weight of the organisms are considered. Male and female organisms are considered separately and are grouped into three age classes: juvenile, immature, and mature.

3.4.4 Land Area/Use Components

The land area and its associated use within an ecological response unit may be classified into four categories: undeveloped, developed, roadways, and other. Additional categories may be created by subdividing these four.

Topographic characteristics and local climate conditions may be specified for each ERU, although the climate conditions may be shared by several ERUs (Sec. 3.1.2).

The topographic characteristics include (1) total acreage and land use acreages, such as roadways or development activities, (2) general elevation, (3) general slope and aspect, (4) soil horizon characteristics, including thickness of layers, soil class, and organic matter content, and (5) interior factors (which are similar to edge factors discussed below).

The land area/use components are fairly constant during the simulation, however, they can be changed through the event structure (Sec. 4.4).

3.4.5 Hydrologic Components

The hydrological section of the aquatic model is driven by input from six locations, three on each of two streams in the study area. This input includes water flow rates (in cubic feet per second) and the concentrations (in units of milligrams per liter) of sodium (Na), magnesium (Mg), calcium (Ca) and fluorine (F), and also a measure of total dissolved solids (TDS).

An important feature of the hydrology of the two streams in the study area is that parts or all of either or both streams run dry at times during the year. When there is no streamflow, hydrological and parts of the biological components of the aquatic model are set to zero.

3.4.5.1 Streamflow

The conceptual design of the hydrologic submodel requires that the contribution of each ecological response unit (ERU) which bounds a stream be considered as a point. Of course, each streamside ERU's contribution to streamflow is the sum of all the groundwater and overland flows from higher ERU's and the water of the contributing ERU. Groundwater flow and overland flow of an ERU are added to any water already in the stream course.

3.4.5.2 Inorganic Ions

Inorganic ion concentrations are important for aquatic plant and animal growth. Some, however, are poisonous to aquatic organisms when present in sufficient concentrations. For these reasons, the concentrations of organic ions are considered in the hydrologic portion of the overall aquatic submodel. Variables considered here include the concentrations of inorganic ions and compounds deposited in the groundwater and the surface soils by natural biological processes and by shale oil development activities. Effluents in the soil can be leached into the water table and thus influence inorganic ion concentration in the groundwater. Inorganic ions may also be carried in rain water and thereby contribute to ion concentration in the overland flow.

3.4.5.3 Organic Compounds

The concentration of organic compounds, those with carbon atoms making up part of their structure, is not measured at any of the six stream monitoring stations in the study area.

The molecular complexity of the compound in question is of primary concern. Its structure determines its rate of incorporation into living organisms, its movement through soils and its rate of degradation. In the case of recurrent or massive rainfall events, organic compound concentration in the aquatic model may be treated like inorganic compounds. When streamflow is high, the chance for organic compounds to remain proximate to sessile and bottom-dwelling organisms is reduced.

However, under conditions of reduced streamflow, deposition and degradation of organic compounds can take place. Consequently, the biological

half-life of the compound must be considered. The biological half-life of an organic compound is a function of environmental and biotic influences. Biotic influences refer to the degradation of organic substances due to the operation of decomposer organisms. In a stream ecosystem, these decomposers include bacteria, fungi and some categories of arthropods (Cooke 1963).

3.4.5.4 Turbidity

A final consideration in the hydrology of the system is the movement and deposition of particulate matter because of the influence of water movement. Vegetation acts as a buffer during rainfall events by holding water and by making soil layers porous through root growth. Removal of vegetation will cause a decrease in a watershed's ability to hold water. This decrease will lead to increased soil erosion and soil deposition in the streams, the latter increasing the turbidity of the water.

3.4.6 Aquatic Biota Components

The model consists of three state variables and twelve flows. The state variables correspond to plant biomass, animal biomass and dead biomass. The additive flow to the plant biomass state variable is photosynthesis; to animal biomass, natality and ingestion; to dead biomass, plant death, animal death and excretion. Losses from the plant state variable are grazing, respiration and death. Losses from the animal biomass state variable are predation, death, respiration, and excretion. Dead biomass losses are decomposition and grazing. Plant and animal death and animal excretion are treated as transfers from plant and animal biomass to dead biomass.

Producer Level. The model considers two types of producers; rooted and non-rooted plants. Rooted plants are considered to be those plants with roots in the stream bed and aerial portions at or above the water surface and those plants which line the stream and have roots on the margins of the water course or on the bank. These latter include reeds, sedges and rushes. Non-rooted plants are those with no roots or microscopic producers. These include mosses, filamentous algae (blue-green and green algae), unicellular algae (diatoms) and some bacteria.

The producer trophic level is the entry point for inorganic compounds and ions via the process of photosynthesis. Photosynthetic rate is a function of light intensity at a given depth, carbon dioxide concentration and water temperature. Incorporation of photosynthate into more complex compounds by the producers is limited by temperature and nutrient concentration.

Biomass additions to the producer level may be through reproduction or cell division and growth. Biomass loss to producers is the result of metabolic activity (anabolism), death and grazing by primary consumers.

Primary Consumer Level. The primary consumer level is composed of zooplankton, insects and insect larvae, snails, worms and small crustaceans. Additions to the primary consumer biomass come from reproduction and grazing of the producer trophic level. Loss to this level occurs through death, anabolism, excretion, and predation by higher trophic levels.

Higher Trophic Levels. The highest trophic level considered in the aquatic ecosystem model is that occupied by a fish or by a crawfish. Additions to the biomass at this level are accomplished through ingestion of prey items and natality. Biomass loss occurs through death, anabolism and excretion.

3.5 SYSTEM FLOW DIAGRAMS

The general flow diagram, Figures 3.1-3.5, illustrates the compartmental structure of flows connecting state variables. There are essentially 10 currencies flowing in this system model. Nine of these currencies have a source and a sink so that the currency may enter and leave the system. The tenth currency, land area, is conservative. Factors affecting flow controls are omitted for simplification but are discussed later with respect to the individual processes. The currencies flowing in the system model include degrees centigrade (calories converted to temperatures), meters (or volume) of water, grams per square meter of herbaceous plant biomass, grams per individual plant of shrub biomass, tree cover, grams per square meter of total plant and animal litter biomass, numbers of shrubs, kilograms per individual animal, numbers of animals, and hectares of land area.

The flow diagrams illustrate the structures within a given terrestrial ecological response unit. Compartments are the boxes and source/sinks are ovals. Flows are labeled along the arrows. The third dimension depicted for some subsystems (herb biomass, shrub biomass, tree cover, shrub numbers, animal biomass, and animal numbers) refers to the different species or groups that might be included.

There is a correspondence in the belowground layers for soil temperature, soil water, and herb and shrub roots. The number and thickness of the layers can vary between ecological response units. The subsystems of Fig. 3.1-3.4 are repeated for different terrestrial ecological response units. The subsystems of Fig. 3.5 are repeated for different aquatic ecological response units.

The unique numbers of compartments and flows by subsystems within an individual ecological response unit model are as follows:

<u>Subsystem</u>	<u>State Variables</u>	<u>Flows</u>
Soil Temperature	1 per soil layer	3 + 1 per soil layer
Soil Moisture	2 + 1 per soil layer	7 + 2 per soil layer
Herb Biomass	3 + 1 per root depth	12 + 3 per root depth
Shrub Biomass	3 + 1 per root depth	13 + 3 per root depth
Tree Cover	1	4
Litter Biomass	1	8
Shrub Numbers	1 per height class	2 + 2 per height class
Animal Biomass	1 + 1 per cohort	5 per cohort
Animal Numbers	1 + 1 per cohort	5 per cohort
Land Area/Use	6	8
Hydrology	4	21
Aquatic Biota	3	15

Figure 3.1. Forrester flow diagram for the soil heat and soil water submodels.

Figure 3.2. Forrester flow diagram for tree, litter, shrub, and herbaceous submodels.

Figure 3.3. Forrester flow diagram for the fauna submodel.

Figure 3.4. Forrester flow diagram for the land area submodel.

Figure 3.5. Forrester flow diagram for the aquatic submodels.
A. Hydrologic submodel, and B. Biotic submodel.

Note that in the flow diagrams there are occasionally flows in and out of two adjoining compartments. For example, there is conduction flow of heat between the top soil layer and the lower soil layer. The flow is only one direction at a given timestep, but both directions of flow are illustrated.

Similarly, flows may come from several sources into a compartment. For example, the litter biomass source has four flow lines entering into the litter compartment. All of these will be summed but they are represented separately here to show the different sources of plant and animal litter inputs into the litter compartment. Also, the aquatic model shows three flows entering the dead biomass compartment, and two flows entering the animal biomass compartment. These flows are treated in a manner similar to those of the terrestrial system.

3.6 PROCESS EFFECTS MATRIX

The factors used to calculate each flow are summarized in a process-effects matrix in Table 3.2. The columns in this matrix represent time, naturally occurring driving variables, management and development driving variables, and the system state variables in the various submodels. The rows in this matrix represent the individual flows in each of the submodels.

3.7 SPATIAL CONFIGURATION

The initial spatial organization is the definition of a region, which establishes a mapping correspondence between real world locations and "locations" within the model. A region is defined as a grid of land-blocks, which might represent drainages, allotments or management areas. In our case, land-blocks represented townships, such that nearly all the Piceance Basin was contained within the defined region. These land-blocks may be either activated or inactivated, so that the simulation may focus on a few areas of special interest, or can expand its scope to the "big picture."

Within each land-block, lists of terrestrial ecosystem response units (ERUs) are organized into elevation zones. Four elevation zones were used for describing the Piceance Basin, these were highland, upland, lowland, and bottomland.

Much of the topographic relief and man-related relief is implemented through the description of edges and their associated factors. Each ERU has a list of edges with adjacent ERUs. The adjacent ERUs contain a "reciprocal" description of the edge in their list. This arrangement allows the same edge to be described differently when approached from different directions, i.e., a cliff face. A complex mosaic of ERU patterns may be created within and among land-blocks. Fig. 3.6 illustrates a simplified description of the Piceance Basin using six ERUs.

Each edge may have a list of factors associated with it. These factors might include topographic relief, man-related structures, such as a fence line, or man-related activities, such as traffic volume. If a certain edge, such as a canyon side, were considered very important to the conceptual model, then that edge could be defined as an ERU and be described by its own

ECOLOGICAL RESPONSE UNIT JUXTAPOSITION

Figure 3.6. Juxtaposition of six ERUs describing the Piceance Basin, with an example set of edge factors.

A.

B.

Figure 3.7. Model structure for inter-township water flow. A. Major topographic features of the Piceance Basin. B. Model representation of water flow in the basin.

Table 3.2 A process-effects matrix showing the items (time, driving variables, or state variables) that are used in calculating each flow in the different subsystems.

	DRIVING VARIABLES			SYSTEM STATE VARIABLES									
	CLIMATIC DRIVING VARIABLES	OIL SHALE DEVELOPMENT DRIVING VARIABLES	MANAGEMENT DRIVING VARIABLES	HEAT	WATER	HERB BIOMASS	SHRUB BIOMASS			SHRUB NUMBERS	ANIMAL BIOMASS	ANIMAL NUMBERS	LAND AREA
	TIME TEMPERATURE, MAX TEMPERATURE, MIN RELATIVE HUMIDITY PRECIPITATION SOLAR RADIATION INPUT WIND VELOCITIES	DIRECT NPPM INTERACTION	STOCKING HUITING SEASONS CONTROLLED BURN HERBICIDE APPLICATION RESEEDING (REVEGETATION) FERTILIZATION	TEMPERATURE, DEPTH J	SHDW RETAINED CHANNEL WATER VOLUME, DEPTH J WOODWATER	STORAGE ROOTS, DEPTH J GREEN SHOOTS STANDING DEAD	STORAGE ROOTS, DEPTH J GREEN SHOOTS STANDING DEAD	TREE COVER	LITTER	SHRUBS, CLASS Q	COHORT (N.O.) DEAD ANIMALS	COHORT (N.O.) DEAD ANIMALS	UNMODIFIED INDUSTRIAL SITE ROADS SAW SHALE PILES SPENT SHALE PILES REHABILITATED, STAGE 1 REHABILITATED, STAGE 2
<u>Heat Flow Submodel</u>													
1. Shortwave radiation.	X				X					X			
2. Longwave radiation.	X X			X	X					X			
3. Vaporization loss from soil depth I.	X X X X				X	X				X			
4. Reradiation from soil depth I.	X X		X										
5. Net conduction between layers J and J+1.			X										
<u>Water Flow Submodel</u>													
1. Rainfall.	X X X												
2. Interception.	X X X												
3. Snowfall.	X X X												
4. Snow melt to retention.	X X												
5. Runoff.	X X X			X	X								
6. Infiltration soil depth I.	X X				X X X	X X							
7. Evaporation from soil depth I.	X X X X				X	X X		X X	X	X			
8. Net percolation between layers J and J+1.					X			X X	X	X			
9. Transpiration from soil depth J.	X X X				X	X		X		X			
10. Drainage - in.					X								
11. Drainage - out.					X X								
12. Groundwater flow from sources.					X								
13. Groundwater flow to sink.					X								
<u>Land Area Flow</u>													
1. Development of industrial site areas.	X												X X
2. Development of road areas.	X												X X
3. Development of raw shale pile areas.	X												X X
4. Development of spent shale pile areas.	X												X X
5. Reclamation of industrial site areas.													X
6. Reclamation of road areas.													X
7. Reclamation of raw shale pile areas.													X
8. Reclamation of spent pile areas.													X
<u>Herbage Biomass Flow</u>													
1. Photosynthetic input.	X X		X		X	X		X	X	X			
2. Translocation, to root depth J.	X X X					X X X							
3. Translocation, to live shoots.	X X X					X X X							
4. Respiration, from storage.	X X					X							
5. Respiration, from root depth J.						X							
6. Respiration, from live shoots.	X X			X		X							
7. Death from storage.	X X X					X							
8. Shoot death.	X X X		X			X							
9. Death, of root depth J.	X X X		X			X							
10. Standing dead shattering.	X		X			X							
11. Fire loss, live shoots.	X		X			X							
12. Fire loss, standing dead.	X		X			X							
13. Shoot grazing.						X					X	X	
14. Dead grazing.						X					X	X	

Table 3.2. (Continued)

	DRIVING VARIABLES			SYSTEM STATE VARIABLES									
	CLIMATIC DRIVING VARIABLES	OIL SHALE DEVELOPMENT DRIVING VARIABLES	MANAGEMENT DRIVING VARIABLES	HEAT	WATER	HERB BIOMASS	SHRUB BIOMASS			SHRUB NUMBERS	ANIMAL BIOMASS	ANIMAL NUMBERS	LAND AREA
	TIME TEMPERATURE, MAX TEMPERATURE, MIN RELATIVE HUMIDITY PRECIPITATION SOLAR ENERGY INPUT WIND VELOCITIES	DIRECT HUMUS INTERACTION	STOCKING HUNTING SEASONS CONTROLLED BURN HERBICIDE APPLICATION RESEEDING (REVEGETATION) FERTILIZATION	TEMPERATURE, DEPTH J	SNOW RETAINED CHANNEL WATER VOLUME, DEPTH J GROUNDWATER	STORAGE ROOTS, DEPTH J GREEN SHOOTS STANDING DEAD	STORAGE ROOTS, DEPTH J GREEN SHOOTS STANDING DEAD	TREE COVER	LITTER	SHRUBS, CLASS Q	COHORT (N,0) DEAD ANIMALS	COHORT (N,0) DEAD ANIMALS	UNMODIFIED SITE INDUSTRIAL SITE ROADS RAW SHALE PILES SPENT SHALE PILES REHABILITATED, STAGE 1 REHABILITATED, STAGE 2
<u>Shrub Biomass Flow</u>													
1. Photosynthesis.	X X		X		X	X X	X X	X		X			
2. Translocation, to root depth J.	X X X				X		X X X X			X X			
3. Translocation, to green shoots.	X X X				X		X X X X			X X			
4. Translocation to woody material.							X X X X			X			
5. Storage respiration.	X X				X					X			
6. Respiration, from root depth J.				X	X		X			X			
7. Respiration, from green shoots.	X X				X		X			X			
8. Respiration, from woody material.	X X		X		X		X			X			
9. Storage death.	X X X				X					X			
10. Death of green shoots.	X X X		X							X			
11. Death of woody material.	X X		X							X			
12. Death of root depth J.	X X X				X		X			X			
13. Fire loss of green shoots.	X X		X				X			X			
14. Fire loss of woody material.	X		X				X			X			
15. Green shoot grazing.							X				X		
16. Woody material grazing.							X				X		
<u>Tree Cover Flow</u>													
1. Tree growth.	X							X X					
2. Tree loss.	X												
3. Harvest.	X												
4. Fire loss.	X		X										
<u>Litter Biomass Flow</u>													
1. Input, herb shattering.	X					X X				X			
2. Input, shrub shattering.	X						X X			X			
3. Input, tree needle and twigs.	X							X					
4. Input, fecal material.	X										X	X	
5. Input, dead animals.											X	X	
6. Decomposition.				X	X				X				
7. Fire loss.	X										X	X	
8. Litter grazing.			X										
<u>Shrub Numbers Flow</u>													
1. Recruitment of small shrubs.	X X				X	X	X X X	X		X			
2. Maturation of small shrubs.										X			
3. Mortality of shrubs, class Q.	X		X										
4. Fire loss of shrubs, class Q.	X		X										
<u>Animal Biomass Flow</u>													
1. Consumption by cohort (N,0).	X X X				X	X X	X			X	X	X	
2. Mortality of cohort (N,0).	X					X X	X X	X		X	X	X	
3. Immigration/emigration of cohort (N,0).	X X X		X X		X	X X	X X			X	X	X	
4. Respiration of cohort (N,0).	X X				X	X X	X			X	X	X	
5. Mortality of cohort (N,0).	X X X		X			X X	X X	X		X	X X	X	
6. Dead animals to sink.													
<u>Animal Numbers Flow</u>													
1. Mortality of cohort (N,0).	X												
2. Immigration/emigration of cohort (N,0).	X X X		X X		X	X X	X X			X	X		
3. Maturation, cohort (N,0) to cohort (N+1,0).	X										X		
4. Mortality of cohort (N,0).	X		X			X X	X X			X	X	X	
5. Dead animals to sink.												X	

appropriate characteristics. Thus, by adjusting the variability restrictions in defining ERUs, the resolution and the scope of the model may be modified.

3.8 TEMPORAL DESCRIPTION

Although change in any variable is continuous, time can also be aggregated. Thus, incremental changes rather than continuous changes of the above currencies (flows) or materials are considered. As a compromise between mechanistic detail and practicality, different time steps or increments can be used in calculating changes in content of soil heat, soil water, plant and animal biomass and numbers, or land area within different components of an ecological response unit.

Consideration of the method for calculation of these changes leads to an initial attempt to express heat and water changes daily, plant biomass and numbers changes weekly, animal biomass changes weekly, and tree cover and land area on a yearly basis.

3.9 NOMENCLATURE MASTER LIST

At this point it is useful to explicitly list the driving variables, system state variables, system intermediate variables and parameters. These are noted in Table 3.3. The variable names shown in Table 3.3 correspond with those in the text and computer code. The units and definition for each variable are indicated.

Table 3.3. A summary of terms used in the numerically implemented model. Terms include driving variables, state variables, flows, intermediate variables, and parameters. Terms are given both in a standardized notation for model descriptions and in the PASCAL code. The key to the standard notation follows:

Standard Notation	Interpretation	Pascal Code Subscripts	Interpretation
Z(t,#)	Driving variables t indicates the type of driving variables: C - climatic D - development H - hydrologic M - management	G H I J K L M N O P Q R S T U	compass direction percent-slope category day of year soil depth-layer soil class plant class fauna class fauna age cohort fauna sex cohort season of year shrub size class plant species fauna species time step Ecological Response Unit
X(s,#)	State variables s indicates the associated submodel: 1 - soil temperature 2 - soil water 3 - herbaceous biomass 4 - shrub biomass 5 - tree basal area 6 - litter biomass 7 - shrub numbers 8 - animal biomass 9 - animal numbers 10 - land area 11 - air borne effluents 12 - hydrology 13 - aquatic biota	V W Y	plant activity level element (ion) species organic compound
F(s,#)	Flow s indicates associated submodel		
I(s,#)	Intermediate variables s indicates submodel which calculates it		
P(s,#)	Parameter s indicates associated submodel		

In all cases, # indicates a sequential numbering system

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
Z(C,1)	DATE	3.1.1	days	Julian date
Z(C,2)	TEMPMAX[1]	3.1.1	°C	Maximum air temperature of 1-th day
Z(C,3)	TEMPMIN[1]	3.1.1	°C	Minimum air temperature of 1-th day
Z(C,4)	TEMPMEAN[1]	3.1.1	°C	Mean air temperature of 1-th day
Z(C,5)	HUMID	3.1.1	% max	Relative humidity
Z(C,6)	WIND	3.1.1	km hr ⁻¹	Average daily wind velocity
Z(C,7)	PRECIP	3.1.1	cm day ⁻¹	Total daily precipitation
Z(C,8)	SOLAR	3.1.1	ly day ⁻¹	Shortwave radiation entering the upper atmosphere
Z(C,9)	DAYLIGHT	3.1.1	hr	Hours of daylight
Z(D,1)	EFFLUENT.SO2	3.1.3	mg m ⁻³	SO ₂ concentration in air
Z(D,2)	EFFLUENT.NO2	3.1.3	mg m ⁻³	NO ₂ concentration in air
Z(D,3)	EFFLUENT.HC	3.1.3	mg m ⁻³	Hydrocarbon concentration in air
Z(D,4)	EFFLUENT.PARTICULATES	3.1.3	mg m ⁻³	Particulate concentration in air

Table 3.3. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
Z(H,1)	STREAMFLOW		l sec ⁻¹	Stream flow rate (entering the system)
Z(H,2)	NA CONC	3.4.5	mg l ⁻¹	Concentration of sodium in the stream
Z(H,3)	MG CONC	3.4.5	mg l ⁻¹	Concentration of magnesium in the stream
Z(H,4)	CA CONC	3.4.5	mg l ⁻¹	Concentration of calcium in the stream
Z(H,5)	FL CONC	3.4.5	mg l ⁻¹	Concentration of fluorine in the stream
Z(H,6)	TDSC CONC	3.4.5	mg l ⁻¹	Concentration of total dissolved solids in the stream
Z(H,7)	CO ₂ CONC	4.3.4	ppm	Concentration of CO ₂ in the stream
Z(H,8)	WATER TEMP	4.3.4	°C	Water temperature of the stream
Z(M,1)	INTENSITY	4.4.1	%	Fire intensity measured as percentage of vegetation burned
Z(M,2)	SPRAYSUCCESS	4.4.1	%	Percent kill of shrubs by herbicide
Z(M,3)	HUNT.SUCCESS	4.4.1	%	Hunter success as a percent of species population
Z(M,4)	HUNT.WOUND	4.4.1	%	Wounding loss as a percent of species population
Z(M,5)	STOCK.POPULATION	4.4.1	numbers	Number of animals stocked (or removed) from an ERU
X(1,1)	LAYER[J].TEMP	4.2.1	°C	Temperature of J-th soil layer
X(2,1)	SNOW	4.2.2	cm	Depth of snow on surface of top soil layer
X(2,2)	RETAIN	4.2.2	m ³	Volume of water retained on surface of soil
X(2,3)	LAYER[J].MOIST	4.2.2	m ³	Volume of water in J-th soil layer
X(3,1)	BIOMASS.STORAGE	4.3.1.6	g m ⁻²	Storage biomass, herbaceous sp.
X(3,2)	BIOMASS.ROOT[J]	4.3.1.6	g m ⁻²	Root biomass in J-th soil layer, herbaceous sp.
X(3,3)	BIOMASS.GREEN	4.3.1.2	g m ⁻²	Green biomass, herbaceous sp.
X(3,4)	BIOMASS.NONGREEN	4.3.1.6	g m ⁻²	Standing dead biomass, herbaceous sp.
X(4,1)	BIOMASS.STORAGE	4.3.1.6	g (plant) ⁻¹	Carbohydrate reserves, shrub sp.
X(4,2)	BIOMASS.ROOT[J]	4.3.1.6	g (plant) ⁻¹	Roots in J-th soil layer, shrub sp.
X(4,3)	BIOMASS.GREEN	4.3.1.6	g (plant) ⁻¹	Green biomass, shrub sp.
X(4,4)	BIOMASS.NONGREEN	4.3.1.2	g (plant) ⁻¹	Woody aboveground biomass, shrub sp.
X(5,1)	TREECOVER	4.3.1.5	%	Tree cover
X(6,1)	LITTER.WEIGHT	4.3.2	g m ⁻²	Total litter biomass
X(7,1)	POPULATION	4.3.1.2	numbers m ⁻²	Number of shrubs of height class Q
X(8,1)	COHORT[N,O] .WEIGHT	4.3.3.1	g	Live biomass of N-th age and O-th sex cohort of a fauna species
X(8,2)	DEADWT	4.3.3.1	g	Dead biomass of a fauna species
X(9,1)	COHORT[N,O] .POPULATION	4.3.3.2	numbers	Individuals of N-th age and O-th sex cohort of a fauna species
X(9,2)	DEADIND	4.3.3.2	numbers	Dead individuals of a fauna species
X(10,1)	ACREAGE	4.2.4	ha	Undeveloped acreage within ERU
X(10,2)	MINESITE	4.2.4	ha	Industrial site acreage within ERU
X(10,3)	ROAD	4.2.4	ha	Roadway acreage within ERU
X(10,4)	RAWSHALE	4.2.4	ha	Raw shale pile acreage within ERU
X(10,5)	RETORT	4.2.4	ha	Retort shale pile acreage within ERU
X(10,6)	REHAB	4.2.4	ha	Rehabilitated acreage within ERU
X(12,1)	STREAMVOLUME	4.2.3.1	l	Stream volume
X(12,2)	INORGION	4.2.3.2	mg l ⁻¹	Concentration of inorganic ions in the stream
X(12,3)	ORGO COMPOUND	4.2.3.3	mg l ⁻¹	Concentration of organic compounds in the stream
X(12,4)	SEDIMENT	4.2.3.4	mg l ⁻¹	Concentration of suspended solids (sediment load) in stream
X(13,1)	AQUAFLORA[R]	4.3.4	g	Aquatic plant biomass of R-th species
X(13,2)	AQUAFAUNA[S]	4.3.4	g	Aquatic animal biomass of S-th species
X(13,3)	AQUADEITRUS	4.3.4	g	Total aquatic dead biomass

Table 3.3. (Continued)

STANDARD INITIATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
F(1,1)	RADIATE	4.2.1	cal cm ⁻² day ⁻¹	Effective incoming shortwave radiation
F(1,2)	VAPORIZE	4.2.1	cal cm ⁻² day ⁻¹	Heat loss due to evaporation from soil surface
F(1,3)	RERADIATE	4.2.1	cal cm ⁻² day ⁻¹	Effective longwave radiation flux
F(1,4)	CONDUCT	4.2.1	cal cm ⁻² day ⁻¹	Heat conduction flux between soil layers
F(2,1)	driving variable	4.2.2	m ³ day ⁻¹	Total daily precipitation as rainfall
F(2,2)	INTERCEPTION	4.2.2	m ³ day ⁻¹	Precipitation intercepted by plants
F(2,3)	input value	4.2.2	cm day ⁻¹	Total daily precipitation as snowfall
F(2,4)	no specific term	4.2.2	m ³ day ⁻¹	Snow melt water
F(2,5)	no specific term	4.2.2	m ³ day ⁻¹	Runoff to channel
F(2,6)	INFILTRATE	4.2.2	m ³ day ⁻¹	Water from surface into upper soil layer
F(2,7)	EVAPORATE	4.2.2	m ³ day ⁻¹	Volume of water evaporated
F(2,8)	PERCOLATE	4.2.2	m ³ day ⁻¹	Water flow between soil layers
F(2,9)	TRANSPIRE[J]	4.2.2	m ³ day ⁻¹	Water taken up by plant roots from J-th soil layer
F(3,1)	NETPHOT	4.3.1.6	g m ⁻² day ⁻¹	Flow of CO ₂ to green biomass, herb. sp.
F(3,2)	ROOTTRANSL[J]	4.3.1.6	g m ⁻² day ⁻¹	Flow from carbo. reserves to roots, J-th soil layer
F(3,3)	GREENTRANSL	4.3.1.6	g m ⁻² day ⁻¹	Flow from carbo. reserves to green biomass, herb. sp.
F(3,4)	STORAGERESPIRE	4.3.1.6	g m ⁻² day ⁻¹	Respiration from storage biomass, herb. sp.
F(3,5)	ROOTRESPIRE[J]	4.3.1.6	g m ⁻² day ⁻¹	Respiration from roots, J-th soil layer
F(3,6)	GREENRESPIRE	4.3.1.6	g m ⁻² day ⁻¹	Respiration from shoots, herb. sp.
F(3,7)	STORAGEDEATH	4.3.1.6	g m ⁻² day ⁻¹	Loss from storage due to mortality, herb. sp.
F(3,8)	GREENDEATH	4.3.1.6	g m ⁻² day ⁻¹	Flow from aboveground live to standing dead, herb. sp.
F(3,9)	ROOTDEATH[J]	4.3.1.6	g m ⁻² day ⁻¹	Loss due to mortality from roots, J-th soil layer
F(3,10)	GREENBURN	4.3.1.6	g m ⁻² day ⁻¹	Fire consumption of green biomass, herb. sp.
F(3,11)	GREENGRAZE	4.3.3.1	g m ⁻² day ⁻¹	Grazing of green biomass, herb. sp.
F(3,12)	DEADSHATTER	--	g m ⁻² day ⁻¹	Flow from standing dead to litter, herb. sp.
F(3,13)	DEADBURN	--	g m ⁻² day ⁻¹	Fire consumption of standing dead biomass, herb. sp.
F(3,14)	DEADGRAZE	4.3.3.1	g m ⁻² day ⁻¹	Grazing of standing dead biomass, herb. sp.
F(3,15)	LEAFFALL	4.3.1.6	g m ⁻² day ⁻¹	Flow from green biomass to litter, herb. sp.
F(4,1)	NETPHOT	4.3.1.6	g m ⁻² day ⁻¹	Flow from CO ₂ to green biomass, shrub sp.
F(4,2)	ROOTTRANSL[J]	4.3.1.6	g plant ⁻¹ day ⁻¹	Flow from carbo. reserves to roots, J-th soil layer
F(4,3)	GREENTRANSL	4.3.1.6	g plant ⁻¹ day ⁻¹	Flow from carbo. reserves to green biomass, shrub sp.
F(4,4)	STORAGERESPIRE	4.3.1.6	g plant ⁻¹ day ⁻¹	Respiration from storage biomass, shrub sp.
F(4,5)	ROOTRESPIRE[J]	4.3.1.6	g plant ⁻¹ day ⁻¹	Respiration from roots, J-th soil layer
F(4,6)	GREENRESPIRE	4.3.1.6	g plant ⁻¹ day ⁻¹	Respiration from shoots, shrub sp.
F(4,7)	STORAGEDEATH	4.3.1.6	g plant ⁻¹ day ⁻¹	Loss from storage due to mortality, shrub sp.
F(4,8)	LEAFFALL	4.3.1.6	g plant ⁻¹ day ⁻¹	Flow from green biomass to litter, shrub sp.
F(4,9)	ROOTDEATH[J]	4.3.1.6	g plant ⁻¹ day ⁻¹	Loss due to mortality from roots, J-th soil layer, shrub sp.
F(4,10)	GREENBURN	--	g plant ⁻¹ day ⁻¹	Fire consumption of green biomass, shrub sp.
F(4,11)	GREENGRAZE	4.3.3.1	g plant ⁻¹ day ⁻¹	Grazing of green biomass, shrub sp.
F(4,12)	WOODYTRANSL	4.3.1.6	g plant ⁻¹ day ⁻¹	Flow from carbo. reserves to woody biomass, shrub sp.
F(4,13)	WOODYRESPIRE	4.3.1.6	g plant ⁻¹ day ⁻¹	Respiration from woody biomass, shrub sp.
F(4,14)	WOODYBURN	--	g plant ⁻¹ day ⁻¹	Fire consumption of woody biomass, shrub sp.
F(4,15)	WOODYGRAZE	4.3.3.1	g plant ⁻¹ day ⁻¹	Grazing of woody biomass, shrub sp.
F(4,16)	LITTERFALL	--	g plant ⁻¹ day ⁻¹	Flow from woody biomass to litter, shrub sp.
F(5,1)	TREEGROWTH	4.3.1.5	m ² day ⁻¹	Flow from source to tree cover, tree sp.
F(5,2)	TREELOSS	4.3.1.5	m ² day ⁻¹	Flow from cover to sink, tree sp.
F(5,3)	TREELOSS	4.3.1.5	m ² day ⁻¹	Rate of harvest of trees
F(5,4)	TREEBURN	4.3.1.5	m ² day ⁻¹	Rate of burning of trees

Table 3.3. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
F(6,1)	no specific term	4.3.2	g m ⁻² day ⁻¹	Transfer to litter from herbs
F(6,2)	no specific term	4.3.2	g m ⁻² day ⁻¹	Transfer to litter from shrubs
F(6,3)	no specific term	4.3.2	g m ⁻² day ⁻¹	Transfer to litter from trees
F(6,4)	EXCRETION	4.3.2	g m ⁻² day ⁻¹	Transfer to litter from animal feces
F(6,5)	CARCASS	4.3.2	g m ⁻² day ⁻¹	Transfer to litter from dead animals
F(6,6)	DECOMPOSE	4.3.2	g m ⁻¹ day ⁻¹	Flow of litter to sink
F(6,7)	LITTERBURN	4.3.2	g m ⁻² day ⁻¹	Consumption rate of litter by fire
F(6,8)	LITTERGRAZE	4.3.2	g m ⁻² day ⁻¹	Grazing of litter by animals
F(7,1)	RECRUITMENT	4.3.1.7	numbers m ⁻² day ⁻¹	Flow from sources to number small shrubs
F(7,2)	MATURATION	4.3.1.7	numbers m ⁻² day ⁻¹	Flow from small shrub to large shrub numbers
F(7,3)	SHRUBDEATH	4.3.1.7	numbers m ⁻² day ⁻¹	Natural mortality of shrubs of a height class
F(7,4)	SHRUBBURN	4.3.1.7	numbers m ⁻² day ⁻¹	Fire caused mortality of shrubs of a height class
F(8,1)	ASSIMILATE	4.3.3.1	g day ⁻¹	Consumption, assimilation and respiration by faunal species cohorts
F(8,2)	RECRUIT	4.3.3.2	g day ⁻¹	Recruitment of male and female juveniles
F(8,3)	IMMIGRATE/ EMIGRATE	4.3.3.2	g day ⁻¹	Immigration/emigration of faunal species cohorts
F(8,4)	BEDEAD	4.3.3.1	g day ⁻¹	Mortality of faunal species cohorts
F(8,5)	DECOMPOSE	--	g day ⁻¹	Decomposition of dead animals
F(9,1)	RECRUIT	4.3.3.2	numbers day ⁻¹	Recruitment of male and female juveniles
F(9,2)	IMMIGRATE/ EMIGRATE	4.3.3.2	numbers day ⁻¹	Immigration/emigration of faunal species cohorts
F(9,3)	AGING	4.3.3.2	numbers day ⁻¹	Maturation of male and female cohorts
F(9,4)	BEDEAD	4.3.3.2	numbers day ⁻¹	Mortality of faunal species cohorts
F(9,5)	DECOMPOSE	--	numbers day ⁻¹	Decomposition of dead animals
F(10,1)	Not coded	4.2.4	ha day ⁻¹	Development of industrial site areas
F(10,2)	Not coded	4.2.4	ha day ⁻¹	Development of road areas
F(10,3)	Not coded	4.2.4	ha day ⁻¹	Development of raw shale pile areas
F(10,4)	Not coded	4.2.4	ha day ⁻¹	Development of spent shale pile areas
F(10,5)	Not coded	4.2.4	ha day ⁻¹	Reclamation of industrial site areas
F(10,6)	Not coded	4.2.4	ha day ⁻¹	Reclamation of road areas
F(10,7)	Not coded	4.2.4	ha day ⁻¹	Reclamation of raw shale pile areas
F(10,8)	Not coded	4.2.4	ha day ⁻¹	Reclamation of spent shale pile areas
F(12,1)	GROUND INPUT	4.2.3.1	l	Ground water contribution to stream volume
F(12,2)	OVERLAND INPUT	4.2.3.1	l	Overland flow (runoff) contribution to stream volume
F(12,3)	PRECIP INPUT	4.2.3.1	l	Precipitation falling on water surface
F(12,4)	DISCHARGE	4.2.3.1	l	Volume of water exiting the aquatic ERU through streamflow
F(12,5)	EVAP SURFACE	4.2.3.1	l	Volume of water lost from evaporation of water surface
F(12,6)	IONMANAGE[W]	4.2.3.2	mg l ⁻¹	Concentration of W-th ion from management activities (effluents)
F(12,7)	IONBIOTIC[W]	4.2.3.2	mg l ⁻¹	Concentration of W-th ion from biological activities
F(12,8)	IONOVERLAND[W]	4.2.3.2	mg l ⁻¹	Concentration of W-th ion from overland flow (runoff)
F(12,9)	IONMETAB[W]	4.2.3.2	mg	Amount of W-th ion metabolized by biological activities
F(12,10)	IONDISCHARGE[W]	4.2.3.2	mg	Amount of W-th ion exiting the aquatic ERU through streamflow
F(12,11)	ORGMANAGE[Y]	4.2.3.3	mg l ⁻¹	Concentration of Y-th organic compound from management activities (effluents)
F(12,12)	ORGBIOTIC[Y]	4.2.3.3	mg l ⁻¹	Concentration of Y-th organic compound from biological activities

∞
∞

Table 3.3. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
F(12,13)	ORGOVERLAND[Y]	4.2.3.3	mg l ⁻¹	Concentration of Y-th organic compound from overland flow (runoff)
F(12,14)	ORGNETA INC[Y]	4.2.3.3	mg	Amount of Y-th organic compound metabolized by biological activities
F(12,15)	ORGDEPOSIT[Y]	4.2.3.3	mg	Amount of Y-th organic compound deposited on the stream bottom
F(12,16)	ORGDISCHARGE[Y]	4.2.3.3	mg	Amount of Y-th organic compound exiting the aquatic ERU through streamflow
F(12,17)	EROSION	4.2.3.4	g	Amount of large particles from overland flow (runoff)
F(12,18)	SCOURING	4.2.3.4	g	Amount of large particles from scouring action of the stream
F(12,19)	SEDIMENTATION	4.2.3.4	g	Amount of large particles deposited on the stream bottom
F(12,20)	SEDISCHARGE	4.2.3.4	g	Amount of large particles exiting the aquatic ERU through streamflow
F(12,21)	INTERCON	4.2.3.2	l	Interflow contribution to stream volume
F(13,1)	AQUAPHOTO	4.3.4	g	Aquatic plant photosynthesis
F(13,2)	AQUAGRAZE	4.3.4	g	Grazing loss of aquatic plants
F(13,3)	AQUARESPIRE	4.3.4	g	Respiration of aquatic plants
F(13,4)	AQUADEATH	4.3.4	g	Death of aquatic plant parts
F(13,5)	AQUANATALITY	4.3.4	g	Natality of aquatic animal species
F(13,6)	AQUAINGEST	4.3.4	g	Ingestion by aquatic animal species
F(13,7)	AQUAPREDATE	4.3.4	g	Predation loss of aquatic animal species
F(13,8)	AQUAMORTALITY	4.3.4	g	Mortality of aquatic animal species
F(13,9)	AQUABREATH	4.3.4	g	Respiration by aquatic animal species
F(13,10)	AQUAEXCRETE	4.3.4	g	Excretion from aquatic animal species
F(13,11)	AQUAPDEAD	4.3.4	g	Dead aquatic plant biomass
F(13,12)	AQUAADCAD	4.3.4	g	Dead aquatic animal biomass
F(13,13)	AQUATEXCRETE	4.3.4	g	Total excretion by aquatic animal species
F(13,14)	AQUADECOMP	4.3.4	g	Decomposition of aquatic detritus
F(13,15)	AQUADGRAZE	4.3.4	g	Grazing of aquatic detritus
I(1,1)	C[J]	4.2.1	cal (cm ³ °C) ⁻¹	Volumetric heat capacity of J-th soil layer
I(1,2)	LAMDA[J]	4.2.1	cal (cm sec °C) ⁻¹	Thermal conductivity of J-th soil layer
I(2,1)	THIETA[J]	4.2.2	%	Volumetric water content of J-th soil layer
I(2,2)	LAYER[J] .POTENTIAL	4.2.2	bars	Difference in free energy per unit volume between matrically bound water and that of pure water of J-th soil layer
I(2,3)	H[J]	4.2.2	m	Hydraulic suction head of J-th soil layer
I(2,4)	K[J]	4.2.2	m sec ⁻¹	Hydraulic conductivity of J-th soil layer
I(2,5)	KAVE[J]	4.2.2	m sec ⁻¹	Average hydraulic conductivities between the J-th and (J+1) soil layers
I(2,6)	WFACTOR[J]	4.2.2	no units	Weighting factor for metric potential of J-th soil layer
I(2,7)	WSUM	4.2.2	no units	Sum of weighting factors
I(2,8)	MAXRATE	4.2.2	cm	Maximum infiltration rate
I(2,9)	IS[L]	4.2.2	cm	Interception storage modified by amount of rainfall for L-th plant class
I(3,1)	LEAFAREA	4.3.1.2	dm ² m ⁻²	Leaf area index, top side of leaf
I(3,2)	MU	4.3.1.6	%	Maximum net photosynthesis rate as a function of soil water potential
I(3,3)	WATEREFFECT	4.3.1.6	%	Reduction in photosynthate allocation to roots and tops due to reduced soil water
I(3,4)	no specific term	4.3.1.6	%	Effect of soil water and temperature on net photosynthesis
I(3,5)	FERTIL	4.3.1.5	%	Site quality effect on photosynthesis

Table 3.3. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
I(3,6)	TH	4.3.1.6	°C	Maximum temperature for net photosynthesis
I(3,7)	TOX	4.3.1.6	°C	Optimal temperature for net photosynthesis
I(3,8)	TEMPEFFECT	4.3.1.6	%	Decrease in total translocation as temperature becomes less than optimal
I(3,9)	SHADE	4.3.1.6	dm ² m ⁻²	Amount of leaf area shading
I(3,10)	AVEPOTENTIAL[V]	4.3.1.6	bars	Soil water potential in the wettest zone containing roots for days in activity class V
I(3,11)	TRANS	4.3.1.6	g m ⁻² or g plant ⁻¹	Total translocate
I(3,12)	STRUCTURE	4.3.1.6	g m ⁻² or g plant ⁻¹	Total structural biomass
I(3,13)	TOTALCOVER	4.3.1.6	%	Total area covered by vegetation, live + dead
I(3,14)	LIVECOVER	4.3.1.6	%	Percent of total live cover by species
I(3,15)	TOTCOVER	4.3.1.6	%	Percent of total cover by species
I(3,16)	ACTIVE	4.3.1.1	no units	Index value for activity class V
I(3,17)	INACTIVE	4.3.1.1	no units	Index value for activity class V
I(3,18)	PLANTDAYS[V]	4.3.1.1	days	Number of days in activity class V
I(3,19)	AVEMAXT[V]	4.3.1.1	°C	Average maximum temperature for days in activity class V
I(3,20)	AVEMINT[V]	4.3.1.1	°C	Average minimum temperature for days in activity class V
I(3,21)	AVETEMP[V]	4.3.1.1	°C	Average daily mean temperature for days in activity class V
I(3,23)	DROUGHTDAYS	4.3.1.1	days	Number of days during which available soil water is below the wilting point
I(3,24)	DROUGHTSTRESS	4.3.1.1	bars	Average water potential for days below the wilting point
I(3,25)	ROOTDAYS[J]	4.3.1.1	days	Number of days during which soil layer J is above the wilting point and above freezing
I(3,26)	ROOTWATER[J]	4.3.1.6	bars	Soil water potential in the J-th layer averaged for days above the wilting point
I(3,27)	ROOTTEMP[J]	4.3.1.6	°C	Soil temperature in the J-th layer averaged for days above the wilting point
I(4,1)	WATERRECRUIT	4.3.1.7	%	Effect of surface soil moisture on small shrub invasion
I(4,2)	TCOMP	4.3.1.7	%	Effect of competition on small shrub invasion
I(4,3)	TEMPRECR	4.3.1.7	%	Effect of surface soil temperature on shrub germination
I(5,1)	MAXCOVER	4.3.1.5	%	Maximum tree cover that can be attained on an ERU with the given average rainfall
I(8,1)	METABASE	4.3.3.1	cal g ⁻¹	Calories needed for basal metabolism
I(8,2)	CONDUCTANCE	4.3.3.1	cal °C ⁻¹	Rate at which an animal body gains or losses heat
I(8,3)	CRITICALTEMP	4.3.3.1	°C	Lower critical temperature of thermoneutrality
I(8,4)	METATHERM	4.3.3.1	cal g ⁻¹	Calories needed for maintenance of thermal regulation
I(8,5)	MOVEMENT	4.3.3.1	km	Distance traveled during one time step
I(8,6)	VELOCITY	4.3.3.1	km hr ⁻¹	Average velocity of movement
I(8,7)	METAXOVE	4.3.3.1	cal g ⁻¹	Metabolic calories needed for activity
I(8,8)	METAGROW	4.3.3.1	cal g ⁻¹	Calories needed for biomass production
I(8,9)	ENERGYBASE	4.3.3.1	cal	Calories needed for all metabolic needs other than growth
I(8,10)	ENERGYGROW	4.3.3.1	cal	Calories needed for all metabolic needs
I(8,11)	NEED	4.3.3.1	g	Biomass needed of a food species
I(8,12)	AVAILABLE	4.3.3.1	g	Biomass available of a food species
I(8,13)	ABUNDANCE	4.3.3.1	%	Relative abundance of a food species to its total demand
I(8,14)	RELSCARCITY	4.3.3.1	%	Relative scarcity of a food species to an individual consumer species
I(8,15)	ALLOT	4.3.3.1	g	Biomass of a food specie allotted to a consumer specie

Table 3.3. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
I(8,16)	ENERGYFLUX	4.3.3.1	cal	Difference between the metabolic needs and the calories supplied through all foods consumed
I(8,17)	NORMALPREF	4.3.3.1	%	Diet preference factor for the s-th species based on availability
I(9,1)	AGEOF	4.3.3.2	days	Age of a particular species cohort
I(9,2)	NATDEATH	4.3.3.2	numbers	Number of individuals dying of "natural" causes
I(9,3)	PREDATE	4.3.3.2	numbers	Number of individuals dying from predation
I(9,4)	HUNT	4.3.3.2	numbers	Number of individuals dying from legal hunting and wounding losses
I(9,5)	CONDITION	---	%	Index of animal condition
I(9,6)	HABVAR[SNOW]	4.3.3.2	no units	Habitat rating of an ERU's snow condition for a species
I(9,7)	HABVAR[TEMP]	4.3.3.2	no units	Habitat rating of an ERU's temperature condition for a species
I(9,8)	HABVAR[COVER]	4.3.3.2	no units	Habitat rating of an ERU's cover condition for a species
I(9,9)	HABVAR[FOOD]	4.3.3.2	no units	Habitat rating of an ERU's food condition for a species
I(9,10)	HABVAR[PREVPOP]	4.3.3.2	no units	Habitat rating of an ERU's population condition for a species
I(9,11)	HABVAR[COMBINED]	4.3.3.2	no units	Sum of an ERU's habitat condition ratings for a species
I(9,12)	TWNTOTAL	4.3.3.2	numbers	Total species population existing within a township
I(10,1)	LAYER[J].MIDDEPTH	4.2.4	m	Depth at midpoint of J-th soil layer
I(11,1)	STOMATERESIST	5.2.1.2	---	Stomatal resistance during actual transpiration
I(11,2)	ADJLTEC	5.2.1.2	ppm	Daily leaf tissue exposure concentration of SO ₂ , adjusted for NO ₂
I(11,3)	ETHYLREDUCGROW	5.2.1.2	%	Percent reduction in growth due hydrocarbons
I(11,4)	SO2LTEC	5.2.1.2	ppm	Leaf tissue exposure concentration of a SO ₂
I(11,5)	NECROSED	5.2.1.2	%	Percent of leaf area necrosed per day
I(11,6)	CONVERTNO2	5.2.1.2	%	NO ₂ multiplier factor
I(11,7)	RELGROWTH	5.2.1.2	%	Relative daily growth rate of a plant
I(11,8)	PHOTOTHRESHOLD	5.2.1.2	%	Photosynthetic inhibition threshold concentration
I(11,9)	RESPONSE	5.2.1.2	%	Photosynthesis stimulated by SO ₂ as a percent of normal photosynthesis
I(12,1)	DEPTH	4.2.3.1	m	Depth of stream
I(12,2)	MOMENTUM	4.2.3.1	g m ⁻¹ sec ⁻¹	Water momentum of stream
I(12,3)	STREAMVELOCITY	4.2.3.1	mg sec ⁻¹	Stream point mean velocity
I(12,4)	GROUNDION	4.2.3.2	mg l ⁻¹	Concentration of inorganic ions in groundwater flow
I(12,5)	OVERLANDION	4.2.3.2	mg l ⁻¹	Concentration of inorganic ions in overland flow
I(12,6)	INTERFLOWION	4.2.3.2	mg l ⁻¹	Concentration of inorganic ions in interflow
I(13,1)	LIGHTDEPTH	4.3.4	lu da ⁻¹	Light intensity at a fraction of total depth in lumens
I(13,2)	O2DECOMPTOT	4.3.4	mg l ⁻¹	Total oxygen necessary to decompose utilizable biomass
I(13,3)	O2DECOMPTIME	4.3.4	mg l ⁻¹	Oxygen necessary to decompose utilizable biomass during time-step
I(C,1)	SATVAPOR	4.2.2	mm Hg	Equilibrium pressure of pure water vapor over a plane surface of pure liquid water
I(C,2)	PEVAP	4.2.2	mm	Potential evaporation from a pan of water
I(C,3)	TEMPFACTOR	3.1.2	%	Percent adjustment to driving variable temperature based on elevation
I(C,4)	RAINFACOR	3.1.2	%	Percent adjustment to driving variable rainfall based on elevation
I(C,5)	PTRANS	4.2.2	mm	Potential transpiration

Table 3.3. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
I(D,1)	DENSITYDRY	3.1.3	gm m ⁻³	Density of dry air
I(D,2)	DENSITYMOIST	3.1.3	gm m ⁻³	Density of water vapor
I(D,3)	no specific term	3.1.3	numbers	Nitrogen molecules in a cubic meter of air
I(D,4)	no specific term	3.1.3	numbers	Molecules in a cubic meter of air
I(D,5)	no specific term	3.1.3	numbers	Argon molecules in a cubic meter of air
I(D,6)	no specific term	3.1.3	numbers	Water molecules in a cubic meter of air
I(D,7)	AIRMOLECULES	3.1.3	numbers	Air molecules in a cubic meter of air
I(D,8)	SO2MOLECULES	3.1.3	numbers	SO ₂ molecules in a cubic meter of air
I(D,9)	NO2MOLECULES	3.1.3	numbers	NO ₂ molecules in a cubic meter of air
I(D,10)	HCMOLECULES	3.1.3	numbers	Hydrocarbon molecules in a cubic meter of air
I(D,11)	EFFMOLECULES	3.1.3	numbers	Particulates in a cubic meter of air
I(D,12)	PPM.SO2	3.1.3	ppm	Daily SO ₂ concentration in air
I(D,13)	PPM.NO2	3.1.3	ppm	Daily NO ₂ concentration in air
I(D,14)	PPM.HC	3.1.3	ppm	Daily hydrocarbon concentration in air
I(D,15)	PPM.PARTICULATES	3.1.3	ppm	Daily particulate concentration in air
P(1,1)	SPDEN[K]	4.2.1	g cm ⁻²	Specific density of K-th soil type
P(1,2)	SPHEAT[K]	4.2.1	cal (g °C) ⁻¹	Specific heat of K-th soil type
P(1,3)	EARTHTEMP	4.2.1	°C	Temperature of earth below lowest layer
P(1,4)	EMISSIVITY	4.2.1	%	Relative ability of the earth to radiate energy
P(1,5)	ALBEDOPLANT	4.2.1	%	Average plant surface albedo
P(1,6)	LMINERAL	4.2.1	10 ⁻³ cal (cm sec °C) ⁻¹	Thermal conductivity of mineral component of the soil
P(1,7)	LORGANIC	4.2.1	10 ⁻³ cal (cm sec °C) ⁻¹	Thermal conductivity of organic matter component of the soil
P(1,8)	LWATER	4.2.1	10 ⁻³ cal (cm sec °C) ⁻¹	Thermal conductivity of water component of the soil
P(1,10)	STEFBOLTZ	4.2.1	cal (cm ² °C day) ⁻¹	Stefan Boltzman constant
P(1,11)	VAPORBASE	4.2.1	cal	Energy required for vaporization at 0°C
P(1,12)	VAPORGRAD	4.2.1	cal °C ⁻¹	Energy gradient for vaporization per 0°C
P(1,13)	BASEKELVIN	4.2.1	°K	Converts °C to °K
P(1,14)	SPHEATH2O	4.2.1	cal (g °C) ⁻¹	Specific heat of water
P(1,15)	SPDENH2O	4.2.1	g cm ⁻²	Specific density of water
P(1,16)	SPHEATHUMUS	4.2.1	cal (g °C) ⁻¹	Specific heat of humus
P(1,17)	SPDENHUMUS	4.2.1	%	Specific density of humus
P(2,1)	SATK[K]	4.2.2	m sec ⁻¹	Hydraulic conductivity at saturation of K-th soil type
P(2,2)	SATTHETA[K]	4.2.2	%	Volumetric water content at saturation of K-th soil type
P(2,3)	FIELD CAP[K]	4.2.2	%	Volumetric content of field capacity of K-th soil type
P(2,4)	BAR3THETA[K]	4.2.2	%	Volumetric water content at 3 bars water tension for K-th soil type
P(2,5)	WILTTHETA[K]	4.2.2	%	Volumetric water content at wilting point for K-th soil type
P(2,6)	COE[L]	4.2.2	%	Intercepted water evaporated from plant surface for L-th plant class
P(2,7)	ISC[L]	4.2.2	%	Intercepted water retained on plant surface for L-th plant class
P(2,8)	DEWTEMP	4.2.2	°C	Threshold evaporation temperature
P(2,9)	MELTRATE	4.2.2	cm °C ⁻¹	Rate of snow melt
P(2,10)	MELTTEMP	4.2.2	°C	Threshold melting temperature
P(2,11)	STREAM.RATE	4.2.2	m ³ day ⁻¹	Stream discharge rate
P(2,12)	SLEPPRATE	4.2.2	%	Seepage rate from stream to deep soil layer
P(2,13)	SNOWMOIST	4.2.2	cm (cm H ₂ O) ⁻¹	Moisture content of snow
P(2,14)	SNOWTEMP	4.2.2	°C	Threshold snowfall temperature

Table 3.3. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
P(3,1)	B	4.3.1.6	%	Parameter controlling relative allocation of photosynthate
P(3,2)	PSIMORT	4.3.1.6	$\text{g m}^{-2} \text{ bar}^{-1}$	Rate at which green biomass dies per unit of moisture potential below PSIMORT
P(3,3)	K3	4.3.1.6	no units	Shape parameter
P(3,4)	K4	4.3.1.6	no units	Parameter for rate of reduction of MU with water potential
P(3,5)	K5	4.3.1.6	no units	Parameter for rate of reduction of TH with water potential
P(3,6)	K6	4.3.1.6	no units	Parameter for rate of reduction of TOP with water potential
P(3,7)	KD	4.3.1.6	$\% \text{ day}^{-1}$	Effect of temperature on respiration
P(3,8)	ROOTDEPTH	4.3.1.6	cm	Depth in cm of deepest penetration of roots by a specie
P(3,9)	PMAX	4.3.1.6	$(\text{g dry wt}) \text{ dm}^{-2} \text{ hr}^{-1}$	Maximum net photosynthetic rate in g dry weight
P(3,10)	PSIMORT	4.3.1.6	bars	Moisture potential causing plant mortality
P(3,11)	RS	4.3.1.6	g day^{-1}	Maximum translocation rate at high levels of stored energy
P(3,12)	GPRORITY	4.3.1.6	%	Green biomass at which all translocation goes to green, as a percent of all structural biomass except green
P(3,13)	MINSTORAGE	4.3.1.6	g	Storage biomass at which plant die back begins as a percent of total biomass
P(3,14)	TL	4.3.1.6	$^{\circ}\text{C}$	Minimum temperature for net photosynthesis
P(3,15)	TMAX	4.3.1.6	$^{\circ}\text{C}$	Maximum temperature for net photosynthesis under nonlimiting soil water
P(3,16)	TOPT	4.3.1.6	$^{\circ}\text{C}$	Optimal temperature for net photosynthesis under nonlimiting soil water
P(3,17)	XDEATH	4.3.1.6	%	Rate of death of green biomass per unit of temperature below threshold
P(3,18)	TRANSBELOW	4.3.1.6	%	Percent of total translocate which goes belowground
P(3,19)	EXPAND	4.3.1.6	bars	Soil water potential at which leaf expansion is inhibited
P(3,20)	RDEATH	4.3.1.6	%	Root death rate per unit of soil water potential below PSIMORT
P(3,21)	XSHADE	4.3.1.6	%	Percent reduction in net photosynthesis due to competing vegetation
P(3,22)	GTOLA I	4.3.1.2	$\text{dm}^2 \text{ g}^{-1}$	Conversion factor for leaf area per g of leaf biomass
P(3,23)	SHATTER	--	g day^{-1}	Nominal rate of transfer of standing dead to litter
P(3,24)	WILTPT	4.3.1.6	bars	Wilting point
P(3,25)	EFFICIENCY	4.3.1.6	%	Conversion efficiency of carbohydrates to structure
P(3,26)	FREEZE	4.3.1.6	$^{\circ}\text{C}$	Temperature at which mortality of green biomass begins
P(3,27)	XPALL	4.3.1.6	$^{\circ}\text{C}$	Temperature below which translocation is inhibited
P(3,28)	PROTEIN.LEAF	4.3.1.6	%	Percent protein of leaves
P(3,29)	PROTEIN.ROOTS	4.3.1.6	%	Percent protein of roots
P(3,30)	ATMOSRESIST	--	--	Atmospheric resistance
P(3,31)	GROWTHADJUST	--	--	Adjust right-hand intercept
P(3,32)	INJURYCONC	--	ppm	Concentration for a specific degree of injury
P(3,33)	PAPRESDIFF	--	bars	Partial pressure difference of gas inside and outside leaf
P(3,34)	RESISTFACTOR	--	--	Constant reflecting inherent plant and external resistance factors
P(3,35)	STOMRESIST	--	--	Leaf or stomatal resistance
P(4,1)	ZRECRUIT	--	g	Average woody biomass above which recruitment begins to larger size class
P(4,2)	ZAI	4.3.1.7	$\text{numbers m}^{-2} \text{ day}^{-1}$	Nominal shrub germination rate
P(4,3)	ZCA	4.3.1.7	dm^{-2}	Effect of shade on shrub invasion

Table 3.3. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
P(4,4)	ZLEAFDEATH	--	%	Percent of leaves lost during leaf abscission
P(4,5)	ZLEAFFALL	--	julian date	Date at which leaves fall
P(4,6)	ZSTEMDEATH	--	%	Nominal stem death rate
P(4,7)	ZRECR	4.3.1.7	% day ⁻¹	Percent of small shrubs that move to large size class per day
P(4,8)	PROTEIN.WOODY	4.3.1.6	%	Percent protein of shrub stems
P(5,1)	TREEGROW	4.3.1.5	m ² day ⁻¹	Nominal growth rate for a tree species
P(5,2)	TREEGPERM2	--	g m ⁻²	Grains of leaf per m ² of cover
P(5,3)	TREEGTOLA1	--	dm ² g ⁻¹	Conversion factor for leaf area from units of leaf biomass
P(5,4)	TREEPK4	--	no units	Rate of reduction of transpiration with decreasing soil water potential
P(5,5)	TREEWILT	--	bars	Wilting point for trees
P(6,1)	LWILT	4.3.2	bars	Wilting point for litter
P(6,2)	LK7	4.3.2	°C ⁻¹	Effect of litter temperature on litter decay rate
P(6,3)	LRESPSCALE	4.3.2	no units	Scale factor for litter respiration function
P(8,1)	GAMMA[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,2)	ALPHA1[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,3)	BETA1[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,4)	ALPHA2[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,5)	BETA2[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,6)	ALPHA3[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,7)	BETA3[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,8)	ALPHA4[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,9)	BETA4[M]	4.3.3.1	no units	Regression coefficient of M-th fauna class
P(8,10)	--	--	--	--
P(8,11)	--	--	--	--
P(8,12)	PALATABILITY	4.3.3.1	%	Palatability of non-green plant biomass
P(8,13)	ANABOLISM	4.3.3.1	%	Efficiency of converting energy to body tissue
P(8,14)	CATABOLISM	4.3.3.1	%	Efficiency of converting body tissues to energy
P(8,15)	CRITICALLOSS	4.3.3.1	%	Percent of body weight which can be lost before death
P(8,16)	BODYTEMP[M]	4.3.3.1	°C	Average body temperature of M-th fauna class
P(8,17)	ADULTWEIGHT[O]	4.3.3.1	g	Average weight of adult of a species of O-th sex
P(8,18)	CALORIES	4.3.3.1	cal g ⁻¹	Caloric content of a species by dry weight
P(8,19)	DIGESTION	4.3.3.1	%	Digestibility of a species
P(8,20)	PREF[P]	4.3.3.1	%	Relative preference of a species by a consumer species during the P-th season
P(8,21)	BIRTHWEIGHT	--	g	Biomass of newly born
P(9,1)	BEGINBIRTH	4.3.3.2	julian date	Beginning date of population birth period
P(9,2)	ENDBIRTH	4.3.3.2	julian date	Ending date of population birth period
P(9,3)	REPROSUCCESS	4.3.3.2	%	Percent of mature females bearing surviving young
P(9,4)	YOUNGBORN	4.3.3.2	numbers	Average number of young born to a mature female
P(9,5)	MATUREAT[N]	4.3.3.2	days	Duration of time before an individual of ages to next N-th age class
P(9,6)	MORTALITY[N,P]	4.3.3.2	%	Percent of population dying from natural causes for the N-th age class and P-th season
P(9,7)	DAILYRANGE	4.3.3.2	km	Daily home range traveled by specie
P(9,8)	CRITICALDEPTH	4.3.3.2	cm	Critical threshold snow depth which restricts species movement
P(9,9)	MOVEIMPETUS [SNOW]	4.3.3.2	%	Relative importance of snow condition in initiating species movement
P(9,10)	MOVEIMPETUS [TEMP]	4.3.3.2	%	Relative importance of temperature condition in initiating species movement

Table 3.3. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
P(9,11)	MOVE IMPETUS [COVER]	4.3.3.2	%	Relative importance of cover condition in initiating species movement
P(9,12)	MOVE IMPETUS [FOOD]	4.3.3.2	%	Relative importance of food condition in initiating species movement
P(9,13)	MOVE IMPETUS [PREVPOP]	4.3.3.2	%	Relative importance of population condition in initiating species movement
P(9,14)	PREDLOSS[N]	4.3.3.2	%	Percent of total species predation losses from the N-th age class
P(9,15)	HIBERNATION. START	4.3.3.2	julian date	julian date for initiation of hibernation
P(9,16)	HIBERNATION. STOP	4.3.3.2	julian date	julian date for termination of hibernation
P(10,1)	ASPECT	4.2.4	direction	Direction of slope of soil surface
P(10,2)	SLOPE	4.2.4	%	Degree of incline of soil surface
P(10,3)	ALBEDO	4.2.4	%	Reflectivity of bare soil
P(10,4)	LAYER[J] .THICKNESS	4.2.4	m	Thickness of J-th soil layer
P(10,5)	LAYER[J].CLASS	4.2.4	attribute	Soil-class category of J-th soil layer
P(10,6)	ELEV	4.2.4	feet	ERU elevation
P(10,7)	LAYER[J].HUMUS	4.2.4	%	Soil organic matter of J-th soil layer
P(12,1)	GRAVITY	4.2.3.1	m sec ⁻²	Force of gravity
P(12,2)	STREAMSLOPE	4.2.3.1	%	Slope of streambed
P(12,3)	STREAMFRICTION	4.2.3.1	%	Friction of streambed
P(12,4)	HALFLIFE[Y]	4.2.3.3	days	Biological half-life of y-th organic compound
P(12,5)	BREAKCOEF[Y]	4.2.3.3	day ⁻¹	Breakdown coefficient of y-th organic compound
P(12,6)	RELATION	4.2.3.3	no units	Constant in breakdown coefficient and half-life expression
P(12,7)	PARTICLECONC	4.2.3.3	mg l ⁻¹	Particle concentration at reference depth
P(12,8)	REFDEPTH	4.2.3.3	m	Reference depth
P(12,9)	FALLVELOCITY	4.2.3.3	m sec ⁻¹	Velocity of fall of a suspended particle
P(12,10)	PARTICLERED	4.2.3.3	m	Distance suspended particle must fall to streambed
P(13,1)	CO2DEPLETION	4.3.4	no units	Exponent for CO ₂ concentration depletion
P(13,2)	KFACTOR	4.3.4	mg C day ⁻¹	Constant in phytoplankton grazed expression
P(13,3)	KOEFFICIENT1	4.3.4	l day ⁻¹ g C ⁻¹	Coefficient in liters per day per gram of carbon in phytoplankton population
P(13,4)	CARBIO MASS	4.3.4	no units	Conversion factor for units of carbon to units of biomass
P(13,5)	KOEFFICIENT2	4.3.4	no units	Coefficient in algal photosynthesis expression
P(13,6)	LUMENS	4.3.4	lumens	Light saturation intensity
P(13,7)	PROPOR	4.3.4	no units	Proportionality constant in algal photosynthesis expression
P(13,8)	KOEFFICIENT3	4.3.4	no units	Coefficient in plant respiration expression
P(13,9)	GROWTHRATE	4.3.4	no units	Intrinsic rate of growth of S-th faunal species
P(13,10)	INTERACT	4.3.4	gC _r gC _s ⁻¹	Interaction coefficient between R-th plant species and S-th faunal species
P(13,11)	FAUNADEATH	4.3.4	day ⁻¹	Zooplankton death rate
P(13,12)	BODYEXPONENT	4.3.4	no units	Species specific decimal exponent for metabolic body weight
P(13,13)	KRATECON	4.3.4	no units	First order rate constant in biomass decomposition expression
P(13,14)	BOTTOMAREA	4.3.4	m ²	Streambed bottom area

Table 3.3. (Continued)

STANDARD NOTATION	PASCAL CODE	REFERENCED	UNITS	DEFINITION
P(C,1)	TEMP LAPSE	3.1.2	% (1000 ft) ⁻¹	Temperature lapse rate per 1000 ft. change in elevation
P(C,2)	TEMP INTERCEPT	3.1.2	%	Intercept for temperature lapse rate regression
P(C,3)	RAIN LAPSE	3.1.2	% (1000 ft) ⁻¹	Rain lapse rate per 1000 ft. change in elevation
P(C,4)	RAIN INTERCEPT	3.1.2	%	Intercept for rain lapse rate regression
P(C,5)	ADJUST ASPECT	3.1.2	°C	Mean daily temperature difference from horizontal for the G-th direction
P(C,6)	ADJUST SLOPE	3.1.2	%	Percent difference in solar radiation from horizontal for the G-th direction, the H-th slope category and the P-th season

4. A.E.S.O.P MODEL FUNCTION

The implemented model may be described as a forced system of nonlinear difference equations with lag effects and discontinuities. The model is canonical in form; the same general structure may occur from one ecological response unit to the next and different groups of variables of the same class have identical structures. Thus, different herbaceous plants within an ecological response unit and between ecological response units would have the same compartmental structure. The specific processes vary due to different parameter and coefficient values.

4.1 DEVELOPMENT OF PROCESS FUNCTIONS

Individual processes are described in a general narrative and through algebraic equations using a standardized notation.

4.1.1 Selection of Process Components

The development of any given flow equation requires a great deal of testing to determine appropriate components and parameter values. State variables are selected which represent the desired resolution for the process.

These coefficient values are modified during the development and evaluation of the flow functions and a "nominal" value of the coefficient is determined. Next, the response of the flow function to changes in the variables of the function is evaluated. Thus, graphs are plotted showing the flow value as the dependent variable, and one of the factors affecting the flow as the independent variable. These factors can be time, a driving variable, or a state variable. The flow functions are multivariable functions, since many factors may influence a given process. However, for simplicity, only the partial influence of one factor is plotted.

For discussing the mathematical form of the process functions a simplified notation is used: Z_i for a driving variable; F_i for a flow; X_i for a state variable; P_i for a parameter; I_i for intermediate variables. A full description is provided in Table 3.3.

4.1.2 Estimation of Parameters

Values for parameters must be specified in the model, and these must be based on the best estimates available. In some cases, sufficient experimental work has been accomplished or field measurements completed so that parameters are well documented. A model operation is dependent upon values specified for the parameters, and the model makes no distinction between those that are well documented and those that are based on estimated relationships.

The parameters in the present model are deterministic rather than stochastic. That is, for any given simulation run there are no random variations in parameter values.

4.2 ABIOTIC PROCESSES

4.2.1 Soil Temperature

The currency is calories. Temperature, in degrees centigrade, is calculated based upon volumetric heat capacities. The processes considered include the following, as diagrammed in Fig. 3.1:

- 1) Shortwave radiation
- 2) Net longwave radiation
- 3) Vaporization loss from soil surface
- 4) Heat conduction from soil layer i to layer j

Heat may enter or leave the system through three separate processes. Two of these processes, shortwave radiation and longwave radiation, influence the temperature of the surface soil, while deep conduction influences the lower soil layer temperature.

Shortwave Radiation. Shortwave radiation is considered to be that shortwave radiation which is absorbed by the surface soil. Therefore, reductions are made in the total incoming shortwave radiation due to the soil albedo and floral cover (Fig. 4.1b).

$$F(1,1) = Z(C,8) \cdot (1 - P(10,3)) \cdot (1 - (I(3,13) \cdot P(1,5)))$$

Vaporization. Vaporization refers to the heat lost from the surface soil due to evaporation of soil water (Fig. 4.1c). The amount of energy required for vaporization is assumed to be directly related to the daily mean air temperature (Masterton 1969).

$$F(1,2) = F(2,7) \cdot [P(1,11) + P(1,12) \cdot Z(C,3)]$$

Longwave Radiation. Longwave radiation from the surface soil is a function of the daily mean air temperature and the temperature of the surface soil (Fig. 4.1a). If the soil is cooler than the air, the soil will lose heat in the form of longwave radiation. Otherwise, the soil will gain heat. It is assumed that the earth acts as a constant grey body (deVries 1975, Van Wijk 1963).

$$F(1,3) = [(Z(C,3) - X(1,1)) + P(1,13)]^4 \cdot P(1,10) \cdot P(1,4)$$

$$F(1,3) = -F(1,3); \quad \text{if } X(1,1) > Z(C,3)$$

$$F(1,3) = F(1,3); \quad \text{if } X(1,1) \leq Z(C,3)$$

In order to determine the results of these flows, the heat capacity of a soil layer is calculated. Heat capacity is a function of three major soil components; mineral, water, and organic; and the thickness of the layer of soil. The distribution of these components is assumed to be homogenous. Volumetric heat capacity is determined from the specific heats and specific densities of these components (deVries 1975, Van Wijk 1963).

Figure 4.1. Major pathways of heat entering or exiting the surface soil layer. a) Longwave radiation as a function of the difference between the soil temperature and the ambient temperature b) Shortwave radiation reduced by plant cover c) Vaporization energy as a function of ambient temperature.

Table 4.1. Parameter values for soil temperature submodel.

STANDARD NOTATION	VALUE	REFERENCE
- Sand -		
P(1,1)	2.73	Arbitrarily assigned
P(1,2)	0.180	Arbitrarily assigned
- Siltsand -		
P(1,1)	2.70	Van Wijk (1963)
P(1,2)	0.176	Van Wijk (1963)
- Sandclay -		
P(1,1)	2.76	Van Wijk (1963)
P(1,2)	0.197	Van Wijk (1963)
- Clay -		
P(1,1)	2.83	Arbitrarily assigned
P(1,2)	0.210	Arbitrarily assigned
- Claysilt -		
P(1,1)	2.79	Arbitrarily assigned
P(1,2)	0.180	Arbitrarily assigned
- Silt -		
P(1,1)	2.65	Van Wijk (1963)
P(1,2)	0.164	Van Wijk (1963)
P(1,3)	7.3	Arbitrarily assigned
P(1,4)	85.0	Van Wijk (1963)
P(1,5)	20.0	Larcher (1975)
P(1,6)	4.65	Van Wijk (1963)
P(1,7)	0.60	Van Wijk (1963)
P(1,8)	1.42	Van Wijk (1963)
P(1,9)		
P(1,10)	1.664E-7	Van Wijk (1963)
P(1,11)	596.0	Masterton (1969)

Table 4.1. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
P(1,12)	-0.56	Masterton (1969)
P(1,13)	273.0	Masterton (1969)
P(1,14)	1.0	Van Wijk (1963)
P(1,15)	1.0	Van Wijk (1963)
P(1,16)	0.46	Van Wijk (1963)
P(1,17)	4.0	Arbitrarily assigned

$$I(1,1) = P(10,4) \cdot [(P(1,2) \cdot P(1,1)) + (P(1,14) \cdot P(1,15) \cdot X(2,3)) + (P(1,16) \cdot P(1,17) \cdot P(10,7))]$$

Another important characteristic of the soil is its volumetric thermal conductivity. Like heat capacity, it is a function of the three major soil components and their individual conductivities (deVries 1975, Van Wijk 1963).

$$I(1,2) = P(1,6) + P(1,8) \cdot X(2,3) + P(1,7) \cdot P(10,7)$$

Conduction. Conduction, although relatively slow, is the major pathway of heat flow within the soil. It is assumed that horizontal conduction is self-compensating so that net conduction flows only in the vertical direction toward the cooler soil layer, either above or below. Thus, conduction is a function of the difference in soil layer temperatures, the thermal conductivity of the soil layers, and the distance the heat must flow (Fig. 4.2). The parent material is assumed to have a constant temperature during a simulation run and, thus, can act as both a source and a sink (Van Wijk 1963).

$$F(1,4) = I(1,2) \cdot X(1,j) - X(1,j+1) \div [(P(10,4)_j + P(10,4)_{j+1}) \div 2]$$

where "j" indicates a soil layer.

The temperature of any soil layer is a function of its previous temperature, the net flux and the heat capacity of the entire layer (Van Wijk 1963). For soil layers below the surface, $F(1,1)$, $F(1,2)$ and $F(1,3)$ equal zero.

$$X(1,1)_{t+1} = X(1,1)_t + [(F(1,1) + F(1,2) - F(1,3) - F(1,4)) + (I(1,1) \cdot P(10,4))]$$

where "t" indicates a time step.

4.2.2 Soil Moisture

The currency is meters (or cubic meters) of water. The processes considered include the following, as diagrammed in Fig. 3.1:

- 1) Total daily rainfall
- 2) Rainfall intercepted by plants
- 3) Total daily snowfall
- 4) Snow melt water
- 5) Runoff to channel
- 6) Infiltration to surface soil layer
- 7) Percolation from depth i to depth j
- 8) Evaporation from surface soil layer
- 9) Transpiration by plant roots from soil depth i
- 10) Water moving from stream channels
- 11) Water accumulator in groundwater supply

Water enters the system primarily as precipitation with additions from ground water flow, i.e., springs, and from upstream drainage.

Figure 4.2. Effects of soil components upon heat conduction through the soil. a) Volumetric water content b) Volumetric organic matter content c) Density of soil mineral content.

Precipitation. Rainfall and snowfall represent the same amount of precipitation in different physical states. If the temperature is below a given threshold, the precipitation is assumed (Fig. 4.3c) to occur as snowfall. The depth of the snow is a function of the snow moisture content. At the current time, all snowfall is assumed to fall on the soil surface (Dougal 1971).

$$\begin{aligned} F(2,3) &= 0.0 & \text{if } Z(C,3) > P(2,14) \\ F(2,1) &= Z(C,7) \end{aligned}$$

$$\begin{aligned} F(2,3) &= Z(C,7) \cdot P(2,13) & \text{if } Z(C,3) \leq P(2,14) \\ F(2,1) &= 0.0 \end{aligned}$$

Snow melt. Snow melt is assumed to be directly influenced by mean air temperature (Fig. 4.3a). The melt water is added to the surface retained water and an appropriate snow depth is subtracted (Dougal 1971).

$$F(2,4) = P(2,9) \cdot (Z(C,3) - P(2,10)) \quad \text{if } Z(C,3) \geq P(2,10)$$

$$F(2,4) = 0.0 \quad \text{if } Z(C,3) < P(2,10)$$

$$X(2,1) = X(2,1) - F(2,4) \cdot P(2,13)$$

Interception. Interception of rainfall by vegetation (Figs. 4.4-4.8) is a function of plant cover and precipitation. Each plant category, i.e., litter, grasses, forbs, shrubs, and trees, has an assigned interception storage capacity and a coefficient of evaporation. The values of these factors were determined from regressions found in the literature. The interception storage capacity is modified by the amount of precipitation. For simplicity, snow is not intercepted at present (Zinke 1967, USFS 1968, Couturier 1973).

$$I(2,9) = P(2,7) \cdot (1 - \exp(-Z(C,7) \div P(2,7)))$$

$$F(2,2) = \sum_{r=1}^R I(3,14)_r \cdot (Z(C,7) \cdot I(2,9) + P(2,6))$$

where "r" indicates a plant species.

The majority of the water flows within the soil are functions of the soil water potential (or matric potential) and the volumetric water content of the different soil layers. The hydraulic conductivity and the hydraulic suction head potential are calculated from water potential and volumetric content.

Matric potential is calculated from regression equations as a function of soil type and volumetric water content (Fig. 4.9-4.10) (Cole 1976, Hillel 1977).

$$I(2,1) = X(2,3) \div P(10,4)$$

$$I(2,2) = 0.3 \cdot [(0.6 - I(2,1)) + (0.6 - P(2,2))]$$

$$\text{if } P(2,2) > I(2,1)$$

Figure 4.3. a) Snow melt as a function of ambient temperature
b) Water evaporation as a function of soil moisture content
c) Depth of snow cover as a function of precipitation

Figure 4.4. Rainfall intercepted by litter cover at three rain intensities a) 0.1 cm rain b) 1.0 cm rain c) 3.0 cm rain.

Figure 4.5. Rainfall intercepted by forb cover at three rain intensities
a) 0.1 cm rain b) 1.0 cm rain c) 3.0 cm rain

Figure 4.6. Rainfall intercepted by grass cover at three rain intensities a) 0.1 cm rain b) 1.0 cm rain c) 3.0 cm rain.

Figure 4.7. Rainfall intercepted by shrub cover at three rain intensities
a) 0.1 cm rain b) 1.0 cm rain c) 3.0 cm rain

Figure 4.8. Rainfall intercepted by tree cover at three rain intensities
a) 0.1 cm rain b) 1.0 cm rain c) 3.0 cm rain

Figure 4.9. Matric potential as a function of volumetric water content for three soil types a) sandclay b) siltsand c) sand.

Figure 4.10. Matric potential as a function of volumetric water content for three soil types a) silt b) claysilt c) clay.

$$I(2,2) = 0.3 + 2.7 \cdot [(P(2,2) - I(2,1)) + (P(2,2) - P(2,4))]$$

$$\text{if } P(2,4) < I(2,1) \leq P(2,2)$$

$$I(2,2) = 3.0 + 12.0 \cdot [(P(2,4) - I(2,1)) + (P(2,4) - P(2,5))]$$

$$\text{if } P(2,5) < I(2,1) \leq P(2,4)$$

The hydraulic suction head is directly related to the soil water potential and the thickness of the soil layer (Hillel 1977).

$$I(2,3) = I(2,2) - P(10,4)$$

The hydraulic conductivity is a function of the conductivity at saturation and the volumetric water content (Fig. 4.11). It is weighted by the water potentials of the soil layers (Hillel 1977, Van Wijk 1963).

$$I(2,4) = P(2,1) \cdot I(2,1) \cdot \sum_{j=1}^j [((2 \cdot j) + 1 - (2 \cdot i)) + I(2,2)^{1/2}] + \sum_{j=1}^j [(2 \cdot j) - 1] + I(2,2)^{1/2}]$$

The average hydraulic conductivity is also weighted by the thickness of the soil layers (Jackson 1972).

$$I(2,5) = (I(2,4)_{j-1} \cdot P(10,4)_{j-1} + I(2,5)_j \cdot P(10,4)_j) \\ + (P(10,4)_{j-1} + P(10,4)_j)$$

Infiltration. Infiltration from the water retained on the surface to the surface soil is a function of the matric potential, hydraulic suction head, hydraulic conductivity, and soil layer thickness. A maximum infiltration rate is calculated (Fig. 4.12) which is modified by the amount of cover (Fig. 4.11). It is assumed that ground cover increases the infiltration rate by preventing the soil structure from being disturbed from the impact of rain drops. The minimum infiltration rate is assumed to equal the hydraulic conductivity at saturation (Hillel 1977).

$$I(2,8) = -I(2,3) \cdot (P(2,1) + I(2,4)) + (2 \cdot P(10,4))$$

$$F(2,6) = P(2,1) + \left(\sum_{r=1}^R I(3,13)_r \right)^{1/2} \cdot (I(2,8) - P(2,1))$$

Percolation. Percolation transfers water from one soil layer to the lower soil layer. However, it can also draw water up if the hydraulic suction head is greater for the upper soil layer. Percolation is also related to the average hydraulic conductivity and the distance between soil layer midpoints (Hillel 1977).

$$F(2,8) = I(2,3)_j - I(2,3)_{j-1} \cdot I(2,5) + ((P(10,4)_j + P(10,4)_{j-1}))$$

Evaporation. Evaporation is calculated based on saturation vapor pressure, relative humidity, wind speed, and plant cover.

Figure 4.11. Effect of flora cover on infiltration rate and hydraulic conductivity as a function of volumetric water content for six soil types. A. Sandclay infiltration rate, B. Sandclay hydraulic conductivity, C. Clay infiltration rate, D. Clay hydraulic conductivity, E. Siltsand infiltration rate, F. Siltsand hydraulic conductivity, G. Sand infiltration rate, H. Sand hydraulic conductivity, I. Claysilt infiltration rate, J. Claysilt hydraulic conductivity, K. Silt infiltration rate, and L. Silt hydraulic conductivity.

Figure 4.11. (continued from previous page)

Figure 4.11. (continued from previous page)

Figure 4.12. Maximum infiltration rates as a function of volumetric water content for six soil types at three soil thicknesses. A. Sandclay at 0.05 m, B. Sandclay at 0.5 m, C. Sandclay at 1.0 m, D. Siltsand at 0.05 m, E. Siltsand at 0.5 m, F. Siltsand at 1.0 m, G. Sand at 0.05 m, H. Sand at 0.5 m, I. Sand at 1.0 m, J. Clay at 0.05 m, K. Clay at 0.5 m, L. Clay at 1.0 m, M. Claysilt at 0.05 m, N. Claysilt at 0.5 m, O. Claysilt at 1.0 m, P. Silt at 0.05 m, Q. Silt at 0.5 m, and R. Silt at 1.0 m.

Figure 4.12. (continued from previous page)

Figure 4.12. (continued from previous page)

Figure 4.12. (continued from previous page)

Figure 4.12. (continued from previous page)

Figure 4.12. (continued from previous page)

Table 4.2. Parameter values for soil water submodel.

STANDARD NOTATION	VALUE	REFERENCE
- Sand -		
P(2,1)	5.6E-4	Van Wijk (1963)
P(2,2)	31.0	Cole (1976)
P(2,3)	25.0	Cole (1976)
P(2,4)	15.0	Cole (1976)
P(2,5)	10.0	Cole (1976)
- Siltsand -		
P(2,1)	8.3E-6	Van Wijk (1963)
P(2,2)	22.0	Cole (1976)
P(2,3)	18.0	Cole (1976)
P(2,4)	12.0	Cole (1976)
P(2,5)	7.0	Cole (1976)
- Sandclay -		
P(2,1)	8.3E-8	Van Wijk (1963)
P(2,2)	36.0	Cole (1976)
P(2,3)	29.0	Cole (1976)
P(2,4)	18.0	Cole (1976)
P(2,5)	12.0	Cole (1976)
- Clay -		
P(2,1)	1.4E-9	Van Wijk (1963)
P(2,2)	36.0	Cole (1976)
P(2,3)	32.0	Cole (1976)
P(2,4)	18.0	Cole (1976)
P(2,5)	13.0	Cole (1976)
- Claysilt -		
P(2,1)	2.8E-8	Van Wijk (1963)
P(2,2)	36.0	Cole (1976)
P(2,3)	25.0	Cole (1976)
P(2,4)	18.0	Cole (1976)
P(2,5)	13.0	Cole (1976)

Table 4.2. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Silt -		
P(2,1)	1.7E-8	Van Wijk (1963)
P(2,2)	19.0	Cole (1976)
P(2,3)	16.0	Cole (1976)
P(2,4)	10.0	Cole (1976)
P(2,5)	6.0	Cole (1976)
- Trees -		
P(2,6)	11.0	Zinke (1967), USFS (1968)
P(2,7)	1.0	Zinke (1967), USFS (1968)
- Shrubs -		
P(2,6)	6.2	Zinke (1967), USFS (1968)
P(2,7)	8.3	Zinke (1967), USFS (1968)
- Forbs -		
P(2,6)	8.9	Zinke (1967), USFS (1968)
P(2,7)	11.5	Zinke (1967), USFS (1968)
- Grass -		
P(2,6)	3.2	Zinke (1967), USFS (1968)
P(2,7)	7.4	Zinke (1967), USFS (1968)
-Litter -		
P(2,6)	1.5	Zinke (1967), USFS (1968)
P(2,7)	2.5	Zinke (1967), USFS (1968)
P(2,8)	3.5	Arbitrarily assigned
P(2,9)	0.108	Dougal (1971)
P(2,10)	0.0	Dougal (1971)
P(2,11)	0.0	Arbitrarily assigned
P(2,12)	3.0	Arbitrarily assigned
P(2,13)	25.4	Dougal (1971)
P(2,14)	2.5	Arbitrarily assigned

The saturation vapor pressure is calculated from a regression equation as a function of mean air temperature (Cole 1976).

$$I_{(C,1)} = 0.75 \cdot \exp(5418.38 \cdot (0.00366 - (1 \div (Z_{(C,3)} + P_{(1,13)}))) + \ln(6.11)))$$

Potential evaporation is calculated from a regression equation as a function of the saturation vapor pressure, the relative humidity and the wind speed (Kohler et al. 1955). This potential is for an open pan of water.

$$I_{(C,2)} = \exp[0.88 \cdot \ln(I_{(C,1)} \cdot (1 - Z_{(C,5)}))] + (0.37 + 0.0041 \cdot 24 \cdot 0.62 \cdot Z_{(C,6)})$$

Evaporation is assumed never to equal the potential because evaporation occurs from the soil rather than from an open pan of water (Fig. 4.3b). Maximum evaporation would occur with no plant cover and a soil at saturation.

$$F_{(2,7)} = I_{(C,2)} \cdot [1 - \exp(\sum_{k=1}^R I_{(3,13)} - 1)] \cdot (I_{(2,1)} + P_{(2,2)}^{1/2})$$

Transpiration. Transpiration from each soil layer is the sum of transpiration losses due to each plant group. For any particular group, transpiration per unit area of cover is equal to potential transpiration when water is not limiting. As the soil water potential in the wettest zone containing roots becomes larger negatively, transpiration is reduced until it becomes zero at the plant wilting point. All water transpired by a species is taken from the zone with the smaller negative potential (Detling et al. 1978).

Potential transpiration is equal to the potential evaporation minus the evaporation.

It is assumed that when snow is present all plants smaller than large shrubs do not transpire. This is because nearly all of such plants will be buried in snow and the small portions that might protrude would be cooled by the snow to such a degree that no transpiration would occur. Trees and large shrubs do transpire during periods with snow if the potential rate of transpiration is non-zero.

$$F_{(2,9)} = \sum_{r=1}^R [I_{(C,5)} \cdot I_{(3,14)_r} \cdot I_{(3,13)_r} \cdot \exp(P_{(3,4)} \cdot I_{(3,10)_r})]$$

4.2.3 Hydrologic Processes

4.2.3.1 Streamflow

The hydrology model (Fig. 3.5B) first considers the streamflow rate $Z_{(H,1)}$. Woolhiser (1973) has reviewed a number of watershed models. The following equation is derived from his discussion. Given that $I_{(12,3)}$ is the

point mean velocity of the stream, $l_{(12,1)}$ is the depth of the stream at that point, $P_{(12,1)}$ is the acceleration of gravity, $P_{(12,2)}$ is the slope of the streambed and $P_{(12,3)}$ is the friction of the slope, then the momentum $l_{(12,2)}$ of a three-dimensional portion of the stream is expressed by:

$$l_{(12,2)} = P_{(12,1)} \cdot (P_{(12,2)} - P_{(12,3)}) - Z_{(H,1)} \cdot l_{(12,3)} + l_{(12,1)}$$

The momentum of a stream is important when considering turbidity and nutrient loading.

4.2.3.2 Inorganic Ions

Bond (1980) defines the concentration $X_{(12,2)}$ of an ion on one day in the stream as:

$$F_{(12,8)} = [F_{(12,2)} \cdot l_{(12,4)} + F_{(12,1)} \cdot l_{(12,5)} + F_{(12,21)} \cdot l_{(12,6)}] + F_{(12,4)}$$

where $l_{(12,4)}$, $l_{(12,5)}$ and $l_{(12,6)}$ are ion concentrations for a day in the groundwater flow, the overland flow and the interflow, respectively. Bond considers interflow to be water that moves rapidly through the soil along rootlines or other underground channels. It is also the water that drains rapidly from areas adjacent to the stream. The term $F_{(12,4)}$ is the stream discharge for one day and is the sum over the day of the inflow rate $Z_{(H,1)}$. For our consideration, $F_{(12,4)}$ could be subscripted to indicate any of the streamside ERU's. The variables $F_{(12,2)}$, $F_{(12,1)}$ and $F_{(12,21)}$ are the water volumes of groundwater flow, the overland flow and the interflow respectively. As mentioned, the nominal source of streamflow in the overall model is groundwater flow, hence $F_{(12,1)}$ and $F_{(12,21)}$ are effectively zero during most of the year. As Bond (1980) points out, interflow occurs only when streamflow is moderately high, meaning this variable takes on a value only after a series of rainfall events or after an unusually heavy rain occurs during a simulation time step. When such events happen:

$$F_{(12,4)} = F_{(12,2)} + F_{(12,1)} + F_{(12,21)}$$

4.2.3.3 Organic Compounds

Transport of organic compounds, one of four currencies shown in Fig. 3.5B, is a function of half-life and the amount of material deposited the stream from overland flow, groundwater and interflow. Frere (1975) has proposed a model of organic compound transport in the soil of a watershed and, with suitable variable entries, it may be used here. Given $X_{(12,3)_0}$ is the initial amount of concentration deposited in the stream and that $X_{(12,3)_t}$ is the amount remaining after the interval $Z_{(H,8)}$, the initial and remaining amounts of the compound may be related to $Z_{(H,8)}$ by the exponential function of $Z_{(H,8)}$:

$$X_{(12,3)_t} = X_{(12,3)_0} \cdot \exp(-P_{(12,5)} \cdot Z_{(H,8)})$$

The term $P_{(12,5)}$ in the above expression is a breakdown coefficient in reciprocal time units.

Table 4.3 Parameter values for the hydrologic process submodel.

STANDARD NOTATION	VALUE	REFERENCE
P(12,1)	9.80171	Weast (1968)
P(12,2)		
P(12,3)		
P(12,4)		
P(12,5)		
P(12,6)	0.693	Menzie (1972)
P(12,7)		
P(12,8)		
P(12,9)		
P(12,10)		

Menzie (1972) has related the breakdown coefficient to the half-life of many complex carbon compounds. He found that it is related to half-life $P_{(12,4)}$ on average as:

$$P_{(12,5)} = P_{(12,6)} \div P_{(12,4)}$$

4.2.3.4 Turbidity

Hornbeck (1972) and Harr et al. (1975) demonstrated that road building and vegetation removal affect water flow to streams. Such activities increase the volume of sediment transported and decrease the time between rainfall event and the appearance of sediment transported by overland flow in the streams. Vegetation removal also affects the rate of water movement over land and underground when that water comes from snowmelt.

The turbidity of a moving body of water is a function of the water density, the momentum of the stream and the concentration of particles in the water. Water temperature is assumed to be a constant value during warm months and constant at a second value during the cold months. This allows essentially two phases in which the water can occur in a stream, liquid or solid, and hence, only two water densities.

Modelling the movement of suspended particles that move out of the stream, or sediment discharge ($F_{(12,20)}$), requires an approximation of particle concentration $P_{(12,7)}$ at a reference depth $P_{(12,8)}$, which provides the expression:

$$\ln (F_{(12,20)} \div P_{(12,7)}) = -P_{(12,9)} \int_{P_{(12,8)}}^{P_{(12,10)}} (d(P_{(12,10)} - l_{(12,2)})$$

where $P_{(12,9)}$ is the velocity of fall of the suspended particle which is a function of the particle radius and viscosity of the water, $l_{(12,2)}$ is momentum, and $P_{(12,10)}$ is the distance the particle must fall to reach the bottom of the stream (Linsley et al. 1949).

The above expression moves particles out of the stream segment. The function for deposition of sediment is clearly dependent on some threshold value of momentum. The exact relation has not been determined.

Scouring of the stream channel by the action of water on soil particles also has not been determined.

4.2.4 Land Area/Use

The currency is hectares of land. As shown in Fig. 3.4, land is conservative, therefore there is no source nor sink. Land area is assumed to be constant relative to simulation time and has no flows per se.

Table 4.4a. Parameter values for land area submodel.

STANDARD NOTATION	VALUE	REFERENCE
-- Highland C-b Tract --		
P(10,1)	NE	
P(10,2)	0.05	
P(10,3)	0.20	
- Layer 1 -		
P(10,4)	0.08	
P(10,5)	Siltsand	
P(10,7)	0.10	
- Layer 2 -		
P(10,4)	0.42	
P(10,5)	Siltsand	
P(10,7)	0.07	
- Layer 3 -		
P(10,4)	0.70	
P(10,5)	Sandclay	
P(10,7)	0.03	
P(10,6)	7200.0	

Table 4.4b. Parameter values for land area submodel.

STANDARD NOTATION	VALUE	REFERENCE
-- Upland C-b Tract --		
P(10,1)	NE	
P(10,2)	0.05	
P(10,3)	0.20	
- Layer 1 -		
P(10,4)	0.07	
P(10,5)	Silt	
P(10,7)	0.20	
- Layer 2 -		
P(10,4)	0.33	
P(10,5)	Siltsand	
P(10,7)	0.14	
- Layer 3 -		
P(10,4)	0.50	
P(10,5)	Sandclay	
P(10,7)	0.06	
- Layer 4 -		
P(10,4)	0.60	
P(10,5)	Sandclay	
P(10,7)	0.03	
P(10,6)	6300.0	

Table 4.4c. Parameter values for land area submodel.

STANDARD NOTATION	VALUE	REFERENCE
-- Lowland C-b Tract --		
P(10,1)	West	
P(10,2)	0.80	
P(10,3)	0.20	
- Layer 1 -		
P(10,4)	0.05	
P(10,5)	Sand	
P(10,7)	0.19	
- Layer 2 -		
P(10,4)	0.45	
P(10,5)	Siltsand	
P(10,7)	0.12	
- Layer 3 -		
P(10,4)	0.50	
P(10,5)	Sandclay	
P(10,7)	0.06	
P(10,6)	5100.0	

Table 4.4d. Parameter values for land area submodel.

STANDARD NOTATION	VALUE	REFERENCE
-- Bottomland C-b Tract --		
P(10,1)	NE	
P(10,2)	0.05	
P(10,3)	0.20	
- Layer 1 -		
P(10,4)	0.10	
P(10,5)	Sand	
P(10,7)	0.25	
- Layer 2 -		
P(10,4)	0.30	
P(10,5)	Sandclay	
P(10,7)	0.16	
- Layer 3 -		
P(10,4)	0.80	
P(10,5)	Clay	
P(10,7)	0.10	
P(10,6)	4900.0	

Major changes in land use are implemented through the event structure rather than the flow structure, since these changes generally occur sporadically, often as a result of management practices (Sec. 4.4). Most of the changes will either add or remove land from "production." Only land in the undeveloped category is considered in production by the biotic submodels.

Another important change involves modifying edge descriptions between ERUs. Although this change does not necessarily change conditions within an ERU it can drastically alter accessibility and thus migration routes of animals.

Successional changes which occur on developed land, such as reclamation of a spoil pile, are not handled explicitly by the land submodel, but rather are reflected in the state variables of the soil and biotic submodels.

4.3 BIOTIC PROCESSES

4.3.1 Terrestrial Floral Processes

In the numerical model there are five floral currencies: tree cover, herbaceous plant biomass per unit area, shrub biomass per individual plant, numbers of shrubs per unit area, and amount of litter per unit area. The degree of resolution varies according to the currency. For example, tree cover, litter, and shrub numbers have a coarse degree of resolution, while herbaceous plant biomass and shrub biomass have a greater degree of resolution. This greater degree of resolution is needed to model plant responses to management practices.

4.3.1.1 Variable Timesteps: The Active Days Concept

Since plants are strongly affected by climatic and abiotic variables, implementation of a timestep longer than that used in the abiotic section of the model involves averaging the relevant abiotic variables. This averaging process not only involves a loss of information but may actually be misleading. For example, if air temperatures are averaged for a week during which there are five moderately warm days and two very cold days, the resulting average may be lower than the minimum required for photosynthesis, although photosynthesis would have occurred on the five warm days but not on the cold days.

The active days concept conserves the maximum amount of information during the averaging process. Active days calculations for aboveground plant parts illustrate the concept. If the mean air temperature is above the photosynthetic minimum, the water potential in the wettest soil layer with roots is greater than the wilting point, and there is no snow, then $l(3,18)_v$, $v = l(3,16)$ is incremented and that day's values are added to the variables $l(3,19)$, $l(3,20)$, $l(3,21)$, and $l(3,10)$. In this way, days too extreme for photosynthesis to occur do not affect the average.

There are four counters in the model for types of days. $l(3,18)$, described above, is used for photosynthesis, translocation, and aboveground res-

piration calculations. $I_{(3,23)}$ keeps track of the number of days below the wilting point. $I_{(3,24)}$ gives the severity of the drought. This information is used in calculating mortality. $I_{(3,25)}$ keeps track of days during which soil layer j is above the wilting point. This information is used for root respiration.

In this model, the state variables are updated by adding the product of daily flows multiplied by the timestep. For plants, the days of activity act as the timestep. The three types of active days result in different timesteps for different flows. For example, given a model timestep of seven days, if a cold spell results in one day warm enough for photosynthesis, while the soil is warm and wet the entire week, the flow for photosynthesis per day is multiplied by one and the root respiration flows are multiplied by seven.

4.3.1.2 Cover and Leaf Area

Cover and leaf area are important components of plants in the model. Cover is used to determine the proportion of potential evapotranspiration accounted for by bare soil, for allocating transpiration among species, and for calculating rainfall interception. Trees are modeled in units of cover. Cover must be calculated for other species based on leaf biomass. Regression equations were obtained from the literature. Shrub cover was taken from Rittenhouse (1977) for sagebrush, which is used as representative of all sagebrush ecosystem shrubs:

$$I_{(3,14)} = 0.01004969433 \cdot X_{(4,4)}^{1.076426265} \cdot X_{(7,1)}$$

Cover equations for forbs and grasses are from Payne (1974). Payne's equations have been adjusted for plot size and units of cover. Live and standing dead cover are based on the same functions.

For forbs:

$$I_{(3,14)} = 0.002 + 0.00354 \cdot X_{(3,3)}$$

For warm-season grasses:

$$I_{(3,14)} = 0.0078 + 0.0052 \cdot X_{(3,3)}$$

For cool-season grasses:

$$I_{(3,14)} = 0.0076 \cdot X_{(3,3)} \quad (\text{original intercept: } -0.0034)$$

For cool-season annual grasses:

$$I_{(3,14)} = 0.0004 + 0.0047 \cdot X_{(3,3)}$$

For litter:

$$I_{(3,15)} = 0.0005 \cdot X_{(6,1)}$$

Cover per species is then adjusted to be a percent of the total live cover, which does not exceed 100%.

Total cover is cover based on live plus standing dead biomass and litter.

Leaf area is calculated as a constant percent of leaf biomass:

$$l(3,1) = P(3,22) \cdot X(3,3)$$

Leaf area is used in photosynthesis to calculate the shading leaf area over a plant, which reduces photosynthesis. Taller plants shade lower ones and plants in the same stratum shade each other. The order of shading is: TREES > LARGE SHRUBS > FORBS = WARM-SEASON GRASS = COOL-SEASON GRASS = COOL-SEASON ANNUAL GRASS > SMALL SHRUBS.

4.3.1.3 Germination and Extinction

The model does not assume steady state conditions and the process of recovery from disturbance is modeled explicitly. This is achieved by allowing species to become established or reestablished on the site.

Germination is allowed at any time. Certain conditions must be met before germination of any species may occur. Snow must not have been present for a limited period of time prior to germination. Soil water in the surface layer must have been above the wilting point for a similar period of time. Also, temperatures must be favorable.

Once these conditions are met, the species to germinate are determined by examining the sets of parameters. It is assumed that all plants may reach all ERU's but may not necessarily be allowed to germinate. If there are any species which can inhabit the ERU but are not present, then those species will germinate. New species begin with arbitrary small amounts of biomass in the green, storage, and upper root zone categories. Trees begin with an arbitrary small amount of cover. Litter is never allowed to become extinct and thus never needs to "germinate".

Under certain conditions, plant species may become extinct within an ERU during the simulation. There are several conditions that cause extinction in the model. If the population of both size classes of shrubs is zero, the species becomes extinct. For shrubs and herbaceous species, the absence of green and storage biomass or the absence of roots removes all possibility of photosynthesis and signals extinction. Trees with zero cover also become extinct. When a plant species becomes extinct in an ERU, all woody, standing dead, and green biomass for that species is transferred to litter.

4.3.1.4 Phenology

There are three phenological states considered in the model: seedling status, dormancy, and season of leaf fall. After a species enters an ERU via the germination function, it remains a seedling for 60 days. While a plant is a seedling it has roots only in the top two soil layers. In this way, the greater sensitivity of seedlings to drought is simulated in a simple manner. If the user defines the site so that the second soil layer is very deep, seedlings will not be drought sensitive, and some model realism will be lost.

Plants are dormant during the winter season, which is defined by date rather than by temperature. Dormant plants do not attempt translocation. Translocation activity is reduced by three-fourths in the autumn.

Leaf fall for shrubs is defined to occur on a particular date in the fall. It is a pulse event, occurring entirely on the given date, rather than over a period of time.

4.3.1.5 Tree Processes

The currency is cover of trees. The units are square meters per square meter. Only four kinds of flows are involved, as diagrammed in Fig. 3.2:

- 1) growth of cover
- 2) loss of cover
- 3) harvest loss
- 4) fire loss

Growth of cover. Cover growth is based on site quality, current site fertility, and current cover. The maximum cover attainable by a species on an ERU ($I_{(5,1)}$) is determined as a linear function of the average yearly rainfall. This relationship is based on data in Tueller et al. (1979). This maximum is adjusted by the current site fertility ($I_{(3,5)}$). The growth rate is a modified logistic in which the asymptote is the product of maximum cover and fertility:

$$F_{(5,1)} = X_{(5,1)} \cdot P_{(5,3)} \cdot (I_{(3,5)} \cdot I_{(5,1)} - X_{(5,1)}) \div (I_{(3,5)} \cdot I_{(5,1)})$$

The growth rate parameter ($P_{(5,3)}$) was calculated by hand to match qualitative literature discussions of growth rates of pinyon and juniper.

Cover-weight relationships for pinyon and juniper were obtained from Meeuwig et al. (1979). Meeuwig showed that this relationship is nearly independent of crown size or tree age. Since tree cover is the state variable, leaf area index and leaf biomass are obtained as intermediate variables based on aerial cover from data in Meeuwig et al. (1979).

Loss of Cover. Cover loss represents natural mortality. Litter fall rates for trees are based on an assumed three year life span for needles of pinyon pine and juniper. The daily turnover rate is then:

$$P_{(5,6)} = 1.0 \div (3 \cdot 365)$$

Harvest and Fire Loss. Harvest loss and fire loss are functions of the intensity of harvest and fire respectively.

4.3.1.6 Herbaceous and Shrub Processes

The currency is grams dry weight of biomass per plant for shrubs and grams dry weight per square meter for herbaceous species. As shown in Fig. 3.2, the following processes are considered:

Table 4.5a. Parameter values for Juniperus osteosperma.

STANDARD NOTATION	VALUE	REFERENCE
P(5,1)	100.0	Tueller et al. 1979
P(5,2)	25.0	Tueller et al. 1979
P(5,3)	0.000274	See text
P(5,4)	2770.0	Meeuwig et al. 1979
P(5,5)	0.25	Meeuwig et al. 1979
P(5,6)	0.05	Model tuning
P(5,7)	-30.0	First estimate

Table 4.5b. Parameter values for Pinus edulis.

STANDARD NOTATION	VALUE	REFERENCE
P(5,1)	100.0	Tueller et al. 1979
P(5,2)	25.0	Tueller et al. 1979
P(5,3)	0.000274	See text
P(5,4)	2150.0	Meeuwig et al. 1979
P(5,5)	0.25	Meeuwig et al. 1979
P(5,6)	0.05	Model tuning
P(5,7)	-30.0	First estimate

- 1) photosynthesis
- 2) respiration
- 3) translocation
- 4) death of plant parts
- 5) grazing

Plant biomass arises through photosynthesis into a storage organ of the plant. There translocation carries biomass into roots or shoots. Death and respiration are possible for all root and shoot components. Fire loss may claim shoots or standing dead, and shattering may also remove standing dead. The shattering and death losses lead to an increase of litter.

Photosynthesis. Daytime net photosynthesis is calculated as a function of leaf area, site fertility, availability of soil water, mean temperature, and hours of daylight (Fig. 4.13-4.14). Leaf area is an intermediate variable, derived from biomass. Available water refers to the soil layer with the least limiting soil water potential. The photosynthesis equation is based on the concept of optimal conditions for photosynthesis. At temperatures other than the optimum, photosynthesis is reduced. Also, soil water potentials less than zero reduce photosynthesis.

Figure 4.13 illustrates the shape of the photosynthesis response. The outermost curve represents non-limiting soil water while the inner curves show greater water stress. Notice that changing soil water potential alters the optimum and maximum temperature and the total amplitude of the response. The equations governing photosynthesis are adapted from Detling and Parton (1978). All variables for this function are calculated using abiotic variables for active days. The parameters $P(3,4)$, $P(3,5)$, and $P(3,6)$ were determined such that the equation they are used in became very small at the wilting point.

The effect of soil water on maximum rate of photosynthesis is calculated as a decreasing exponential truncated at the wilting point:

$$I(3,2) = \exp(P(3,4) \cdot I(3,10)); \text{ if } I(3,10) > P(3,24) \\ = 0; \quad \text{if } I(3,10) \leq P(3,24)$$

The parameter, $P(3,4)$, is based on the assumption that at the wilting point the stomates are 90% closed:

$$P(3,4) = \ln(0.1) \div P(3,24)$$

The maximum temperature at which photosynthesis occurs at field capacity and is decreased as available water becomes more limiting:

$$I(3,6) = P(3,15) + P(3,5) \cdot I(3,10)$$

The optimal temperature for photosynthesis follows the same type of relationship:

$$I(3,7) = P(3,16) + P(3,6) \cdot I(3,10)$$

Figure 4.13. Photosynthesis as a function of soil water and temperature. Upper curve is for non-limiting soil water. Lower curves are for increasing water stress.

Figure 4.14. Effect of competing leaf area on net daily photosynthesis.

Figure 4.15. Daily respiration as a function of translocation rate.

An intermediate variable is then computed:

$$I(3,4) = I(3,2) \cdot \left(\frac{I(3,6) - Z(C,2)}{I(3,6) - I(3,7)} \right) \cdot \left(\frac{Z(C,2) - P(3,14)}{I(3,7) - P(3,14)} \right) \left(\frac{I(3,7) - P(3,14)}{I(3,6) - I(3,7)} \right)^{P(3,3)}$$

The form of this equation is illustrated in Figure 4.13. Total photosynthesis per day is then calculated from the following equation which includes a reduction factor for the effects of shade.

$$F(3,1) = I(3,4) \cdot P(3,9) \cdot I(3,1) \cdot I(C,3) \cdot (1 - P(2,21) \cdot I(3,9)) \cdot I(3,18)$$

$P(2,21)$ is based on the assumption that $1.0 + P(2,21)$ produces complete shade (McCree and Troughton 1966). The fertility multiplier adjusts photosynthesis rates for all species to the same degree. It adjusts for actual site fertility which is not reflected by the soil characterizations in the model, and for the fact that plants do not photosynthesize at the maximum rate all day due to variations in light intensity and water potentials.

Respiration. It is logical to assume that the protein degradation rate, $P(3,7)$, varies as a function of temperature and water, at least.

However, no model for these relationships could be located which is compatible with the overall model as formulated. Therefore, an initial estimate was made using the values for barley and maize in Barnes and Hole (1978). Since their data were for nearly optimal growing conditions, the values obtained should be near the maximum year long values. Adjustments were made accordingly.

Conversion efficiency of carbohydrates into structural biomass, $P(3,25)$, is given by de Vries (1972) as ranging from 0.7 to 0.75 which is well within the theoretical limits discussed by Barnes and Hole (1978).

The protein contents of plant parts were estimated by season. Total protein content values in the literature were separated into structural and metabolic fractions (McGill et al. 1981).

	Percent of Nitrogen	
	structural	metabolic
roots	46	54
shoots	35	65

The metabolic fraction times the total plant protein gave the percent metabolic protein ($P(3,28)$, $P(3,29)$, $P(4,8)$). Seasonal data was used where available. Stem percentages were assumed to be the same as for roots. Because of the large amount of nonliving wood in older shrubs, roots and woody protein contents were reduced by a factor of 0.10 for the larger size class of shrubs.

The respiration equation may then be translated into standard notation as

$$F(3,4) = 0$$

$$F(3,5) = [((1-P(3,25)) + P(3,25)) \cdot P(3,7) \cdot P(3,29)p \\ \cdot X(3,2) + (1-P(3,25)) \cdot F(3,2)] \cdot (Z(C,8) + 24.0) \cdot dt$$

$$F(3,6) = [((1-P(3,25)) + P(3,25)) \cdot P(3,7) \cdot P(3,28)p \\ \cdot X(3,3) + (1-P(3,25)) \cdot F(3,3)] \cdot dt$$

$$F(4,13) = [((1-P(3,25)) - P(3,25)) \cdot P(3,7) \cdot P(4,8)p \\ \cdot X(4,4) + (1-P(3,25)) \cdot F(4,12)] \cdot dt$$

The calculation of translocation is a little more complex. First, photosynthesis and basal respiration for the current timestep are added to storage. Then translocation is computed if stored biomass is larger than $P(3,13) \cdot I(3,12)$ and subtracted from storage. Thus, storage is updated twice, reflecting the fact that growth occurs only if there are surplus carbohydrates.

Translocation. Translocation to structural parts of the plant from the storage organs depends upon the amount of material stored, availability of water, and root biomass. Because all photosynthate passes through the storage compartment in the model before becoming structural materials, the allocation equations are particularly important in determining plant proportions and ability to respond to grazing. The first step involves the allocation of photosynthate to total structural growth (new shoots and roots). This equation is based on Thornley (1976) and allocates photosynthate based on the relative amounts of structural and storage biomasses. All factors which vary by activity level are calculated with $I(3,16)$.

$$I(3,11) = P(3,11) \cdot I(3,12) \cdot X(3,1) + (X(3,1) + P(3,1) \cdot I(3,12))$$

This equation is essentially the Michaelis-Menton function for first order kinetics, and represents the rate of translocation as a function of the sink strength.

This total amount of translocate is reduced by limiting soil water (Fig. 4.17). It is assumed that leaf expansion is more limited than is photosynthesis by shortage of soil water (Detling and Parton 1978). Thus, under limiting soil water, photosynthate accumulates in the storage organs, affecting a recharge of materials used during spring growth.

$$I(3,3) = 1.0 - I(3,10) + P(3,19)$$

The amount translocated is also reduced by sub-optimal temperatures, which also affects fall recharge of storage (Fig. 4.16).

$$A = P(3,14) + (P(3,16) - P(3,14)) + 2.0$$

$$I(3,8) = 1.0 - (A - I(3,19)) + A$$

Figure 4.16. Effect of daily maximum air temperature on the rate of total translocation.

Figure 4.17. Effect of water potential for the wettest zone containing roots on the rate of total translocation.

Table 4.5c. Parameter values for Agropyron sp.

STANDARD NOTATION	VALUE	REFERENCE
P(3,1)	0.7	Model tuning
P(3,2)	0.1	Model tuning
P(3,3)	0.75	Based on wilting point (see text)
P(3,4)	0.1	Based on wilting point (see text)
P(3,5)	0.1	Based on wilting point (see text)
P(3,6)	0.1	Based on wilting point (see text)
P(3,7)	0.0841	DePuit and Caldwell 1975
P(3,8)	120.0	Harris 1967
P(3,9)	0.06	Redman 1974
P(3,10)	-100.0	Reece 1974
P(3,11)	0.12	Model tuning
P(3,12)	0.05	Model tuning
P(3,13)	0.10	Model tuning
P(3,14)	3.0	Cole 1976
P(3,15)	45.0	Cole 1976
P(3,16)	26.0	Cole 1976
P(3,17)	0.08	Model tuning
P(3,18)	0.5	Marshall 1977
P(3,19)	-15.0	Trlica (personal communication)
P(3,20)	0.001	Model tuning
P(3,21)	0.00333	McCree and Troughton 1966 (see text)
P(3,22)	0.755	DePuit and Caldwell 1975
P(3,23)	0.01	Model tuning
P(3,24)	-30.0	Cole 1976

Table 4.5d. Parameter values for Bromus tectorum.

STANDARD NOTATION	VALUE	REFERENCE
P(3,1)	0.7	Model tuning
P(3,2)	0.1	Model tuning
P(3,3)	0.75	Based on wilting point (see text)
P(3,4)	0.1	Based on wilting point (see text)
P(3,5)	0.1	Based on wilting point (see text)
P(3,6)	0.1	Based on wilting point (see text)
P(3,7)	0.0841	
P(3,8)	120.0	Harris 1967
P(3,9)	0.09	Same value as Agropyron
P(3,10)	-80.0	Less than Agropyron
P(3,11)	0.12	Model tuning
P(3,12)	0.05	Model tuning
P(3,13)	0.05	Model tuning
P(3,14)	0.0	Cole 1976
P(3,15)	40.0	Cole 1976
P(3,16)	20.0	Cole 1976
P(3,17)	0.08	Model tuning
P(3,18)	0.5	Marshall 1977
P(3,19)	-15.0	Trlica (personal communication)
P(3,20)	0.001	Model tuning
P(3,21)	0.00333	McCree and Troughton 1966 (see text)
P(3,22)	0.755	DePuit and Caldwell 1975
P(3,23)	0.01	Model tuning
P(3,24)	-30.0	Cole 1976

Both of these reduction factors range from zero to one.

The final rate of translocation to structural biomass is then given by

$$l(3,11) = l(3,11) \cdot l(3,3) \cdot l(3,8) \cdot l(3,18)$$

The quantity to be translocated is then allocated to shoots and roots based on arbitrary relative priorities of growth, which force plant part proportions within set bounds. These bounds are relaxed in the spring to allow a draw-down of reserves.

Once a portion of the total to be translocated is allocated to the roots, this amount is divided between the roots in the soil layers based on the thickness of the layer and the water potential of the layer.

While it has been shown (de Vries, 1972) that the conversion efficiency for storage carbohydrates into structural parts of the plant is around .70 to .75, no conversion factor is used in the model. This is because the biomass lost is in the form of respiration biomass. Since parameters for respiration were obtained from studies in which no account was taken of the cause of the respiration, it is not possible to separate growth respiration from maintenance respiration.

Death of Plant Parts. Death of plant parts may occur due to senescence, adverse climate, carbohydrate deficit and perturbations.

Senescence occurs at a constant nominal death rate of plant part biomass, which reflects the average longevity of that part of the plant. The storage component is considered to be labile and, therefore, has no death rate. Only a small part of the total death of plant part biomass occurs through this process. In addition, curing may cause a constant rate of transfer between green and standing dead biomass.

Drought and cold both cause death of plant parts. Drought causes death of green biomass in proportion to the severity and duration of drought below a critical moisture stress.

$$F(3,8) = P(3,10) - l(3,24) \cdot P(3,2) \cdot l(3,23) \cdot X(3,3)$$

Cold has a similar effect on death of green biomass:

$$F(3,8) = (P(3,26) - l(3,20)) \cdot P(3,17) \cdot X(3,3) \cdot l(3,18)$$

where $l(3,18)$ and $l(3,20)$ are based on $l(3,17)$.

The effects of cold and drought are additive for green biomass. Woody portions are not affected by drought or cold. Roots are affected by drought in the same fashion as leaves, but not by temperature, since extreme temperatures are rare in the soil.

An important cause of die-back of plant parts in semiarid regions is shortage of carbohydrates. Arid zone perennial plants change size from year to year, often shrinking drastically in dry years. This ability to adjust the size of the organism is important in arid regions where rainfall varies

greatly from year to year. Ignoring the homeostatic mechanism of adjusting the plant size in response to the carbohydrate energy status of the plant may explain the annoying tendency of plant models to "drift" over long periods of time. This homeostatic mechanism is implemented during the updating of state variables. If the respiration demand would draw carbohydrate reserves below a critical minimum, then 20% of this extra demand is taken from storage and twice the amount of shortage is taken from woody and roots via increased death rates. Thus, the plant shrinks in proportion to an energy shortage, while at the same time, reserves are gradually used up, causing eventual death.

Perturbations such as fire, grazing, and herbicides directly remove plant parts and may kill the entire plant. These processes are discussed in other sections.

Grazing. Grazing of plant parts is the sum of grazing losses from all animal species. Grazing does not occur without also simulating the animal species dynamics. There is no grazing of belowground or storage components. The total grazing loss of green biomass, dead biomass and woody biomass for each plant species is calculated by the fauna submodel.

4.3.1.7 Shrub Population Processes

The currency is numbers of individuals per unit area. The flows as diagrammed in Fig. 3.2 are:

- 1) recruitment
- 2) mortality
- 3) fire loss

There are two size classes of shrubs: those greater than 15 cm high and those less than 15 cm high. The two size classes are used to distinguish between processes leading to shrub invasion and those allowing mature shrub persistence. Small shrubs must compete directly with grass and forbs for light and water due to their small size and shallow rooting depths. Larger shrubs have a height advantage over herbaceous species and can draw water from deep layers inaccessible to herbs. Thus, large shrubs may be in normal condition, while shrub seedlings are unable to become established.

Recruitment. Recruitment of small shrubs depends on the availability of water in the top soil layer, air temperature and the lack of competing vegetation (Fig. 4.18-4.20). These relationships are given by

$$I(4,1) = P(4,2) \cdot (1.0 - I(3,10) \div P(3,24))$$

$$I(4,2) = \exp(P(4,3) \cdot I(3,9))$$

$$I(4,3) = 1.0 - (P(3,16) - I(3,19)) \div (P(3,16) - P(3,14))$$

$$F(7,1) = I(4,1) \cdot I(4,2) \cdot I(4,3) \cdot dt$$

where dt indicates a time step.

Figure 4.18. Nominal germination rate as a function of water potential in the top soil layer.

Figure 4.19. Effect of daily maximum air temperature on shrub germination.

Figure 4.20. Shrub germination multiplier as a function of competing shade.

Table 4.5e. Parameter values for Artemesia tridentata.

STANDARD NOTATION	VALUE	REFERENCE
P(3,1)	0.5	Model tuning
P(3,2)	0.1	Model tuning
P(3,3)	0.75	Based on wilting point (see text)
P(3,4)	0.1	Based on wilting point (see text)
P(3,5)	0.1	Based on wilting point (see text)
P(3,6)	0.1	Based on wilting point (see text)
P(3,7)	0.0841	DePuit and Caldwell 1975
P(3,8)	180.0	Sturges 1977
P(3,9)	0.03	DePuit and Caldwell 1973
P(3,10)	-100.0	Reece 1974
P(3,11)	0.12	Model tuning
P(3,12)	0.05	Model tuning
P(3,13)	0.05	Model tuning
P(3,14)	8.0	Cole 1976
P(3,15)	45.0	Cole 1976
P(3,16)	35.0	Cole 1976
P(3,17)	N.A.	—
P(3,18)	0.5	Marshall 1977
P(3,19)	-15.0	Trlica (personal communication)
P(3,20)	0.001	Model tuning
P(3,21)	0.003	McCree and Troughton 1966 (see text)
P(3,22)	0.943	DePuit and Caldwell 1975
P(3,23)	N.A.	—
P(3,24)	-30.0	Cole 1976
P(4,1)	100.0	Arbitrary
P(4,2)	0.001	Arbitrary
P(4,3)	-0.024	McCree and Troughton 1966
P(4,4)	0.5	By definition
P(4,5)	300.0	Based on general phenology
P(4,6)	0.001	Model tuning
P(4,7)	0.001	Arbitrary

Recruitment of large shrubs begins when small shrubs reach a threshold size. An arbitrary percent of the small shrubs graduate to the large class at each time step if the threshold size is passed.

Mortality. Because shrubs are quite long-lived relative to the length of model runs, large shrub natural mortality will usually be near zero. Small shrubs will suffer mortality from drought and competition. Mortality to both classes will occur due to herbicide application.

Fire Loss. Fire loss will affect both size classes. Sagebrush, for example, is fire-sensitive and almost all shrubs would be eliminated by a fire.

4.3.2 Litter Processes

The currency is grams per square meter of combined plant and animal litter. The different flows considered are, as diagrammed in Fig. 3.2:

- 1) input of herb shattering
- 2) input of shrub shattering
- 3) input of tree needle and twigs
- 4) input of feces
- 5) input of dead animals
- 6) decomposition
- 7) fire loss

Inputs. Inputs from plant compartments to litter are described in the previous sections, except for inputs of tree needles and twigs. For simplicity, tree litter fall is modeled as a constant rate such that 100% of leaf biomass would fall over a 3 year period.

Decomposition. Decomposition is computed as a respiration function as described above for live plant components. The temperature and moisture potential used are those of the top soil layer, since the oldest and wettest litter occurs at the soil surface and decomposition proceeds fastest there.

Fire. Fire removes some proportion of the litter when it occurs.

4.3.3 Terrestrial Fauna Processes

The fauna simulation submodel has two components, a "typical individual" biomass component and a total population component.

The biomass component allows simulation of general animal condition and energetics and provides feedback to the population dynamics component. Also, it allows a more mechanistic approach to be used in simulating the interaction of fauna and flora populations or predator and prey populations.

The population component simulates total population dynamics over both time and space. For the more "important" species, additional resolution is obtained by dividing the population into cohorts of sex and age classes. Likewise, additional typical individuals are simulated for each cohort. The

Table 4.6 . Parameter values for litter.

STANDARD NOTATION	VALUE	REFERENCE
P(6,1)	-30.0	Cole 1976
P(6,2)	0.0417	Model tuning

possible cohorts are combinations of female, male and mature, immature or juvenile age classes. The least resolution permitted is a mature female cohort.

The major animal classes represented are Mammalia, Aves, Reptilia, Amphibia, Pices, Crustacea, and Insecta. Within these classes, key species are selected for simulation based upon their value to man or their role in the ecosystem. Since not all species can be simulated, the species selected are considered to be characteristic of a grouping of species. The species currently considered for the simulation are:

Mule deer	(ruminant)
Cottontail	(small herbivore)
Coyote	(mammalian predator)
Chipmunk	(rodent)
Cattle	(domestic livestock)

4.3.3.1 Biomass Processes

The currency is kilograms of live body weight per individual organism of the appropriate sex-age cohort. Several biomass flows may be calculated for each simulated species cohort. For many of the species, the calculations are identical except for changes in parameters. The flows diagrammed in Fig. 3.3 are:

- 1) Consumption by individuals of a cohort
- 2) Natality of youngest-cohort individual
- 3) Recruitment/maturation from younger cohort
- 4) Immigration/emigration by individuals of a cohort
- 5) Mortality of individuals of a cohort
- 6) Decomposition of dead animals

Consumption. Consumption represents the total amount of food biomass consumed by a cohort based upon the metabolic needs of a typical individual (Lasiewski 1967, McNab 1979). A cohort is assumed to only feed from within one ERU during a timestep. These metabolic needs are divided into four constituents. The first three are calculated from regression equations developed by Wunder (1975).

First, the basal metabolic need refers to the minimum energy requirement for the maintenance of normal body functions. This need is assumed to be an allometric function of the individual's weight and also depends upon its taxonomic class (Zar 1967, Kendeigh 1970) (Fig. 4.21).

$$I(8,1) = P(8,1) \cdot P(8,2) \cdot [X(8,1)]^{P(8,3)}$$

For hibernating species, the basal metabolic need is reduced 70% during hibernation.

Second, the thermal metabolic need is the energy required for maintenance of body temperature. This need is of minor importance to poikilotherms. It is assumed that the amount of energy needed for thermal regulation is equal to the amount of heat energy either lost or gained by the body due to conduc-

Figure 4.21. Basal metabolism energy requirement.

Figure 4.22. Thermal metabolism energy requirement.

Figure 4.23. Thermal metabolism energy requirement.

Figure 4.24. Activity metabolism energy requirement.

tance. Thus, it assumes that an equal amount of energy is required to cool or warm an animal. This flux is influenced by the difference between the ambient temperature and the body's critical temperature, which is influenced by its insulation capacity (Herreid 1967, McNab 1970, Wunder 1975, Kendeigh 1969) (Fig. 4.22-4.23)

$$I(8,2) = P(8,4) \cdot X(8,1)^{P(8,3)}$$

$$I(8,3) = P(8,16) - P(8,6) \cdot X(8,1)^{P(8,7)}$$

$$I(8,4) = I(8,2) \cdot \text{abs}(I(8,3) - Z(C,3))$$

The thermal metabolic needs are also reduced 70% during hibernation.

Third, the metabolic need for activity and locomotion presently considers only movement in a horizontal plane at an average hourly velocity. Movement is based upon the animal's daily range and dispersal distance (Fig. 4.24).

$$I(8,6) = P(9,7) + I(8,5)$$

$$I(8,7) = I(8,6) \cdot P(8,8) \cdot X(8,1)^{P(8,9)}$$

Fourth, the metabolic need for an individual's body growth is based upon a Brody growth curve (Brody 1945, Humphreys 1979, Ricklefs 1968) (Fig. 4.25).

$$I(8,8) = P(8,17) \cdot (1.0 - \exp(P(8,17) \cdot (I(9,1) \div P(9,5))))$$

The difference between the individual's expected weight and current body weight is converted to calories of energy. These calories are added to the three base metabolisms to determine total daily caloric requirements. Although an individual may attempt to obtain compensatory weight gain, the growth rate is still limited by the assimilation conversion efficiency (Milchunas et al. 1978).

$$I(8,9) = (I(8,8) - X(8,1)) \div P(8,13)$$

The total metabolic need is the sum of these four constituents.

$$I(8,10) = I(8,1) + I(8,4) + I(8,7) + I(8,9)$$

It is assumed that an animal will always attempt to obtain enough energy for growth, although this attempt will not always be successful.

Foods are allocated on the basis of total demand and total availability (Watt 1968). Total demand is presently calculated from the amount of a food which would be needed to supply the total energy demand and its relative desirability or preference. A food's digestibility and caloric content are important in determining the amount needed to supply the energy demand.

$$I(8,11) = P(8,20) \cdot I(8,10) \div (P(8,18) \cdot P(8,19))$$

Total availability has different meanings for the various food items which can be consumed. For woody flora species, availability includes green biomass and that portion of woody twigs which is palatable. For herbaceous

Figure 4.25. Animal growth rate (based upon a maximum weight of 100,000 gm and a life expectancy of 1,825 days).

Figure 4.26. Food Relative Scarcity Index (based upon a demand of 501 gm).

Figure 4.27. Food Relative Scarcity Index (based upon an available 1,001 gm)

Figure 4.28. Food Relative Scarcity Index (based upon an available 1,001 gm and a total demand of 501 gm. At values greater than 501 gm, the total demand is made to equal the individual's food need).

species, it includes green biomass and a portion of standing dead. For fauna species, availability includes the biomass of all cohorts, but the younger cohorts are assumed to receive a much greater proportion of the predation.

For woody floral species:

$$I(8,12) = (X(4,5) + P(8,12) \cdot X(4,4)) \cdot X(7,q)$$

where "q" indicates the size class of the shrub.

For herbaceous floral species:

$$I(8,12) = X(3,3) + P(8,12) \cdot X(3,4)$$

For fauna species:

$$I(8,12) = X(8,1) \cdot X(9,1)$$

If the available biomass of a species is less than the demand for it, then its relative abundance is reduced proportionally.

$$I(8,13) = 1.0 \quad \text{if } I(8,12) \geq \sum_{s=1}^S I(8,11)$$

$$I(8,13) = I(8,12) \div \sum_{s=1}^S I(8,11) \quad \text{if } I(8,12) < \sum_{s=1}^S I(8,11)$$

where "s" indicates consumer species.

Relative scarcity reflects the likelihood of a consumer species finding the amount of forage or prey desired while competing with other consumer species for the same food, a limited resource (Fig. 4.26-4.28).

$$I(8,14) = \exp[-(I(8,11) \cdot \sum_{s=1}^S I(8,11) \div I(8,12)^2)]$$

Thus, the amount of a forage or prey species allocated to a consumer species is a function of the amount desired, its relative abundance, and its relative scarcity.

$$I(8,15) = I(8,11) \cdot I(8,13) \cdot I(8,14)$$

Conversions are made to determine the total availability within the consumer's foraging or hunting range proportional to the acreage of the ERU (Burge et al. 1973).

$$I(8,16) = 1.0 \quad \text{if } P(9,7) > (X(10,1) \div 2)^{1/2}$$

$$I(8,16) = P(9,7) \div (X(10,1) \div 2)^{1/2} \quad \text{if } P(9,7) \leq (X(10,1) \div 2)^{1/2}$$

Table 4.7a. Parameter values for fauna biomass submodel.

STANDARD NOTATION	VALUE	REFERENCE
- Mammalia -		
P(8,1)	1.22	Wunder (1975)
P(8,2)	3.8	Wunder (1975)
P(8,3)	-0.25	Wunder (1975)
P(8,4)	4.91	Wunder (1975)
P(8,5)	-0.505	Wunder (1975)
P(8,6)	4.0	Wunder (1975)
P(8,7)	0.25	Wunder (1975)
P(8,8)	8.46	Wunder (1975)
P(8,9)	-0.4	Wunder (1975)
P(8,16)	38.0	Wunder (1975)
-Aves -		
P(8,1)		
P(8,2)		
P(8,3)		
P(8,4)	4.95	Herreid (1967)
P(8,5)	-0.536	Herreid (1967)
P(8,6)	8.59	McNab (1970)
P(8,7)	0.17	McNab (1970)
P(8,8)		
P(8,9)		
P(8,16)	42.0	McNab (1970)
- Reptilia -		
P(8,1)		
P(8,2)		
P(8,3)		
P(8,4)	22.59	Herreid (1967)
P(8,5)	-0.370	Herreid (1967)
P(8,6)		
P(8,7)		
P(8,8)		
P(8,9)		
P(8,16)		

Table 4.7a. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Amphibia -		
P(8,1)		
P(8,2)		
P(8,3)		
P(8,4)		
P(8,5)		
P(8,6)		
P(8,7)		
P(8,8)		
P(8,9)		
P(8,16)		
- Pices -		
P(8,1)		
P(8,2)		
P(8,3)		
P(8,4)		
P(8,5)		
P(8,6)		
P(8,7)		
P(8,8)		
P(8,9)		
P(8,16)		
- Crustacea -		
P(8,1)		
P(8,2)		
P(8,3)		
P(8,4)		
P(8,5)		
P(8,6)		
P(8,7)		
P(8,8)		
P(8,9)		
P(8,16)		

Table 4.7a. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Insecta -		
P(8,1)		
P(8,2)		
P(8,3)		
P(8,4)		
P(8,5)		
P(8,6)		
P(8,7)		
P(8,8)		
P(8,9)		
P(8,16)		
P(8,10)	N/A	Refers to parameters not yet implemented in the model
P(8,11)	N/A	Refers to parameters not yet implemented in the model
P(8,12)	0.01	Arbitrarily assigned
P(8,13)	0.40	Arbitrarily assigned
P(8,14)	0.80	Arbitrarily assigned
P(8,15)	0.30	Nage, et al. (1974)

Table 4.7b. Parameter values for mule deer diet.

STANDARD NOTATION	VALUE	REFERENCE
- Female -		
P(8,17)	7000.0	Anderson (1974)
- Male -		
P(8,17)	17000.0	Anderson (1974)
<u>Agropyron</u>		
P(8,18)	4000.0	Golley (1961)
P(8,19)	0.39	Golley (1961)
- Winter -		
P(8,20)	1.0	Taylor (1956), Rue (1978)
- Spring -		
P(8,20)	1.0	Taylor (1956), Rue (1978)
- Summer -		
P(8,20)	1.0	Taylor (1956), Rue (1978)
- Autumn -		
P(8,20)	1.0	Taylor (1956), Rue (1978)
<u>Artemisia tridentata</u>		
P(8,18)	2500.0	Golley (1961)
P(8,19)	0.20	Golley (1961)
- Winter -		
P(8,20)	0.8	Taylor (1956), Rue (1978)
- Spring -		
P(8,20)	0.2	Taylor (1956), Rue (1978)
- Summer -		
P(8,20)	0.1	Taylor (1956), Rue (1978)
- Autumn -		
P(8,20)	0.4	Taylor (1956), Rue (1978)

Table 4.7b. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Winter - P(8,20)	0.0	Taylor (1956), Rue (1978)
- Spring - P(8,20)	0.3	Taylor (1956), Rue (1978)
- Summer - P(8,20)	0.0	Taylor (1956), Rue (1978)
- Autumn - P(8,20)	0.0	Taylor (1956), Rue (1978)

Table 4.7c. Parameter values for cottontail diet.

STANDARD NOTATION	VALUE	REFERENCE
- Female -		
P(8,17)	1400.0	Morris (1965)
- Male -		
P(8,17)	1500.0	Morris (1965)
<u>Agropyron</u>		
P(8,18)	4000.0	Golley (1961)
P(8,19)	0.49	Golley (1961)
- Winter -		
P(8,20)	0.2	Hamilton (1939)
- Spring -		
P(8,20)	0.6	Hamilton (1939)
- Summer -		
P(8,20)	0.8	Hamilton (1939)
- Autumn -		
P(8,20)	0.6	Hamilton (1939)
<u>Artemisia tridentata</u>		
P(8,18)	2500.0	Golley (1961)
P(8,19)	0.25	Golley (1961)
- Winter -		
P(8,20)	0.8	Hamilton (1939)
- Spring -		
P(8,20)	0.2	Hamilton (1939)
- Summer -		
P(8,20)	0.1	Hamilton (1939)
- Autumn -		
P(8,20)	0.4	Hamilton (1939)
<u>Bromus tectorum</u>		
P(8,18)	3500.0	Golley (1961)
P(8,19)	0.45	Golley (1961)

Table 4.7c. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Winter - P(8,20)	0.0	Hamilton (1939)
- Spring - P(8,20)	0.2	Hamilton (1939)
- Summer - P(8,20)	0.1	Hamilton (1939)
- Autumn - P(8,20)	0.0	Hamilton (1939)

Table 4.7d. Parameter values for chipmunk diet.

STANDARD NOTATION	VALUE	REFERENCE
- Female -		
P(8,17)	70	Gordon (1943)
- Male -		
P(8,17)	75	Gordon (1943)
<u>Agropyron</u>		
P(8,18)	4000.0	Golley (1961)
P(8,19)	0.38	Golley (1961)
- Winter -		
P(8,20)	0.2	Gordon (1943)
- Spring -		
P(8,20)	0.3	Gordon (1943)
- Summer -		
P(8,20)	0.9	Gordon (1943)
- Autumn -		
P(8,20)	0.6	Gordon (1943)
<u>Artemisia tridentata</u>		
P(8,18)	2500.0	Golley (1961)
P(8,19)	0.20	Golley (1961)
- Winter -		
P(8,20)	0.8	Gordon (1943)
- Spring -		
P(8,20)	0.5	Gordon (1943)
- Summer -		
P(8,20)	0.1	Gordon (1943)
- Autumn -		
P(8,20)	0.4	Gordon (1943)
<u>Bromus tectorum</u>		
P(8,18)	3500.0	Golley (1961)
P(8,19)	0.40	Golley (1961)

Table 4.7d. Parameter values for chipmunk diet.

STANDARD NOTATION	VALUE	REFERENCE
- Female -		.
P(8,17)	70	Gordon (1943)
- Male -		
P(8,17)	75	Gordon (1943)
<u>Agropyron</u>		
P(8,18)	4000.0	Golley (1961)
P(8,19)	0.38	Golley (1961)
- Winter -		
P(8,20)	0.2	Gordon (1943)
- Spring -		
P(8,20)	0.3	Gordon (1943)
- Summer -		
P(8,20)	0.9	Gordon (1943)
- Autumn -		
P(8,20)	0.6	Gordon (1943)
<u>Artemisia tridentata</u>		
P(8,18)	2500.0	Golley (1961)
P(8,19)	0.20	Golley (1961)
- Winter -		
P(8,20)	0.8	Gordon (1943)
- Spring -		
P(8,20)	0.5	Gordon (1943)
- Summer -		
P(8,20)	0.1	Gordon (1943)
- Autumn -		
P(8,20)	0.4	Gordon (1943)
<u>Bromus tectorum</u>		
P(8,18)	3500.0	Golley (1961)
P(8,19)	0.40	Golley (1961)

Table 4.7d. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Winter -		
P(8,20)	0.0	Gordon (1943)
- Spring -		
P(8,20)	0.2	Gordon (1943)
- Summer -		
P(8,20)	0.1	Gordon (1943)
- Autumn -		
P(8,20)	0.0	Gordon (1943)

Table 4.7d. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Winter -		
P(8,20)	0.0	Gordon (1943)
- Spring -		
P(8,20)	0.2	Gordon (1943)
- Summer -		
P(8,20)	0.1	Gordon (1943)
- Autumn -		
P(8,20)	0.0	Gordon (1943)

Table 4.7e. Parameter values for coyote diet.

STANDARD NOTATION	VALUE	REFERENCE
- Female -		
P(8,17)	22000.0	Van Wormer (1964)
- Male -		
P(8,17)	23000.0	Van Wormer (1964)
<u>Chipmunk</u>		
P(8,18)	5050.0	Golley (1961)
P(8,19)	0.65	Golley (1961)
- Winter -		
P(8,20)	0.5	Van Wormer (1964)
- Spring -		
P(8,20)	0.5	Van Wormer (1964)
- Summer -		
P(8,20)	0.5	Van Wormer (1964)
- Autumn -		
P(8,20)	0.4	Van Wormer (1964)
<u>Cottontail</u>		
P(8,18)	5000.0	Golley (1961)
P(8,19)	0.59	Golley (1961)
- Winter -		
P(8,20)	0.8	Van Wormer (1964)
- Spring -		
P(8,20)	0.4	Van Wormer (1964)
- Summer -		
P(8,20)	0.5	Van Wormer (1964)
- Autumn -		
P(8,20)	0.5	Van Wormer (1964)
<u>Mule Deer</u>		
P(8,18)	5000.0	Golley (1961)
P(8,19)	0.50	Golley (1961)

Table 4.7e. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Winter -		
P(8,20)	0.15	Van Wormer (1964)
- Spring -		
P(8,20)	0.1	Van Wormer (1964)
- Summer -		
P(8,20)	0.0	Van Wormer (1964)
- Autumn -		
P(8,20)	0.1	Van Wormer (1964)

The diet preference of the consumer species is assumed to be constant over a season, but does vary with forage or prey availability. The value of the diet preference parameter must be determined prior to the simulation based upon the prey and forage species chosen for simulation. Therefore, it more truly represents seasonal relative diet preference between simulated species. This selectivity factor improves the accuracy and flexibility of the diet selection calculations (Ellis et al. 1976).

First, the diet preference parameters are normalized to reflect the presence or absence of a food species.

$$I(8,17)_s = P(8,20)_s + \sum_{s=1}^s P(8,20)_s$$

for all s such that $I(8,15)_s > 0.0$

$$I(8,17)_s = 0$$

for all s such that $I(8,15)_s \leq 0.0$

The relative availabilities of the present food species also affect the preference rating such that abundant species will be utilized more, although minor species will receive relatively greater emphasis.

$$I(8,17)_s = I(8,17)_s \cdot \text{SQRT} [I(8,15)_s + \sum_{s=1}^s I(8,15)_s]$$

for all s such that $I(8,15)_s > 0.0$

The preference rating is also adjusted to reflect how well the available food species meet the usual complement of food species making up the diet.

$$I(8,17)_s = I(8,17)_s \cdot \text{SQRT} \left[\sum_{s=1}^s P(8,20)_s + \sum_{r=1}^s P(8,20)_r \right]$$

for all s such that $I(8,15)_s > 0.0$

The amount of food allocated is determined by normalizing the resulting diet preference ratings.

$$F(3,11) = [I(8,17)_s + \sum_{s=1}^s I(8,17)_s] \cdot \sum_{s=1}^s I(8,15)_s$$

$$F(3,14) = [I(8,17)_s + \sum_{s=1}^s I(8,17)_s] \cdot \sum_{s=1}^s I(8,15)_s$$

$$F(4,11) = [I(8,17)_s + \sum_{s=1}^s I(8,17)_s] \cdot \sum_{s=1}^s I(8,15)_s$$

$$F(4,15) = [I(8,17)_s + \sum_{s=1}^s I(8,17)_s] \cdot \sum_{s=1}^s I(8,15)_s$$

$$F(8,4) = [I(8,17)_s : \sum_{s=1}^s I(8,17)_s] \cdot \sum_{s=1}^s I(8,15)_s$$

Assimilation, as used in the model, may apply to either anabolism or catabolism. As previously mentioned, an animal will attempt to consume enough food for growth. Any energy acquired above the amount needed for basal, thermal, and activity metabolisms will be used in anabolism. However, if insufficient energy is acquired, the animal catabolizes body tissue to offset the insufficiency. Anabolism is considered to be 40% efficient, while catabolism is considered to be 80% efficient. An animal is assumed to die if it has catabolized more than 30% of its maximum attained body tissue (Nagy et al. 1974).

$$I(8,16) = \sum_{rs=1}^{RS} (I(8,15)_{rs} \cdot P(8,18) \cdot P(8,19)) - I(8,9)_{rs}$$

where "rs" indicates the food species consumed.

$$F(8,1) = I(8,16) \cdot P(8,13) \cdot P(8,18) \quad \text{if } I(8,16) \geq 0.0$$

$$F(8,1) = I(8,16) \div P(8,14) \cdot P(8,18) \quad \text{if } I(8,16) < 0.0$$

Natality, recruitment, immigration, emigration, and mortality. These processes are basically accounting functions that are reflections of corresponding population processes. Shifts in the weight of the "typical" individual assume that the weights within the cohort population are normally distributed.

Decomposition. Decomposition of dead animals presently occurs at a similar rate to other litter decomposition. Decomposed carcass weights are added to the litter biomass.

4.3.3.2 Population Processes

The currency is number of individuals of a sex-age cohort for each fauna species. Like the biomass processes, population flows may be calculated for each species cohort simulated and many of the calculations are identical except for changes in the cohort's parameters. As shown in Fig. 3.3, the processes are:

- 1) Natality of youngest cohort population
- 2) Recruitment/maturation of younger-cohort population
- 3) Immigration/emigration of cohort population
- 4) Mortality of cohort population

Natality. Natality is controlled by time. It is a function of the number of mature females in the population, their condition as indicated by

body weight and species specific reproduction parameters. The sex ratio of newborns is assumed to be 1:1 (Tanner 1966).

$$F(9,1) = 0.50 \cdot I(9,5) \cdot P(9,3) \cdot P(9,4) \div (P(9,2) - P(9,1))$$

Recruitment/Maturation. Recruitment and/or maturation may be a function of time, weight or both depending upon the species. It is primarily an accounting function which moves a portion of the younger cohort into the next age class. This portion is calculated assuming a normal population age distribution (Fig. 4.29-4.30).

$$A = (I(9,1)_n - I(9,1)_{n-1}) \div [2.5071326 \cdot 0.1 \cdot I(9,1)_n]$$

$$B = 0.5 \cdot (I(9,1)_n - I(9,1)_{n-1})$$

$$C = 2.0 \cdot 0.1 \cdot I(9,1)_n$$

$$D = A \cdot \exp(-B^2 \div C^2)$$

$$F(9,3) = X(9,1)_{n-1} \cdot D \quad \text{if } I(9,1) \geq P(9,5) \text{ or } X(8,n-1) \geq P(8,7)$$

$$I(9,1) = I(9,1) + dt \quad \text{if } I(9,1) < P(9,5) \text{ or } X(8,n-1) < P(8,7)$$

Immigration/Emigration. There are three classes of mobility possible for a species: (1) limited, the species is not allowed to move from the ERU in which it resides, (2) local, the species may move among suitable, adjacent ERUs, and (3) regional, the species may move among suitable ERUs regardless of juxtaposition.

In general, movement represents habitat selection by mobile species. The selection is based upon a series of habitat rating indices, in addition to food availability (Walters et al 1971, Whitaker et al 1976). Currently, these indices reflect (1) snow conditions, (2) temperature conditions, (3) plant cover conditions, (4) food availability, and (5) previous (timestep) population utilization. These indices are calculated in the same manner for all fauna species, however, the importance of an index to a particular species may vary. Additional indices can be added to the determination.

- (1) Snow Conditions (Gilbert et al. 1970)
(Fig. 4.31)

$$I(9,6) = 0 \quad \text{if } X(2,1) > P(9,8)$$

$$I(9,6) = 1 - (X(2,1) \div P(9,8))^2 \quad \text{if } X(2,1) \leq P(9,8)$$

- (2) Temperature Conditions
(Fig. 4.32 and 4.33)

$$I(9,7) = \exp((Z(C,3) - I(8,3)) \div 3.0) \quad \text{if } I(C,1) > I(8,3)$$

$$I(9,7) = \exp((2 \cdot P(8,16) - I(8,3)) \div 3.0) \quad \text{if } I(C,1) > (2 \cdot P(8,16) - I(8,3))$$

$$I(9,7) = 1.0 \quad \text{if } I(C,1) \leq I(8,3) \text{ and}$$

$$I(C,1) \leq (2 \cdot P(8,16) - I(8,3))$$

Figure 4.29. Population Proportion Shift.

Figure 4.30. Population Proportion Shift (based upon a difference of 100 between the means).

Figure 4.31. Habitat Condition Index for snow cover (based upon a critical depth of 50 cm).

Figure 4.32. Habitat Condition Index for ambient temperature.

Figure 4.33. Habitat Condition Index for ambient temperature.

(3) Plant Cover Conditions

$$I(9,8) = \sum_{l=1}^L (I(3,13)_l \cdot I(3,14)_l)$$

where "l" indicates plant class

(4) Food Availability

$$I(9,9) = I(8,15) \div I(8,11)$$

(5) Previous Population Utilization

$$I(9,10) = 1 - \left(\sum_{no=1}^{NO} X(9,1) \div I(9,12)_{no} \right) \quad \text{if } P(9,13) < 0$$

$$I(9,10) = \sum_{no=1}^{NO} X(9,1)_{no} \div I(9,12)_{no} \quad \text{if } P(9,13) > 0$$

The habitat rating of an ERU for an animal species is calculated as a weighted sum of the condition indices. The weights are the relative importance values (0-1) of the index to a particular species.

$$I(9,11) = (P(9,9) \cdot I(9,6)) + (P(9,10) \cdot I(9,7)) + (P(9,11) \cdot I(9,8)) \\ + (P(9,12) \cdot I(9,9)) + (P(9,13) \cdot I(9,10))$$

All adjacent ERUs are considered accessible to "locally" mobile species and all suitable ERUs are considered to be accessible to "regionally" mobile species. Thus, each mobile species has a subset of accessible ERUs based upon its own mobility and location. Thus, if an ERU can potentially be utilized by a species, then that ERU is evaluated for the species, even though the ERU may not be currently inhabited by the species. In this way, habitat colonization is permitted.

The population within each subset, "vicinity," is allocated among the ERUs proportionally to their relative ratings.

$$F(9,2) = [(I(9,11) + \sum_{u=1}^u I(9,11)_u) \cdot X(9,1)] - X(9,1)$$

The movement of species between ERUs may be affected by the factors associated with the edge (Sec. 3.7). Each factor affects the individual species differently.

Mortality. Mortality involves three types of mortality: natural mortality including starvation, predation mortality, and hunting or man-related mortality (Siler 1979).

Natural mortality also includes death from accidents and diseases. These causes are assumed to be fairly constant over time; however they may be augmented or diminished by the condition of the "typical" individual, as mentioned previously.

Table 4.8a. Parameter values for mule deer population.

STANDARD NOTATION	VALUE	REFERENCE
P(9,1)	145.0	Rue (1978)
P(9,2)	175.0	Rue (1978)
P(9,3)	0.69	Robinette (1955)
P(9,4)	1.5	Robinette (1955)
- Juvenile -		
P(9,5)	365.0	Arbitrarily assigned
P(9,14)	0.50	Robinette (1955)
- Winter -		
P(9,6)	0.0025	Robinette (1955)
- Spring -		
P(9,6)	0.0020	Robinette (1955)
- Summer -		
P(9,6)	0.0005	Robinette (1955)
- Autumn -		
P(9,6)	0.0015	Robinette (1955)
- Immature -		
P(9,5)	1100.0	Arbitrarily assigned
P(9,14)	0.35	Robinette (1955)
- Winter -		
P(9,6)	0.0015	Robinette (1955)
- Spring -		
P(9,6)	0.0010	Robinette (1955)
- Summer -		
P(9,6)	0.0005	Robinette (1955)
- Autumn -		
P(9,6)	0.0005	Robinette (1955)

Table 4.8a. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Mature -		
P(9,5)	2900.0	Robinette (1955)
P(9,14)	0.15	Robinette (1955)
- Winter -		
P(9,6)	0.0020	Robinette (1955)
- Spring -		
P(9,6)	0.0020	Robinette (1955)
- Summer -		
P(9,6)	0.0005	Robinette (1955)
- Autumn -		
P(9,6)	0.0010	Robinette (1955)
P(9,7)	10.0	Rue (1978)
P(9,8)	50.0	Arbitrarily assigned
P(9,9)	0.7	Arbitrarily assigned
P(9,10)	0.5	Arbitrarily assigned
P(9,11)	0.7	Arbitrarily assigned
P(9,12)	1.0	Arbitrarily assigned
P(9,13)	0.6	Arbitrarily assigned
P(9,15)	400.0	Arbitrarily assigned
P(9,16)	0.0	Arbitrarily assigned

Table 4.8b. Parameter values for cottontail population.

STANDARD NOTATION	VALUE	REFERENCE
P(9,1)	100.0	Morris (1965)
P(9,2)	270.0	Morris (1965)
P(9,3)	0.80	Morris (1965)
P(9,4)	6.0	Morris (1965)
- Juvenile -		
P(9,5)	120.0	Hamilton (1939)
P(9,14)	0.45	Arbitrarily assigned
- Winter -		
P(9,6)	0.0025	Arbitrarily assigned
- Spring -		
P(9,6)	0.0025	Arbitrarily assigned
- Summer -		
P(9,6)	0.0005	Arbitrarily assigned
- Autumn -		
P(9,6)	0.0005	Arbitrarily assigned
- Immature -		
P(9,5)	300.0	Hamilton (1939)
P(9,14)	0.30	Arbitrarily assigned
- Winter -		
P(9,6)	0.0020	Arbitrarily assigned
- Spring -		
P(9,6)	0.0020	Arbitrarily assigned
- Summer -		
P(9,6)	0.0005	Arbitrarily assigned
- Autumn -		
P(9,6)	0.0005	Arbitrarily assigned

Table 4.8b. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Mature -		
P(9,5)	1460.0	Hamilton (1939)
P(9,14)	0.25	Arbitrarily assigned
- Winter -		
P(9,6)	0.0015	Arbitrarily assigned
- Spring -		
P(9,6)	0.0015	Arbitrarily assigned
- Summer -		
P(9,6)	0.0005	Arbitrarily assigned
- Autumn -		
P(9,6)	0.0005	Arbitrarily assigned
P(9,7)	3.0	Morris (1965)
P(9,8)	50.0	Arbitrarily assigned
P(9,9)	0.09	Arbitrarily assigned
P(9,10)	1.0	Arbitrarily assigned
P(9,11)	1.0	Arbitrarily assigned
P(9,12)	0.8	Arbitrarily assigned
P(9,13)	0.6	Arbitrarily assigned
P(9,15)	400.0	Arbitrarily assigned
P(9,16)	0.0	Arbitrarily assigned

Table 4.8c. Parameter values for chipmunk population.

STANDARD NOTATION	VALUE	REFERENCE
P(9,1)	120.0	Gordon (1943)
P(9,2)	250.0	Gordon (1943)
P(9,3)	0.80	Gordon (1943)
P(9,4)	6.0	Gordon (1943)
- Juvenile -		This cohort not simulated
P(9,5)	N/A	
P(9,14)	N/A	
- Winter -		
P(9,6)	N/A	
- Spring -		
P(9,6)	N/A	
- Summer -		
P(9,6)	N/A	
- Autumn -		
P(9,6)	N/A	
- Immature -		
P(9,5)	290.0	Arbitrarily assigned
P(9,14)	0.60	Arbitrarily assigned
- Winter -		
P(9,6)	0.0030	Arbitrarily assigned
- Spring -		
P(9,6)	0.0010	Arbitrarily assigned
- Summer -		
P(9,6)	0.0010	Arbitrarily assigned
- Autumn -		
P(9,6)	0.0010	Arbitrarily assigned

Table 4.8c. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Mature -		
P(9,5)	1100.0	Arbitrarily assigned
P(9,14)	0.40	Arbitrarily assigned
- Winter -		
P(9,6)	0.0020	Arbitrarily assigned
- Spring -		
P(9,6)	0.0005	Arbitrarily assigned
- Summer -		
P(9,6)	0.0010	Arbitrarily assigned
- Autumn -		
P(9,6)	0.0010	Arbitrarily assigned
P(9,7)	1.0	Gordon (1943)
P(9,8)	50.0	Arbitrarily assigned
P(9,9)	0.9	Arbitrarily assigned
P(9,10)	1.0	Arbitrarily assigned
P(9,11)	0.8	Arbitrarily assigned
P(9,12)	0.7	Arbitrarily assigned
P(9,13)	0.3	Arbitrarily assigned
P(9,15)	340.0	Arbitrarily assigned
P(9,16)	100.0	Arbitrarily assigned

Table 4.8d. Parameter values for coyote population.

STANDARD NOTATION	VALUE	REFERENCE
P(9,1)	120.0	Van Wormer (1964)
P(9,2)	180.0	Van Wormer (1964)
P(9,3)	0.69	Van Wormer (1964)
P(9,4)	10.0	Van Wormer (1964)
- Juvenile -		This cohort not simulated
P(9,5)	N/A	
P(9,14)	N/A	
- Winter -		
P(9,6)	N/A	
- Spring -		
P(9,6)	N/A	
- Summer -		
P(9,6)	N/A	
- Autumn -		
P(9,6)	N/A	
- Immature -		
P(9,5)	270.0	Arbitrarily assigned
P(9,14)	0.95	Arbitrarily assigned
- Winter -		
P(9,6)	0.0015	Arbitrarily assigned
- Spring -		
P(9,6)	0.0010	Arbitrarily assigned
- Summer -		
P(9,6)	0.0005	Arbitrarily assigned
- Autumn -		
P(9,6)	0.0010	Arbitrarily assigned

Table 4.8d. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Mature -		
P(9,5)	1500.0	Arbitrarily assigned
P(9,14)	0.05	Arbitrarily assigned
- Winter -		
P(9,6)	0.0010	Arbitrarily assigned
- Spring -		
P(9,6)	0.0020	Arbitrarily assigned
- Summer -		
P(9,6)	0.0005	Arbitrarily assigned
- Autumn -		
P(9,6)	0.0005	Arbitrarily assigned
P(9,7)	20.0	Arbitrarily assigned
P(9,8)	50.0	Arbitrarily assigned
P(9,9)	0.4	Arbitrarily assigned
P(9,10)	0.6	Arbitrarily assigned
P(9,11)	0.6	Arbitrarily assigned
P(9,12)	1.0	Arbitrarily assigned
P(9,13)	0.3	Arbitrarily assigned
P(9,15)	400.0	Arbitrarily assigned
P(9,16)	0.0	Arbitrarily assigned

$$I(9,2) = P(9,6) \cdot X(9,1)$$

Predation mortality is a result of the consumption processes. The younger age classes are assumed to receive larger predation losses than the older classes.

$$I(9,3) = [P(9,4)_s \cdot \sum_{s=1}^S I(8,15)_s] - X(9,1)$$

where "s" indicates the consumer species.

Hunting is implemented in the submodel as an event, since it is not viewed as a natural ecosystem function. It is a function of time, fauna population, human population or hunters, and other environmental factors such as snow cover and vegetation cover.

$$I(9,4) = X(9,1) \cdot (Z(m,3) + Z(m,4))$$

Thus, mortality is the sum of all these factors.

$$F(9,4) = I(9,2) + I(9,3) + I(9,4)$$

4.3.4 Aquatic Biota Processes

Producer Level. Both DiToro et al. (1971) and Richey (1974) have proposed models of aquatic systems which consider algal photosynthesis as a function of ion concentration. A more general equation for algal photosynthesis is given by Wiegert and Fraleigh (1972). It is:

$$F(13,1) = P(13,5) \cdot Z(C,9) \cdot Z(H,7) \cdot X(13,1)^{P(13,1)}$$

$Z(H,7)$ is the carbon dioxide concentration in parts per million (ppm) $\times 10^{-1}$ and $X(13,1)_r$ is the size of the R-th population. The exponent $P(13,1)$ decreases photosynthesis as population size increases due to CO_2 depletion. This model assumes complete light saturation during all hours of daylight and ignores substrate concentration.

A photosynthesis equation (DiToro et al. 1971) which incorporates light intensity is:

$$F(13,1) = I(13,1) \div P(13,6) \cdot \exp(1 - (I(13,1) \div P(13,6)))$$

where $P(13,6)$ is the light saturation intensity and $I(13,1)$ is solar radiation at a fraction of the total depth and is:

$$I(13,1) = P(13,6) \cdot \exp(-P(13,7) \cdot I(12,1))$$

where $P(13,7)$ is a proportionality constant.

Aquatic plant respiration is described as:

$$F(13,3) = P(13,8) \cdot X(13,1)_r \cdot Z(H,8)$$

where $X(13,1)_r$ is the population size and $Z(H,8)$ is water temperature in degrees celsius (DiToro 1971). From the respiration equation, a term can be added to calculate plant death as a function of water depth and temperature. It is:

$$F(13,4) = P(13,8) \cdot X(13,1)_r \cdot Z(H,8) \exp(-X(13,1)_r \cdot I(12,1))$$

This means that plant death increases exponentially as water volume decreases.

Primary Consumer Level. DiToro et al. (1971) consider that the rate at which phytoplankton are grazed is:

$$F(13,2) = (((P(13,3) \cdot P(13,2)) \cdot (X(13,1)_r \cdot X(13,2)_s)) + (P(13,2) + X(13,1)_r) \cdot P(13,4))$$

where $X(13,1)_r$ and $X(13,2)_s$ are population densities of grazers and plants, $P(13,2)$ is equal to 3 mg of carbon d^{-1} , $P(13,4)$ is a conversion factor that changes units of carbon to units of biomass. The coefficient $P(13,3)$ has units of liters per day per gram of carbon in the plant population.

The function which describes the change in the plant biomass state variable is:

$$X(13,1) = X(13,1) + (F(13,1) - F(13,2) - F(13,3) - F(13,4))$$

Higher Trophic Levels. Animal natality (Fig. 3.5A) may be considered a function of population density, temperature and the density of prey items in the case of the top carnivore or plants in the case of primary consumers. The expression, derived from DiToro et al. (1971), is:

$$F(13,5) = (P(13,9)_s \cdot X(13,2)_{rs} - (P(13,10) \cdot ((X(13,2) \cdot X(13,1)_{rs}) + F(12,4))) \cdot Z(H,1) \exp(Z(H,8))$$

where $X(13,1)_{rs}$ is the prey (or plant) population, $X(13,2)$ is the predator (or herbivore) population, $Z(H,1)$ is the rate at which water enters and leaves a stream segment, $P(13,9)$ is the intrinsic rate of growth and $Z(H,8)$ is temperature. The equation says that population is increased by the number of interactions of predator and prey per volume of stream given a water flow rate. The second term is an exponential function of temperature. The value of $P(13,10)$ is 0.6 grams of carbon per gram of carbon in the predator population for the phytoplankton to zooplankton interaction. The value of the interaction coefficient for the top carnivore feeding on primary consumers is undetermined at present.

The ingestion of a prey item may be considered as a simple interaction between those ingested and those ingesting. As such

$$F(13,6) = ((P(13,10) \cdot X(13,1)_{rs} \cdot X(13,2)) + F(12,4)) \cdot Z(H,1)$$

where each term is defined as in $F(13,5)$. Temperature is not directly considered in $F(13,6)$ since prey item density and predator densities are not directly affected by temperature. Temperature would need to be incorporated into $F(13,6)$ if mobility of the organisms is explicitly considered.

Aquatic animal death is most directly affected by the amount of water in a stream segment. Temperature and prey density are also important variables. DiToro et al. (1975) and Richey (1974) consider zooplankton death rate as simply a constant $P(13,11)$ multiplied by the animal population size. We have modified that expression by incorporating volume and flow rate to get:

$$F(13,8) = (P(13,11) \cdot X(13,2)_s + F(12,4)) + Z(H,1)$$

It is assumed that as flow rate decreases there is less water in a stream segment thereby increasing death loss to animal biomass.

The loss to the animal biomass state variable due to anabolic processes is a function of body size in large animals or population density in the case of microscopic animals. It is consequently species specific and in some instances developmental stage specific. For example, Wiegert and Fraleigh (1972) found egg and adult fly respiration energy loss to be 0.06 and 0.47 $\text{kcal}^{-1}\text{day}^{-1}$ respectively. The respiratory loss to animal biomass is at present a power function of amount of biomass ($X(13,2)_s$ and $P(13,2)$) is a decimal constant or:

$$F(13,9) = X(13,2)^{P(13,12)}$$

DiToro et al. (1971) contend that excretion of waste material is dependent on prey item encounters and therefore equal to the ingested less the amount of prey item unassimilated or:

$$\begin{aligned} F(13,10) &= (P(13,9) \cdot X(13,1)_{rs} \cdot X(13,2)) - X(13,2)^{P(13,12)} \\ &= F(13,6) - F(13,9) \end{aligned}$$

The change in state variable $X(13,2)$ is then

$$X(13,2) = X(13,2) + (F(13,5) + F(13,6) - F(13,8) - F(13,9) - F(13,10))$$

Loss of dead biomass through decomposition is accomplished by the decomposer subsystem. Uhlman (1975) considers decomposition to be a function of oxygen deficit in milligrams per liter and the density of the decomposer population(s). The curve is an exponential decay curve, described by:

$$F(13,11) = P(13,13) \cdot (l(13,2) - l(13,3))$$

where $P(13,13)$ is a first order rate constant for decomposer oxygen consumption, $l(13,2)$ is the total amount of oxygen required for the decompo-

sition of utilizable organic material and $l_{(13,3)}$ is the amount of oxygen consumed in one time step. That intermediate amount is related to $l_{(13,3)}$ as:

$$l_{(13,3)} = l_{(13,2)} \cdot (1 - \exp(-P_{(13,3)} \cdot 1))$$

Grazing by bottom feeders is a loss to the dead biomass state variable (Fig. 3.5A). Uhlman (1975) gives ranges of $53 - 750 \text{ g m}^{-2}\text{day}^{-1}$ for organic material grazed by various species of bottom feeders. The rate of feeding then is:

$$F_{(13,11)} = X_{(13,2)} \cdot (X_{(13,2)})^P_{(13,12)}$$

or the metabolic size of the organism multiplied by population size per square meter of stream bottom.

The change in dead biomass over time is described by:

$$X_{(13,3)} = X_{(13,3)} + (F_{(13,4)} + F_{(13,8)} + F_{(13,10)} - F_{(13,11)} - F_{(13,12)})$$

4.4 RESOURCE MANAGEMENT AND DEVELOPMENT

Although resource management and development is an integrated part of the simulation, it is not an integrated part of any submodel. Resource management and development operates through "events" which modify conditions within a submodel. Events may occur for only one timestep, or over a span of timesteps. For example, livestock is put on an ERU at a set date, while the hunting season extends over several weeks.

The event structure allows various management strategies to be applied to the same baseline simulation conditions. Although there are not flows associated with the events, the results are reflected in the flows and components of the affected submodel. The event's occurrence and effects are also noted on a separate file. This structure also allows for definition of additional management events without requiring drastic changes in the submodels themselves.

Events are considered to be a type of driving variable, since they are not affected (in most cases) by system conditions. Unlike climatic driving variables, events are not read into the system at regular intervals but rather, modify the current system conditions at irregular intervals.

Events are defined during initialization of the simulation, and organized by the submodels affected. When an event's activation time corresponds to the simulation time, the event definition is moved to the activelist, and arranged by submodel affected. Following the simulation of a submodel, the activelist of events for the submodel is checked and any appropriate procedures are carried out. When an event's duration is over, it is removed from the activelist. "Discrete" events are a special class of events which are active for only one time step.

Currently, the events which have been implemented are:

Table 4.9 Parameter values used by the aquatic processes submodel.

STANDARD NOTATION	VALUE	REFERENCE
P(13,1)	.	
P(13,2)	3.00	DiToro (1971)
P(13,3)	0.13	DiToro (1971)
P(13,4)		
P(13,5)	0.04	Wiegert & Fraleigh (1972)
P(13,6)	300.00	DiToro et al. (1971)
P(13,7)		
P(13,8)	0.05	DiToro (1971)
P(13,9)		
P(13,10)	0.60	DiToro et al. (1971)
P(13,11)	0.07	DiToro et al. (1971) Richey (1974)
P(13,12)		
P(13,13)		
P(13,14)		

- 1) Fire
- 2) Herbicides
- 3) Fertilization
- 4) Stocking livestock
- 5) Hunting wildlife
- 6) Tree harvest
- 7) Revegetation
- 8) Land use change
- 9) Modify edge

Fire. Fire is a user-defined event. The user specifies that there will be a fire on a certain date and gives the percent burn in terms of an "intensity" parameter. If a fire is scheduled when snow is present or if there is less than 50 grams of total biomass per m^2 present, the fire is aborted and an informative message is printed. Litter and herbaceous above-ground live and dead biomass and tree cover are reduced by the intensity of the fire. An intensity of 1 eliminates all organic matter aboveground. Biomass per shrub is not reduced by the fire, but the number of shrubs present is reduced. It is assumed that all shrubs present are fire sensitive. Also, a fire increases the site fertility, based on the intensity of the fire.

Herbicides. Herbicide application is a user-defined event. The application is defined in terms of the percent of the shrub population that is killed. Shrubs not killed are unaffected by the spraying and retain pre-spray vigor. Leaf and woody portions of killed shrubs are transferred to litter. All shrub species are affected the same.

Fertilization. The fertility status has two components: base fertility and current fertility. The base fertility can be used to adjust model productivity levels to compensate for site quality differences not accounted for by soil texture and depth, slope, elevation, aspect, and precipitation. The current fertility reflects changes in the fertility of the site due to fire and fertilization of the site. Fire acts as a fertilizing event in proportion to the intensity of the fire. A user-input fertilization event is given in terms of the percent increase in fertility over the current fertility level. The current fertility level gradually returns to the base level over a period of about three years. Because fertility affects the photosynthesis rate, doubling the fertility causes a doubling of the growth rate which produces more than double the net primary production.

Stocking Livestock. Stocking and removal of stock are user-defined events. The user specifies the specie, the numbers of each cohort and the weight of a typical individual of each cohort to be stocked. A specific ERU must also be given. Since livestock are assumed to have "limited" mobility, they cannot move from one ERU to another, except by specific stocking events. The event occurs before simulation of fauna dynamics.

Hunting Wildlife. Hunting seasons are user-defined events. The user specifies the location, the opening day, the season length, the species hunted and the predicted success ratio and wounding loss. The total number of animals harvested during the season is divided evenly among the involved time stops. Like stocking, this event occurs before simulation of fauna dynamics.

Tree Harvest. Trees are harvested based on the percent of extant crown cover that is to be removed. Cover of all species is removed equally from any existing trees.

Revegetation. When a site is to be revegetated, input data having the same format as initial conditions is appended to the event input file. In addition, an event in standard form schedules when and where the revegetation is to occur. When the event is scheduled, all plants are eliminated from that ERU and the new vegetation data is read in.

Land Use Change. Changing the acreage of land used for the various categories is a user-defined event. The user specifies the date and the desired ERU to be modified. The desired acreages for each land use category are then input. If the total acreage is input as 0, the total will be determined by summing the categories. If the total is not 0, then the categories will be normalized to sum to the total, based upon the relative size of each land use category input.

Modify Edge. Modifying edge descriptions is a user-defined event which may be associated with many kinds of management procedures. This is a very powerful event because it can change the entire ERU mosaic described in Section 3.7.

The user specifies the desired ERU and a description of the edge to be modified. New edges may be added, existing edges may be removed and characteristics of existing edges, such as length, may be modified. In addition, the edge factors associated with an edge may also be added, removed, or modified.

5. SHALE OIL DEVELOPMENT

A given scenario will specify the rate of shale oil development in terms of millions of barrels of oil and method of oil extraction. The scenario will also include the type of industrial plants and their locations. Development may have several impacts, including effects on air and water quality, land use and habitat changes, and direct interactions with wildlife.

5.1 LITERATURE REVIEW

5.1.1 Air Pollutants

The development of shale oil in the Piceance Basin will cause an increase in air pollution due to process plant stack emissions. The deposition and plant uptake of the pollutants is one of our concerns. The possible dosages of air pollutants on plants are conceptualized under various conditions: current regulations, possible future lifting of regulations, and possible pollution control failure mismanagement. Acid precipitation of SO_2 is not considered here.

5.1.1.1 Regulations

Smith (1974) has proposed that air pollution has three levels of effects on ecosystems. At low dosage, the vegetation and soil serve as a sink for pollutant chemicals. At the intermediate dosage, various individual plants may be adversely and subtly affected. High pollutant dosage may induce acute morbidity or mortality of plants and animals.

Ambient air quality standards are established to protect the public health (primary standards)¹ and to protect the public welfare (secondary standards)². Individual states may establish additional or more stringent standards, as did Colorado. Ambient concentrations are found by adding calculated concentrations, using applicable meteorological data and realistic plant emissions, to the measured background concentrations. Short-term concentrations can be calculated by adding conservative values (those input values leading to the highest predicted values) to background concentrations. These standards are given in μgm^{-3} units and in annual average dose levels or 1, 3, 8, and 24-hour doses not to be exceeded more than once per year. The ambient standards are shown in Table 5.1

¹Federal Primary - Ambient air quality levels, necessary to protect public health.

²Federal Secondary Standards - Levels required to protect public welfare (including effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility, and climate; damage to and deterioration of property; and hazards to transportation comfort and well-being), as well as effects on persons from any known or anticipated adverse effects associated with presence of the pollutants.

Table 5.1. Federal Ambient Air Quality Standards (Dvorak 1978).

Material	Standards ($\mu\text{g}/\text{m}^3$)	
	Primary	Secondary
Suspended particulates		
Annual average	75	60
24-hr average ¹	260	150
Sulfur dioxide		
Annual average	80	60
24-hr average ¹	365	260
3-hr average ¹	none	1,300
Nitrogen dioxide		
Annual average	100	100
Carbon monoxide		
8-hr average ¹	10	10
1-hr average ¹	40	40
Photochemical oxidants		
1-hr average ¹	160	160
Hydrocarbons		
3-hr average ¹	160	160

¹Not to be exceeded more than once per year.

Table 5.2. Maximum Allowable Increase in Pollutant Concentrations for PSD Areas (Dvorak 1978).

Pollutant	Maximum allowable increase ($\mu\text{g}/\text{m}^3$)		
	Class I	Class II	Class III
Particulates			
Annual geometric mean	5	19	37
24-hr maximum	10	37	75
Sulfur dioxide			
Annual arithmetic mean	2	20	40
24-hr maximum	5	91	182
3-hr maximum	25	512	700

Specific areas of the country fall under a third air quality regulation which classifies regions according to the need to prevent significant deterioration (PSD areas), or to maintain present air quality which is not considered to be in compliance at the outset (metropolitan areas). Class I areas encompass national monuments, primitive areas, preserves, recreation areas, and wild and scenic rivers exceeding 10,000 acres. Class II and Class III are progressively less pristine. The Piceance Creek Basin is in a Class II area. Some increase in pollutant concentrations is allowed in each class above existing concentrations, but no greater than ambient standards or NSPS standards. These maximum allowable increases are shown in Table 5.2.

New Source Performance Standards (NSPS) set limits for the amount of pollutants emitted by a facility. Particulates, oxides of nitrogen and sulfur, and visible emissions are limited. Emission levels are given in lb/10⁶ BTU's.

Colorado air quality standards are more stringent than the Federal standards. Colorado has specified 3 regulation concerns: Categories I and II, which encompass Federal Classes I, II, and III, and Category III, which encompasses the metropolitan non-compliance areas.

Table 5.3. Current (Fall 1977) Federal and Colorado Air Quality Standards for sulfur dioxide (Dvorak 1978)

	Federal		Colorado				Metropolitan Areas	
	Primary (ppm)	Secondary (ppm)	Category I (ppm) ($\mu\text{g}/\text{m}^3$)		Category II (ppm) ($\mu\text{g}/\text{m}^3$)		Category III (ppm) ($\mu\text{g}/\text{m}^3$)	
Annual	0.03	—	0.0007	2	0.004	10	0.005	15
24-hour max.	0.14	—	0.002	5	0.018	50	0.035	100
3-hour max.	—	0.50	0.009	25	0.105	300	0.245	700

Two other terms which need clarification are the following: ppm and $\mu\text{g}/\text{m}^3$. The unit ppm varies with many meteorological variables which change as sites change or as weather changes. In contrast, a concentration measured in $\mu\text{g}/\text{m}^3$ will have different effects on a plant at different elevations due to partial pressure changes of atmospheric gases.

Legal Standards. Colorado Standards are low enough to prevent known plant or animal damage on an annual basis. However, Federal Standards may not protect plants from long-term effects. Lawsuits are pending against both levels of government on the issue of air quality standards. Currently, government-sponsored research is being conducted to analyze the adequacy of the Federal Standards.

For the present, the following instantaneous concentrations of SO₂ will be used as benchmark comparisons to Federal and State Standards:

1. SO₂ at 0.04 ppm will exceed the 24-hour average standard within a few hours.

2. SO_2 at 0.025 ppm is within Colorado Standards, except for Category II which has a 3-hour maximum. If continued at that level for several hours, it would exceed the 24-hour average standard.
3. SO_2 at 0.007 ppm is within the 24-hour average standard even over several weeks, but the annual mean may be exceeded.

5.1.1.2 Abiotic Effects

Very high levels of air pollution, such as found in some metropolitan areas, are known to affect local weather patterns, however, this effect is not anticipated from shale oil development. Likewise, acid rains are not expected to occur.

The major abiotic effect may be the deposition of various chemical compounds onto soils and water bodies. At high levels, the soil characteristics and water quality could be affected. Leaching and runoff may further affect the water quality.

5.1.1.3 Floral Effects

Plants themselves are emitters of compounds which in the last century have become known as pollutants. Four of these compounds are hydrogen sulfide, ammonia, nitrous oxide, and a broad class of hydrocarbons. Plants can also break down toxic compounds for their use. An alfalfa canopy was observed to remove gases from the air in the following order from greatest removal rate to no removal at all:

The rate of uptake was observed to increase with the water solubility of the compounds (Carrier 1977).

Plant stack emissions of hydrocarbons, SO_2 , NO_2 , and particulates are the primary concern of this ecological assessment. Pollutants which are well-studied and known to have a major impact on agriculture are ozone and other oxidants, sulfur dioxide, fluorine, and ethylene (Heck 1973). Compounds which are considered possible pollutants are ammonia, chlorine, volatile trace metals, phenols and other organic compounds, and particulates. Secondary photochemical reactions may further result in production of serious plant toxicants.

Acid rain is a serious problem in mesic climates but in dry regions is not likely to be a serious problem. Significant amounts of acid precipitation occur only at conjunction of two rare events in arid regions: very heavy rainfall along with heavy SO_2 pollution (J. L. Dodd personal communication, 23 February 1980).

Because dosages of the pollutants necessary to induce acute, short-term, vegetation injury are rather high and the projected range of average daily pollutant levels in the basin is rather low, the probability of acute injury

is minimal. However, chronic injury resulting from long-term, low level exposure may be significant (Table 5.4).

Both acute and chronic effects may result in changes in diversity, productivity, and stability of biotic communities. If the vegetational disturbance became excessive, soil erosion could also become a serious problem. These changes would in turn affect the animal components of the ecosystem via changes in habitat, food availability, and population dynamics.

Sensitivity. Impact is affected by climatological factors such as humidity, radiant intensity, soil water, and soil nutrient supply. Most plants display maximum absorption and sensitivity when environmental conditions are most favorable for maximum growth, i.e., temperatures greater than 40°F, relative humidity above 50%, daylight, and ample soil water. Plants growing at maximum rates are normally more susceptible to injury than those growing at a reduced rate because of reduced stomatal resistance. Any genetic or environmental factor which reduces growth rate, such as age of plant or unfavorable environmental conditions, will normally increase stomatal resistance and thereby decrease absorption and sensitivity.

Each species has unique stomatal responses, and pre-exposure conditions cause unpredictable stomatal responses. Therefore general stomatal conditions of the field site at the outset of exposure are very difficult to quantify.

Levels of sensitivity and accumulation effects have not been adequately field-tested or field-simulated until recently when such a study was done by an EPA-funded project in Montana near a coal-fired powerplant. Most of the research is on sulfur dioxide, however, some work has been conducted on uptake of fluorides, nitrogen dioxide, and mercury by plants. It is generally accepted that field experiments are preferable to greenhouse experiments in the study of atmospheric pollutant effects on plants because natural environmental fluctuations affect synergistic reactions, susceptibility, and dosages. However, the highly variable conditions of a field experiment present unique research problems.

Plant Group Response. The Pinyon-Juniper plant group, Juniperus osteosperma and Pinus edulis, appears to be relatively resistant to SO₂ and NO₂ (Dvorak 1978, Hill et al. 1974). Sagebrush, Artemesia tridentata, and wheatgrass, Agropyron smithii, are of intermediate sensitivity to SO₂ (Dvorak 1978). Hill et al. (1974) found that arid perennial grasses, including two other species of Agropyron, were generally of low sensitivity to SO₂, with the exception of the highly sensitive Indian Ricegrass, Oryzopsis hymenoides (Gaud 1979) (Fig. 5.1).

Terminology. The following definitions were prepared by the Pollution Damage on Plants Committee of the American Phytopathological Society (1973):

Injury: any change in the appearance and/or function of a plant that is deleterious to the plant.

Visible injury: injury producing identifiable leaf markings such as areas of necrotic tissue.

Subtle injury: injury not readily identifiable from visible analyses of leaf surfaces; often referred to as physiological injury; normally associated with alterations in normal metabolic processes such as

Table 5.4. Types of chronic low-level plant effects and probable mechanisms involved (Carrier 1977).

Type of effect	Probable mechanisms	Pollutants involved ¹
Reduced growth	Decreased <u>photosynthesis</u>	SO ₂ , O ₃ , NO _x , HF, PAN, Pb
	Increased respiration	HF, SO ₂
	Biochemical changes	
	Enzyme inhibition	SO ₂ , O ₃ , PAN, HF, As
	Electron (energy) transport	HF, O ₃ , PAN
	Effects on photopigments	SO ₂ , HF, O ₃ , PAN, NO _x
	Stomatal function	SO ₂ , O ₃
	Membrane permeability	O ₃ , PAN, SO ₂ , HF, metals
	Premature senescence of leaves	SO ₂ , O ₃ , PAN, NO ₂
	Physical changes	
	UV reflectivity	Acid rain
	Heat exchange	Acid rain
	Gas exchange	Acid rain
	Changes in symbiosis	O ₃ , acid rain
	Effects on nutrient flux	SO ₂ , acid rain
Reduced reproduction	Reduced carbohydrate availability for reproductive structures	SO ₂ , O ₃ , HF, PAN, Pb, NO ₂
	Effects on reproductive processes	
	Flower or fruit production	Smog, HF, SO ₂
	Pollen germination or tube elongation	SO ₂ , O ₃ , HF
	Mutagenesis	SO ₂
	Effects on pollinating insects	HF
Increased morbidity	Inadequate carbohydrate supply to support autotrophic respiration and resist diseases; reduced growth and loss of ability to compete with other vegetation	SO ₂ , O ₃ , HF, PAN, NO ₂ , heavy metals

¹ Includes pollutants for which specific effects have been documented and those whose biochemical symptomology strongly implicate them as probable causal agents.

Figure 5.1. Dose-injury curve for SO₂ damage to plants. A. Sensitive, B. Intermediate, and C. Resistant plant classes. From Dvorak (1978).

increased respiration or reduced photosynthesis. Cumulative effects are often reflected by reductions in forage or grain yield.

Acute injury: injury, usually involving necrosis, which develops within several hours to a few days after a short-term exposure to a pollutant, and expressed as fleck, scorch, bifacial necrosis, etc.

Chronic injury: injury which develops only after long-term or repeated exposure to an air pollutant, and expressed as chlorosis, bronzing, premature senescence, reduced growth, etc., can include necrosis.

Chlorosis: common injury symptom whereby green plant tissue becomes pale green, yellow, or even white because of reduced chlorophyll content; normally associated with chronic exposures.

Necrosis: injury resulting in death of plant cells and tissues.

Necrosis is normally associated with acute exposures but may result from chronic exposures as reflected by an increase in leaf senescence.

Damage: a measure of the decrease in economic or aesthetic value resulting from plant injury by pollutants.

Dose: a measured concentration of a toxicant for a known duration of time (concentration per unit time) to which a receptor is exposed.

For example, a dose of 1.0 ppm may arise from either a 2-hour exposure at a concentration of 0.5 ppm or a 1-hour exposure at a concentration of 1.0 ppm.

Impacts of Pollutants on Plants

Sulfur dioxide. Inter-relations of time and concentration (effective dose) are being studied in order to assess current standards. Studies on doses lower than standard legal doses are not yet complete, but indications are that relaxation of the EPA standards will establish SO_2 as a widespread influential factor affecting the structure and function of many ecosystems.

SO_2 -sensitive plants have been identified by Jacobson and Hill (1970), Davis and Wilhour (1976), and Hill et al. (1974) (Table 5.5). Complicating factors are discussed by Benedict and Breen (1955), Davis and Gerhold (1976), Davis and Wilhour (1976), Dreisinger and McGovern (1970), Guderian (1977), Krupa (1976), Linzon (1978), Skelly and Lambe (1974), and U.S. EPA (1973 and 1976). Karnowsky (1977) discusses the sensitivity of Populus tremuloides.

The gaseous pollutants considered here; SO_2 , NO_2 , and hydrocarbons; enter the plants primarily via the stomata (Katz 1949, Thomas and Hendricks 1951, Bennett et al. 1973, U.S. EPA. 1973, Steinhar et al. 1976, and Guderian et al. 1977). Stomates have been induced to open in some plants and induced to close in others by fumigation with SO_2 .

Mansfield and Majernik (1970) reported an increase in stomatal opening in response to SO_2 exposures at relative humidities above 40% but a depression of opening at lower relative humidities. Buron and Cornic (1973) found that a 3-minute exposure of 2.5 ppm SO_2 induced stomatal opening in Sinapis alba plants but a 40-minute exposure induced closure. Biscoe et al. (1973) found that low concentrations of SO_2 up to 0.5 ppm induced stomata to open in Vicia faba. Unsworth et al. (1972) reported stomatal opening was increased in numerous crops by ambient SO_2 levels.

To the contrary, Jensen and Kozlowski (1975) found four tree species had reduced SO_2 absorption rates after 20 hours of pre-fumigation with 0.75 ppm

Table 5.5. Percent of the total leaf area injured by different concentrations of SO_2 in two-hour field fumigation studies. (Data from Hill et al. (1974). Most data points represent only a few trials.)

SPECIES	AVERAGE PERCENT INJURY					
	SO_2					
	.5 ppm	1 ppm	2 ppm	4 ppm	6 ppm	10 ppm
<i>Abies concolor</i> (White fir)		0		0	0	
<i>Abies lasiocarpa</i> (Alpine fir)					0	22
<i>Acer glabrum</i> (Rocky Mountain maple)		0		10	60	
<i>Achillea millefolium</i> (Yarrow)		0	0	0	16	38
<i>Agoseris glauca</i> (Mountain dandelion)		0	0	10	15	
<i>Agropyron caninum</i> (Wheatgrass)			0	0	0	78
<i>Agropyron desertorum</i> (Crested wheatgrass)					20	
<i>Ambrosia</i> sp. (Ragweed)		0	0	0	1	1
<i>Amelanchier utahensis</i> (Utah serviceberry)	0	0.2	3	22	33	80
<i>Artemisia ludoviciana</i> (Louisiana sage)		0		0	21	
<i>Artemisia tridentata</i> (Big sagebrush)			0	4	9	2
<i>Aster chilensis</i> (Aster)		0	0	1	5	
<i>Astragalus utahensis</i> (Locoweed)		2	0	30	50	
<i>Atriplex canescens</i> (Fourwing saltbush)				0	0	
<i>Atriplex confertifolia</i> (Shadscale)				0	0	
<i>Bromus ciliatus</i> (Fringed brome)		0	0	0	13	96
<i>Bromus inermis</i> (Smooth brome)						0.6
<i>Bromus tectorum</i> (Cheatgrass)			0	0	0	10
<i>Cercocarpus ledifolius</i> (Curl-leaf mountain mahogany)					0.4	25
<i>Cercocarpus montanus</i> (Mountain mahogany)				5		
<i>Chenopodium fremontii</i> (Goosefoot)		0	2	5	7	
<i>Chrysothamnus nauseosus</i> (Big rubber rabbitbrush)				0	1	40
<i>Chrysothamnus stenophyllus</i> (Little-leaf rabbitbrush)				0		
<i>Chrysothamnus viscidiflorus</i> (Sticky-flower rabbitbrush)		0		0	5	
<i>Cirsium undulatum</i> (Thistle)		0		6	14	
<i>Cowania mexicana</i> (Cliffrose)					0	3

Table 5.5. (Continued)

SPECIES	AVERAGE PERCENT INJURY					
	SO ₂					
	.5 pmm	1 pmm	2 pmm	4 pmm	6 pmm	10 pmm
<i>Descurainia californica</i> (Tansy mustard)				0		40
<i>Ephedra viridis</i> (Mormon tea)		0		0	2	95
<i>Equisetum</i> sp. (Horsetail)		0	0	0	0	
<i>Eriogonum racemosum</i> (Buckwheat)		0		43	19	
<i>Euphorbia serpyllifolia</i> (Spurge)		0	0	12	15	
<i>Eurotia lanata</i> (Winterfat)				6	0	
<i>Geranium richardsonii</i> (White geranium)			3	7	86	
<i>Gila aggregata</i> (Scarlet gilia)			0.8	3	14	
<i>Gutierrezia sarothrae</i> (Snakeweed)			0	0	21	78
<i>Juniperus osteosperma</i> (Utah juniper)					0	28
<i>Juniperus scopulorum</i> (Rocky Mountain juniper)		0		0	0	25
<i>Machaeranthera canescens</i> (Spiny-leaved aster)				25		
<i>Malacothrix sonchoides</i> (Desert dandelion)				0		
<i>Opuntia</i> sp. (Prickly pear cactus)					0	
<i>Oryzopsis hymenoides</i> (Indian ricegrass)	0.2	2	2	17	29	90
<i>Oryzopsis micrantha</i> (Ricegrass)				4		
<i>Pachystima myrsinites</i> (Mountain lover)					0	
<i>Penstemon</i> sp. (Penstemon)				15		70
<i>Picea pungens</i> (Blue spruce)			0	0	0	
<i>Pinus edulis</i> (Pinyon pine)				0	0.06	2
<i>Pinus ponderosa</i> (Ponderosa pine)				0	0	1
<i>Populus angustifolia</i> (Narrowleaf cottonwood)	0	0	2	11	20	
<i>Populus tremuloides</i> (Quaking aspen)	0	0	0	12	7	0
<i>Pseudotsuga taxifolia</i> (Douglas fir)				0	0.8	
<i>Quercus gambelii</i> (Gambel oak)					0	8
<i>Rhus trilobata</i> (Squawbush)					0.3	0
<i>Rosa woodsii</i> (Wild rose)		0	1	15	90	60
<i>Salsola kali</i> (Russian thistle)				7	3	

Table 5.5. (Continued)

SPECIES	AVERAGE PERCENT INJURY					
	SO ₂					
	.5 ppm	1 ppm	2 ppm	4 ppm	6 ppm	10 ppm
<i>Senecio streptanthifolius</i> (Groundsel)				0	8	
<i>Sitanion hystrix</i> (Squirreltail)			0			
<i>Sphaeralcea</i> sp. (Cutleaf globe mallow)			0	0.03	17	40
<i>Sphaeralcea parvifolia</i> (Globe mallow)	20	22	43	38	30	
<i>Sporobolus cryptandrus</i> (Sand dropseed)		0	0	0	0	0
<i>Stipa occidentalis</i> (Needlegrass)					0	73
<i>Symphoricarpos oreophilus</i> (Snowberry)		0.3	6	18	32	
<i>Tragopogon dubius</i> (Goatsbeard)			0	4	8	
<i>Trisetum spicatum</i> (Trisetum)						90
<i>Viola</i> sp. (Viola)					25	
<i>Yucca</i> sp. (Yucca)						0

SO₂. Bonte et al. (1975) found that SO₂ induced Pelargonium hortorum stomata to close. Jerry Dodd (personal communication) indicated that Agropyron smithii stomata were induced to close by SO₂ fumigation. In summary, the response of stomates to SO₂ exposure shows conflicting results and is not adequately understood at this time.

Once SO₂ enters the leaf it quickly goes into solution in the aqueous medium bathing the mesophyll cells. SO₂ has a relatively high solubility in water (Bennett et al. 1973). Hocking and Hocking (1977) suggest that sulfur enters the mesophyll cells primarily in the form of aqueous, unreacted sulfur dioxide (SO₂ · H₂O). Once in the cells, it is converted to sulfite (SO₃) and bisulfite (HSO₃) ions (Ferenbaugh 1979). SO₃ is then converted to sulfate (SO₄) which in turn is converted to organic sulfur (Thomas et al. 1944, Daines 1968, Barrett and Benedict 1970, and Schiff and Hodson 1973). Both SO₃ and SO₄ can be toxic to plants in high concentrations.

Agropyron smithii was studied as a perennial producer species in the Montana grasslands. SO₂ was found to stimulate new leaf growth while simultaneously accelerating senescence (Heitschmidt et al. 1978). Lesions typical of SO₂ toxicity were not found. Since this new leaf production was noted only after midsummer, the authors hypothesized that during the early part of the growing season, plants incorporated atmospheric sulfur without any adverse effects; however, with the reduced metabolic activity in late summer, a plant's capacity to incorporate this sulfur is limited, and SO₂ derivatives accumulated to levels disrupting normal leaf physiological processes.

Dodd et al. (1979) reported that in long-term SO₂ field fumigations of Agropyron smithii at concentrations less than or equal to 0.1 ppm increased leaf senescence was observed for the reduced growth portion of the growing season (mid-June to mid-July) but not for the high growth portion (beginning growth to mid-June) (Fig. 5.2). They concluded the reason for this was that, during the high growth period, the plants grew at a sufficient rate to incorporate SO₂ sulfur into normal metabolites, thereby preventing toxic levels of SO₃ or SO₄ from accumulating. This hypothesis is supported by the work of Miller and Xerillos (1979). They found the greater SO₂ resistance of certain cultivars of soybeans to be a function of their ability to rapidly convert SO₃ to SO₄. After the SO₃ flux into plant tissue surpasses the plants' ability to convert it to SO₄, detrimental levels of SO₃ may build up in the tissue. SO₃ is estimated to be 30 times more toxic than SO₄ because of its reducing potential (Barrett and Benedict 1970). It is also hypothesized that as SO₃ progressively accumulates in leaf tissue above a deleterious threshold level all plants probably exhibit a similar injury response curve.

Chronic injury occurs in response to long-term, relatively low-level exposures to SO₂. It is a result of deleterious levels of SO₄ being maintained in the leaf tissue over an extended period of time (Daines 1968, Barrett and Benedict 1970, and Kabe 1976) and of the long-term cumulative effects of sub-acute levels of SO₃ in leaf tissue, as suggested by Ziegler's (1975) and Malhorta and Hocking's (1976) discussions on SO₃ effects on enzymes and chlorophyll. Chronic injury, depending on its degree, may manifest itself by necrosis, chlorosis, increased leaf senescence, and/or reduced productivity.

Figure 5.2. Leaf growth rate response of Agropyron smithii for the field to fumigation with ambient levels of SO₂ (Dodd et al. 1979).

From the literature it appears that chronic responses start to significantly manifest themselves after about a month's duration. Nearly all of these experimentally determined chronic responses are based on a continuous or regular fumigation pattern at a constant level of exposure.

Chronic visible injury response to SO_2 exposure has been reported for a variety of different plants under a variety of different exposure concentrations and durations. However, there seems to be a void of comprehensive long-term investigations on chronic plant responses to SO_2 under varying but controlled conditions of plant sensitivity and exposure concentration and duration. Results from a number of investigations on chronic plant response are presented in Fig. 5.3. These investigations were conducted under favorable growth conditions, i.e., conditions of reduced stomatal resistance. The plotted responses suggest a basic linear increase in injury with increasing SO_2 concentration of approximately equivalent exposure durations. They also suggest that the incipient injury threshold concentration is higher for resistant plants.

A number of investigators have reported that reduction in yield is apparent in plants fumigated with SO_2 until levels sufficient to cause visible damage are reached (O'Gara 1922, Hill and Thomas 1933, Swain and Johnson 1936, Katz and Ledhingham 1939, Brisley et al. 1959, Fallor 1970, Davis 1972, and Bennett and Hill 1973a).

Reduction in alfalfa yield was not measureable by Thomas (1956) and Katz (1949) below a minimum of 5% of the leaf area destroyed. Katz reported that exposures of 7 hours at 1.1 ppm SO_2 produced no leaf injury, whereas exposures of 66 hours at 0.46 ppm produced 11.3% visible injury and reduced yield about 12%. However, subtle injury due to atmospheric SO_2 in eastern Colorado resulted in physiological injury without accompanying visible injury. Thomas (1956) fumigated alfalfa in field plots and found that continuous doses of 0.2 ppm reduced the photosynthetic rate about 10% upon the 23rd day of treatment; noticeable effects had begun on the 10th day. At 0.3 ppm, a 25% reduction in photosynthetic rate was noted after 2 weeks of continuous fumigation. Although part of this was attributed to visible injury (leaf damage), a slightly heavier dose of 0.45 ppm significantly reduced photosynthetic rate without visible injury. The normal photosynthetic rate recovered after 1 to 2 hours. Visible injury did not occur until 1.0 ppm for 2 hours was reached. The photosynthetic rate (measured as CO_2 uptake) was reduced from 60% of normal at the lower dosages to 30% of normal at the higher dosage.

Bennett and Hill (1973a) found that 2-hour exposures of barley and alfalfa to increasing concentrations of SO_2 between 0.2 and 1.0 ppm progressively increased apparent photosynthetic inhibition without causing visible injury. Siji and Swanson (1974) exposed corn, grown in hydroponic solution, to 1-hour exposures of 1.0 and 3.0 ppm SO_2 with 13% and 50% reductions in apparent photosynthesis and no visible injury. Bell and Clough (1973) reported a significant reduction in yield, number of leaves and tillers, and total leaf area in Lolium perenne (Perennial Ryegrass) without visible injury when exposed to either 0.067 or 0.12 ppm SO_2 throughout the entire growing season. Bleasdale (1973) found analogous responses when exposing Lolium perenne to ambient air containing concentrations of SO_2 generally less than 0.2 ppm for long periods.

Figure 5.3. Measures of sensitive plant responses to relatively long-term SO_2 exposure. Numbers by data points indicate weeks of exposure.

Recent field research has been conducted on plots of native mid-grass prairie in southeastern Montana by scientists from the U.S. EPA, Montana State University, University of Montana, and the Natural Resource Ecology Laboratory at Colorado State University. The research has been conducted throughout the growing seasons of 1975 through 1979. Treatments have been applied to the grassland ecosystem for durations of 30 days at median concentrations of 0.02, 0.05, and 0.10 ppm SO_2 with large daily fluctuations. Other sites were continuously fumigated with 0.2, 0.4, and 0.7 ppm of SO_2 during the entire growing seasons of 1975 and 1976. Reports from these experiments show that:

- 1) sulfur dioxide stimulated western wheatgrass leaf growth by increasing the number of leaves per plant, but that, probably through an increase in physiological activity, the leaves senesced more rapidly,
- 2) sulfur dioxide treatments did not significantly alter the net production, the growth rates, the net assimilation rates, nor the leaf area ratios of western wheatgrass or the entire community,
- 3) the effects of SO_2 on leaf growth and the nitrogen:sulfur ratios in plant material, indicated possible sulfur deficiency in the grasslands studied (Heitschmidt et al. 1978).

The effect of SO_2 on photosynthesis is not always inhibitory. A number of studies have found an apparent stimulation of photosynthesis at low levels of exposure. Thomas and Hill (1937) found the photosynthetic rate in alfalfa to increase slightly in response to SO_2 fumigation of 0.24 ppm for 3 days, 0.19 ppm for 11 days, and 0.14 ppm for 39 days. Katz et al. (1939) found SO_2 exposures of 0.16 to 0.18 ppm caused an apparent increase of photosynthesis in alfalfa. Thomas et al. (1943) observed an increase of apparent photosynthesis in alfalfa grown in sulfur deficient soil at 0.1 ppm SO_2 . However, at the same concentration, they found photosynthetic inhibition in plants grown in sulfur-adequate soil. Muller et al. (1977) found SO_2 levels above 0.1 ppm inhibited photosynthesis in field-fumigated soybeans whereas SO_2 levels below 0.1 ppm stimulated photosynthesis. In a 6-week laboratory fumigation of the sensitive perennial grass Oryzopsis hymenoides, Ferenbaugh (1979) observed an increase in yield of 19% and 21% at SO_2 fumigation levels of 0.03 and 0.06 ppm, respectively. Ziegler (1975) reports a 40% increase in net photosynthesis at an SO_3 concentration of 0.25 μM .

The fertilizing effect of sulfur, an important plant nutrient, by SO_2 exposure is not the only explanation for the observed increases in productivity at low levels of SO_2 exposure. Libera et al. (1973) reported that photo-reduction of NADP to NADPH in the Hill-reaction was stimulated by the presence of SO_3 at 0.25–3.0 μM concentrations in isolated spinach chloroplasts. Ziegler and Libera (1975) further examined this physiological stimulation of photosynthesis. Their findings suggest that SO_3 is oxidized forming HSO_3 which acts as an additional electron acceptor in Photosystem I thus being reduced to SO_3 . An additional electron acceptor might be particularly advantageous at high photosynthetic rates where electron acceptors would more likely be limiting. At increased SO_3 levels the benefits of an additional electron acceptor are outweighed by the competitive inhibition of ribulose -1, 5-diphosphate carboxylase (RuDP-carboxylase) (Ziegler 1975) in C-3 and C-4

plants and by the competitive inhibition of phosphoenolpyruvate carboxylase (PEP-carboxylase) (Ziegler 1973) and inhibition of malate dehydrogenase (Ziegler 1974) in C-4 plants by SO_3 ions.

From these studies it is apparent that physiological injury does occur. Even the enhancement of plant process rates appears to take its toll through early leaf senescence. Normally, concentrations exceeding 0.15 ppm are sufficient to induce measurable subtle injury even for short-term exposures. Sprugel et al. (1979) shows even lower threshold levels in soybean plants (Table 5.6). SO_2 has been reported to affect not only photosynthesis but also respiration. The cumulative effect of altering these processes would be reductions in yield.

The physiological and biochemical investigations of SO_2 effects on photosynthesis reveal a rather consistent pattern of response to increasing SO_2 concentration from low levels. Above SO_2 concentrations of about 0.01 ppm, which is considered "normal" air (Ziegler 1975 and Garland and Branson 1976), there is a stimulation of net photosynthesis (Thomas et al. 1943, Ziegler 1972, Libera et al. 1973, Ziegler 1975). Apparently above SO_2 exposure levels of about 0.1–0.2 ppm the detrimental photosynthetic effects of SO_3 outweigh its stimulation effect (Thomas et al. 1943, Ziegler 1972, Libera et al. 1973, Ziegler and Libera 1975, Malhorta 1977, Muller et al. 1977, and Ferenbaugh 1979). This upper threshold also depends on factors such as the plant species and age (Ziegler 1975) and growth rate.

NO_2 . Air pollution related nitrogen oxides, NO_x , encompass nitrous oxide (N_2O), nitric oxide (NO), and nitrogen dioxide (NO_2).

Plants readily absorb NO_2 because it is highly water-soluble. Uptake is enhanced by temperature increases, low CO_2 concentrations, and high humidity (Srivastava et al. 1975a, b).

In the atmosphere, nitrogen oxides have a relatively short residence time of approximately 5 days (Carrier 1977). The N_2O may react with ozone to produce NO_2 . On the other hand, partly oxidized hydrocarbons are unstable and may react with NO to produce NO_2 and ozone (Holm 1972).

In oats and alfalfa, NO and NO_2 levels below 0.6 ppm for 45–90 minutes inhibited apparent photosynthesis (Hill and Bennett 1970). Growth suppression and leaf distortion occurred at 0.5 ppm over several weeks while visible injury was not noticed until concentrations exceeded 50 ppm over 8 hours, 150 ppm over 4 hours, or 250 ppm over 1 hour. Taylor and Eaton (1966), MacLean et al. (1968), and Mudd (1973) found that NO_2 had only a slight effect on transpiration rate and stomatal diffusion resistance.

When NO_2 enters the leaf it reacts with the aqueous medium bathing the mesophyll cells and forms a stoichiometric mixture of nitrous and nitric acids (Taylor et al. 1975). When the concentrations of these acids exceed a given threshold, injury occurs. The biochemical effects include enzyme inactivation, chlorophyll impairment, increased amino acid synthesis, and decreased organic acid synthesis (Taylor et al. 1975).

NO_2 injury manifests itself similarly to SO_2 injury (NAPCA 1971, MacLean 1975, Taylor et al. 1975, and Glass 1978a, b). However, the dosages

Table 5.6. Yield reductions in soybeans subjected to varying concentrations of SO₂ in the open-air fumigation system, 1977-1978 (Sprugel et al. 1978). Values are given $\pm$ standard error.

Plot	Mean SO ₂ concentration (ppm)	"Dose" (ppm-hr)	Yield (kg/ha)		Yield reduction (%)
			Fumigated	Control	
1977					
Ambient	0.005-0.015	—	2566 ± 77	2577 ± 73	0.3 ± 4.2
Low	0.117	13.3	3052 ± 92	3478 ± 101	12.3 ± 4.3 (p < .01)
Medium	0.300	34.2	2482 ± 65	3140 ± 48	20.5 ± 3.1 (p < .001)
High ^a	0.790 ^b	89.6	1636 ± 52	2992 ± 120	45.3 ± 3.7 (p < .001)
1978					
Low 1	0.095	6.8	2370 ± 27	2531 ± 47	6.4 ± 2.1 (p < .01)
Low 2	0.108	7.8	2256 ± 39	2379 ± 44	5.2 ± 2.5 (p < .05)
Medium 1	0.192	13.5	2191 ± 65	2494 ± 41	12.2 ± 3.1 (p < .001)
Medium 2	0.255	18.9	2008 ± 27	2485 ± 42	19.2 ± 2.0 (p < .001)
High ^a	0.362 ^b	26.1	1859 ± 48	2209 ± 45	15.9 ± 3.0 (p < .001)

^a Visible Injury Observed on Fumigated Plants.

^b Exceeded U.S. Environmental Protection Agency Secondary Air Quality Standards for Sulfur Oxides.

required to produce degrees of injury similar to SO_2 require concentrations of NO_2 approximately three times greater than for SO_2 MacLean (1975). Middleton et al. (1958) found 3-4 times as much NO_2 was required to produce the same degree of injury as that by SO_2 in pinto beans. Van Haut and Strattman (1961) fumigated 60 plant species with a 1:1 mixture of nitrogen oxide (NO) and NO_2 and compared the degree of acute leaf injury to that caused by SO_2 . They found similar injury for the two groups of pollutants but NO_2 was 1.2-5 times less toxic. The incipient visible injury (about 5% necrosis) threshold concentration for short-term exposures listed by Heck and Brandt (1977) indicate that the threshold concentrations are approximately three times higher for NO_2 at all five exposure durations up to eight hours. Although concentrations of NO_2 seldom reach the injury threshold when acting alone, White et al. (1974) observed a synergistic effect on the apparent photosynthesis of alfalfa when combined with SO_2 . They reported that when alfalfa was exposed to 2-hour doses of 0.25 ppm of SO_2 or NO_2 the apparent photosynthesis rate was reduced only 2-3% by SO_2 , and NO_2 caused no reduction. However a fumigation of a mixture of the two pollutants resulted in a 9-15% inhibition of apparent photosynthesis (NAPCA 1970a). Tingey et al. (1971) reported that below 2 ppm NO_2 or 0.5 ppm SO_2 no leaf injury occurred, but plants exposed to mixtures of 0.05 to 0.25 ppm of both gases were injured, indicating a synergistic effect.

Hill et al. (1974) in fumigation experiments on 87 native cold desert species failed to observe synergistic effects using mixtures with as much as 28% NO_2 . However, at the relatively high exposure concentrations they were using (0.5, 1, 2, 4, 6, and 10 ppm) NO_2 probably had a rather small contributing effect, as suggested by White et al. (1974) who showed the contributing effect of NO_2 becoming progressively less with increasing concentrations of SO_2 until a negligible contribution existed at 0.5 ppm SO_2 .

Effects on alfalfa of SO_2 alone and in combination with O_3 and NO_2 with 1-hour doses of less than 0.5 ppm are listed below:

Alfalfa	0.15 ppm SO_2	inhibits photosynthesis, percent not given (White, 1974)
	0.15 ppm NO_x	
		synergistic effects

Alfalfa	0.15 ppm SO_2	greater than additive inhibition (7%) (Heagle 1973)
	0.15 ppm NO_2	

Alfalfa	0.30 ppm SO_2	additive inhibition of photosynthesis (Heagle 1973)
	0.10 ppm O_3	

2-hour exposure of NO_2 + SO_2 @ 0.15 ppm caused 7% reduction in apparent photosynthesis (White 1974)

4-hour exposure of	0.10 ppm SO_2	caused 24% leaf injury (Tingey et al. 1978)
	0.10 ppm O_3	

Douglas Fir	< 0.01 ppm SO ₂	growth abnormalities
	0.01 ppm NO ₂	needle loss
	0.07 ppm HF	tissue loss
	0.05 ppm O ₃	
	4 month average during growing season	

(US EPA, 1971)

In summary, nitrous oxides are significant pollutants in themselves and contribute considerably to the formation of other pollutants by participation in photochemical reactions. The gross effects of acute NO₂ exposures on metabolism, growth, and yield of crop plants, population changes in natural plant communities, and the importance of soils and vegetation canopies as sinks for the removal of NO₂ are not well understood (Glass 1978a, b). NO₂ can be phyto-toxic at high levels, but exposure, dose, and response information is scarce (Naegele 1974).

Hydrocarbons. Hydrocarbons are of concern due to possible accumulative effects within the food chain. Accumulation to toxic levels varies by species (Ratsch 1974), but it appears that hydrocarbons can react with enzymes and may also behave as plant hormones. Other hydrocarbon complexes can damage membrane permeability (Auerbach 1975).

After reviewing the literature on hydrocarbon effects on plants, the National Air Pollution Control Administration (NAPCA 1970c) reported that ethylene (C₂H₄) is the only hydrocarbon that should have adverse effects on vegetation at ambient concentrations of 1 ppm or less. The hydrocarbon gases closest in effect to ethylene are acetylene and propylene, but concentrations of at least 60–500 times that of ethylene are required to produce adverse effects (NAPCA 1970c).

Atmospheric ethylene is degraded by three mechanisms; ozone oxidation, a light-dependent reaction with NO₂, and uptake by soil microflora (Abeles et al. 1972).

Unlike most air pollutants, ethylene does not directly cause destruction of plant tissues (Crocker 1948). Its primary effect appears to be one of growth regulation. Some of the more important growth-regulating responses caused by ethylene are inhibition of shoot and root elongation, hastening of fruit ripening, epinasty of leaves, inhibition of leaf expansion, inhibition of flowering, and increased senescence and abscission of leaves (Abeles and Heggestad 1973). Ethylene is in fact a natural physiological product of plants. Its production in various plant parts is generally observed to increase during the latter stages of maturation or aging in these parts.

At 1 ppb over 24-hour dose duration, marigolds were injured (Naegele 1974). Chronic effects are distortion of growth, epinasty, chlorosis, necrosis, leaf and bud abscission, and stimulation of lateral buds and shoot (Brandt and Heck 1968). Ethylene effects have also been described as growth inhibition, loss of geotropic sensitivity, leaf drop, and development of abnormal growths (Carrier 1977).

Although ethylene most likely comes into contact with receptive plant tissues via the stomata, it is not metabolized or taken up by plants (Abeles and Heggestad 1973). Hansen (1942) found that if levels of ethylene

surrounding plant material are monitored, they are never observed to decrease. Consequently, after a short period of time, less than 24 hours, the internal leaf and atmospheric concentration of ethylene reach equilibrium. Therefore, a daily average projected ethylene concentration probably adequately represents daily average internal leaf concentration.

Burg (1968) suggests that ethylene inhibits elongation in stems and roots by inducing cell wall microfibril deposition which allows for greater radial expansion and inhibits longitudinal expansion of the cells.

Ethylene apparently reduces leaf expansion by an inhibition of cell division (Burg et al. 1971). Middleton et al. (1958) found that concentrations as low as 0.05 ppm caused abnormal growth of marigold and 0.1 ppm caused leaf abnormalities in tomato.

Flowering is apparently one of the plant processes most sensitive to ethylene exposure. Abeles and Heggstad (1973) reported the number of Cutler soybean flowers was reduced by 91% in response to fumigation with ethylene at 0.025 ppm for 50 days. They also reported that the number of male cucumber flowers was reduced by 83% by the same ethylene concentration for 46 days. Heck et al. (1961) reported that while fumigating four cotton plants with 0.6 ppm ethylene for three months only one flower was observed whereas for the same period 13 flowers were observed on the four central plants. Their examination of the effect of ethylene on flower production, plant height, leaf area, and leaf abscission in cotton indicate inhibition of flower production to be the most dramatic response.

Epinasty in plants also appears to be quite sensitive to ethylene exposure. Epinasty occurred in sensitive plants after a 3-hour exposure to a 3 ppm ethylene concentration and after a 24-hour exposure to a 0.3 ppm ethylene concentration (NAPCA 1970c). Exposure to as little as 0.001 ppm for 20 hours caused epinasty in the very sensitive African marigold (NAPCA 1970c).

Leaf senescence is also accelerated by ethylene exposure. Increased chlorophyllase activity, believed to play a role in chlorophyll degradation, was observed in response to ethylene exposure (Abeles 1973). Protein and RNA levels in leaves have been observed to diminish after ethylene exposure (Abeles 1973). In addition, leaf abscission has been found to be directly coupled to increased leaf senescence (Abeles et al. 1971).

The data on leaf senescence suggests that the ability of ethylene to accelerate degradation is indirect (Abeles 1973). Ethylene appears to regulate some master reaction, such as central of auxin levels, which in turn regulates the juvenility of plant tissue (Abeles 1973).

Even though ethylene causes a multiplicity of effects in plants, there is a feeling that rather uniform doses produce threshold, half-maximal, and maximal responses for numerous different effects. Using results reported for a number of ethylene fumigation studies, Burg (1968) summarizes threshold, half-maximal, and maximal response ethylene concentration levels for nine different plant responses. His reported levels show this uniformity and suggest that the threshold, half-maximal, and maximal responses occur rather consistently around 0.01, 0.2, and 2 ppm, respectively. Abeles et al. (1971) states that the threshold and half-maximal response ethylene concentration

levels for shoot elongation are 0.01 and 0.1 ppm, respectively. However, he indicates that saturation (maximal) response occurs at 10 ppm. These observations suggest a linearly increasing plant response with the increasing log of ethylene concentration. Figure 5.4 shows the results of a number of long-term investigations on plant response to ethylene fumigation. Burg's (1968) threshold, half-maximal, and maximal response concentrations are also plotted here. These observed long-term responses seem fairly compatible with Burg's (1968) response levels.

Carbon Monoxide. Plants will not be affected by carbon monoxide since they do not remove CO from the air. The dose required to cause plant injury is extremely high (Dvorak 1978).

Particulates. Particulate pollution is unique in several ways. Its effect is very local due to a low dispersion rate (high rate of deposition) directly related to particulate sizes.

Because particulates are suspended solids rather than atmospheric gases, they are often discussed in terms of heavy metals emitted during combustion or in terms of dust-suspended solids with varying diameters. To date, the data base from which to draw specific conclusions is very limited. There is little data available on the delayed effects on plants and effects on soil (NAPCA 1979). Not only has research been sparse and inconsistent, but toxicity indexes are of little use due to the multitude of unique plant-soil combinations (Lagerwerff 1967).

In general, metal particulates that gain entry via stomates remain biologically inert, whereas metals entering via root uptake can cause immediate phytotoxicity. Accumulation to toxic levels is also species-specific (Ratsch 1974). Although accumulator plants may have developed a mechanism for coping with potential toxic concentrations, such an accumulation may have deleterious effects on the ecosystem (Tyler 1972).

Heavy metal particulates may cause visible lesions or physiological alterations. Physiological alterations in plants can have delayed but long-term effects on the ecosystem, especially as soil chemistry is altered (NAPCA 1979).

Dust particulates affect plants differently depending upon the size of the particulate. The finer sizes tend to enter stomates and clog physiological mechanisms, whereas the larger particles remain external, possibly reducing photosynthetic utilization of sunlight. If rainfall dissolves chemical constituents of the dust particle, further damage can occur.

Other. Ozone, NO_x , sulfur, carbon, hydrocarbons and related acids contribute to photochemical smog. The sun's ultraviolet rays are naturally converted by high altitude stratosphere ozone and therefore do not reach the earth. Lower energy ultraviolet rays, however, do filter through and break apart the NO_2 molecule producing nitric oxide (NO) and oxygen atoms (O). The oxygen atoms combine with molecular oxygen to produce ozone which reacts with NO producing NO_2 and O_2 . Yet a small amount of ozone becomes established in the lower atmosphere. In addition, hydrocarbons in smog indirectly provide a way for newly formed NO to be re-oxidized to NO_2 without using ozone, thereby allowing ozone accumulation. Peroxyacyl nitrate (PAN) is a

Figure 5.4. Various plant responses to long-term ethylene exposure.

potent eye irritant and a plant irritant causing chlorosis (Holum 1972). PAN can be formed from a reaction of most hydrocarbons with ozone. Also, nitric oxide strips an oxygen atom from a hydrocarbon, which in turn reacts with O_2 and NO_2 to form PAN.

PAN-induced injury is dependent on the age of leaves (Dugger 1962) and such environmental factors as sunlight (Taylor et al. 1961).

Another pollution factor in photochemical pollution is that SO_2 and O_3 mixtures, and SO_2 and NO_2 mixtures are known to have synergistic effects on plants.

5.1.1.4 Faunal Effects

Sulfur Dioxide. SO_2 exposure may affect forage quality. A reduction in crude protein was noted with increasing SO_2 concentrations after two years of fumigation. Crude protein content decreased from 10% to 8% after a second year of exposure to very low levels of SO_2 . Herbivores will be affected by secondary (food chain or habitat change) impacts.

It is possible that animals with more mucosal tissues relative to their body size would be more sensitive to exposure. Chronic exposure over several months resulting in irreversible pulmonary dysfunction in dogs occurs at $13,000 \mu g m^{-3}$. At $500 \mu g m^{-3}$, pulmonary problems which have been observed are reversible (Colucci 1976). Some insects are adversely affected at low levels of SO_2 , but no threshold has been identified (Lewis et al. 1976). Table 5.7 summarizes current knowledge of SO_2 effects on animals.

Nitrogen Oxides. Possible effects upon guinea pigs have been noted during exposure for several days at levels of about $1000 \mu g m^{-3}$ (Ziskind and Haus Knecht 1976). More definitive effects occur only above $2000 \mu g m^{-3}$ over several hours or $1000 \mu g m^{-3}$ over several months. Table 5.8 summarizes current knowledge of NO_x effects on animals.

Carbon Monoxide. The lowest exposure producing structural changes to the heart and brain of animals is 50 ppm ($58 \mu g m^{-3}$). This level is still far above expected pollution levels (NAPCA 1970b).

Hydrocarbons. Derivatives of aliphatic and alicyclic hydrocarbons can cause biologically reactive effects at 500 ppm. The aromatic hydrocarbons are both biochemically and biologically active, and are also more irritating. At levels of 25 ppm, systematic injury can result from the inhalation of vapors of aromatic compounds.

Other. In general, animal effects are very closely related to photochemical smog. However, some data is available on specific aldehydes. At a level of 0.06 ppm ($70 \mu g m^{-3}$) eyes are irritated. A level of 2 ppm ($2460 \mu g m^{-3}$) has been found to double the total expiratory resistance of guinea pigs (NAPCA 1970).

Table 5.7. Summary of toxicological experiments with Sulfur Dioxide (SO₂)^a.

Species	Concentration (10 ⁵ µg/m ³)	Duration	Effects
Monkey	<0.034	78 weeks	None
Donkey	<0.078 <0.78		None Impaired bronchial clearance
Dog	0.13	21 hours/day for 620 days	None
Monkey	0.13	78 weeks	None
Guinea pig	<0.13	22 hours/day for 365 days	None
Dog	0.13	21 hours/day for 225 days	Increased pulmonary resistance
Rat	0.026-0.079	12 hours/day for 4 months	None
Mouse	0.18 -0.26	7 days	Increased sensitivity to pneumonia infection
Rabbit	0.26	3-10 days	Increased S-sulfonate clearance
Mouse	0.26	Up to 72 hours	Lesions in respiratory tract
Rat	0.26	6 hours/day, 5 days/week for 113 days	None
	2.6	6 hours/day, 5 days/week, for 22 days	40% mortality
	~15	6 hours/day, 5 days/week, for 12 days	~90% mortality
Guinea pig	0.26	6 hours/day for 20 days	None
Cat	0.52		Increase in pulmonary flow resistance
Rabbit	~0.52	14 and 62 hours	Formation of S-sulfonate
Mouse	13	5 min/day, 5 days/week for 300 days	Accelerated onset of neoplasia
Hamster	14	3 hours/day for 75 days	Increased pulmonary infection
Dog	13-14	2 hours/2 times/week for 4 to 5 months	Change in goblet cells of bronchi and bronchioles
Rat	13-78		Change in goblet cell release
Rat	26	Up to 6 weeks	None
	52	Up to 6 weeks	Bronchial damage
	104	Up to 6 weeks	Death within 22 days
Rat	78	6 hours/day for 10 days	Increased acid phosphatase activity
Rat	78	2 hours	Gastric inhibition
Mouse	≤78	10 exposures of 10 minutes, with 3 or 7 minutes recovery between exposures	Initial decrease in respiratory rate, then progressive return to preexposure rate; desensitization to successive exposures.
Mouse	Various		Sensitized mice to pneumonia infection

^aData extracted from summary of Colluci (1976) and presented in order of increasing concentration, except where there is more than one entry for a single experiment.

Table 5.8. Summary of toxicological experiments with Nitrogen Oxides (NO_x)^a.

Species	Concentration ($10^5 \mu\text{g}/\text{m}^3$)	Duration	Effects
<u>Acute exposures</u>			
Guinea pig	0.01-0.20	4 to 24 hours/day for up to 14 days	Elevated protein in urine
Guinea pig	0.04	Up to 21 days	Increased average area per alveolar wall cell
Mouse	0.02-0.30	Up to 17 hours	Impaired bacterial defense
Monkey	0.2 -1.0	2 hours	Decreased tidal volume, progressive histopathological damage
Rat	0.30-0.34	48 hours	Increase in Type II pneumocytes
Rabbit	0.16-1.2	3 hours	Impaired bacterial defense at all levels of exposure
Hamster	0.60-0.70	7 to 10 days	Bronchiolitic lesions
<u>Chronic exposures</u>			
Mouse	0.01	Up to 12 months	Reduction of functional lung tissue
Monkey	0.02	493 days	Slight to moderate emphysema
Monkey	0.04	14 months	Hypertrophy of bronchiolar epithe- lium in bronchiole
Rat	0.02	14 months	Marginal changes in epithelium
Guinea pig	0.02	6 months	Higher mortality
Rat	~0.06	9 months	Decrease in lung compliance
Rat	0.04	Lifetime	"Emphysema-like" injury suggested
Rat	0.04	Up to 360 days	Increase in number of cells prepar- ing to divide
	0.34	Up to 7 days	
Rat	0.12	6 weeks	Interstitial edema, vascular congestion
Rat	0.20	90 days	Decreased body size
Rat	0.30	90 days	Decreased body size
Mouse	~0.80	Up to 8 weeks	Epithelial damage near terminal bronchioles
Hamster	0.9-1.1	10 weeks	Respiratory rate increased, hyper- plasia and hypertrophy in termi- nal and respiratory bronchioles

^aData extracted from summary of Ziskind and Hausknecht (1976) and presented in order of increasing concentration, except where there is more than one entry for a single experiment.

5.1.2 Construction and Operations

Most of the adverse environmental impacts on land features would occur during the construction phase. The only other significant adverse impact could occur should there be an accident or natural disaster causing an oil leak or spill from storage tanks or pipelines.

During construction, vegetation will be disrupted at the complex site. Erosion is common to the area because of weather extremes often experienced. Severe thunderstorms with very high rates of precipitation are especially effective in eroding the soil and causing the streams in the area to become highly sedimented. During construction of the complex, the erosion potential will be increased wherever and whenever protective cover is removed and existing drainage paths are changed or disrupted.

Revegetation of the disturbed area is important to reduce any adverse impacts and to help prevent soil erosion. Chemical characteristics of the soil influence the ease with which revegetation can be accomplished. Special care should be taken to use soils with the lowest salinity for "top soils" since top soils are more difficult to revegetate with desirable plants. High saline concentrations also enhance the spread of halogeton (Halogeton glomeratus), a plant poisonous to livestock, especially sheep. It thrives on disturbed halophytic sites and long linear disturbances, such as pipelines and roads, which enhance its spread into new areas (Eckert and Kinsinger 1960, Kinsinger and Eckert 1961). In general, surface soils should be removed and "stored" during complex construction and returned to cover appropriate areas when shale oil extraction plants have been built.

Water quality will decrease as a result of an increase in sediment loads and total dissolved solids (TDS) concentrations. These increases will affect turbidity, water temperature, oxygen content, metallic, and non-metallic concentrations. Shale oil development will also affect amounts of surface flow and flow patterns. The primary source for increased sediment loads and TDS concentrations will be the 400 million tons of processed shale oil over years of extraction, raw shale, spent catalyst, green coke, and process water. Increased sediment loads and TDS levels will be caused by extraction plant construction, various pipelines, road construction and improvements, railroad sidings and building construction, and construction of water intake facilities on the Colorado River near Grand Valley.

Some increased runoff resulting in increased sediment load and TDS may be expected from powerline construction and service facilities related to increased population. Clean-up of oil spills will also produce increased sediment levels and TDS concentrations. This latter will depend on the size of the spill, time of year, presence or absence of access roads to the spill and size and number of equipment.

Most of the area affected by shale oil mining embodies a unique combination of natural and cultural conditions that promote good upland habitat, which is ecologically fragile. Desert floras and the associated fauna are of relatively recent origin (Axelrod 1950). Existing as they do in water scarce regions, these formations are especially responsive to perturbations in rainfall regimes. They are, therefore, particularly susceptible to man-induced changes in available water and run-off patterns.

The Federal Task Force concedes that mule deer, elk, pronghorn antelope, and sage grouse would decline in numbers due to industrial activity and increased human population (Weaver 1973). Even if revegetation programs were successful, at least 15 years would be required for shrubs and trees to become capable of providing food and cover for mule deer. Restoration of pinyon-juniper areas may take 50 to 100 years (Weaver 1973). Besides altering the habitat, the shale oil industry will also drastically affect water availability and quality (Quale 1973).

Cringan (1974) and Carlson and Cringan (1975) have evaluated the impacts of shale oil development during three phases of development (construction, operation, and post-operation) and at three levels of influence (local, intermediate, and extended).

Greatest impact will occur at the local level of influence. The major factors here will be the operating procedures, disposal of residues, and the actual mine sites. Nearly all species of wildlife are expected to decline because of loss of habitat and from all forms of human activity. Many mammals and bird species will be reduced by 25 to 50% within 3 to 10 years. These reduced populations include mountain lions, bobcats, elk, black bear, skunks, porcupines, coyotes, weasels, badgers, mule deer, wild horses, golden eagles, bald eagles, sage grouse, mourning doves, owls, woodpeckers, turkey vultures, nighthawks, and hummingbirds.

Intermediate impacts will be caused primarily by downstream water pollution. Species inhabiting riparian communities will consequently be most affected. Mammal species, such as muskrats and raccoons, and waterfowl and shorebirds will undergo moderate to high declines.

Maintenance of riparian habitats might mitigate the above declines as would development of compensatory tracts of lands.

The extended impacts will come primarily from the expected influx of residents due to the available job market. Mammal and avian species will undergo moderate to high declines as a result. New (human) community developments are expected to cause major problems for waterfowl, great blue heron, chukar, and beaver.

A mature, producing oil shale industry would also be detrimental to the local livestock industry because of reduced water supplies for cattle. However, this livestock reduction, if followed by reduced predator control, might help increase the populations of coyote, bobcat, black bear, mountain lion, and golden eagle.

In all, it seems likely that beaver, mountain lion, elk, and sage grouse will be eliminated from the shale oil region by a mature shale oil industry. It is likely that only beaver and elk would be reestablished after operations cease.

5.1.3 Human Related Disturbance

One further aspect of human disturbance in the area deserves mention; that of road kill of mule deer. Rio Blanco County consistently has a large

number of deer-auto collisions and in combination with Garfield County, has often led the state in highway deer kill. Most of these kills occur along Colorado Highway 13 south of Meeker and Colorado 64 west of Meeker. Both of these highways cut across deer migration routes and lie in a portion of their winter range (Yeager 1972). Such accidents pose a danger not only to the animal involved but to the automobile occupants as well.

Mule deer constituted nearly all the road kills, most of which were mature does (Boyd 1964). Between 1968 and 1970, 338 known highway kills were reported in Rio Blanco County (Pojar 1971). However, a road-strip count of dead deer indicated that 45% of the deer hit by automobiles get far enough away from the highway after being hit that they are neither detected nor reported (Boyd 1962).

The monthly kill is primarily a function of the average hourly traffic volume, rather than deer abundance near the highway (Yeager 1970). Myers (1970) found that although weekly spotlight counts showed deer were concentrated along the highway between January and April, 40% of the total yearly collisions occurred in October, November, and July. The October deer-auto kill is three times higher than any other month (Pojar 1971). This high October rate results from the combination of the large number of migrating deer and the heavy hunter-traffic volume. Over 50% of the collisions occur on weekend evenings (Myers 1970), with 71% of the collisions occurring at known deer crossings (Boyd 1962, Pojar 1971).

The monthly road-kill is also related to the relative ruggedness of the terrain along the roadway (Yeager 1970). Myers and Reed (1969) found that 6% of the adjacent land was relatively flat, 60% was gently rolling, 20% was moderately rough, and 11% was rough. The vegetation types consisted of 43% sagebrush, 10% pinyon-juniper, and 22% other browse. Most collisions take place at lower elevations, in moderately rough to rough terrain with a high percentage of pinyon-juniper close by (Myers and Reed 1969).

Removal of brush from highway edges has no significant effect in decreasing the number of accidents (Myers and Reed 1969). However, installation of 8-foot fencing reduced deer crossings by 82% and reduced deer kill 61% on Colorado Highway 82 (Woodward 1973). One-way gates in conjunction with 8-foot fences were 96.2% effective in one-way passage allowing deer to escape the highway right-of-way (Reed 1973, 1975).

For almost 100 years the mule deer in the area of the White River drainage have been a major source of protein food and recreation for local citizens. In addition, for some 50 years these residents have enjoyed a significant income from outsiders through sale of pass-rights, guiding services, food and lodging, retail sales of hunting supplies, and automotive supplies. Statewide comparisons of deer hunter success ratios by hunting units show that the Basin units have been consistently among the highest in Colorado for the past 20 years (RBOSP 1977, McKean and Burkhard 1978). These trends and figures should continue with shale oil development providing industrial developments and other related activities do not destroy the deer winter habitat.

The proposed developments and the attendant water supply augmentation would provide water for industrial, municipal, and domestic use in connection

with anticipated exploitation of local coal and shale oil reserves. Local agriculture could be stabilized and enhanced through provision of a more firm water supply for irrigation of an estimated 10,500 acres of land presently providing a surplus crop of wheat to non-surplus feed crops (such as alfalfa) for livestock. Regulated streamflow and reservoir levels would enhance recreation, fisheries, and maintenance of wildlife (McKean and Burkhard 1978).

5.2 MODELLING APPROACH

5.2.1 Air Pollutants

5.2.1.1 Abiotic Modelling Steps

At the current time, literature is being reviewed to determine possible pathways for deposition and transfer of pollutants through the abiotic system. If the magnitudes of the effects are found to be insignificant, then they will not be incorporated into the model. If the effects are incorporated, they will be treated as continuous events (Sec. 4.4.2).

5.2.1.2 Floral Modelling Steps

Overall, we need to get the driving variable data into parts per million, combine the effects of NO_2 and SO_2 , calculate the relative growth rate, use this to get an achieved growth rate, calculate an average value of the effluent effect, reduce photosynthesis using a subsidy-stress philosophy, and calculate a death injury response.

NO_2 and SO_2 are the only effects included; the other effluents are disregarded because they are too low to be of major consequence in comparison to the preceding two.

Plants are classed into three susceptibility levels. For our purposes, "resistant plants" include the genera Pinus and Juniperus. The "high sensitivity plants" include Oryzopsis hymenoides. The "low sensitivity plants" include the other grasses and the forbs. Thus, most of our plants are of low sensitivity.

Leaf Tissue Exposure Concentration. Initially, SO_2 and NO_2 projected daily average concentrations (ppm) are converted to leaf tissue exposure concentrations, $l_{(11,2)}$, by considering leaf and atmospheric resistances to gaseous flux into the leaves. The daily average SO_2 leaf tissue exposure concentration is adjusted for the contributing effect of the daily average NO_2 level. Next, the relative daily growth rates, $l_{(11,7)}$, are calculated for the different plants at the present time step.

The ratio between actual and potential transpiration is given as an approximation to the electrical resistance analog model of diffusion into a leaf, which reflects relative stomatal resistance in a leaf.

$$l_{(11,1)} = \exp (P_{(3,4)} \cdot l_{(3,10)})$$

Since the documented experimental plant responses to pollutant exposure were primarily determined under favorable growth conditions (conditions of reduced stomatal resistance), the actual transpiration-potential transpiration ratio when multiplied times the projected atmospheric pollutant concentration provides an estimate of the internal leaf concentration. In the model, this product is termed the adjusted leaf tissue exposure concentration, $l_{(11,2)}$.

The effect of NO_2 is considered as producing a contributory effect on plant response as a function of the projected SO_2 concentration. The functional relationship used to model this contributory effect is shown in Fig. 5.5. The dependent factor in this relationship is a function of the SO_2 exposure concentration and when it is multiplied times the NO_2 exposure concentration transforms it into a concentration equivalent in effect to SO_2 at that concentration. This multiplier is given by:

$$\begin{aligned} l_{(11,6)} &= 1.0 && \text{if } l_{(11,4)} \leq 0.14 \text{ ppm} \\ l_{(11,6)} &= 2.25 \cdot \text{EXP}(-5.95 \cdot l_{(11,4)}) && \text{if } l_{(11,4)} > 0.14 \text{ ppm} \end{aligned}$$

This transformation factor is calculated as a function of the SO_2 exposure concentration and then multiplied times the NO_2 exposure concentration and the result then added to the SO_2 exposure concentration to increase its effective concentration. The new SO_2 exposure concentration is termed the NO_2 adjusted SO_2 exposure concentration $l_{(11,3)}$. For lack of good data on high-level and long-term exposures to mixtures of NO_2 and SO_2 , it is hypothesized that this functional relationship is also sufficiently realistic for these conditions. Threshold concentration values and exposure durations which produce leaf necrosis is illustrated in Fig. 5.6.

A check is made to determine if it is greater than 0.01 ppm. When it is, the upper limit daily average SO_2 leaf tissue exposure concentration at which net photosynthetic stimulation will occur is determined for a plant group as a function of its relative daily growth rate. A check is then made to determine if the daily average SO_2 leaf tissue exposure concentration is less than this upper limit. If it is, photosynthetic stimulation is determined. If not, then photosynthetic inhibition is determined.

Any dose of SO_2 (even ambient) will increase leaf senescence.

Effect on Photosynthesis. Photosynthetic stimulation is simulated by the upper half of a sine curve as a function of daily average SO_2 exposure concentration for a domain between 0.01 ppm and the incipient threshold for photosynthetic inhibition, which is determined as a function of the relative daily growth rate (Fig. 5.7). The incipient photosynthetic inhibition threshold concentration ranges from 0.05 ppm for $l_{(11,7)} = 0$ to 0.21 ppm for $l_{(11,7)} = 1$. The maximum photosynthetic stimulation is a 20% increase. This relationship is given by:

Figure 5.5. Relative effect of NO₂ on the apparent net photosynthetic rate in combination with equivalent or greater concentrations of SO₂. Data points from White et al. (1974) for alfalfa.

Figure 5.6. Threshold SO_2 concentrations that will produce about 5 percent leaf necrosis in sensitive, intermediate, and resistant plants grown under sensitive conditions (Heck and Brandt 1977).

Figure 5.7. Effluent effect on net photosynthesis. The figure illustrates the most sensitive species at full growth rate.

Figure 5.8. Effluent effect on daily leaf death rate.

$$I_{(11,9)} = 1.0 + 0.2 \sin \left[\frac{\pi}{(I_{(11,8)} - 0.01)} (I_{(11,2)} - 0.01) \right]$$

$$\text{if } 0.01 \leq I_{(11,2)} \leq I_{(11,8)}$$

When the daily average SO₂ exposure concentration exceeds the incipient photosynthetic inhibition threshold concentration but is still below the incipient acute visible injury (5% necrosis) threshold concentration, the inhibition is simulated as an increasing linear response from zero inhibition at the incipient photosynthetic inhibition threshold concentration to 20% inhibition at the acute, visible injury threshold concentration.

$$I_{(11,9)} = 1.0 - \frac{0.2}{P - I_{(11,15)}} \cdot (I_{(11,2)} - P)$$

$$\text{if } I_{(11,2)} > I_{(11,7)}$$

where P = 1.22, 0.73, or 0.32 for resistant, intermediate, and sensitive plants (derived below).

In the above equation the intermediate variable $I_{(11,8)}$ adjusts the right-hand intercept based on relative growth rate:

$$I_{(11,8)} = 0.05 + 0.16 \cdot I_{(11,8)}$$

where the relative growth rate is given by:

$$I_{(11,7)} = [f(I_{(11,1)}) \cdot f(I_{(3,1)}) \cdot f(I_{(3,9)}) \cdot I_{(3,18)}] \div dt$$

The net photosynthetic rate of visibly non-injured leaf tissue is reduced by 20% for daily exposure concentration values above incipient, acute injury, threshold concentrations. The underlying hypothesis in this formulation is that when leaf tissue is physiologically disturbed to an extent which would cause greater than 20% inhibition of net photosynthesis, the tissue exhibits visible necrosis. Another assumption made here, because of lack of data, is that at daily exposure concentration levels above the incipient visible injury threshold concentration the photosynthetic rate of the live leaf tissue is consistently reduced by 20%.

Injury Response. The visible injury and senescence responses in the model are determined as a function of a 30-day average NO₂ adjusted SO₂ leaf tissue exposure concentration. The chronic response for each plant group in the model is evaluated at each 1-day time step as a function of $I_{(11,2)}$.

The senescence response is coupled with an increase in leaf growth rate. Because Dodd et al. (1979) observed the leaf senescence/growth response in Agropyron smithii without associated chronic visible injury at relatively low SO₂ levels, the leaf senescence/growth effect is simulated to occur in response to all levels of pollution.

O'Gara's (1922) acute SO₂ dose-response model modified by Thomas and Hill (1935):

$$B = (I_{(D,12)} - A) \cdot dt$$

was used to determine sensitive class acute injury response. For three SO_2 injury levels (incipient, 50%, and 100% leaf necrosis) in alfalfa they reported values for A and B with $I_{(D,12)}$ measured in ppm and dt in hours:

	A	B
Incipient (threshold) injury	0.24	0.94
50% leaf destruction	1.40	2.10
100% leaf destruction	2.60	3.20

Heck and Brandt (1977) indicated that this model provided a reasonable fit for exposure durations up to 10–12 hours but should not be extrapolated beyond this duration. Twelve-hour SO_2 concentrations for the three injury levels in alfalfa are plotted in Fig. 5.7. The sensitive class injury response curve was determined by drawing it through its extrapolated 12-hour incipient injury threshold, yielding a value of 0.32

This species-specific parameter (P) represents the dose level for approximately 12 hours that would be required to produce 5% necrosis according to the O'Gara model as noted above. This can be solved for by using the incipient (threshold) injury values for the parameters A and B and the value of 12 hours and solving for $I_{(D,12)}$. We assume the stomates would not be open for more than 12 hours and, thus, gases would not be entering the leaf. Then, using the data in Figure 5.6, and assuming times of one or two hours we ratio the values for the intermediate and resistant plants to give values of 0.32, 0.73, and 1.22. These levels are expressed in parts per million.

The exponential equations estimated in Fig. 5.8 and below are based on 5% necrosis being detected at the levels of 0.32, 0.73, and 1.22 ppm defined as thresholds above. The exponential part of the equation is then simply fitted through the points (0,1) and (1,1.05) where I represents the three levels noted above.

The visible injury/senescence in the model is determined as an exponential function of $I_{(11,2)}$. The injury-response relation is given by:

$$\text{sensitive} \quad I_{(11,5)} = e^{0.15I_{(11,2)}} - 1.0$$

$$\text{intermediate} \quad I_{(11,5)} = e^{0.067I_{(11,2)}} - 1.0$$

$$\text{resistant} \quad I_{(11,5)} = e^{0.040I_{(11,2)}} - 1.0$$

The intermediate variable $I_{(11,5)}$ is the percent of leaf area necrosed per day.

The biomass lost per time step is then:

$$F_{(3,8)} = (I_{(11,5)} \cdot I_{(3,1)} \div P_{(3,22)}) \cdot dt$$

This must be less than or equal to the total green biomass.

Response to Ethylene. The vegetative response to ethylene in the model is determined directly as a function of its projected impingement concentration rather than as a function of a calculated leaf tissue exposure concentration as previously described for the effects of SO_2 and NO_2 .

Ethylene is modeled differently from SO_2 and NO_2 . Initially, a daily average ethylene concentration (ppm) is projected for the existing 1-day time step. Using this daily average concentration, a 30-day weighted moving average ethylene concentration is calculated. A check is then made to determine if this is greater than an incipient inhibition threshold concentration for each plant group. If it is, the general response (fractional plant response reduction) is determined for that plant group as a function of the ethylene concentration. This 30-day based response is then divided by 30 to obtain a response to be implemented for the present 1-day time step. Leaf senescence is increased by this fraction and leaf growth is reduced by it. If the ethylene concentration is not beyond the incipient inhibition threshold concentration, no effect is simulated.

The general plant response to ethylene exposure for three sensitivity classes in the model is a function of the 30-day weighted moving average ethylene concentration. The functional relationships used to determine the plant responses of the three sensitivity classes are given in Fig. 5.9. The sensitive class response is primarily based on Burg's (1968) threshold, half-maximal, and maximal general plant responses. Since the concentrations he reported for these response levels were primarily determined from investigations on sensitive plants, nearly always in the seedling stage, it is inferred that these responses are representative of the sensitive class. The intermediate and resistant class responses are hypothesized to exhibit threshold, half-maximal, and maximal responses at somewhat higher ethylene concentrations.

Heck and Pries (1962b) survey of the response of a large number of plants to 10-day ethylene exposures at 2, 5, and 10 ppm indicated that grasses are rather insensitive and that Juniper is somewhat more sensitive than the grasses, showing abscission of branchlets at the 5 ppm exposure level. Consequently, the Agropyron smithii plant group is considered representative of the resistant class and the Pinyon/Juniper plant group is considered representative of the intermediate class in the model. Due to a lack of information on the sensitivity of desert shrubs, the Artemisia tridentata plant group is hypothesized to be a representative of the intermediate class in the model.

It is also hypothesized in the model, until more information is obtained, that the numerous kinds of plant responses to ethylene are equivalent in degree.

At the present time, the actual plant responses implemented in the model will be increased leaf senescence and reduced leaf growth. Because the model responses are a function of a 30-day weighted average daily ethylene concentration and are based on long-term responses considered from the literature, the inhibitional response determined from the functional relationships in Fig. 5.9 are divided by 30 to produce a response appropriate for a 1-day time step.

Figure 5.9. Simulation of general plant response to ethylene in the model for three sensitivity classes.

The equations in Fig. 5.9 are:

$$\begin{aligned} I_{(11,3)} &= 0 + 1.443 \cdot \ln(I_{(D,14)}) && \text{sensitive} \\ I_{(11,3)} &= 0.02 + 0.707 \cdot \ln(I_{(D,14)}) && \text{intermediate} \\ I_{(11,3)} &= 0.03 + 0.541 \cdot \ln(I_{(D,14)}) && \text{resistant} \end{aligned}$$

where $I_{(11,5)}$ is the percent reduction in growth and $I_{(D,14)}$ is the projected daily average ethylene concentration (ppm).

5.2.1.3 Faunal Modelling Steps

As indicated by the literature review (Sec. 5.1.1.4) the effects of development effluents on fauna metabolism are many and varied. In addition, most of the effects are on body organs or processes which are not within the scope or resolution of the simulation model. For these reasons, fauna metabolism is not affected by development emissions. The effluents will affect animal condition indirectly through changes in plant production and availability.

5.2.2 Construction and Human Related Disturbance

The primary development effects on fauna involve land use changes and human-related activity. Obviously, loss of habitat, especially critical seasonal habitat, has profound affect on the fauna populations. Furthermore, perturbations due to construction or related activities could include transmission lines, power lines, paved roads and associated traffic, barriers such as fences and culverts, increased recreational pressure, and noise.

These effects are implemented through the event structure, primarily the land-use-change event and modify-edge event (Sec. 4.4). The results of these events manifest themselves in the habitat selection and dispersal procedures of the fauna submodel (Sec. 4.3.3.2). During the initialization of fauna species parameters, development factors which affect that species must be defined and rated according to the importance of that factor to the species. Then, during the simulation, the modify edge event is called to add the development factors to the landscape. During the habitat selection procedure, the magnitude of the factor and the importance to the fauna species are considered. Also, during the dispersal procedure, flows may be modified due to the factors present.

Although this approach may appear simplistic, it affords much versatility and power in defining and simulating effects, especially when these effects are not known well enough quantitatively. Thus, additional qualitative aspects may be incorporated during initialization of the simulation, without requiring changes in the simulation algorithm or computer code.

6. A.E.S.O.P. SIMULATIONS EVALUATION

6.1 SCENARIO DESCRIPTIONS

6.1.1 Driving Variable Records

The driving variable records are derived from the meteorology or air quality task groups. Data for temperature, relative humidity, and wind come from the meteorology task force at Battelle (PNL). Precipitation and solar radiation records have been altered from the climate tape. Day length values are calculated according to procedures outlined in Sellars' book Physical Climatology.

Driving variable records are described in two ways. Actual input values for the base climate data are given in Appendix 1L. Plots of the variables (Fig. 6.1) show general trends and variability of the data. Specific values of standard statistics such as the mean, maximum, and minimum are given for each driving variable on each ERU (Table 6.1). All driving variables are adjusted for elevation except hours of daylight, incoming solar radiation, humidity, and wind.

Air temperature values show the expected seasonal patterns (Fig. 6.1F-H). Minimum air temperatures are approximately -30°C . During midsummer, maximum air temperatures range from 25 to 38°C .

Relative humidity values have their lowest point in late summer with highest values in winter (Fig. 6.1I).

Wind velocities are relatively uniform throughout the year (Fig. 6.1C). However, there is a considerable degree of variation from day to day. Average wind velocities were generally in the order of 10 km hr^{-1} .

Precipitation events occurred 31 times during the year (Table 6.1 and Fig. 6.1A). They are frequently grouped on successive days. Highest individual inputs were of the order of 2 cm. Major inputs occur during the late spring through late summer interval. Snow and rain are differentiated only in the modelling process, not in the driving variable records.

Solar shortwave radiation (Fig. 6.1E) and day length (Fig. 6.1D) follow a sinusoidal function. Although solar radiation values are within acceptable ranges, there is a dramatic increase to maximum levels in the spring, which is not typical of the Piceance Basin.

Saturation vapor pressure, potential evaporation, and potential transpiration (Fig. 6.1B, J, K) are calculated from the other driving variables.

6.1.2 Initial Conditions

To run a numerical difference equation model requires an initial value for each of the system state variables. Initial condition values for system state variables are based on general reasoning and a survey of literature

Table 6.1. Statistical summary for climatic driving variables used for prototype simulation. Each block in the table is an ERU except the top block which is the base input climate adjusted to a 5000 foot elevation. (ERU 0, ERU 1, ERU 2, ERU 3 represent highland, upland, lowland, and bottomland, respectively)

AN ECOSYSTEM SIMULATION OF PERTURBATIONS DRIVING-VARIABLE STATISTICS										
	UNITS	MEAN	ZEROS	MAXIMUM			MINIMUM			STANDARD DEVIATIONS
				VALUE	DAY	NO.	VALUE	DAY	NO.	
BASE CLIMATE FOR GRID 5.14										
1. DAYLIGHT	HR	12.000	0	14.700	156	25	9.000	339	25	1.887
2. SHORTWAVE	LY	499.242	0	900.000	109	23	200.000	5	34	222.618
3. TEMPMAX	C	14.939	2	39.200	183	1	-15.000	310	1	12.904
4. TEMPMIN	C	0.102	0	21.100	183	1	-29.500	11	1	11.828
5. TEMPMEAN	C	7.390	1	32.600	239	1	-22.100	310	1	12.252
6. PRECIP	CM	0.051	334	2.100	92	1	0.000	1	334	0.244
7. HUMIDITY	%	0.548	1	1.000	36	3	0.000	196	1	0.193
8. PEVAP	CM	0.015	4	0.045	239	1	0.000	36	4	0.012
9. PTRANS	CM	0.015	4	0.045	239	1	0.000	36	4	0.012
10. SATVAPOR	%	10.099	0	37.380	239	1	0.790	310	1	7.642
11. WIND	KM/HR	12.122	9	25.100	82	1	0.000	69	9	5.172
DRIVEVAR CLIMATE FOR ERU 5.14- 0 C-B TRACT										
1. TEMPMAX	C	11.811	2	31.100	183	1	-11.900	310	1	10.157
2. TEMPMIN	C	0.084	0	16.800	183	1	-23.500	11	1	9.393
3. TEMPMEAN	C	5.852	1	25.800	239	1	-17.500	310	1	9.718
4. PRECIP	CM	0.119	333	4.700	92	1	0.000	1	333	0.539
5. PEVAP	CM	0.012	5	0.032	189	5	0.000	36	5	0.009
6. PTRANS	CM	0.012	5	0.032	189	5	0.000	36	5	0.009
7. SATVAPOR	%	8.262	0	25.070	239	1	1.160	310	1	5.153
DRIVEVAR CLIMATE FOR ERU 5.14- 1 C-B TRACT										
1. TEMPMAX	C	13.072	2	34.400	183	1	-13.200	310	1	11.238
2. TEMPMIN	C	0.095	0	18.500	183	1	-26.000	11	1	10.392
3. TEMPMEAN	C	6.475	1	28.600	239	1	-19.400	310	1	10.753
4. PRECIP	CM	0.093	333	3.700	92	1	0.000	1	333	0.420
5. PEVAP	CM	0.013	4	0.036	189	5	0.000	36	4	0.010
6. PTRANS	CM	0.013	4	0.036	189	5	0.000	36	4	0.010
7. SATVAPOR	%	8.956	0	29.580	239	1	0.990	310	1	6.087
DRIVEVAR CLIMATE FOR ERU 5.14- 2 C-B TRACT										
1. TEMPMAX	C	14.753	2	38.800	183	1	-14.800	310	1	12.684
2. TEMPMIN	C	0.104	0	20.900	183	1	-29.300	11	1	11.726
3. TEMPMEAN	C	7.311	1	32.300	239	1	-21.900	310	1	12.137
4. PRECIP	CM	0.057	334	2.300	92	1	0.000	1	334	0.260
5. PEVAP	CM	0.015	4	0.044	239	1	0.000	36	4	0.012
6. PTRANS	CM	0.015	4	0.044	239	1	0.000	36	4	0.012
7. SATVAPOR	%	10.005	0	36.720	239	1	0.800	310	1	7.513
DRIVEVAR CLIMATE FOR ERU 5.14- 3 C-B TRACT										
1. TEMPMAX	C	15.030	2	39.600	183	1	-15.100	310	1	12.924
2. TEMPMIN	C	0.106	0	21.300	183	1	-29.900	11	1	11.950
3. TEMPMEAN	C	7.448	1	32.900	239	1	-22.300	310	1	12.371
4. PRECIP	CM	0.050	335	2.000	92	1	0.000	1	335	0.230
5. PEVAP	CM	0.015	4	0.045	239	1	0.000	36	4	0.012
6. PTRANS	CM	0.015	4	0.045	239	1	0.000	36	4	0.012
7. SATVAPOR	%	10.194	0	38.050	239	1	0.770	310	1	7.774

Figure 6.1. Climatic driving variables used for prototype simulation. ERU 0, ERU 1, ERU 2, ERU 3 represent highland, upland, lowland, and bottomland areas, respectively. X-axis is time in days. A. Precipitation (cm). B. Saturation vapor pressure (mm Hg). C. Wind (km/hr). D. Hours of daylight, E. Shortwave radiation (Ly/day), F. Maximum temperature ($^{\circ}\text{C}$), G. Minimum temperature ($^{\circ}\text{C}$), H. Mean temperature ($^{\circ}\text{C}$), I. Humidity (%), J. Potential evaporation (cm), and K. Potential transpiration (cm).

Figure 6.1. (Continued)

Figure 6.1. (Continued)

Table 6.2a. Initial conditions for simulation of highland C-b tract.

STANDARD NOTATION	VALUE	REFERENCE
--- Highland C-b Tract ---		
X(10,1)	40.0	
X(10,2)	0.0	
X(10,3)	0.0	
X(10,4)	0.0	
X(10,5)	0.0	
X(10,6)	0.0	
X(2,1)	0.0	
X(2,2)	0.0	
- Soil Layer 1 -		
X(1,1)	4.5	
X(2,3)	0.01	
- Soil Layer 2 -		
X(1,1)	5.4	
X(2,3)	0.08	
- Soil Layer 3 -		
X(1,1)	6.3	
X(2,3)	0.07	
- Soil Layer 4 -		
X(1,1)	not simulated	
X(2,3)		
X(6,1)	50.0	
-- Pinyon --		
X(5,1)	0.10	
-- Juniper --		
X(5,1)	0.15	
-- Agropyron --		
X(3,1)	50.0	
X(3,3)	0.0	
X(3,4)	100.0	

Table 6.2a. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Soil Layer 1 -		
X(3,2)	25.0	
- Soil Layer 2 -		
X(3,2)	200.0	
- Soil Layer 3 -		
X(3,2)	100.0	
- Soil Layer 4 -		
X(3,2)	not simulated	
-- Mule Deer --		
- Mature Female -		
X(8,1)	65000.0	
X(9,1)	11.0	
- Immature Female -		
X(8,1)	50000.0	
X(9,1)	15.0	
- Juvenile Female -		
X(8,1)	40000.0	
X(9,1)	13.0	
- Mature Male -		
X(8,1)	100000.0	
X(9,1)	8.0	
- Immature Male -		
X(8,1)	60000.0	
X(9,1)	15.0	
- Juvenile Male -		
X(8,1)	46000.0	
X(9,1)	13.0	
X(8,2)	0.0	
X(9,2)	0.0	

Table 6.2a. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
-- Cottontail --		
- Mature Female -		
X(8,1)	1200.0	
X(9,1)	400.0	
- Immature Female -		
X(8,1)	950.0	
X(9,1)	350.0	
- Juvenile Female -		
X(8,1)	700.0	
X(9,1)	150.0	
- Mature Male -		
X(8,1)	1200.0	
X(9,1)	400.0	
- Immature Male -		
X(8,1)	950.0	
X(9,1)	350.0	
- Juvenile Male -		
X(8,1)	700.0	
X(9,1)	150.0	
X(8,2)	0.0	
X(9,2)	0.0	
-- Chipmunk --		
- Mature Female -		
X(8,1)	50.0	
X(9,1)	2250.0	
- Immature Female -		
X(8,1)	35.0	
X(9,1)	2800.0	

Table 6.2a. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Juvenile Female -		
X(8,1)	not simulated	
X(9,1)		
- Mature Male -		
X(8,1)	50.0	
X(9,1)	2250.0	
- Immature Male -		
X(8,1)	35.0	
X(9,1)	2800.0	
- Juvenile Male -		
X(8,1)	not simulated	
X(9,1)		
X(8,2)	0.0	
X(9,2)	0.0	

Table 6.2b. Initial conditions for simulation of Upland C-b tract.

STANDARD NOTATION	VALUE	REFERENCE
--- Upland C-b Tract ---		
X(10,1)	1072.9	
X(10,2)	0.0	
X(10,3)	0.0	
X(10,4)	0.0	
X(10,5)	0.0	
X(10,6)	0.0	
X(2,1)	0.0	
X(2,2)	0.0	
- Soil Layer 1 -		
X(1,1)	4.5	
X(2,3)	0.01	
- Soil Layer 2 -		
X(1,1)	5.4	
X(2,3)	0.08	
- Soil Layer 3 -		
X(1,1)	6.3	
X(2,3)	0.07	
- Soil Layer 4 -		
X(1,1)	6.5	
X(2,3)	0.06	
X(6,1)	100.0	
-- Pinyon --		
X(5,1)	0.05	
-- Juniper --		
X(5,1)	0.03	
-- Agropyron --		
X(3,1)	50.0	
X(3,3)	0.0	
X(3,4)	100.0	

Table 6.2b. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Soil Layer 1 -		
X(3,2)	25.0	
- Soil Layer 2 -		
X(3,2)	200.0	
- Soil Layer 3 -		
X(3,2)	100.0	
- Soil Layer 4 -		
X(3,2)	50.0	
-- Sage --		
X(4,1)	25.0	
X(4,3)	100.0	
X(4,4)	300.0	
- Soil Layer 1 -		
X(4,2)	50.0	
- Soil Layer 2 -		
X(4,2)	250.0	
- Soil Layer 3 -		
X(4,2)	150.0	
- Soil Layer 4 -		
X(4,2)	100.0	
X(7,1)	0.01	
-- Mule Deer --		
- Mature Female -		
X(8,1)	65000.0	
X(9,1)	11.0	
- Immature Female -		
X(8,1)	50000.0	
X(9,1)	15.0	
- Juvenile Female -		
X(8,1)	40000.0	
X(9,1)	13.0	

Table 6.2b. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Mature Male -		
X(8,1)	100000.0	
X(9,1)	8.0	
- Immature Male -		
X(8,1)	60000.0	
X(9,1)	15.0	
- Juvenile Male -		
X(8,1)	46000.0	
X(9,1)	13.0	
X(8,2)	0.0	
X(9,2)	0.0	
-- Cottontail --		
- Mature Female -		
X(8,1)	1200.0	
X(9,1)	400.0	
- Immature Female -		
X(8,1)	950.0	
X(9,1)	350.0	
- Juvenile Female -		
X(8,1)	700.0	
X(9,1)	150.0	
- Mature Male -		
X(8,1)	1200.0	
X(9,1)	400.0	
- Immature Male -		
X(8,1)	950.0	
X(9,1)	350.0	
- Juvenile Male -		
X(8,1)	700.0	
X(9,1)	150.0	
X(8,2)	0.0	
X(9,2)	0.0	

Table 6.2b. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
-- Chipmunk --		
- Mature Female -		
X(8,1)	50.0	
X(9,1)	2250.0	
- Immature Female -		
X(8,1)	35.0	
X(9,1)	2800.0	
- Juvenile Female -		
X(8,1)	not simulated	
X(9,1)		
- Mature Male		
X(8,1)	50.0	
X(9,1)	2250.0	
- Immature Male -		
X(8,1)	35.0	
X(9,1)	2800.0	
- Juvenile Male -		
X(8,1)	not simulated	
X(9,1)		
X(8,2)	0.0	
X(9,2)	0.0	
-- Coyote --		
- Mature Female -		
X(8,1)	20000.0	
X(9,1)	3.0	
- Immature Female -		
X(8,1)	18000.0	
X(9,1)	3.0	
- Juvenile Female -		
X(8,1)	not simulated	
X(9,1)		

Table 6.2b. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Mature Male		
X(8,1)	50000.0	
X(9,1)	2.0	
- Immature Male -		
X(8,1)	19000.0	
X(9,1)	3.0	
- Juvenile Male -		
X(8,1)	not simulated	
X(9,1)		
X(8,2)	0.0	
X(9,2)	0.0	

Table 6.2c. Initial conditions for simulation of Lowland C-b tract.

STANDARD NOTATION	VALUE	REFERENCE
--- Lowland C-b Tract ---		
X(10,1)	875.1	
X(10,2)	0.0	
X(10,3)	0.0	
X(10,4)	0.0	
X(10,5)	0.0	
X(10,6)	0.0	
X(2,1)	0.0	
X(2,2)	0.0	
- Soil Layer 1 -		
X(1,1)	4.5	
X(2,3)	0.01	
- Soil Layer 2 -		
X(1,1)	5.4	
X(2,3)	0.08	
- Soil Layer 3 -		
X(1,1)	6.3	
X(2,3)	0.07	
- Soil Layer 4 -		
X(1,1)	not simulated	
X(2,3)		
X(6,1)	100.0	
-- Agropyron --		
X(3,1)	50.0	
X(3,3)	0.0	
X(3,4)	100.0	

Table 6.2c. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Soil Layer 1 -		
X(3,2)	25.0	
- Soil Layer 2 -		
X(3,2)	200.0	
- Soil Layer 3 -		
X(3,2)	100.0	
- Soil Layer 4 -		
X(3,2)	not simulated	
-- Sage --		
X(4,1)	25.0	
X(4,3)	50.0	
X(4,4)	300.0	
- Soil Layer 1 -		
X(4,2)	50.0	
- Soil Layer 2 -		
X(4,2)	250.0	
- Soil Layer 3 -		
X(4,2)	150.0	
- Soil Layer 4 -		
X(4,2)	not simulated	
X(7,1)	0.01	
-- Chipmunk --		
- Mature Female -		
X(8,1)	50.0	
X(9,1)	2250.0	
- Immature Female -		
X(8,1)	35.0	
X(9,1)	2800.0	
- Juvenile Female -		
X(8,1)	not simulated	
X(9,1)		

Table 6.2c. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Mature Male -		
X(8,1)	50.0	
X(9,1)	2250.0	
- Immature Male -		
X(8,1)	35.0	
X(9,1)	2800.0	
- Juvenile Male -		
X(8,1)	not simulated	
X(9,1)		
X(8,2)	0.0	
X(9,2)	0.0	
-- Cottontail --		
- Mature Female -		
X(8,1)	1200.0	
X(9,1)	200.0	
- Immature Female -		
X(8,1)	950.0	
X(9,1)	175.0	
- Juvenile Female -		
X(8,1)	700.0	
X(9,1)	75.0	
- Mature Male -		
X(8,1)	1200.0	
X(9,1)	200.0	
- Immature Male -		
X(8,1)	950.0	
X(9,1)	175.0	
- Juvenile Male -		
X(8,1)	700.0	
X(9,1)	75.0	
X(8,2)	0.0	
X(9,2)	0.0	

Table 6.2d. Initial conditions for simulation of Bottomland C-b tract.

STANDARD NOTATION	VALUE	REFERENCE
--- Bottomland C-b Tract ---		
X(10,1)	35.0	
X(10,2)	0.0	
X(10,3)	0.0	
X(10,4)	0.0	
X(10,5)	0.0	
X(10,6)	0.0	
X(2,1)	0.0	
X(2,2)	0.0	
- Soil Layer 1 -		
X(1,1)	4.5	
X(2,3)	0.01	
- Soil Layer 2 -		
X(1,1)	5.4	
X(2,3)	0.08	
- Soil Layer 3 -		
X(1,1)	6.3	
X(2,3)	0.07	
- Soil Layer 4 -		
X(1,1)	not simulated	
X(6,1)	25.0	
-- Agropyron --		
X(3,1)	20.0	
X(3,3)	0.0	
X(3,4)	30.0	

Table 6.2d. (Continued)

STANDARD NOTATION	VALUE	REFERENCE
- Soil Layer 1 - X(3,2)	10.0	
- Soil Layer 2 - X(3,2)	80.0	
- Soil Layer 3 - X(3,2)	40.0	
- Soil Layer 4 - X(3,2)	not simulated	

information. In this case, the initial date is 1 January.

In order to demonstrate the capabilities of the model, a range of ERU types was selected for simulation. Highland (ERU 0), upland (ERU 1), lowland (ERU 2), and bottomland (ERU 3) were the physiographic units chosen with vegetation types of pinyon-juniper woodland, pinyon-juniper rangeland, sagebrush rangeland, and meadow, respectively. Detailed initial conditions are given in Table 6.2a-d, but can be more easily examined as the initial point in Figs. 6.2-6.7, which are time-series graphs for state variables for the one year run.

6.2 SIMULATION DYNAMICS

Computer operation of the model described in Sections 3 and 4 results in many very large tables of numbers, representing the predicted values of the state variables and processes over time. These simulation results are then summarized by standard descriptive statistics and time series graphs for ease of user interpretation. The actual output tables are not presented here, but are available upon request.

There is a one-to-one correspondence between the summary statistics and graphs, and the flow diagrams (Fig. 3.1 through 3.5) and the flow-effect matrix (Table 3.2). However, for simplicity, several of the less important processes and intermediate variables have been omitted. State variables are represented by continuous lines because the quantity exists through time. The process flows, on the other hand, are represented by bar graphs because the quantity exists at a discrete point in time.

These graphs and statistical summaries may be used to validate the simulation model. The output may be compared to the expected nominal dynamics of the system (Fig. 2.1-2.5). Thus, the time of year at which plant growth begins, time of peak standing crop, seasonal dynamics of animal populations, etc., may all be examined for correspondence to observed values. More specific items, such as the maximum and minimum values, may be examined for realism.

6.2.1 Without Development

In this section the results of a simulation run are presented and discussed for the non-development and non-management case. This provides the basis for evaluation of development and management scenarios.

Soil Temperature Submodel. In general, the soil temperatures exhibit a sinusoidal behavior which reflects a similar pattern of incoming radiation and air temperature. Soil temperature fluctuations are most pronounced in the surface layer and are damped in the deeper layers. Also, lower layer fluctuations occur later, or lag, those of the upper layers. Example results are summarized in Table 6.3 and Fig. 6.2.

The ranges for the various components are within those discussed in Sec. 2. However, there is an anomaly with shortwave radiation. Shortwave radiation increases dramatically and first reaches the yearly maximum in early

Table 6.3. Statistical summary of simulation results for soil temperature state variables and processes. (ERU 0, ERU 1, ERU 2, ERU 3 represent highland, upland, lowland, and bottomland, respectively)

AESOP SOIL TEMPERATURE SUMMARY STATISTICS										
ERU : C-B TRACT - 0										
	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
					VALUE	DAY	NO	VALUE	DAY	NO
TEMPERATURE LAYER 1	28.644	15.1698	10493.84	0	49.6	146	1	4.5	0	1
TEMPERATURE LAYER 2	25.799	12.0091	9442.28	0	43.6	152	1	5.2	1	1
TEMPERATURE LAYER 3	19.545	9.2494	7160.64	0	30.9	153	1	6.3	0	1
SHORTWAVE RADIATION	353.408	211.3507	129347.46	1	720.0	109	23	0.0	0	1
LONGWAVE RADIATION	-277.742	112.9074	-101452.51	1	0.5	3	1	-519.7	149	1
VAPORIZATION	9.539	51.6054	3125.45	331	549.8	170	1	0.0	0	331
CONDUCTION LAYER 1	0.045	0.0269	16.21	9	0.1	147	1	0.0	14	2
CONDUCTION LAYER 2	0.044	0.0241	16.22	2	0.1	148	1	0.0	2	4
CONDUCTION LAYER 3	0.044	0.0241	16.16	2	0.1	154	1	0.0	1	3
ERU : C-B TRACT - 1										
	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
					VALUE	DAY	NO	VALUE	DAY	NO
TEMPERATURE LAYER 1	27.456	15.9866	10049.02	0	48.5	151	1	2.3	34	1
TEMPERATURE LAYER 2	25.437	14.2219	9209.77	0	42.8	152	1	3.2	35	1
TEMPERATURE LAYER 3	21.422	10.9134	7840.59	0	35.2	156	2	4.7	39	1
TEMPERATURE LAYER 4	16.290	6.4569	5962.31	0	24.4	159	1	6.3	40	1
SHORTWAVE RADIATION	348.474	222.9234	127541.42	1	720.0	109	23	0.0	0	1
LONGWAVE RADIATION	-265.278	115.0181	-97691.82	1	5.9	3	1	-501.0	149	1
VAPORIZATION	28.599	90.4965	10467.25	197	772.0	170	1	0.0	0	197
CONDUCTION LAYER 1	0.037	0.0386	12.63	5	0.1	147	1	0.0	365	1
CONDUCTION LAYER 2	0.037	0.0326	12.59	3	0.1	149	2	0.0	31	3
CONDUCTION LAYER 3	0.037	0.0316	12.57	4	0.1	151	8	0.0	34	6
CONDUCTION LAYER 4	0.037	0.0316	12.53	4	0.1	156	12	0.0	1	7
ERU : C-B TRACT - 2										
	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
					VALUE	DAY	NO	VALUE	DAY	NO
TEMPERATURE LAYER 1	27.967	15.2664	10235.82	0	47.6	172	1	3.7	34	1
TEMPERATURE LAYER 2	24.453	12.4950	8949.05	0	40.1	173	1	4.8	38	1
TEMPERATURE LAYER 3	17.963	7.2614	6582.87	0	27.0	175	1	6.3	0	1
SHORTWAVE RADIATION	354.320	222.1078	129494.88	1	720.0	109	23	0.0	0	1
LONGWAVE RADIATION	-268.149	104.8815	-98142.57	1	15.5	3	1	-478.3	174	1
VAPORIZATION	6.095	20.2959	2220.94	315	354.7	295	1	0.0	0	315
CONDUCTION LAYER 1	0.052	0.0433	19.31	5	0.1	172	2	0.0	32	1
CONDUCTION LAYER 2	0.052	0.0419	19.20	2	0.1	174	1	0.0	32	5
CONDUCTION LAYER 3	0.052	0.0419	19.15	2	0.1	176	1	0.0	1	1

Table 6.3. (Continued)

ERU : C-B TRACT - 3

	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
					VALUE	DAY	NO	VALUE	DAY	NO
TEMPERATURE LAYER 1	29.829	17.3010	10917.46	0	53.2	172	1	1.9	34	1
TEMPERATURE LAYER 2	27.518	15.3477	10071.59	0	47.9	149	1	2.1	36	1
TEMPERATURE LAYER 3	21.360	10.2933	7917.97	0	35.0	150	1	4.9	37	1
SHORTWAVE RADIATION	354.768	222.3047	129845.07	1	726.0	109	23	0.0	0	1
LONGWAVE RADIATION	-292.077	125.8412	-106900.33	1	23.4	243	1	-571.2	133	1
VAPORIZATION	3.444	21.1910	1260.46	329	199.9	143	1	0.0	0	329
CONDUCTION LAYER 1	0.042	0.0419	15.22	1	0.1	172	1	0.0	29	3
CONDUCTION LAYER 2	0.042	0.0345	15.26	5	0.1	174	1	0.0	33	2
CONDUCTION LAYER 3	0.042	0.0342	15.29	5	0.1	154	2	0.0	37	2

DURATION : 365 DAYS TIME STEP : 1 DAYS INTERVALS : 365

.....

Figure 6.2. Example time series dynamics of soil temperature state variables and processes. ERU 0, ERU 1, ERU 2, ERU 3 represent highland, upland, lowland, and bottomland areas, respectively. X-axis is time in days. A. Effective shortwave radiation (ly), B. Soil long-wave radiation (cal), C. Vaporization energy (cal), D. Temperature of soil layer 1 ($^{\circ}\text{C}$), E. Temperature of soil layer 2 ($^{\circ}\text{C}$), F. Temperature of soil layer 3 ($^{\circ}\text{C}$), G. Temperature of soil layer 4 ($^{\circ}\text{C}$), H. Conduction of soil layer 1 (cal), I. Conduction of soil layer 2 (cal), J. Conduction of soil layer 3 (cal) and K. Conduction of soil layer 4 (cal).

Figure 6.2. (Continued)

Figure 6.2. (Continued)

spring. This behavior may not be unrealistic, but it is not typical of the Piceance Basin.

The major inputs to the soil surface, as illustrated in Fig. 3.1, are graphed in Figs. 6.2A-C. Shortwave radiation has the greatest influence on surface temperature, primarily due to the magnitude of the process. Longwave radiation may be both positive (representing energy gain by the soil) or negative (representing energy loss from the soil). During the winter months, the soil tends to gain energy from the air, while in summer, it reradiates energy to the night air. Both shortwave radiation and longwave radiation are similar for each ERU because incoming radiation is not adjusted for elevation (Sec. 3.1.2). On the other hand, vaporization energy is quite different between ERUs. This behavior results from the interaction of ambient air temperature and available soil water (Sec. 4.2.1), both of which reflect adjustments for elevation. The vaporization energy represents the energy required for vaporization of an amount of evaporation calculated by the soil moisture submodel.

The predicted temperatures of the soil layers (only ERU 1 has four layers) are shown in Figs. 6.2D-G. Although each soil layer has different characteristics and depth, the pattern of each graph is very similar on each ERU. This similarity is due primarily to the strong influence of shortwave radiation, which is the same for each ERU. The temperatures of the soil layers decrease with depth. The parent material, assumed to lie just below the lowest soil layer, functions as both a source of heat or a heat sink, dependent upon the temperature of the lowest layer. The parent material is assumed to maintain a constant temperature of 7.3°C.

Gain (or loss) of energy from the parent material is not very important compared to the other inputs. Conduction of energy between soil layers is shown in Figs. 6.2H-K. Note that the scales of these graphs are magnitudes smaller than those for Figs. 6.2A-G. Conduction may be both positive (representing loss from the soil layer) or negative (representing gain by the soil layer). Conduction is strongly influenced by soil temperature, and thus, like soil temperature, exhibits a similar pattern for each soil layer.

Unfortunately, these example dynamics are not typical of the Piceance Basin, due to the anomaly mentioned above. However, these results do indicate the controlling effect of solar shortwave radiation. Obviously, adjustments will have to be made for elevation, but more important are the implications for shale oil development. Management practices which affect surface soil conditions, albedo and plant cover may have significant effects on the success of rehabilitation and revegetation efforts.

Soil Moisture Submodel. In general, the soil moisture results exhibit much variation between ERUs. These differences are due to differing soil characteristics, and are further highlighted by the elevational adjustments of precipitation and air temperature. Example results are summarized in Table 6.4, in which the differences are quite evident, and in Fig. 6.3.

The major source of water is precipitation, either as rain or as snow. The bimodal nature of this source is shown in Figs. 6.3A-B. Much of the precipitation occurs during late fall and late winter. In this example, the

Table 6.4. Statistical summary of simulation results for soil moisture state variables and processes. (ERU 0, ERU 1, ERU 2, ERU 3 represent highland, upland, lowland, and bottomland, respectively)

AECOP SOIL MOISTURE SUMMARY STATISTICS										
ERU : C-B TRACT - 0										
	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
					VALUE	DAY	NO	VALUE	DAY	NO
PRECIPITATION	0.119	0.5394	43.50	334	4.7	92	1	0.0	0	334
SNOW DEPTH	12.457	28.0627	4559.18	265	111.9	321	3	0.0	0	265
WATER CONTENT LAYER 1	0.002	0.0056	0.76	273	0.0	92	1	0.0	2	273
WATER CONTENT LAYER 2	0.029	0.0154	10.68	1	0.1	2	1	0.0	0	1
WATER CONTENT LAYER 3	0.077	0.0190	28.01	1	0.1	100	1	0.0	0	1
GROUND WATER	0.076	0.0059	27.95	1	0.1	365	1	0.0	0	1
RUNOFF	0.000	0.0000	0.00	366	0.0	0	366	0.0	0	366
INFILTRATION	0.001	0.0049	0.40	320	0.0	92	1	0.0	0	320
EVAPORATION LOSS	0.000	0.0009	0.05	348	0.0	170	2	0.0	0	348
PERCOLATION LAYER 1	0.001	0.0052	0.30	274	0.0	92	1	0.0	1	1
PERCOLATION LAYER 2	0.001	0.0015	0.19	1	0.0	1	1	0.0	88	6
PERCOLATION LAYER 3	0.000	0.0005	0.11	252	0.0	1	114	0.0	0	252
TRANSPIRATION LAYER 1	0.000	0.0006	0.06	331	0.0	189	1	0.0	0	331
TRANSPIRATION LAYER 2	0.000	0.0007	0.14	257	0.0	94	6	0.0	0	257
TRANSPIRATION LAYER 3	0.000	0.0004	0.04	339	0.0	101	12	0.0	0	339
ERU : C-B TRACT - 1										
	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
					VALUE	DAY	NO	VALUE	DAY	NO
PRECIPITATION	0.092	0.4202	32.90	334	2.7	92	1	0.0	0	334
SNOW DEPTH	9.378	20.4216	3046.49	276	86.2	321	3	0.0	0	276
WATER CONTENT LAYER 1	0.011	0.0144	4.02	39	0.0	92	1	0.0	170	39
WATER CONTENT LAYER 2	0.025	0.0116	9.31	0	0.1	0	1	0.0	315	2
WATER CONTENT LAYER 3	0.062	0.0149	22.76	1	0.1	10	1	0.0	0	1
WATER CONTENT LAYER 4	0.073	0.0158	26.60	1	0.1	110	3	0.0	0	1
GROUND WATER	0.001	0.0005	0.19	174	0.0	174	192	0.0	0	174
RUNOFF	0.000	0.0013	0.04	362	0.0	71	1	0.0	0	362
INFILTRATION	0.001	0.0023	0.29	325	0.0	294	1	0.0	0	325
EVAPORATION LOSS	0.000	0.0015	0.16	322	0.0	170	1	0.0	0	322
PERCOLATION LAYER 1	0.000	0.0000	0.00	366	0.0	0	366	0.0	0	366
PERCOLATION LAYER 2	0.000	0.0003	0.04	112	0.0	1	2	0.0	20	17
PERCOLATION LAYER 3	0.000	0.0008	0.02	138	0.0	1	1	0.0	34	106
PERCOLATION LAYER 4	0.000	0.0000	0.00	366	0.0	0	366	0.0	0	366
TRANSPIRATION LAYER 1	0.000	0.0003	0.04	332	0.0	124	2	0.0	0	332
TRANSPIRATION LAYER 2	0.000	0.0002	0.01	354	0.0	103	12	0.0	0	354
TRANSPIRATION LAYER 3	0.000	0.0003	0.04	328	0.0	152	2	0.0	0	328
TRANSPIRATION LAYER 4	0.000	0.0003	0.03	328	0.0	115	29	0.0	0	328

DURATION : 365 DAYS TIME STEP : 1 DAYS INTERVALS : 365

Table 6.4. (Continued)

AECOP SOIL MOISTURE SUMMARY STATISTICS

ERU : C-9 TRACT - 2

	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
					VALUE	DAY	NO	VALUE	DAY	NO
PRECIPITATION	0.057	0.2303	20.90	325	2.3	92	1	0.0	0	325
SNOW DEPTH	4.052	11.0405	1485.52	293	51.8	321	3	0.0	0	293
WATER CONTENT LAYER 1	0.001	0.0027	0.51	279	0.0	71	1	0.0	2	279
WATER CONTENT LAYER 2	0.029	0.0177	10.13	1	0.1	2	1	0.0	0	1
WATER CONTENT LAYER 3	0.050	0.0230	21.79	1	0.1	93	1	0.0	0	1
GROUND WATER	0.119	0.0510	43.68	1	0.2	245	1	0.0	0	1
RUNOFF	0.000	0.0000	0.00	366	0.0	0	366	0.0	0	366
INFILTRATION	0.001	0.0029	0.21	330	0.0	92	1	0.0	0	330
EVAPORATION LOSS	0.000	0.0005	0.04	345	0.0	295	1	0.0	0	345
PERCOLATION LAYER 1	0.000	0.0025	0.17	279	0.0	72	1	0.0	1	1
PERCOLATION LAYER 2	0.001	0.0095	0.21	25	0.1	93	1	0.0	104	1
PERCOLATION LAYER 3	0.000	0.0005	0.16	207	0.0	1	159	0.0	0	207
TRANSPIRATION LAYER 1	0.000	0.0002	0.01	263	0.0	125	1	0.0	0	263
TRANSPIRATION LAYER 2	0.000	0.0002	0.02	250	0.0	121	1	0.0	0	250
TRANSPIRATION LAYER 3	0.000	0.0004	0.04	328	0.0	171	1	0.0	0	328

ERU : C-9 TRACT - 3

	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
					VALUE	DAY	NO	VALUE	DAY	NO
PRECIPITATION	0.050	0.2296	18.40	326	2.0	92	1	0.0	0	326
SNOW DEPTH	3.453	9.5986	1262.74	294	46.1	321	3	0.0	0	294
WATER CONTENT LAYER 1	0.002	0.0045	0.72	268	0.0	71	2	0.0	2	268
WATER CONTENT LAYER 2	0.029	0.0140	10.51	2	0.1	70	1	0.0	0	2
WATER CONTENT LAYER 3	0.116	0.0392	42.31	1	0.2	126	1	0.0	0	1
GROUND WATER	0.000	0.0005	0.17	192	0.0	192	174	0.0	0	192
RUNOFF	0.000	0.0000	0.00	366	0.0	0	366	0.0	0	366
INFILTRATION	0.000	0.0021	0.17	330	0.0	92	1	0.0	0	330
EVAPORATION LOSS	0.000	0.0003	0.02	257	0.0	93	4	0.0	0	257
PERCOLATION LAYER 1	0.000	0.0047	0.15	268	0.0	72	2	0.0	104	1
PERCOLATION LAYER 2	0.000	0.0115	0.15	266	0.1	56	1	0.0	136	1
PERCOLATION LAYER 3	0.000	0.0000	0.00	266	0.0	0	266	0.0	0	266
TRANSPIRATION LAYER 1	0.000	0.0000	0.00	266	0.0	0	266	0.0	0	266
TRANSPIRATION LAYER 2	0.000	0.0011	0.04	255	0.0	227	1	0.0	0	255
TRANSPIRATION LAYER 3	0.000	0.0012	0.11	324	0.0	152	1	0.0	0	324

DURATION : 365 DAYS TIME STEP : 1 DAYS INTERVALS : 365

Figure 6.3. Example time series dynamics of soil moisture state variables and processes. ERU 0, ERU 1, ERU 2, ERU 3 represent highland, upland, lowland and bottomland areas, respectively. X-axis is time in days. A. Precipitation through-fall (cm), B. Snow depth (cm), C. Infiltration into soil layer 1 (m^3), D. Evaporation loss from soil layer 1 (m^3), E. Runoff (m^3), F. Ground water (m^3), G. Water content of soil layer 1 (m^3), H. Water content of soil layer 2 (m^3), I. Water content of soil layer 3 (m^3), J. Water content of soil layer 4 (m^3), K. Percolation from soil layer 1 (m^3), L. Percolation from soil layer 2 (m^3), M. Percolation from soil layer 3 (m^3), N. Percolation from soil layer 4 (m^3), O. Transpiration from soil layer 1 (m^3), P. Transpiration from soil layer 2 (m^3), Q. Transpiration from soil layer 3 (m^3), R. Transpiration from soil layer 4 (m^3).

Figure 6.3. (Continued)

Figure 6.3. (Continued)

Figure 6.3. (Continued)

Figure 6.3. (Continued)

winter began with a very large snow storm. Also, note that in Fig. 6.3A, the effect of elevation on precipitation is very evident.

There are three major processes controlling the amount of precipitation which actually supplements soil water (Sec. 4.2.2). These processes, infiltration, evaporation and runoff, which influence the surface soil layer, are shown in Figs. 6.3C-E. Infiltration rates are strongly related to the amount of precipitation. Evaporation, the counterpart to vaporization in the soil temperature submodel, is more strongly associated with ambient air temperature than available soil water. This association is reflected in Fig. 6.3D, where the greatest evaporation occurs during periods of minimal rainfall. Appreciable runoff occurred on only ERU 1, the upland, as a result of the spring snow melt and low percolation rates for this ERU.

For this simulation, ground water functioned as an accumulator of all water percolating through the deep soil layer (Fig. 6.3F). The plots for ERU 0 and ERU 2 actually extend beyond the 0.1 m^3 shown in the figure. It is important to note that some soil types and combinations may serve to contribute to ground water supplies, while other types do not.

The water content of the soil layers is shown in Figs. 6.3G-J. The moisture of soil layer 1 is very closely related to infiltration rates. Also, a draw down of water levels in all layers occurs after the peak, during snow melt, and is recharged during the fall. Although total water content is the state variable (Fig. 3.1), these graphs are somewhat misleading because the total water content is directly related to the thickness of the soil layer. Therefore, in future simulations an additional intermediate variable, either volumetric water content or soil water potential, will also be plotted. These additional graphs will give a better indication of the saturation condition of the soil.

Although percolation may be both positive (representing loss from the soil layer) or negative (representing gain by the soil layer), during this simulation, percolation was one directional as shown in Figs. 6.3K-N. Percolation rates are influenced by total water content, but are more closely related to volumetric water content. An important factor illustrated by these graphs is the effect of the location of a claypan, which dramatically restricts water flow. Thus, although water levels of soil layer 2 (Fig. 6.3H) are similar for ERU 0 and ERU 2, the percolation rates are completely different (Fig. 6.3L).

Transpiration loss to plants is an important soil water process, although the size of this loss is small compared to the size of the other processes (Figs. 6.3O-R). Since plant roots take up water from the soil layer with least resistance, the location (depth) of transpiration serves as an indicator of soil water conditions. As shown, on the drier, lower elevations, much of the water is taken up from the deeper layers.

Soil water dynamics are fairly representative of Piceance Basin conditions. As demonstrated, there are important implications for shale oil development. Management activities which alter soil characteristics, especially compaction, may drastically reduce infiltration and percolation rates and ultimately ground water recharge.

Land Area/Use Submodel. Under nondevelopment, land areas of the various types remain essentially constant. Changes of a geologic nature are of no concern over periods of about 20 years in stable regions such as the Piceance Creek Basin. Some geographic regions, such as areas at the edge of glaciers, along river deltas, or other places where soils and other conditions may change rapidly, would require consideration of geologic changes.

Some types of change in land area are possible, such as normal road building and conversion of land due to agricultural development and farm abandonment. These changes are not considered in the nondevelopment simulation.

Floral Submodels. State variable time series graphs and bar graphs of process rates are shown in Fig. 6.4 and 6.5. Results of the example simulation are summarized in Table 6.5. Bar graphs of process rates show how the processes in Sec. 4.3.1 vary with time during a simulation, but the main items of interest are the state variable graphs.

Plots are shown for all major flows. Flows of lesser interest such as shattering of standing dead, leaf fall, and litter decomposition are considered valuable primarily in program development and checking and were not printed or plotted. Because there are no baseline studies of plant process rates on the Piceance Basin, it is difficult to use these plots for model validation. In general, however, it is clear that the major processes (photosynthesis, respiration, and translocation) are highly dependent on water and temperature, as would be expected from their functional forms (Sec. 4.3.1). All of these processes are most active in the spring and nearly cease during the summer drought, returning to low levels of activity in the fall. Translocation to roots closely follows soil moisture changes. Processes for cheatgrass do not follow a clear pattern due to repeated germination and death. Close comparison with Fig. 6.4 is required for evaluation of cheatgrass flows. An anomaly which results from the resolution of the model is that small rainstorms during the summer drought cause immediate and dramatic increases in photosynthesis (Fig. 6.5A, N, Y). In reality, desert plants require some time to respond to summer rain because the chlorophyll content of the leaves must be reestablished after a long dry spell (Davey 1980). However, the net effect of this bias is small and eliminating this short-term response would require either the modeling of leaf chlorophyll content or extra checks in the model.

In general, the biomass dynamics are as follows. The green biomass reaches a maximum rapidly in the spring, levels off in the midsummer due to water shortage, and exhibits some regrowth in the fall. Storage biomass is drawn down in the spring, fluctuates during the summer, and becomes recharged by fall. There is little importance attached to exact times of root growth for the simulation. The emphasis is primarily on achieving the correct root-shoot ratios.

Departures from these general trends occur for cheatgrass (Brte) on all ERU's and wheatgrass (Agsp) and sage (Artr) green biomass on ERU 2 (Lowland). Cheatgrass germinates frequently on all ERU's but fails to survive for long except on ERU 1. Thus plots of cheatgrass seem discontinuous. On ERU 2 soil type and depth combine with weather to produce severe drought conditions in

Table 6.5. Statistical summary of simulation results for plant state variables and processes. A. State variables, and B. Processes. (ERU 0, ERU 1, ERU 2, ERU 3 represent highland, upland, lowland, and bottomland, respectively)

A.

AN ECOSYSTEM SIMULATION OF PERTURBATIONS PLANT-SUBMODEL STATISTICS

		UNITS	MEAN	ZEROES	MAXIMUM			MINIMUM			STANDARD DEVIATIONS
					VALUE	DAY	NO.	VALUE	DAY	NO.	
SAGE	STATE VARIABLES FOR ERU		5.14- 0	C-B TRACT							
1.	POPULATION	NO/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
2.	GREEN	G/M2	23.097	197	50.000	2	169	0.000	1	197	24.927
3.	STORAGE	G/M2	11.544	197	25.000	2	169	0.000	1	197	12.463
4.	SURROOT	G/M2	3.080	197	6.670	2	169	0.000	1	197	3.325
5.	TOPROOT	G/M2	16.161	197	35.000	2	169	0.000	1	197	17.449
6.	LOWROOT	G/M2	26.934	197	58.330	2	169	0.000	1	197	29.080
7.	DEEPROOT	G/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
8.	NON-GREEN	G/M2	46.175	197	100.000	2	169	0.000	1	197	49.853
AGROPYRON	STATE VARIABLES FOR ERU		5.14- 0	C-B TRACT							
1.	POPULATION	NO/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
2.	GREEN	G/M2	1.023	209	4.670	95	4	0.000	1	209	1.456
3.	STORAGE	G/M2	5.557	223	50.000	1	1	0.000	95	223	11.337
4.	SURROOT	G/M2	5.309	184	25.000	1	3	0.000	138	184	8.092
5.	TOPROOT	G/M2	69.440	127	200.000	1	39	0.000	240	127	73.151
6.	LOWROOT	G/M2	34.171	127	100.000	1	1	0.000	240	127	36.708
7.	DEEPROOT	G/M2	0.288	333	7.000	296	15	0.000	1	333	1.387
8.	NON-GREEN	G/M2	24.520	82	100.000	1	1	0.000	240	82	26.836
CHEATGRASS	STATE VARIABLES FOR ERU		5.14- 0	C-B TRACT							
1.	POPULATION	NO/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
2.	GREEN	G/M2	0.064	347	2.240	125	4	0.000	1	347	0.349
3.	STORAGE	G/M2	0.678	201	1.990	2	1	0.000	1	201	0.796
4.	SURROOT	G/M2	0.446	210	2.240	125	4	0.000	1	210	0.666
5.	TOPROOT	G/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
6.	LOWROOT	G/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
7.	DEEPROOT	G/M2	0.001	349	0.020	156	17	0.000	1	349	0.004
8.	NON-GREEN	G/M2	0.632	211	2.410	253	1	0.000	1	211	0.978
SAGE	STATE VARIABLES FOR ERU		5.14- 1	C-B TRACT							
1.	POPULATION	NO/M2	0.010	0	0.010	1	366	0.010	1	366	0.000
2.	GREEN	G/M2	218.769	0	386.770	300	2	100.300	1	80	103.963
3.	STORAGE	G/M2	62.352	0	146.800	252	1	5.510	97	1	42.397
4.	SURROOT	G/M2	48.689	0	103.790	350	17	18.730	246	1	29.327
5.	TOPROOT	G/M2	170.494	0	250.000	1	1	128.270	120	1	27.409
6.	LOWROOT	G/M2	139.163	0	165.630	184	1	80.760	120	1	27.230
7.	DEEPROOT	G/M2	133.740	0	183.120	183	1	57.230	114	1	49.099
8.	NON-GREEN	G/M2	296.015	0	320.450	182	1	270.230	121	2	14.108
AGROPYRON	STATE VARIABLES FOR ERU		5.14- 1	C-B TRACT							
1.	POPULATION	NO/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
2.	GREEN	G/M2	3.929	138	7.350	184	6	0.000	1	138	3.176
3.	STORAGE	G/M2	5.148	76	50.000	1	1	0.000	91	76	10.095
4.	SURROOT	G/M2	7.143	195	25.000	1	28	0.000	172	195	9.440
5.	TOPROOT	G/M2	66.702	0	200.000	1	28	9.500	0	1	68.917
6.	LOWROOT	G/M2	32.474	0	100.000	1	28	0.170	0	1	35.175
7.	DEEPROOT	G/M2	15.816	70	50.000	1	1	0.000	297	70	17.798
8.	NON-GREEN	G/M2	27.600	0	100.000	1	1	5.320	297	1	25.001
CHEATGRASS	STATE VARIABLES FOR ERU		5.14- 1	C-B TRACT							
1.	POPULATION	NO/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
2.	GREEN	G/M2	1.532	220	11.500	113	7	0.000	1	220	3.458
3.	STORAGE	G/M2	3.039	65	10.710	125	1	0.000	1	65	2.668
4.	SURROOT	G/M2	4.194	64	15.650	134	1	0.000	1	64	5.083
5.	TOPROOT	G/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
6.	LOWROOT	G/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
7.	DEEPROOT	G/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
8.	NON-GREEN	G/M2	2.796	87	15.440	157	1	0.000	1	87	4.093

Table 6.5. (Continued)

A. (Continued)

AN ECOSYSTEM SIMULATION OF PERTURBATIONS PLANT-SUBMODEL STATISTICS

UNITS		MEAN	ZEROS	MAXIMUM			MINIMUM			STANDARD DEVIATIONS
				VALUE	DAY	NO.	VALUE	DAY	NO.	
SAGE STATE VARIABLES FOR ERU 5.14- 2 C-B TRACT										
1. POPULATION	NO/M2	0.010	0	0.010	1	366	0.010	1	366	0.000
2. GREEN	G/M2	101.511	0	242.500	190	14	0.270	246	1	74.771
3. STORAGE	G/M2	69.470	0	152.260	171	1	9.950	96	1	38.485
4. SURROOT	G/M2	31.740	0	50.000	1	3	19.870	170	1	7.866
5. TOPROOT	G/M2	245.487	0	259.760	345	1	209.100	107	1	14.378
6. LOWROOT	G/M2	215.853	0	271.830	190	1	128.070	80	1	56.344
7. DEEPROOT	G/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
8. NON-GREEN	G/M2	287.851	0	308.900	190	1	266.800	0	1	10.831
AGROPYRON STATE VARIABLES FOR ERU 5.14- 2 C-B TRACT										
1. POPULATION	NO/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
2. GREEN	G/M2	23.440	147	74.340	190	7	0.000	1	147	30.792
3. STORAGE	G/M2	11.017	7	50.000	1	1	0.000	360	7	9.325
4. SURROOT	G/M2	4.308	236	25.000	1	3	0.000	131	236	7.383
5. TOPROOT	G/M2	150.514	6	200.000	1	36	0.000	361	6	30.527
6. LOWROOT	G/M2	90.190	6	107.330	190	1	0.000	361	6	16.908
7. DEEPROOT	G/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
8. NON-GREEN	G/M2	42.223	6	100.000	1	1	0.000	361	6	22.934
CHEATGRASS STATE VARIABLES FOR ERU 5.14- 2 C-B TRACT										
1. POPULATION	NO/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
2. GREEN	G/M2	0.096	345	2.440	111	2	0.000	1	345	0.437
3. STORAGE	G/M2	0.759	206	2.670	126	10	0.000	1	206	0.911
4. SURROOT	G/M2	0.456	218	2.440	111	2	0.000	1	218	0.700
5. TOPROOT	G/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
6. LOWROOT	G/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
7. DEEPROOT	G/M2	-0.984	354	0.000	1	354	-30.000	260	12	5.342
8. NON-GREEN	G/M2	0.648	221	2.900	144	1	0.000	1	221	1.055
AGROPYRON STATE VARIABLES FOR ERU 5.14- 3 C-B TRACT										
1. POPULATION	NO/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
2. GREEN	G/M2	55.000	129	172.930	228	4	0.000	1	129	62.431
3. STORAGE	G/M2	36.934	15	88.950	154	1	0.000	107	15	25.621
4. SURROOT	G/M2	0.796	307	10.000	1	3	0.000	60	307	2.195
5. TOPROOT	G/M2	57.712	0	80.000	1	3	36.680	227	1	13.759
6. LOWROOT	G/M2	117.431	0	182.540	217	1	25.450	127	2	66.927
7. DEEPROOT	G/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
8. NON-GREEN	G/M2	40.170	0	148.530	311	1	2.820	235	1	42.314
CHEATGRASS STATE VARIABLES FOR ERU 5.14- 3 C-B TRACT										
1. POPULATION	NO/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
2. GREEN	G/M2	0.083	346	2.430	112	1	0.000	1	346	0.405
3. STORAGE	G/M2	0.650	229	2.370	127	10	0.000	1	229	0.874
4. SURROOT	G/M2	0.388	239	2.430	112	2	0.000	1	239	0.665
5. TOPROOT	G/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
6. LOWROOT	G/M2	0.000	366	0.000	1	366	0.000	1	366	0.000
7. DEEPROOT	G/M2	0.248	310	3.350	111	14	0.000	1	310	0.715
8. NON-GREEN	G/M2	0.693	242	2.560	145	1	0.000	1	242	0.982

Table 6.5. (Continued)

B.

AN ECOSYSTEM SIMULATION OF PERTURBATIONS PLANT-SUBMODEL STATISTICS

		UNITS	MEAN	ZEROS	MAXIMUM			MINIMUM			STANDARD DEVIATIONS
					VALUE	DAY	NO.	VALUE	DAY	NO.	
AGROPYRON PROCESS RATES FOR ERU 5.14- 0 C-B TRACT											
1.	NETPHOT	G/M2/DAY	0.034	317	0.630	110	1	0.000	2	317	0.101
2.	GREENRESP	G/M2/DAY	0.001	317	0.020	90	3	0.000	2	317	0.004
3.	SROOTRESP	G/M2/DAY	0.009	331	0.180	104	2	0.000	4	231	0.029
4.	TROOTRESP	G/M2/DAY	0.340	230	1.900	126	1	0.000	40	230	0.517
5.	LROOTRESP	G/M2/DAY	0.104	237	0.460	102	1	0.000	2	237	0.148
6.	DROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
7.	GREENTRANS	G/M2/DAY	0.015	353	2.600	87	1	0.000	2	353	0.157
8.	SROOTTRANS	G/M2/DAY	0.001	362	0.240	247	1	0.000	2	362	0.013
9.	TROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
10.	LROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
11.	DROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
CHEATGRASS PROCESS RATES FOR ERU 5.14- 0 C-B TRACT											
1.	NETPHOT	G/M2/DAY	0.000	363	0.090	104	1	0.000	2	363	0.006
2.	GREENRESP	G/M2/DAY	0.000	359	0.010	2	6	0.000	3	359	0.001
3.	SROOTRESP	G/M2/DAY	0.003	343	0.230	189	1	0.000	4	343	0.021
4.	TROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
5.	LROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
6.	DROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
7.	GREENTRANS	G/M2/DAY	0.008	349	0.280	103	2	0.000	2	349	0.041
8.	SROOTTRANS	G/M2/DAY	0.004	356	0.240	125	4	0.000	2	356	0.029
9.	TROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
10.	LROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
11.	DROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
SAGE PROCESS RATES FOR ERU 5.14- 1 C-B TRACT											
1.	NETPHOT	G/M2/DAY	4.574	237	95.790	189	1	0.000	3	237	10.618
2.	GREENRESP	G/M2/DAY	0.342	124	2.460	189	1	0.000	185	124	0.377
3.	SROOTRESP	G/M2/DAY	0.254	190	4.640	260	1	0.000	114	190	0.586
4.	TROOTRESP	G/M2/DAY	1.071	193	7.920	158	1	0.000	167	193	1.892
5.	LROOTRESP	G/M2/DAY	0.489	188	3.240	155	1	0.000	173	188	0.813
6.	DROOTRESP	G/M2/DAY	0.223	190	1.290	173	1	0.000	2	190	0.326
7.	GREENTRANS	G/M2/DAY	0.312	251	13.590	253	1	0.000	2	251	1.830
8.	SROOTTRANS	G/M2/DAY	0.270	318	18.120	253	1	0.000	2	318	1.660
9.	TROOTTRANS	G/M2/DAY	0.153	284	3.860	173	1	0.000	2	284	0.407
10.	LROOTTRANS	G/M2/DAY	0.273	279	6.420	172	1	0.000	2	279	0.709
11.	DROOTTRANS	G/M2/DAY	0.387	275	8.240	173	1	0.000	2	275	0.978
12.	WOODYRESP	G/M2/DAY	0.568	124	4.690	189	1	0.000	185	124	0.649
13.	WOODYTRANS	G/M2/DAY	0.271	251	4.530	253	1	0.000	2	251	0.610
AGROPYRON PROCESS RATES FOR ERU 5.14- 1 C-B TRACT											
1.	NETPHOT	G/M2/DAY	0.226	267	2.700	171	1	0.000	2	267	0.425
2.	GREENRESP	G/M2/DAY	0.004	270	0.030	171	2	0.000	2	270	0.006
3.	SROOTRESP	G/M2/DAY	0.033	249	0.520	125	1	0.000	113	249	0.067
4.	TROOTRESP	G/M2/DAY	0.491	193	2.620	134	1	0.000	167	193	0.644
5.	LROOTRESP	G/M2/DAY	0.166	188	0.630	132	1	0.000	173	188	0.191
6.	DROOTRESP	G/M2/DAY	0.056	191	0.160	116	2	0.000	2	191	0.064
7.	GREENTRANS	G/M2/DAY	0.021	342	2.680	83	1	0.000	2	342	0.164
8.	SROOTTRANS	G/M2/DAY	0.000	364	0.010	171	1	0.000	2	364	0.001
9.	TROOTTRANS	G/M2/DAY	0.001	359	0.110	173	1	0.000	2	359	0.007
10.	LROOTTRANS	G/M2/DAY	0.002	355	0.220	172	1	0.000	2	355	0.015
11.	DROOTTRANS	G/M2/DAY	0.003	350	0.240	173	1	0.000	2	350	0.022
CHEATGRASS PROCESS RATES FOR ERU 5.14- 1 C-B TRACT											
1.	NETPHOT	G/M2/DAY	0.132	315	5.830	125	1	0.000	2	315	0.518
2.	GREENRESP	G/M2/DAY	0.001	339	0.030	110	1	0.000	3	339	0.003
3.	SROOTRESP	G/M2/DAY	0.027	204	1.650	171	1	0.000	29	204	0.145
4.	TROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
5.	LROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
6.	DROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
7.	GREENTRANS	G/M2/DAY	0.059	307	1.870	156	1	0.000	2	307	0.211
8.	SROOTTRANS	G/M2/DAY	0.045	316	1.300	126	1	0.000	2	316	0.174
9.	TROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
10.	LROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
11.	DROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000

Table 6.5 (Continued)

B. (Continued)

AN ECOSYSTEM SIMULATION OF PERTURBATIONS PLANT-SUBMODEL STATISTICS

	UNITS	MEAN	ZEROS	MAXIMUM			MINIMUM			STANDARD DEVIATIONS	
				VALUE	DAY	NO.	VALUE	DAY	NO.		
SAGE PROCESS RATES FOR ERU 5.14- 2 C-B TRACT											
1.	NETPHOT	G/M2/DAY	3.113	267	90.460	171	1	0.000	3	267	9.258
2.	GREENRESP	G/M2/DAY	0.098	176	1.470	189	1	0.000	138	176	0.157
3.	SROOTRESP	G/M2/DAY	0.063	324	2.320	189	1	0.000	4	324	0.278
4.	TROOTRESP	G/M2/DAY	0.646	209	5.460	277	1	0.000	48	209	1.073
5.	LROOTRESP	G/M2/DAY	0.288	220	2.560	172	1	0.000	72	220	0.427
6.	DROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
7.	GREENTRANS	G/M2/DAY	0.770	284	30.200	247	1	0.000	2	284	2.657
8.	SROOTTRANS	G/M2/DAY	0.121	345	15.420	189	1	0.000	2	345	1.082
9.	TROOTTRANS	G/M2/DAY	0.227	309	5.690	144	1	0.000	2	309	0.722
10.	LROOTTRANS	G/M2/DAY	0.447	311	18.080	172	1	0.000	2	311	1.852
11.	DROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
12.	WOODYRESP	G/M2/DAY	0.377	175	4.230	189	1	0.000	138	175	0.580
13.	WOODYTRANS	G/M2/DAY	0.199	289	4.520	172	1	0.000	2	289	0.596
AGROPYRON PROCESS RATES FOR ERU 5.14- 2 C-B TRACT											
1.	NETPHOT	G/M2/DAY	0.698	292	14.250	126	1	0.000	2	292	1.965
2.	GREENRESP	G/M2/DAY	0.010	298	0.420	172	1	0.000	2	298	0.034
3.	SROOTRESP	G/M2/DAY	0.004	342	0.090	111	1	0.000	4	342	0.014
4.	TROOTRESP	G/M2/DAY	0.423	211	3.310	277	1	0.000	48	211	0.677
5.	LROOTRESP	G/M2/DAY	0.158	220	1.150	172	1	0.000	72	220	0.222
6.	DROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
7.	GREENTRANS	G/M2/DAY	0.230	284	3.200	128	1	0.000	2	284	0.577
8.	SROOTTRANS	G/M2/DAY	0.001	359	0.130	126	1	0.000	2	359	0.009
9.	TROOTTRANS	G/M2/DAY	0.062	331	2.040	136	1	0.000	2	331	0.244
10.	LROOTTRANS	G/M2/DAY	0.111	325	3.060	127	1	0.000	2	325	0.417
11.	DROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
CHEATGRASS PROCESS RATES FOR ERU 5.14- 2 C-B TRACT											
1.	NETPHOT	G/M2/DAY	0.010	361	1.720	126	1	0.000	2	361	0.119
2.	GREENRESP	G/M2/DAY	0.000	354	0.020	189	1	0.000	3	354	0.002
3.	SROOTRESP	G/M2/DAY	0.003	344	0.200	171	1	0.000	4	344	0.019
4.	TROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
5.	LROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
6.	DROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
7.	GREENTRANS	G/M2/DAY	0.011	347	0.410	136	1	0.000	2	347	0.051
8.	SROOTTRANS	G/M2/DAY	0.007	351	0.240	94	8	0.000	2	351	0.040
9.	TROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
10.	LROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
11.	DROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
AGROPYRON PROCESS RATES FOR ERU 5.14- 3 C-B TRACT											
1.	NETPHOT	G/M2/DAY	1.700	272	42.160	228	1	0.000	2	272	5.294
2.	GREENRESP	G/M2/DAY	0.021	274	1.310	228	1	0.000	2	274	0.089
3.	SROOTRESP	G/M2/DAY	0.000	358	0.020	3	2	0.000	4	358	0.003
4.	TROOTRESP	G/M2/DAY	0.237	289	4.370	144	1	0.000	4	289	0.648
5.	LROOTRESP	G/M2/DAY	0.293	182	3.550	153	1	0.000	2	182	0.500
6.	DROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
7.	GREENTRANS	G/M2/DAY	0.629	295	11.240	155	1	0.000	2	295	2.013
8.	SROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
9.	TROOTTRANS	G/M2/DAY	0.113	334	10.530	262	1	0.000	2	334	0.840
10.	LROOTTRANS	G/M2/DAY	0.451	311	11.840	155	1	0.000	2	311	1.827
11.	DROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
CHEATGRASS PROCESS RATES FOR ERU 5.14- 3 C-B TRACT											
1.	NETPHOT	G/M2/DAY	0.010	360	1.590	127	1	0.000	2	360	0.113
2.	GREENRESP	G/M2/DAY	0.000	357	0.020	248	1	0.000	3	357	0.002
3.	SROOTRESP	G/M2/DAY	0.004	345	0.220	127	1	0.000	2	345	0.021
4.	TROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
5.	LROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
6.	DROOTRESP	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
7.	GREENTRANS	G/M2/DAY	0.009	348	0.370	137	1	0.000	2	348	0.046
8.	SROOTTRANS	G/M2/DAY	0.006	352	0.240	94	6	0.000	2	352	0.025
9.	TROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
10.	LROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000
11.	DROOTTRANS	G/M2/DAY	0.000	365	0.000	2	365	0.000	2	365	0.000

Figure 6.4. Example time series dynamics of plant state variables. ERU 0, ERU 1, ERU 2, ERU 3 represent highland, upland, lowland and bottomland, respectively. X-axis is time in days. A. Pied cover (%), B. Juoc cover (%), C. Artr population ($\#m^{-2}$), D. Artr green biomass ($g\ plant^{-1}$), E. Artr storage biomass ($g\ plant^{-1}$), F. Artr woody biomass ($g\ plant^{-1}$), G. Artr root biomass in layer 1 ($g\ plant^{-1}$), H. Artr root biomass in layer 2 ($g\ plant^{-1}$), I. Artr root biomass in layer 3 ($g\ plant^{-1}$), J. Artr root biomass in layer 4 ($g\ plant^{-1}$), K. Agsp green biomass ($g\ m^{-2}$), L. Agsp storage biomass ($g\ m^{-2}$), M. Agsp root biomass in layer 1 ($g\ m^{-2}$), N. Agsp root biomass in layer 2 ($g\ m^{-2}$), O. Agsp root biomass in layer 3 ($g\ m^{-2}$), P. Agsp root biomass in layer 4 ($g\ m^{-2}$), Q. Agsp standing dead biomass ($g\ m^{-2}$), R. Brte green biomass ($g\ m^{-2}$), S. Brte storage biomass ($g\ m^{-2}$), T. Brte root biomass in layer 1 ($g\ m^{-2}$), U. Brte root biomass in layer 2 ($g\ m^{-2}$), V. Brte root biomass in layer 3 ($g\ m^{-2}$), W. Brte root biomass in layer 4 ($g\ m^{-2}$), X. Brte standing dead biomass ($g\ m^{-2}$), and Y. Total litter biomass ($g\ m^{-2}$).

Figure 6.4. (Continued)

Figure 6.4. (Continued)

Figure 6.4. (Continued)

Figure 6.4. (Continued)

Figure 6.4. (Continued)

Figure 6.4. (Continued)

Figure 6.5. Example time series dynamics of plant processes. ERU 0, ERU 1, ERU 2, ERU 3 represent highland, upland, lowland and bottomland, respectively. X-axis is time in days. A. Artr net photosynthesis ($\text{g plant}^{-1}\text{day}^{-1}$), B. Artr green respiration ($\text{g plant}^{-1}\text{day}^{-1}$), C. Artr root respiration, layer 1 ($\text{g plant}^{-1}\text{day}^{-1}$), D. Artr root respiration, layer 2 ($\text{g plant}^{-1}\text{day}^{-1}$), E. Artr root respiration, layer 3 ($\text{g plant}^{-1}\text{day}^{-1}$), F. Artr root respiration, layer 4 ($\text{g plant}^{-1}\text{day}^{-1}$), G. Artr green translocation ($\text{g plant}^{-1}\text{day}^{-1}$), H. Artr root translocation, layer 1 ($\text{g plant}^{-1}\text{day}^{-1}$), I. Artr root translocation, layer 2 ($\text{g plant}^{-1}\text{day}^{-1}$), J. Artr root translocation, layer 3 ($\text{g plant}^{-1}\text{day}^{-1}$), K. Artr root translocation, layer 4 ($\text{g plant}^{-1}\text{day}^{-1}$), L. Artr woody respiration ($\text{g plant}^{-1}\text{day}^{-1}$), M. Artr woody translocation ($\text{g plant}^{-1}\text{day}^{-1}$), N. Agsp net photosynthesis ($\text{g m}^{-2}\text{day}^{-1}$), O. Agsp green respiration ($\text{g m}^{-2}\text{day}^{-1}$), P. Agsp root respiration, layer 1 ($\text{g m}^{-2}\text{day}^{-1}$), Q. Agsp root respiration, layer 2 ($\text{g m}^{-2}\text{day}^{-1}$), R. Agsp root respiration, layer 3 ($\text{g m}^{-2}\text{day}^{-1}$), S. Agsp root respiration, layer 4 ($\text{g m}^{-2}\text{day}^{-1}$), T. Agsp green translocation ($\text{g m}^{-2}\text{day}^{-1}$), U. Agsp root translocation, layer 1 ($\text{g m}^{-2}\text{day}^{-1}$), V. Agsp root translocation, layer 2 ($\text{g m}^{-2}\text{day}^{-1}$), W. Agsp root translocation, layer 3 ($\text{g m}^{-2}\text{day}^{-1}$), X. Agsp root translocation, layer 4 ($\text{g m}^{-2}\text{day}^{-1}$), Y. Brte net photosynthesis ($\text{g m}^{-2}\text{day}^{-1}$), Z. Brte green respiration ($\text{g m}^{-2}\text{day}^{-1}$), AA. Brte root respiration, layer 1 ($\text{g m}^{-2}\text{day}^{-1}$), BB. Brte root respiration, layer 2 ($\text{g m}^{-2}\text{day}^{-1}$), CC. Brte root respiration, layer 3 ($\text{g m}^{-2}\text{day}^{-1}$), DD. Brte root respiration, layer 4 ($\text{g m}^{-2}\text{day}^{-1}$), EE. Brte green translocation ($\text{g m}^{-2}\text{day}^{-1}$), FF. Brte root translocation, layer 1 ($\text{g m}^{-2}\text{day}^{-1}$), GG. Brte root translocation, layer 2 ($\text{g m}^{-2}\text{day}^{-1}$), HH. Brte root translocation, layer 3 ($\text{g m}^{-2}\text{day}^{-1}$), and II. Brte root translocation, layer 4 ($\text{g m}^{-2}\text{day}^{-1}$).

Figure 6.5. (Continued)

Figure 6.5. (Continued)

Figure 6.5. (Continued)

Figure 6.5. (Continued)

Figure 6.5. (Continued)

Figure 6.5. (Continued)

Figure 6.5. (Continued)

Figure 6.5. (Continued)

Figure 6.5. (Continued)

the fall, causing death of all leaves of sage and wheatgrass. The magnitude of this event is likely exaggerated compared to the real system.

The ERU's represented decrease in elevation to the right in Fig. 6.5 and get drier and warmer with decreasing elevation. ERU 0 (Highland) is an open forest of pinyon and juniper with a total cover of 25%. With this many trees the competition is heavy and wheatgrass dies out. With a lower initial biomass, the wheatgrass would do better due to lower respiration demands. No shrubs were present in this ERU.

ERU 1 (Upland) had 8% total tree cover and 0.01 shrubs per m^2 . This inhibited grasses significantly but allowed survival of cheatgrass. Shrub dynamics on this ERU are typical, though somewhat reduced in magnitude.

On ERU 2 (Lowland) there are no trees. Sage growth is normal but the site is drier than ERU 1. Growth of wheatgrass in the spring is sufficient to inhibit cheatgrass completely.

ERU 3 (Bottomland) shows normal model dynamics for wheatgrass with almost no competition. Note the difference in magnitude from the cases with competition. Cheatgrass is again unable to germinate successfully.

On all ERU's the small size class of sage (not shown) germinated frequently but failed to survive due to intense competition. An anomalous buildup in storage biomass occurred in these small shrubs due to estimated parameter values.

Litter exhibits a gradual buildup on all ERU's. On ERU 0 (highland), however, this buildup reached unreasonable levels due to the estimated parameter for litter fall rates from trees.

Faunal Submodels. In general, species response to the varying ERU conditions is dependent upon the species. Mule deer, cottontail and coyote tend toward stable patterns by moving to more suitable habitats (ERUs) as the conditions change. Unlike those species, chipmunk species were restricted from inter-ERU movement and, therefore, exhibit a more fluctuating pattern. In addition, chipmunk are the only species considered to hibernate. Table 6.6 provides statistical summaries of major components of both the biomass and population submodels. Selected examples of biomass components are presented in Fig. 6.6, and selected examples of population components are presented in Fig. 6.7. For simplicity, one cohort of each species was selected to demonstrate inter-species dynamics, while one species was selected to demonstrate intra-species (or cohort) dynamics. It should also be noted that this simulation also included two additional ERUs (adjacent areas), so that some apparent anomalies are actually due to population movements to these ERUs, which are not included in the summaries.

In Table 6.6, the results for each cohort and the total population are presented. The coding of cohorts is as follows:

Age: mature (0), immature (1), juvenile (2)
Sex: female (0), male (1)

Table 6.6. Statistical summary of simulation results for fauna state variables and processes. A. Mule deer, B. Cottontail, C. Chipmunk, and D. Coyote. (ERU 0, ERU 1, ERU 2, ERU3, represent highland, upland, lowland, and bottomland, respectively)

A.

AESOP FAUNA SUMMARY STATISTICS

ERU : C-B TRACT - 0

SPECIES : MULE DEER

POPULATION

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	2.921	1.2651	149.50	0	11.0	0	1	0.6	357	1
0	1	2.066	0.9713	109.50	0	9.0	0	1	0.7	364	1
1	0	3.999	1.7623	211.90	0	15.0	0	1	1.7	357	1
1	1	4.021	1.7632	213.10	0	15.0	0	1	1.7	357	1
2	0	4.099	1.7357	216.70	0	13.0	0	1	1.1	350	2
2	1	4.145	1.7392	219.70	0	13.0	0	1	1.2	350	2
TOTAL		21.140	8.9594	1120.40	0	75.0	0	1	7.7	357	1

TYPICAL HEIGHT (KG)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	63.159	5.5501	3247.36	0	77.6	357	1	47.4	350	1
0	1	144.412	20.7602	7653.91	0	184.2	364	1	100.0	0	1
1	0	59.513	5.4034	2677.20	0	58.2	329	1	36.3	350	1
1	1	114.469	24.5978	6066.99	0	141.5	329	1	50.0	0	1
2	0	33.916	5.5676	1792.22	0	40.9	140	1	15.6	343	1
2	1	74.979	17.6576	3963.52	0	98.7	140	1	37.5	343	1
TOTAL		481.245	68.6117	25506.00	0	566.7	329	1	356.9	343	1

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1292.000	103.1041	67946.00	0	1464.0	364	1	1100.0	0	1
0	1	1292.000	108.1041	67946.00	0	1464.0	364	1	1100.0	0	1
1	0	534.972	94.7792	26253.50	0	694.0	329	1	365.0	0	1
1	1	534.925	94.7517	26251.00	0	694.0	329	1	365.0	0	1
2	0	265.096	49.7507	14050.10	0	269.8	329	1	175.0	0	1
2	1	265.747	50.2205	14084.80	0	371.2	329	1	175.0	0	1
TOTAL		4164.740	464.3540	220731.20	0	4997.1	329	1	3250.0	0	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-0.420	1.4453	-22.23	1	2.1	99	1	-4.1	245	1
0	1	0.167	3.9718	9.33	1	9.6	99	1	-9.4	245	1
1	0	-0.223	1.2399	-11.93	1	2.1	99	1	-3.6	245	1
1	1	0.642	3.6790	34.01	1	9.9	99	1	-7.4	245	1
2	0	0.129	1.2090	6.30	1	1.7	301	1	-2.6	245	1
2	1	1.259	2.9091	66.67	1	7.5	99	1	-5.3	245	1
TOTAL		1.551	13.9245	92.20	1	31.0	99	1	-31.4	245	1

Table 6.6. (Continued)

A.

(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.024	0.1758	1.28	52	1.3	336	1	0.0	0	52
1	1	0.025	0.1813	1.32	52	1.3	336	1	0.0	0	52
2	0	0.017	0.2110	0.92	45	0.3	147	1	-1.3	336	1
2	1	0.017	0.2157	0.99	45	0.3	147	1	-1.3	336	1
TOTAL		0.083	0.2151	4.40	46	0.7	147	1	0.0	0	46

NATURAL DEATH

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.029	0.1794	1.53	30	1.3	357	1	0.0	0	30
0	1	0.025	0.1813	1.23	51	1.3	354	1	0.0	0	51
1	0	0.053	0.2493	2.79	42	2.7	357	1	0.0	0	42
1	1	0.055	0.2530	2.99	42	2.8	357	1	0.0	0	42
2	0	0.020	0.0963	1.04	20	0.7	350	1	0.0	0	20
2	1	0.020	0.0963	1.05	19	0.7	350	1	0.0	0	19
TOTAL		0.201	0.9590	10.63	17	6.8	357	1	0.0	0	17

PREDATION LOSS

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.001	0.0023	0.03	50	0.0	105	3	0.0	0	50
1	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
2	0	0.007	0.0053	0.39	17	0.0	350	2	0.0	0	17
2	1	0.001	0.0030	0.05	49	0.0	105	5	0.0	0	48
TOTAL		0.009	0.0093	0.46	17	0.0	357	1	0.0	0	17

DISPERSAL

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-0.152	0.9520	-8.03	9	0.9	91	2	-5.4	7	1
0	1	-0.110	0.4198	-5.83	10	0.6	91	2	-4.0	7	1
1	0	-0.185	1.1899	-9.79	5	1.9	354	1	-7.4	7	1
1	1	-0.185	1.1919	-9.78	5	1.9	354	1	-7.4	7	1
2	0	-0.203	1.0419	-10.76	4	1.0	259	1	-6.4	7	1
2	1	-0.203	1.0442	-10.77	4	1.0	259	1	-6.4	7	1
TOTAL		-1.037	5.9179	-54.96	4	6.5	354	1	-37.0	7	1

TYPICAL MOVEMENT (KM)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	71.209	11.5765	3774.04	1	100.5	354	1	0.0	0	1
0	1	71.209	11.5765	3774.04	1	100.5	354	1	0.0	0	1
1	0	71.209	11.5765	3774.04	1	100.5	354	1	0.0	0	1
1	1	71.209	11.5765	3774.04	1	100.5	354	1	0.0	0	1
2	0	71.209	11.5765	3774.04	1	100.5	354	1	0.0	0	1
2	1	71.209	11.5765	3774.04	1	100.5	354	1	0.0	0	1
TOTAL		127.250	19.4591	22441.24	1	600.0	354	1	0.0	0	1

DURATION : 364 DAYS TIME STEP : 7 DAYS INTERVALS : 52

Table 6.6. (Continued)

A.
(Continued)

AESOP FAUNA SUMMARY STATISTICS

ERU : C-8 TRACT - 1

SPECIES : MULE DEER

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	3.789	1.1605	200.80	0	11.0	0	1	2.6	343	1
0	1	2.766	0.8399	146.60	0	9.0	0	1	1.9	343	1
1	0	5.470	1.6335	269.90	0	15.0	0	1	4.3	194	9
1	1	5.496	1.6346	291.30	0	15.0	0	1	4.3	210	6
2	0	5.458	1.4339	289.30	0	13.0	0	1	2.5	343	1
2	1	5.502	1.4331	291.60	0	13.0	0	1	2.6	343	1
TOTAL		28.481	6.8717	1509.50	0	75.0	0	1	21.8	343	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	68.225	0.8316	3615.91	0	69.1	315	1	65.0	0	1
0	1	162.942	11.3093	8635.92	0	167.3	315	1	100.0	0	1
1	0	55.425	3.6835	2937.52	0	61.0	315	1	50.0	21	4
1	1	131.309	16.9211	6959.36	0	148.2	315	1	60.0	0	1
2	0	38.680	4.5770	2050.04	0	45.5	315	1	23.6	336	1
2	1	88.132	14.9232	4671.01	0	110.8	315	1	46.0	0	1
TOTAL		544.713	44.1852	28869.76	0	602.4	315	1	361.0	0	1

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1292.000	108.1041	67946.00	0	1464.0	364	1	1100.0	0	1
0	1	1292.000	108.1041	67946.00	0	1464.0	364	1	1100.0	0	1
1	0	534.943	94.7623	28252.00	0	694.0	329	1	365.0	0	1
1	1	534.915	94.7464	28350.50	0	694.0	329	1	365.0	0	1
2	0	265.402	49.9710	14066.30	0	370.5	329	1	175.0	0	1
2	1	265.921	50.3421	14093.90	0	371.7	329	1	175.0	0	1
TOTAL		4165.181	464.6767	220754.60	0	4968.2	329	1	3290.0	0	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.073	0.1619	3.87	1	1.1	7	1	-1.7	322	1
0	1	1.269	4.3127	57.29	1	25.2	7	1	-1.0	322	1
1	0	0.259	0.3722	12.71	6	1.8	343	1	-1.3	322	1
1	1	1.798	3.6659	94.77	1	21.7	7	1	-3.1	322	1
2	0	0.596	0.6800	31.60	15	3.2	343	1	-0.6	322	1
2	1	2.410	1.9853	127.72	1	10.0	7	1	-1.4	322	1
TOTAL		6.375	9.8988	223.95	1	58.1	7	1	-11.9	322	1

Table 6.6. (Continued)

A.
(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.046	0.2379	2.46	52	2.5	336	1	0.0	0	52
1	1	0.012	0.3461	2.52	52	2.5	336	1	0.0	0	52
2	0	0.003	0.3690	0.17	45	0.4	154	2	-2.5	336	1
2	1	0.002	0.3757	0.11	45	0.4	154	2	-2.5	336	1
TOTAL		0.099	0.2573	5.26	46	0.8	154	2	0.0	0	46

NATURAL DEATH

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.005	0.0050	0.26	27	0.0	7	26	0.0	0	27
0	1	0.004	0.0050	0.23	30	0.0	7	23	0.0	0	30
1	0	0.005	0.0050	0.24	29	0.0	7	24	0.0	0	29
1	1	0.005	0.0050	0.25	28	0.0	7	25	0.0	0	28
2	0	0.007	0.0050	0.38	16	0.0	7	1	0.0	0	16
2	1	0.007	0.0049	0.39	15	0.0	7	1	0.0	0	15
TOTAL		0.033	0.0267	1.75	15	0.1	7	1	0.0	0	15

PREDATION LOSS

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.000	0.0014	0.01	52	0.0	105	1	0.0	0	52
1	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
2	0	0.005	0.0050	0.25	28	0.0	7	25	0.0	0	28
2	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
TOTAL		0.005	0.0054	0.26	28	0.0	105	1	0.0	0	28

DISPERSAL

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-0.138	0.8154	-7.29	11	0.8	350	1	-5.8	7	1
0	1	-0.100	0.5924	-5.32	11	0.6	350	1	-4.2	7	1
1	0	-0.177	1.1314	-9.40	9	1.7	350	1	-7.9	7	1
1	1	-0.177	1.1326	-9.37	9	1.8	350	1	-7.9	7	1
2	0	-0.174	0.9693	-9.24	8	0.8	350	1	-6.9	7	1
2	1	-0.174	0.9701	-9.23	8	0.8	350	1	-6.9	7	1
TOTAL		-0.941	5.6014	-49.85	8	6.4	350	1	-39.7	7	1

TYPICAL MOVEMENT (KM)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	69.185	9.8690	3666.78	1	83.3	350	1	0.0	0	1
0	1	69.185	9.8690	3666.78	1	83.3	350	1	0.0	0	1
1	0	69.185	9.8690	3666.78	1	83.3	350	1	0.0	0	1
1	1	69.185	9.8690	3666.78	1	83.3	350	1	0.0	0	1
2	0	69.185	9.8690	3666.78	1	83.3	350	1	0.0	0	1
2	1	69.185	9.8690	3666.78	1	83.3	350	1	0.0	0	1
TOTAL		415.107	59.2142	22000.63	1	499.9	350	1	0.0	0	1

DURATION : 364 DAYS TIME STEP : 7 DAYS INTERVALS : 52

Table 6.6. (Continued)

A.
(Continued)

AESOP FAUNA SUMMARY STATISTICS

ERU : C-9 TRACT - 2

SPECIES : MULE DEER

POPULATION

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	3.736	0.4599	199.00	1	4.9	70	1	0.0	0	1
0	1	2.726	0.4776	144.50	1	3.5	70	2	0.0	0	1
1	0	5.479	1.4883	290.40	1	10.8	343	1	0.0	0	1
1	1	5.523	1.5149	292.70	1	11.0	343	1	0.0	0	1
2	0	5.462	1.2988	289.50	1	6.9	273	3	0.0	0	1
2	1	5.515	1.3130	292.30	1	7.0	273	3	0.0	0	1
TOTAL		29.442	4.6687	1507.40	1	39.3	343	1	0.0	0	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	66.884	9.3912	3544.87	1	69.1	308	1	0.0	0	1
0	1	160.667	23.7314	8515.34	1	167.7	308	1	0.0	0	1
1	0	54.420	8.4517	2884.27	1	60.9	315	1	0.0	0	1
1	1	129.945	22.9125	6897.08	1	142.0	315	1	0.0	0	1
2	0	37.792	6.9375	2003.00	1	45.6	329	1	0.0	0	1
2	1	87.036	19.2590	4612.93	1	110.8	329	1	0.0	0	1
TOTAL		534.746	83.4859	28447.52	1	600.9	315	1	0.0	0	1

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1261.245	205.4670	66846.00	1	1464.0	364	1	0.0	0	1
0	1	1261.245	205.4670	66846.00	1	1464.0	364	1	0.0	0	1
1	0	529.057	117.8105	27987.00	1	694.0	329	1	0.0	0	1
1	1	529.029	117.7960	27985.50	1	694.0	329	1	0.0	0	1
2	0	262.134	60.6829	13891.50	1	370.5	329	1	0.0	0	1
2	1	262.619	61.0256	13918.50	1	371.7	329	1	0.0	0	1
TOTAL		4103.298	728.4157	217474.50	1	4988.2	329	1	0.0	0	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.071	0.4463	3.77	1	1.0	7	1	-3.0	322	1
0	1	1.264	4.1401	67.01	1	22.6	7	1	-4.9	322	1
1	0	0.260	0.2649	13.80	1	1.2	343	1	-1.7	322	1
1	1	1.791	3.5086	94.95	1	19.7	7	1	-4.1	322	1
2	0	0.593	0.6667	31.43	1	2.9	343	1	-1.0	322	1
2	1	2.402	1.9077	127.30	1	9.3	7	1	-2.5	322	1
TOTAL		6.282	9.5401	328.26	1	52.4	7	1	-16.3	322	1

Table 6.6. (Continued)

292

A.
(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.077	0.5404	4.08	52	4.1	336	1	0.0	0	52
1	1	0.079	0.5728	4.17	52	4.2	336	1	0.0	0	52
2	0	-0.025	0.5834	-1.33	45	0.4	147	1	-4.1	336	1
2	1	-0.027	0.5954	-1.42	45	0.4	147	1	-4.2	336	1
TOTAL		0.104	0.2699	5.50	46	0.9	147	1	0.0	0	46

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.005	0.0050	0.24	27	0.0	7	26	0.0	0	27
0	1	0.005	0.0050	0.25	28	0.0	7	26	0.0	0	28
1	0	0.005	0.0050	0.24	27	0.0	7	26	0.0	0	27
1	1	0.005	0.0050	0.27	24	0.0	7	27	0.0	0	26
2	0	0.007	0.0045	0.29	14	0.0	7	39	0.0	0	14
2	1	0.007	0.0045	0.29	14	0.0	7	39	0.0	0	14
TOTAL		0.034	0.0261	1.92	14	0.1	7	24	0.0	0	14

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.000	0.0014	0.01	52	0.0	105	1	0.0	0	52
1	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
2	0	0.005	0.0050	0.24	29	0.0	42	24	0.0	0	29
2	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
TOTAL		0.005	0.0054	0.25	29	0.0	105	1	0.0	0	29

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.068	0.5929	3.63	6	3.6	7	1	-1.1	350	1
0	1	0.050	0.4317	2.65	7	2.6	7	1	-0.8	350	1
1	0	0.072	0.8892	3.90	5	4.9	7	1	-2.6	350	1
1	1	0.071	0.8724	3.77	5	4.9	7	1	-2.7	350	1
2	0	0.098	0.7845	5.19	4	4.2	7	1	-1.1	350	1
2	1	0.098	0.7690	5.21	4	4.2	7	1	-1.1	350	1
TOTAL		0.458	4.2571	24.25	4	24.5	7	1	-9.6	350	1

TYPICAL MOVEMENT (KM)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	70.419	11.4307	3702.22	1	101.9	336	1	0.0	0	1
0	1	70.419	11.4307	3702.22	1	101.9	336	1	0.0	0	1
1	0	70.419	11.4307	3702.22	1	101.9	336	1	0.0	0	1
1	1	70.419	11.4307	3702.22	1	101.9	336	1	0.0	0	1
2	0	70.419	11.4307	3702.22	1	101.9	336	1	0.0	0	1
2	1	70.419	11.4307	3702.22	1	101.9	336	1	0.0	0	1
TOTAL		422.515	33.5333	22190.22	1	611.1	336	1	0.0	0	1

DURATION : 364 DAYS TIME STEP : 7 DAYS INTERVALS : 52

Table 6.6. (Continued)

A.
(Continued)

AESOP FAUNA SUMMARY STATISTICS

ERU : C-B TRACT - 3

SPECIES : MULE DEER

POPULATION

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	3.073	0.6960	159.80	1	4.5	329	1	0.0	0	1
0	1	2.252	0.5062	117.10	1	3.3	329	1	0.0	0	1
1	0	4.513	1.5230	234.70	1	9.7	336	1	0.0	0	1
1	1	4.581	1.5659	239.20	1	9.9	336	1	0.0	0	1
2	0	4.667	1.9467	242.70	1	8.5	329	1	0.0	0	1
2	1	4.737	1.9929	246.30	1	8.7	329	1	0.0	0	1
TOTAL		23.823	6.9159	1228.80	1	37.5	329	1	0.0	0	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	64.609	9.5060	3259.67	1	68.5	359	1	0.0	0	1
0	1	150.851	27.6484	7844.25	1	166.6	359	1	0.0	0	1
1	0	52.463	9.9986	2729.09	1	59.9	329	1	0.0	0	1
1	1	120.950	29.1787	6299.40	1	145.5	329	1	0.0	0	1
2	0	35.430	6.9522	1842.37	1	44.7	329	1	0.0	0	1
2	1	90.515	20.7910	4186.90	1	109.0	329	1	0.0	0	1
TOTAL		504.819	96.7566	26250.57	1	511.0	329	1	0.0	0	1

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1264.212	206.3225	65709.00	1	1464.0	364	1	0.0	0	1
0	1	1264.212	206.3225	65709.00	1	1464.0	364	1	0.0	0	1
1	0	531.087	116.9105	27616.50	1	694.0	329	1	0.0	0	1
1	1	531.038	116.9369	27614.00	1	694.0	329	1	0.0	0	1
2	0	263.104	59.9747	13681.40	1	319.3	329	1	0.0	0	1
2	1	263.948	60.9171	13725.30	1	371.2	329	1	0.0	0	1
TOTAL		4117.600	726.7999	214115.20	1	4926.5	329	1	0.0	0	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.026	0.5717	1.36	1	1.6	98	1	-1.7	357	1
0	1	1.023	2.0671	53.98	1	7.3	98	1	-3.9	357	1
1	0	0.224	0.5360	11.67	1	1.7	98	1	-1.3	14	1
1	1	1.591	1.8607	92.23	1	7.9	98	1	-2.0	357	1
2	0	0.534	0.7429	27.76	1	1.7	343	1	-1.1	49	1
2	1	2.195	1.3923	112.64	1	6.7	98	1	0.0	0	1
TOTAL		5.589	6.0219	290.63	1	26.3	98	1	-7.8	357	1

Table 6.6. (Continued)

A.
(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	52	0.0	0	52	0.0	0	52
0	1	0.000	0.0000	0.00	52	0.0	0	52	0.0	0	52
1	0	0.073	0.5270	3.60	51	3.9	335	1	0.0	0	51
1	1	0.075	0.5435	3.92	51	3.9	335	1	0.0	0	51
2	0	-0.024	0.5486	-1.24	44	0.4	169	4	-3.9	335	1
2	1	-0.026	0.5548	-1.36	44	0.4	169	4	-3.9	335	1
TOTAL		0.099	0.2525	5.12	45	0.3	169	4	0.0	0	45

NATURAL DEATH

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.003	0.0046	0.15	37	0.0	70	15	0.0	0	37
0	1	0.000	0.0014	0.01	51	0.0	169	1	0.0	0	51
1	0	0.001	0.0024	0.02	49	0.0	70	3	0.0	0	49
1	1	0.001	0.0027	0.04	49	0.0	70	4	0.0	0	48
2	0	0.007	0.0046	0.27	15	0.0	14	37	0.0	0	15
2	1	0.007	0.0046	0.37	15	0.0	14	37	0.0	0	15
TOTAL		0.019	0.0141	0.97	15	0.1	70	3	0.0	0	15

PREDATION LOSS

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	52	0.0	0	52	0.0	0	52
0	1	0.000	0.0000	0.00	52	0.0	0	52	0.0	0	52
1	0	0.001	0.0032	0.06	46	0.0	105	6	0.0	0	46
1	1	0.000	0.0000	0.00	52	0.0	0	52	0.0	0	52
2	0	0.007	0.0048	0.34	18	0.0	42	34	0.0	0	18
2	1	0.001	0.0024	0.03	49	0.0	105	3	0.0	0	49
TOTAL		0.008	0.0076	0.43	18	0.0	105	2	0.0	0	18

DISPERSAL

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.009	0.2363	0.45	9	0.9	329	1	-1.0	350	1
0	1	0.007	0.1719	0.34	11	0.7	329	1	-0.7	350	1
1	0	-0.012	0.4258	-0.68	5	1.3	329	1	-2.2	350	1
1	1	-0.015	0.4343	-0.79	5	1.3	329	1	-2.3	350	1
2	0	0.020	0.3458	1.57	5	1.8	329	1	-1.0	350	1
2	1	0.020	0.3512	1.59	5	1.8	329	1	-1.0	350	1
TOTAL		0.047	1.9146	2.47	4	7.8	329	1	-8.2	350	1

TYPICAL MOVEMENT (KM)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	69.822	10.3544	3630.78	1	99.1	329	1	0.0	0	1
0	1	69.823	10.3544	3630.78	1	99.1	329	1	0.0	0	1
1	0	69.822	10.3544	3630.78	1	99.1	329	1	0.0	0	1
1	1	69.823	10.3544	3630.78	1	99.1	329	1	0.0	0	1
2	0	69.822	10.3544	3630.78	1	99.1	329	1	0.0	0	1
2	1	69.823	10.3544	3630.78	1	99.1	329	1	0.0	0	1
TOTAL		69.936	10.1266	21794.48	1	101.4	329	1	0.0	0	1

DURATION : 364 DAYS TIME STEP : 7 DAYS INTERVALS : 51

Table 6.6. (Continued)

B.

AESOP FAUNA SUMMARY STATISTICS

ERU : C-B TRACT - 0

SPECIES : COTTONTAIL

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	167.599	66.1402	8882.70	0	400.0	0	1	33.5	322	1
0	1	229.304	71.4245	12153.10	0	400.0	0	1	39.5	322	2
1	0	88.472	69.3817	4489.00	0	350.0	0	1	7.5	322	1
1	1	104.108	72.2583	5517.70	0	350.0	0	1	8.9	322	1
2	0	29.532	35.6732	1565.20	12	150.0	0	1	0.0	70	12
2	1	56.024	59.9406	2969.40	11	201.3	266	1	0.0	70	11
TOTAL		675.040	279.4523	35777.10	0	1800.0	0	1	117.6	343	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1.095	0.1867	59.04	0	1.3	199	1	0.7	70	1
0	1	1.146	0.2232	60.75	0	1.4	199	1	0.5	70	1
1	0	0.729	0.2262	38.64	0	1.1	199	1	0.2	364	1
1	1	0.758	0.2402	40.17	0	1.2	199	1	0.3	364	1
2	0	0.099	0.1504	5.26	12	0.7	0	1	0.0	70	12
2	1	0.131	0.1591	6.73	11	0.7	0	1	0.0	70	11
TOTAL		3.958	0.7913	209.77	0	5.7	0	1	2.1	70	1

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	452.047	92.0183	23959.50	0	600.5	364	1	300.0	0	1
0	1	456.858	95.9393	24213.50	0	610.7	364	1	300.0	0	1
1	0	205.521	53.6633	10992.60	0	303.2	199	1	116.9	196	1
1	1	205.433	53.6032	10989.20	0	302.9	199	1	116.9	196	1
2	0	32.397	34.3199	1716.50	12	123.0	28	1	0.0	70	12
2	1	37.399	35.6327	1981.60	11	123.0	28	1	0.0	70	11
TOTAL		1399.640	220.5279	73450.90	0	1780.9	364	1	1030.0	0	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-0.046	0.0852	-2.41	2	0.1	99	1	-0.2	364	1
0	1	-0.035	0.0923	-1.38	1	0.1	94	1	-0.2	364	1
1	0	-0.030	0.0815	-1.61	1	0.1	203	1	-0.2	315	1
1	1	-0.023	0.0977	-1.22	1	0.1	94	1	-0.2	336	1
2	0	-0.004	0.0430	-0.21	12	0.1	301	1	-0.1	7	1
2	1	-0.007	0.0492	-0.35	11	0.1	301	1	-0.1	7	1
TOTAL		-0.145	0.4082	-7.69	1	0.4	301	1	-1.0	315	1

Table 6.6. (Continued)

A.
(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1.255	9.1231	66.49	52	66.5	196	1	0.0	0	52
0	1	1.450	10.5539	76.87	52	76.9	196	1	0.0	0	52
1	0	-0.679	10.1205	-36.00	51	30.5	35	1	-66.5	196	1
1	1	-0.801	11.6518	-42.45	51	34.4	35	1	-76.9	196	1
2	0	7.214	10.3067	382.33	29	22.7	224	1	-30.5	35	1
2	1	7.140	10.5923	378.40	29	22.7	224	1	-34.4	35	1
TOTAL		15.579	17.8286	825.64	29	45.4	224	1	0.0	0	29

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	7.102	24.7551	376.41	1	143.4	42	1	0.0	0	1
0	1	6.047	22.1636	320.49	1	127.5	357	1	0.0	0	1
1	0	5.694	20.9674	301.77	1	125.6	28	1	0.0	0	1
1	1	5.237	18.1609	277.54	1	120.6	28	1	0.0	0	1
2	0	3.580	10.0353	189.72	16	55.1	350	1	0.0	0	16
2	1	3.993	11.0757	211.64	7	68.4	350	1	0.0	0	7
TOTAL		31.652	66.1393	1677.57	1	283.9	28	1	0.0	0	1

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.486	0.1511	25.76	1	0.9	112	1	0.0	0	1
0	1	0.437	0.1864	25.83	1	1.1	112	1	0.0	0	1
1	0	0.917	0.4620	48.60	1	2.7	364	1	0.0	0	1
1	1	0.879	0.3755	46.58	1	2.1	357	1	0.0	0	1
2	0	10.799	11.8474	572.28	12	72.6	280	1	0.0	0	12
2	1	8.540	10.9361	452.63	11	74.7	329	1	0.0	0	11
TOTAL		22.107	18.0926	1171.68	1	90.0	280	1	0.0	0	1

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1.218	33.8290	64.54	1	93.9	350	1	-96.0	322	1
0	1	-0.071	40.9239	-3.77	1	113.2	350	1	-120.2	322	1
1	0	1.979	21.7431	104.90	1	59.6	91	1	-76.2	14	1
1	1	1.647	23.9226	87.29	1	61.4	91	1	-76.2	14	1
2	0	4.234	16.6621	229.70	2	56.1	259	1	-34.2	273	1
2	1	2.563	22.1151	135.96	2	68.4	350	1	-70.7	322	1
TOTAL		11.670	146.8985	618.52	1	426.0	350	1	-391.5	14	1

TYPICAL MOVEMENT (KM)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	29.949	20.8206	1597.28	1	132.7	350	1	0.0	0	1
0	1	29.949	20.8206	1587.28	1	122.7	350	1	0.0	0	1
1	0	29.949	20.8206	1587.28	1	122.7	350	1	0.0	0	1
1	1	29.949	20.8206	1587.23	1	132.7	350	1	0.0	0	1
2	0	18.433	11.8499	976.93	13	46.8	259	1	0.0	0	13
2	1	18.829	11.5633	997.93	12	46.8	259	1	0.0	0	12
TOTAL		157.056	78.9419	9323.98	1	530.9	350	1	0.0	0	1

DURATION : 364 DAYS TIME STEP : 7 DAYS INTERVALS : 52

Table 6.6. (Continued)

B.
(Continued)

AESOP FAUNA SUMMARY STATISTICS

ERU : C-9 TRACT - 1

SPECIES : COTTONTAIL

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	207.506	49.0365	10997.00	0	409.0	0	1	116.4	343	1
0	1	213.357	48.9361	11307.90	0	400.0	0	1	124.8	343	1
1	0	146.125	90.7227	7744.60	0	350.0	0	1	34.3	315	1
1	1	148.396	89.9161	7865.00	0	350.0	0	1	36.9	315	1
2	0	142.669	92.6094	7561.40	0	309.1	273	1	19.2	99	1
2	1	147.936	96.6719	7940.60	0	322.9	273	1	19.2	99	1
TOTAL		1005.997	187.0963	53317.30	0	1900.0	0	1	603.0	343	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1.272	0.0536	67.41	0	1.3	315	1	1.1	336	1
0	1	1.359	0.0642	72.03	0	1.4	315	1	1.2	0	1
1	0	0.909	0.1618	48.16	0	1.2	189	1	0.4	196	1
1	1	0.963	0.1713	51.06	0	1.2	189	1	0.5	196	1
2	0	0.418	0.1561	22.14	0	0.7	29	1	0.2	133	1
2	1	0.448	0.1586	22.75	0	0.7	29	1	0.2	133	1
TOTAL		5.369	0.5051	294.55	0	6.3	315	1	4.2	196	1

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	448.132	78.9311	22751.00	0	592.2	364	1	300.0	0	1
0	1	448.415	79.1509	23766.00	0	592.8	364	1	300.0	0	1
1	0	194.068	49.4690	10265.60	0	304.3	189	1	116.4	196	1
1	1	194.213	49.4119	10293.30	0	304.3	189	1	116.4	196	1
2	0	75.925	25.3031	4024.00	0	123.0	29	1	39.1	133	1
2	1	76.564	25.0196	4057.90	0	124.1	315	1	40.1	133	1
TOTAL		1437.317	208.9597	76177.80	0	1804.6	315	1	1030.0	0	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.004	0.0021	0.19	4	0.1	343	1	-0.1	322	1
0	1	0.006	0.0021	0.29	1	0.1	343	1	-0.2	322	1
1	0	0.019	0.0005	1.01	9	0.1	343	1	-0.1	322	1
1	1	0.021	0.0015	1.14	7	0.1	343	1	-0.1	322	1
2	0	0.022	0.0027	1.72	4	0.1	343	1	-0.1	322	1
2	1	0.026	0.0041	1.89	3	0.1	343	1	-0.1	322	1
TOTAL		0.118	0.1574	6.24	1	0.6	343	1	-0.7	322	1

Table 6.6. (Continued)

B.

(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1.675	12.1921	99.76	52	99.8	196	1	0.0	0	52
0	1	1.694	12.3322	99.73	52	99.8	196	1	0.0	0	52
1	0	1.676	22.3171	98.84	50	123.4	322	1	-99.8	196	1
1	1	1.948	23.4682	97.92	50	123.5	322	1	-99.8	196	1
2	0	4.749	21.8619	252.76	27	21.7	210	1	-123.4	322	1
2	1	4.579	23.0124	242.66	27	21.7	210	1	-123.5	322	1
TOTAL		16.240	19.3955	960.72	29	43.4	210	1	0.0	0	29

NATURAL DEATH

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.206	0.1305	10.94	1	0.4	14	2	0.0	0	1
0	1	0.210	0.1306	11.12	1	0.4	14	2	0.0	0	1
1	0	0.227	0.2104	12.02	1	0.6	42	1	0.0	0	1
1	1	0.229	0.2099	12.11	1	0.6	42	1	0.0	0	1
2	0	0.123	0.0821	7.06	1	0.3	357	2	0.0	0	1
2	1	0.129	0.0858	7.31	1	0.3	357	2	0.0	0	1
TOTAL		1.143	0.7447	60.56	1	2.5	14	1	0.0	0	1

PREDATION LOSS

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.378	0.0969	20.04	1	0.6	105	1	0.0	0	1
0	1	0.354	0.0915	19.78	1	0.6	105	1	0.0	0	1
1	0	0.570	0.2770	35.49	1	1.7	203	1	0.0	0	1
1	1	0.631	0.2571	33.42	1	1.6	203	1	0.0	0	1
2	0	2.413	1.0524	127.99	1	4.0	126	1	0.0	0	1
2	1	2.220	0.9433	117.68	1	3.6	126	1	0.0	0	1
TOTAL		6.666	2.4539	353.29	1	11.5	203	1	0.0	0	1

DISPERSAL

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-4.970	20.8155	-252.09	1	95.1	350	1	-104.5	7	1
0	1	-4.318	22.2324	-228.89	1	107.1	350	1	-104.5	7	1
1	0	-4.997	15.1464	-264.92	1	37.8	350	1	-91.5	7	1
1	1	-4.931	15.6902	-261.25	1	44.1	350	1	-91.5	7	1
2	0	-2.717	11.0477	-144.02	1	49.9	350	1	-39.2	7	1
2	1	-2.409	12.5374	-127.67	1	61.9	350	1	-39.2	7	1
TOTAL		-24.242	95.6329	-1294.84	1	385.9	350	1	-470.4	7	1

TYPICAL MOVEMENT (KM)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	21.396	4.7715	1133.97	1	47.5	350	1	0.0	0	1
0	1	21.396	4.7715	1133.97	1	47.5	350	1	0.0	0	1
1	0	21.396	4.7715	1133.97	1	47.5	350	1	0.0	0	1
1	1	21.396	4.7715	1133.97	1	47.5	350	1	0.0	0	1
2	0	21.396	4.7715	1133.97	1	47.5	350	1	0.0	0	1
2	1	21.396	4.7715	1133.97	1	47.5	350	1	0.0	0	1
TOTAL		128.374	28.6291	6803.82	1	234.9	350	1	0.0	0	1

Table 6.6. (Continued)

B.

(Continued)

AESOP FAUNA SUMMARY STATISTICS

ERU : C-B TRACT - 2

SPECIES : COTTONTAIL

POPULATION

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	228.815	39.6812	12127.20	0	340.9	343	1	159.0	199	1
0	1	255.051	43.7709	13517.70	0	397.5	343	1	191.5	199	1
1	0	148.902	80.9523	7891.80	0	279.6	70	1	37.7	308	1
1	1	159.287	82.9376	8447.50	0	303.0	70	1	43.7	308	1
2	0	157.613	109.9702	8252.50	0	351.9	273	1	13.6	98	1
2	1	164.792	115.7949	8734.00	0	371.5	273	1	14.5	98	1
TOTAL		1114.560	172.7907	59071.70	0	1621.2	343	1	911.4	329	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1.275	0.0494	67.56	0	1.3	308	1	1.1	322	1
0	1	1.363	0.0607	72.22	0	1.4	308	1	1.2	0	1
1	0	0.910	0.1541	48.22	0	1.2	199	1	0.5	196	1
1	1	0.956	0.1641	51.17	0	1.2	199	1	0.5	196	1
2	0	0.415	0.1612	22.00	0	0.7	29	1	0.2	133	1
2	1	0.446	0.1643	23.63	0	0.7	29	1	0.2	133	1
TOTAL		5.374	0.4629	294.20	0	6.2	315	1	4.0	322	1

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	449.642	80.1096	23321.00	0	595.4	364	1	300.0	0	1
0	1	450.679	80.9265	23386.00	0	597.6	364	1	300.0	0	1
1	0	194.074	49.4659	10295.90	0	304.3	199	1	116.2	196	1
1	1	194.251	49.3608	10300.60	0	304.3	199	1	115.3	196	1
2	0	74.639	26.2414	3955.80	0	123.0	29	1	36.8	126	2
2	1	75.343	25.9279	3993.20	0	123.0	29	1	36.9	133	1
TOTAL		1438.726	210.6309	76252.50	0	1809.2	315	1	1030.0	0	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.003	0.0311	0.17	2	0.1	329	1	-0.2	322	1
0	1	0.005	0.0320	0.27	1	0.1	329	1	-0.2	322	1
1	0	0.019	0.0356	1.00	9	0.1	329	1	-0.2	322	1
1	1	0.021	0.0366	1.13	5	0.1	329	1	-0.2	322	1
2	0	0.030	0.0274	1.60	3	0.1	329	1	-0.1	322	1
2	1	0.033	0.0279	1.75	1	0.1	329	1	-0.1	322	1
TOTAL		0.112	0.1819	5.93	1	0.6	329	1	-1.0	322	1

Table 6.6. (Continued)

300

B.
(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1.820	12.3226	94.99	52	97.0	196	1	0.0	0	52
0	1	1.992	14.4984	105.55	52	105.6	196	1	0.0	0	52
1	0	1.335	22.0996	70.73	50	115.6	322	1	-97.0	196	1
1	1	1.427	24.1826	75.65	50	129.1	322	1	-105.6	196	1
2	0	6.310	21.8373	334.43	27	26.5	217	1	-115.6	322	1
2	1	6.054	23.3109	320.95	27	26.5	217	1	-129.1	322	1
TOTAL		18.949	21.6015	1004.30	29	53.0	217	1	0.0	0	29

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.220	0.1195	11.65	1	0.4	21	1	0.0	0	1
0	1	0.242	0.1231	12.82	1	0.5	70	1	0.0	0	1
1	0	0.227	0.1995	12.03	1	0.6	70	1	0.0	0	1
1	1	0.240	0.2071	12.70	1	0.6	70	1	0.0	0	1
2	0	1.041	6.5469	55.16	1	47.8	329	1	0.0	0	1
2	1	1.137	7.2069	60.29	1	52.6	329	1	0.0	0	1
TOTAL		3.106	13.6848	164.64	1	100.7	329	1	0.0	0	1

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.392	0.1004	20.27	1	0.6	105	1	0.0	0	1
0	1	0.357	0.0941	19.92	1	0.6	105	1	0.0	0	1
1	0	0.676	0.2935	35.91	1	1.9	203	1	0.0	0	1
1	1	0.635	0.2629	33.67	1	1.6	203	1	0.0	0	1
2	0	2.541	1.2453	134.69	1	4.6	126	1	0.0	0	1
2	1	2.330	1.1097	123.49	1	4.1	126	2	0.0	0	1
TOTAL		6.922	2.7950	366.94	1	12.1	203	1	0.0	0	1

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-1.307	31.3937	-69.26	1	143.9	336	1	-112.0	350	1
0	1	-0.851	37.6048	-45.11	1	166.6	336	1	-130.9	350	1
1	0	-1.260	21.7626	-66.79	1	99.2	336	1	-76.1	350	1
1	1	-1.033	24.9274	-54.99	1	101.7	336	1	-86.3	350	1
2	0	-2.232	19.3183	-119.30	1	96.8	336	1	-60.9	350	1
2	1	-1.849	22.2105	-99.02	1	111.2	336	1	-67.5	350	1
TOTAL		-8.556	152.7683	-453.47	1	709.4	336	1	-534.0	350	1

TYPICAL MOVEMENT (KM)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	22.911	8.3769	1214.26	1	74.6	336	1	0.0	0	1
0	1	22.911	8.3769	1214.26	1	74.6	336	1	0.0	0	1
1	0	22.911	8.3769	1214.26	1	74.6	336	1	0.0	0	1
1	1	22.911	8.3769	1214.26	1	74.6	336	1	0.0	0	1
2	0	22.911	8.3769	1214.26	1	74.6	336	1	0.0	0	1
2	1	22.911	8.3769	1214.26	1	74.6	336	1	0.0	0	1
TOTAL		127.442	50.2169	7255.56	1	447.5	336	1	0.0	0	1

DURATION : 364 DAYS TIME STEP : 7 DAYS INTERVALS : 52

Table 6.6. (Continued)

B.
(Continued)

AESOP FAUNA SUMMARY STATISTICS

ERU : C-B TRACT - 3

SPECIES : COTTONTAIL

POPULATION

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	222.056	95.3742	11598.90	1	427.1	329	1	0.0	0	1
0	1	330.613	122.6443	17191.90	1	536.2	329	1	0.0	0	1
1	0	67.940	32.0736	3532.90	1	133.9	189	1	0.0	0	1
1	1	96.777	41.0716	5032.40	1	190.8	189	1	0.0	0	1
2	0	94.240	90.4471	4900.50	7	277.5	329	1	0.0	0	7
2	1	117.763	116.8410	6123.70	7	371.9	329	1	0.0	0	7
TOTAL		920.390	394.7048	48260.30	1	1902.4	329	1	0.0	0	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1.121	0.2433	58.79	1	1.3	259	1	0.0	0	1
0	1	1.186	0.2939	61.65	1	1.4	259	1	0.0	0	1
1	0	0.812	0.2232	42.55	1	1.1	189	1	0.0	0	1
1	1	0.853	0.2420	44.34	1	1.2	189	1	0.0	0	1
2	0	0.176	0.1572	9.16	7	0.5	350	1	0.0	0	7
2	1	0.199	0.1690	10.25	7	0.6	343	1	0.0	0	7
TOTAL		4.362	1.0197	226.84	1	5.7	343	1	0.0	0	1

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	455.172	104.2664	23619.00	1	612.2	364	1	0.0	0	1
0	1	457.192	105.7392	23774.00	1	617.4	364	1	0.0	0	1
1	0	202.040	57.1692	10504.10	1	303.4	189	1	0.0	0	1
1	1	200.648	56.3521	10433.70	1	303.5	189	1	0.0	0	1
2	0	45.256	38.4361	2353.30	7	124.7	350	1	0.0	0	7
2	1	46.691	38.1162	2427.40	7	123.0	29	2	0.0	0	7
TOTAL		1406.990	321.0594	73123.50	1	1956.7	343	1	0.0	0	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-0.009	0.0514	-0.40	3	0.1	34	1	-0.1	14	1
0	1	0.001	0.0496	0.06	4	0.1	34	1	-0.1	257	1
1	0	-0.002	0.0534	-0.10	1	0.1	34	1	-0.2	14	1
1	1	0.007	0.0508	0.26	1	0.1	203	1	-0.2	14	1
2	0	0.010	0.0243	0.50	7	0.0	252	1	-0.1	14	1
2	1	0.012	0.0236	0.63	8	0.0	252	1	-0.1	14	1
TOTAL		0.020	0.2479	1.06	1	0.4	54	1	-0.9	14	1

Table 6.6. (Continued)

B.

(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1.532	11.0441	79.64	51	79.6	196	1	0.0	0	51
0	1	2.074	14.9533	107.93	51	107.9	196	1	0.0	0	51
1	0	-0.094	13.7934	-4.88	49	54.2	357	1	-79.6	196	1
1	1	-0.143	18.9742	-7.46	49	79.3	350	1	-107.8	196	1
2	0	9.246	15.3553	480.80	25	31.7	245	1	-54.2	357	1
2	1	8.754	19.0716	455.19	25	31.7	245	1	-79.3	350	1
TOTAL		21.368	25.0019	1111.12	28	63.4	245	1	0.0	0	28

NATURAL DEATH

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1.994	13.0545	103.71	1	94.3	25	1	0.0	0	1
0	1	0.279	0.1013	14.53	1	0.5	357	1	0.0	0	1
1	0	3.418	14.1512	177.73	1	76.1	28	1	0.0	0	1
1	1	2.781	13.3970	144.63	1	72.8	23	1	0.0	0	1
2	0	0.598	2.9371	31.09	9	21.1	29	1	-0.4	105	1
2	1	0.613	2.9543	31.87	8	20.4	29	1	-0.4	105	1
TOTAL		9.684	31.5425	533.56	1	191.0	28	1	0.0	0	1

PREDATION LOSS

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.606	0.1970	31.51	1	1.2	112	1	0.0	0	1
0	1	0.608	0.2478	31.61	1	1.6	112	1	0.0	0	1
1	0	1.024	0.4685	53.23	1	2.6	203	1	0.0	0	1
1	1	0.994	0.4386	51.69	1	2.5	203	1	0.0	0	1
2	0	8.851	7.4763	450.23	7	21.0	161	1	0.0	0	7
2	1	7.783	6.6185	404.71	7	19.2	161	1	0.0	0	7
TOTAL		19.865	14.6022	1032.99	1	42.3	161	1	0.0	0	1

DISPERSAL

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	2.453	25.4137	127.83	1	77.1	329	1	-122.7	350	1
0	1	1.667	32.3381	86.70	1	84.3	329	1	-164.7	350	1
1	0	3.882	12.4850	201.84	1	61.9	329	1	-39.4	350	1
1	1	3.888	13.9937	202.19	1	67.2	329	1	-35.4	350	1
2	0	0.736	15.5707	38.23	2	59.4	329	1	-76.8	350	1
2	1	0.729	20.1574	37.93	2	61.5	329	1	-102.5	350	1
TOTAL		13.361	114.9151	694.77	1	411.4	329	1	-531.5	350	1

TYPICAL MOMENT (MM)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	23.419	5.9490	1217.80	1	41.5	25	1	0.0	0	1
0	1	23.419	5.9490	1217.80	1	41.5	25	1	0.0	0	1
1	0	23.419	5.9490	1217.80	1	41.5	25	1	0.0	0	1
1	1	23.419	5.9490	1217.80	1	41.5	25	1	0.0	0	1
2	0	20.503	9.3363	1026.18	7	41.5	25	1	0.0	0	7
2	1	20.503	9.3363	1026.18	7	41.5	25	1	0.0	0	7
TOTAL		124.694	33.6274	7023.56	1	249.0	25	1	0.0	0	1

DURATION : 364 DAYS TIME STEP : 7 DAYS INTERVALS : 51

Table 6.6. (Continued)

C.

AESOP FAUNA SUMMARY STATISTICS

ERU : C-B TRACT - 0

SPECIES : CHIPMUNK

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1003.825	935.8018	53202.70	11	2250.0	0	1	0.0	294	11
0	1	1209.891	949.5240	64071.20	11	2250.0	0	1	0.0	294	11
1	0	1967.296	1198.9533	104255.70	13	3019.0	245	1	0.0	290	13
1	1	2093.458	1214.8054	110953.30	11	3399.1	245	1	0.0	294	11
TOTAL		6273.470	3351.4458	332493.90	11	10100.0	0	1	0.0	294	11

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.039	0.0232	2.04	11	0.1	252	1	0.0	294	11
0	1	0.038	0.0241	2.00	11	0.1	203	5	0.0	294	11
1	0	0.026	0.0183	1.38	14	0.1	252	2	0.0	273	14
1	1	0.028	0.0190	1.49	11	0.1	252	1	0.0	294	11
TOTAL		0.131	0.0837	6.92	11	0.2	252	1	0.0	294	11

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	343.528	193.1753	19207.00	11	577.0	297	1	0.0	294	11
0	1	343.528	193.1753	18207.00	11	577.0	297	1	0.0	294	11
1	0	147.245	89.4286	7809.30	13	247.7	273	1	0.0	280	13
1	1	159.606	89.0992	8406.10	11	267.9	297	1	0.0	294	11
TOTAL		993.008	549.0897	52629.40	11	1627.6	273	1	0.0	294	11

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-0.003	0.0093	-0.14	30	0.0	175	1	0.0	266	1
0	1	-0.002	0.0095	-0.08	30	0.0	175	2	0.0	266	1
1	0	0.000	0.0071	-0.03	28	0.0	175	1	0.0	266	1
1	1	-0.001	0.0093	-0.05	26	0.0	175	1	0.0	266	1
TOTAL		-0.006	0.0321	-0.30	25	0.0	175	1	-0.1	266	1

Table 6.6. (Continued)

304

C.
(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	25.548	60.6362	1884.06	35	272.9	126	1	0.0	0	35
1	1	25.548	60.6362	1884.06	35	272.9	126	1	0.0	0	35
TOTAL		71.097	121.2724	3768.12	35	545.7	126	1	0.0	0	35

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	32.821	111.7278	1740.02	12	582.1	133	1	0.0	0	12
0	1	29.244	105.6122	1549.93	11	551.0	134	1	0.0	0	11
1	0	46.479	210.0730	2463.41	14	1459.0	252	1	0.0	0	14
1	1	64.094	270.7757	3396.99	11	1800.3	252	1	0.0	0	11
TOTAL		172.648	556.4271	9150.35	11	3565.2	252	1	0.0	0	11

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	9.622	10.4711	509.97	14	40.9	126	1	0.0	0	14
0	1	13.209	26.2783	700.07	14	183.5	280	1	0.0	0	14
1	0	41.898	167.0299	2220.62	16	1223.9	290	1	0.0	0	16
1	1	24.282	39.2345	1287.00	14	256.8	290	1	0.0	0	14
TOTAL		89.012	233.0417	4717.66	14	1691.4	280	1	0.0	0	14

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
TOTAL		0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53

TYPICAL MOVEMENT (KM)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	3.566	3.5329	189.00	26	7.0	105	27	0.0	0	26
0	1	3.566	3.5329	189.00	26	7.0	105	27	0.0	0	26
1	0	3.392	3.5278	175.00	28	7.0	105	25	0.0	0	28
1	1	3.566	3.5329	189.00	26	7.0	105	27	0.0	0	26
TOTAL		14.000	13.9325	742.00	26	28.0	105	25	0.0	0	26

DURATION : 364 DAYS TIME STEP : 7 DAYS INTERVALS : 52

.....

Table 6.6. (Continued)

C.
(Continued)

AESOP FAUNA SUMMARY STATISTICS

ERU : C-9 TRACT - 1

SPECIES : CHIPMUNK

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1824.798	449.2210	97244.30	0	2250.0	0	1	729.7	364	1
0	1	1847.519	446.9461	97913.50	0	2250.0	0	1	733.0	364	1
1	0	3638.926	1995.2137	192863.10	7	6306.2	245	1	0.0	322	7
1	1	3663.032	2020.1472	194140.70	7	6363.8	245	1	0.0	322	7
TOTAL		10994.275	4422.7827	592166.60	0	16259.4	245	1	1453.7	364	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.042	0.0155	2.22	0	0.1	210	1	0.0	329	1
0	1	0.045	0.0160	2.36	0	0.1	210	1	0.0	329	1
1	0	0.028	0.0114	1.51	7	0.0	259	2	0.0	322	7
1	1	0.030	0.0120	1.59	7	0.0	259	2	0.0	322	7
TOTAL		0.145	0.0513	7.68	0	0.2	210	1	0.0	329	1

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	472.000	108.1041	25016.00	0	654.0	364	1	290.0	0	1
0	1	472.000	108.1041	25016.00	0	654.0	364	1	290.0	0	1
1	0	157.451	67.8161	8344.90	7	236.0	315	1	0.0	322	7
1	1	157.711	67.9219	8359.70	7	236.7	315	1	0.0	322	7
TOTAL		1259.162	206.3892	66735.60	0	1682.7	315	1	910.0	0	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-0.001	0.0051	-0.05	27	0.0	149	5	0.0	322	1
0	1	-0.001	0.0055	-0.06	27	0.0	149	4	0.0	322	1
1	0	0.000	0.0016	0.00	26	0.0	149	4	0.0	322	1
1	1	0.000	0.0017	0.00	24	0.0	147	5	0.0	322	1
TOTAL		-0.002	0.0196	-0.11	22	0.0	149	4	-0.1	322	1

Table 6.6. (Continued)

306

C.
(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	85.840	121.3573	4549.53	35	273.3	126	1	0.0	0	35
1	1	85.840	121.3573	4549.53	35	273.3	126	1	0.0	0	35
TOTAL		171.680	242.1196	9099.06	35	546.7	126	1	0.0	0	35

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	15.398	84.1958	816.08	1	615.2	322	1	0.0	0	1
0	1	16.976	92.3727	899.74	1	673.9	322	1	0.0	0	1
1	0	117.010	817.3506	6201.54	7	5955.1	322	1	0.0	0	7
1	1	118.584	828.6258	6284.94	7	6037.2	322	1	0.0	0	7
TOTAL		267.968	1821.9602	14202.30	1	13281.4	322	1	0.0	0	1

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	13.456	21.5472	713.17	8	152.8	336	1	0.0	0	8
0	1	11.646	15.6022	617.25	8	106.4	336	1	0.0	0	8
1	0	21.660	19.9717	1147.97	10	60.9	105	1	0.0	0	10
1	1	20.086	17.7331	1064.53	10	60.9	105	1	0.0	0	10
TOTAL		66.848	58.6005	3542.97	8	259.2	336	1	0.0	0	8

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
TOTAL		0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53

TYPICAL MOVEMENT (KM)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	4.491	3.3390	238.00	19	7.0	105	24	0.0	0	19
0	1	4.491	3.3390	238.00	19	7.0	105	24	0.0	0	19
1	0	4.094	3.4822	217.00	22	7.0	105	21	0.0	0	22
1	1	4.094	3.4822	217.00	22	7.0	105	21	0.0	0	22
TOTAL		17.170	13.3499	910.00	19	28.0	105	21	0.0	0	19

DURATION : 364 DAYS TIME STEP : 7 DAYS INTERVALS : 52

Table 6.6. (Continued)

C.
(Continued)

AESOP FAUNA SUMMARY STATISTICS

ERU : C-B TRACT - 2

SPECIES : CHIPMUNK

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	1811.455	534.6367	96007.10	0	2250.0	0	1	206.9	364	1
0	1	1837.357	495.0807	97379.90	0	2250.0	0	1	427.3	364	1
1	0	3665.836	2024.2740	194342.30	7	6375.7	245	1	0.0	322	7
1	1	3688.251	2045.6265	195477.30	7	6427.3	245	1	0.0	322	7
TOTAL		11003.899	4594.8701	583206.60	0	16424.8	245	1	634.2	364	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.048	0.0108	2.54	0	0.1	210	1	0.0	322	1
0	1	0.050	0.0108	2.67	0	0.1	210	1	0.0	322	1
1	0	0.030	0.0122	1.60	7	0.0	259	3	0.0	322	7
1	1	0.032	0.0130	1.70	7	0.0	259	2	0.0	322	7
TOTAL		0.160	0.0431	8.51	0	0.2	210	1	0.0	322	1

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	472.000	108.1041	25016.00	0	654.0	364	1	290.0	0	1
0	1	472.000	108.1041	25016.00	0	654.0	364	1	290.0	0	1
1	0	157.481	67.8207	8346.50	7	226.1	315	1	0.0	322	7
1	1	157.694	67.9281	8357.80	7	226.7	315	1	0.0	322	7
TOTAL		1259.175	206.4194	66736.30	0	1682.8	315	1	310.0	0	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-0.001	0.0067	-0.03	27	0.0	329	1	0.0	322	1
0	1	-0.001	0.0069	-0.03	27	0.0	329	1	0.0	322	1
1	0	0.000	0.0057	-0.01	25	0.0	175	2	0.0	322	1
1	1	0.000	0.0060	-0.01	24	0.0	175	2	0.0	322	1
TOTAL		-0.002	0.0247	-0.09	24	0.0	329	1	-0.2	322	1

Table 6.6. (Continued)

C.

(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	96.345	121.7574	4576.29	35	273.9	126	1	0.0	0	35
1	1	96.345	121.7574	4576.29	35	273.9	126	1	0.0	0	35
TOTAL		172.690	243.5149	9152.58	35	547.8	126	1	0.0	0	35

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	23.787	89.2575	1260.71	1	586.4	322	1	0.0	0	1
0	1	23.944	96.4661	1269.05	1	647.0	322	1	0.0	0	1
1	0	119.935	830.4345	6298.26	7	6050.4	322	1	0.0	0	7
1	1	120.231	940.4382	6372.24	7	6123.2	322	1	0.0	0	7
TOTAL		266.797	1838.3094	15200.26	1	13407.1	322	1	0.0	0	1

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	14.762	35.6534	782.39	8	262.5	329	1	0.0	0	8
0	1	10.447	11.6327	553.68	8	72.6	329	1	0.0	0	8
1	0	20.340	18.0892	1079.04	10	61.2	105	1	0.0	0	10
1	1	19.944	17.0283	1004.05	10	61.3	105	1	0.0	0	10
TOTAL		64.494	62.5563	3419.16	8	235.1	329	1	0.0	0	8

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
TOTAL		0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53

TYPICAL MOVEMENT (KM)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	4.491	2.3890	239.00	19	7.0	105	34	0.0	0	19
0	1	4.491	2.3890	239.00	19	7.0	105	34	0.0	0	19
1	0	4.094	2.4822	217.00	22	7.0	105	31	0.0	0	22
1	1	4.094	2.4822	217.00	22	7.0	105	31	0.0	0	22
TOTAL		17.170	12.3499	910.00	19	28.0	105	31	0.0	0	19

DURATION : 364 DAYS TIME STEP : 7 DAYS INTERVALS : 52

Table 6.6. (Continued)

D.
(Continued)

AESOP FAUNA SUMMARY STATISTICS

ERU : C-9 TRACT - 0

SPECIES : COYOTE

POPULATION

AGE	SEX	MEAN	STODEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.675	0.1543	35.80	1	0.9	98	6	0.0	0	1
0	1	0.534	0.1358	28.30	1	0.7	98	8	0.0	0	1
1	0	1.623	0.9607	86.00	1	2.6	175	9	0.0	0	1
1	1	1.623	0.9607	86.00	1	2.6	175	9	0.0	0	1
TOTAL		4.455	2.0407	236.10	1	6.6	175	4	0.0	0	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STODEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	19.683	2.8448	1043.22	1	21.1	364	1	0.0	0	1
0	1	34.470	9.4595	1826.92	1	49.9	7	1	0.0	0	1
1	0	10.758	5.5248	570.16	1	18.0	7	1	0.0	0	1
1	1	11.297	5.9399	598.20	1	19.0	7	1	0.0	0	1
TOTAL		76.198	20.4134	4038.50	1	106.8	7	1	0.0	0	1

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STODEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	421.960	111.4852	22363.90	1	600.1	364	1	0.0	0	1
0	1	415.706	109.9291	22032.40	1	591.6	364	1	0.0	0	1
1	0	141.370	77.8214	7492.60	1	276.0	91	1	0.0	0	1
1	1	141.370	77.8214	7492.60	1	276.0	91	1	0.0	0	1
TOTAL		1120.406	287.6890	59281.50	1	1651.1	364	1	0.0	0	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STODEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.034	0.1211	1.92	1	0.4	105	1	-0.4	84	1
0	1	-0.183	0.2953	-8.66	25	0.0	0	25	-1.2	98	1
1	0	0.362	0.3297	19.21	1	1.5	105	1	-0.4	84	1
1	1	0.376	0.2597	19.94	1	1.5	105	1	-0.4	84	1
TOTAL		0.609	1.0105	32.30	1	2.4	105	1	-2.4	84	1

Table 6.6. (Continued)

D.
(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.007	0.0494	0.36	52	0.4	98	1	0.0	0	52
0	1	0.007	0.0494	0.36	52	0.4	98	1	0.0	0	52
1	0	0.043	0.1315	2.27	44	0.4	126	1	-0.4	98	1
1	1	0.043	0.1315	2.27	44	0.4	126	1	-0.4	98	1
TOTAL		0.099	0.2391	5.26	45	0.7	126	1	0.0	0	45

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
TOTAL		0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
TOTAL		0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.007	0.0902	0.39	24	0.6	7	1	-0.1	21	2
0	1	0.005	0.0613	0.26	26	0.4	7	1	-0.1	203	1
1	0	0.007	0.1187	0.36	19	0.6	7	1	-0.4	308	1
1	1	0.007	0.1187	0.36	19	0.6	7	1	-0.4	308	1
TOTAL		0.026	0.3796	1.37	15	2.2	7	1	-0.9	308	1

TYPICAL MOVEMENT (KM)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	139.295	19.5672	7329.13	1	155.6	7	1	0.0	0	1
0	1	139.295	19.5672	7329.13	1	155.6	7	1	0.0	0	1
1	0	139.295	19.5672	7329.13	1	155.6	7	1	0.0	0	1
1	1	139.295	19.5672	7329.13	1	155.6	7	1	0.0	0	1
TOTAL		553.142	78.2687	29316.52	1	622.4	7	1	0.0	0	1

DURATION : 364 DAYS TIME STEP : 7 DAYS INTERVALS : 52

Table 6.6. (Continued)

D.
(Continued)

AESOP FAUNA SUMMARY STATISTICS

ERU : C-B TRACT - 1

SPECIES : COYOTE

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.734	0.2391	38.90	0	3.0	0	1	0.5	21	11
0	1	0.577	0.2342	30.60	0	2.0	0	1	0.3	49	7
1	0	1.706	0.9648	90.40	0	3.0	0	1	0.2	98	4
1	1	1.706	0.9648	90.40	0	3.0	0	1	0.2	98	4
TOTAL		4.723	2.1707	250.30	0	11.0	0	1	1.8	49	7

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	20.117	0.7690	1066.21	0	21.2	336	1	19.1	98	1
0	1	35.952	9.0535	1900.15	0	50.0	0	1	29.9	364	1
1	0	11.178	5.4578	592.42	0	18.0	0	1	2.6	147	1
1	1	11.729	5.7616	621.66	0	19.0	0	1	2.7	147	1
TOTAL		78.976	17.9151	4180.45	0	107.0	0	1	56.0	140	1

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	427.055	97.0697	22633.90	0	600.1	364	1	270.0	0	1
0	1	420.800	94.4789	22202.40	0	591.6	364	1	270.0	0	1
1	0	144.860	75.4720	7677.60	0	276.0	91	1	32.2	140	1
1	1	144.860	75.4720	7677.60	0	276.0	91	1	32.2	140	1
TOTAL		1137.575	243.2597	60291.50	0	1651.1	364	1	799.3	133	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.035	0.1297	1.93	1	0.4	105	1	-0.4	84	1
0	1	-0.109	0.2746	-5.75	23	0.0	0	33	-1.2	99	1
1	0	0.365	0.2323	19.35	1	1.5	105	1	-0.4	84	1
1	1	0.379	0.2533	20.69	1	1.5	105	1	-0.4	84	1
TOTAL		0.670	0.2967	35.52	1	2.4	105	1	-2.4	94	1

D.
(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.006	0.0467	0.34	52	0.3	98	1	0.0	0	52
0	1	0.006	0.0467	0.34	52	0.3	98	1	0.0	0	52
1	0	0.042	0.1278	2.23	44	0.3	126	1	-0.3	98	1
1	1	0.042	0.1278	2.23	44	0.3	126	1	-0.3	98	1
TOTAL		0.097	0.2326	5.14	45	0.7	126	1	0.0	0	45

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
TOTAL		0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
TOTAL		0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	-0.048	0.2936	-2.56	29	0.0	364	1	-2.1	7	1
0	1	-0.023	0.1957	-1.73	29	0.0	112	3	-1.4	7	1
1	0	-0.051	0.2951	-2.71	22	0.1	364	1	-2.1	7	1
1	1	-0.051	0.2951	-2.71	22	0.1	364	1	-2.1	7	1
TOTAL		-0.183	1.0784	-9.71	21	0.3	364	1	-7.8	7	1

TYPICAL MOVEMENT (KM)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	137.534	19.2720	7291.94	1	143.3	364	1	0.0	0	1
0	1	137.534	19.2720	7291.94	1	143.3	364	1	0.0	0	1
1	0	137.534	19.2720	7291.94	1	143.3	364	1	0.0	0	1
1	1	137.534	19.2720	7291.94	1	143.3	364	1	0.0	0	1
TOTAL		550.235	77.0979	29167.76	1	573.4	364	1	0.0	0	1

DURATION : 364 DAYS TIME STEP : 7 DAYS INTERVALS : 52

.....

Table 6.6. (Continued)

D.
(Continued)

AESOP FAUNA SUMMARY STATISTICS

ERU : C-B TRACT - 2

SPECIES : COYOTE

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.723	0.1723	33.30	1	0.9	112	8	0.0	0	1
0	1	0.543	0.1647	28.80	1	0.7	98	14	0.0	0	1
1	0	1.770	1.0897	93.80	1	3.0	343	1	0.0	0	1
1	1	1.770	1.0897	93.80	1	3.0	343	1	0.0	0	1
TOTAL		4.806	2.3365	254.70	1	7.6	343	1	0.0	0	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	19.713	2.8492	1044.79	1	21.2	326	1	0.0	0	1
0	1	34.711	9.1460	1839.70	1	49.6	7	1	0.0	0	1
1	0	10.316	5.5556	573.25	1	17.9	7	1	0.0	0	1
1	1	11.347	5.9597	601.40	1	19.9	7	1	0.0	0	1
TOTAL		76.538	20.3647	4059.14	1	106.1	7	1	0.0	0	1

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	421.960	111.4852	22363.90	1	600.1	364	1	0.0	0	1
0	1	415.706	103.9391	22032.40	1	591.5	364	1	0.0	0	1
1	0	141.370	77.9214	7492.60	1	276.0	91	1	0.0	0	1
1	1	141.370	77.9214	7492.60	1	276.0	91	1	0.0	0	1
TOTAL		1120.406	287.6890	59381.50	1	1651.1	364	1	0.0	0	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.035	0.1294	1.93	1	0.4	105	1	-0.4	84	1
0	1	-0.114	0.2778	-6.03	33	0.0	0	33	-1.2	98	1
1	0	0.365	0.3369	19.32	1	1.5	105	1	-0.4	84	1
1	1	0.377	0.2594	20.07	1	1.5	105	1	-0.4	84	1
TOTAL		0.664	1.0009	35.20	1	3.4	105	1	-2.4	84	1

Table 6.6. (Continued)

D.
(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.006	0.0467	0.34	52	0.3	98	1	0.0	0	52
0	1	0.006	0.0467	0.34	52	0.3	98	1	0.0	0	52
1	0	0.046	0.1362	2.42	44	0.4	126	3	-0.3	98	1
1	1	0.016	0.1362	2.42	44	0.4	126	3	-0.3	98	1
TOTAL		0.105	0.2505	5.54	45	0.7	126	3	0.0	0	45

NATURAL DEATH

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
TOTAL		0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53

PREDATION LOSS

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
0	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	0	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
1	1	0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53
TOTAL		0.000	0.0000	0.00	53	0.0	0	53	0.0	0	53

DISPERSAL

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.007	0.0784	0.38	24	0.5	7	1	-0.2	350	1
0	1	0.004	0.0546	0.21	27	0.2	7	1	-0.1	350	1
1	0	-0.002	0.1222	-0.12	19	0.5	7	1	-0.6	350	1
1	1	-0.002	0.1222	-0.12	19	0.5	7	1	-0.6	350	1
TOTAL		0.007	0.3655	0.35	16	1.9	7	1	-1.5	350	1

TYPICAL MOVEMENT (KM)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	128.396	19.7144	7334.97	1	164.9	7	1	0.0	0	1
0	1	128.396	19.7144	7334.97	1	164.9	7	1	0.0	0	1
1	0	128.396	19.7144	7334.97	1	164.9	7	1	0.0	0	1
1	1	128.396	19.7144	7334.97	1	164.9	7	1	0.0	0	1
TOTAL		513.593	78.9576	29339.88	1	659.4	7	1	0.0	0	1

DURATION : 364 DAYS TIME STEP : 7 DAYS INTERVALS : 52

Table 6.6. (Continued)

D.
(Continued)

AESOP FAUNA SUMMARY STATISTICS

ERU : C-B TRACT - 3

SPECIES : COYOTE

POPULATION

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.687	0.1783	35.70	1	0.9	336	5	0.0	0	1
0	1	0.302	0.1229	15.70	1	0.6	98	3	0.0	0	1
1	0	1.762	1.1290	91.60	1	3.2	343	2	0.0	0	1
1	1	1.762	1.1290	91.60	1	3.2	343	2	0.0	0	1
TOTAL		4.512	2.3546	234.60	1	7.6	343	2	0.0	0	1

TYPICAL WEIGHT (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	18.871	2.7940	981.30	1	21.1	364	1	0.0	0	1
0	1	31.730	9.5869	1649.95	1	47.9	14	1	0.0	0	1
1	0	9.744	5.6659	506.67	1	17.3	14	1	0.0	0	1
1	1	10.219	5.9663	531.41	1	18.2	14	1	0.0	0	1
TOTAL		70.564	21.0319	3669.33	1	102.6	14	1	0.0	0	1

TYPICAL AGE (DAYS)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	424.748	110.6919	22066.90	1	600.1	364	1	0.0	0	1
0	1	418.373	108.2402	21755.40	1	591.6	364	1	0.0	0	1
1	0	140.396	78.2560	7300.60	1	276.0	91	1	0.0	0	1
1	1	140.396	78.2560	7300.60	1	276.0	91	1	0.0	0	1
TOTAL		1123.913	289.2490	59423.50	1	1651.1	364	1	0.0	0	1

TYPICAL ASSIMILATION (KG)

AGE	SEX	MEAN	STDDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.050	0.0758	2.58	1	0.2	357	1	-0.3	94	1
0	1	-0.658	0.4058	-34.20	1	0.0	0	1	-1.3	168	1
1	0	0.342	0.2419	17.80	1	0.7	105	1	-0.2	94	1
1	1	0.355	0.2576	18.47	1	0.7	105	1	-0.2	94	1
TOTAL		0.090	0.3178	4.66	1	1.4	357	1	-1.8	94	1

Table 6.6. (Continued)

D.
(Continued)

RECRUITMENT

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.006	0.0430	0.31	51	0.3	99	1	0.0	0	51
0	1	0.006	0.0430	0.31	51	0.3	99	1	0.0	0	51
1	0	0.027	0.1122	1.90	43	0.3	168	1	-0.3	99	1
1	1	0.027	0.1122	1.90	43	0.3	168	1	-0.3	99	1
TOTAL		0.065	0.2022	4.42	44	0.6	168	1	0.0	0	44

NATURAL DEATH

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	52	0.0	0	52	0.0	0	52
0	1	0.009	0.0421	0.48	49	0.3	161	1	0.0	0	49
1	0	0.000	0.0000	0.00	52	0.0	0	52	0.0	0	52
1	1	0.000	0.0000	0.00	52	0.0	0	52	0.0	0	52
TOTAL		0.009	0.0431	0.48	49	0.3	161	1	0.0	0	49

PREDATION LOSS

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.000	0.0000	0.00	52	0.0	0	52	0.0	0	52
0	1	0.000	0.0000	0.00	52	0.0	0	52	0.0	0	52
1	0	0.000	0.0000	0.00	52	0.0	0	52	0.0	0	52
1	1	0.000	0.0000	0.00	52	0.0	0	52	0.0	0	52
TOTAL		0.000	0.0000	0.00	52	0.0	0	52	0.0	0	52

DISPERSAL

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	0.005	0.0369	0.26	27	0.2	21	1	-0.1	112	1
0	1	0.005	0.0272	0.27	29	0.1	21	1	-0.1	112	1
1	0	0.016	0.0722	0.83	22	0.3	343	1	-0.2	364	1
1	1	0.016	0.0722	0.83	22	0.3	343	1	-0.2	364	1
TOTAL		0.042	0.1990	2.19	21	0.7	343	1	-0.5	364	1

TYPICAL MOVEMENT (KM)

AGE	SEX	MEAN	STDEV	TOTAL	ZERO	MAXIMUM			MINIMUM		
						VALUE	DAY	NO	VALUE	DAY	NO
0	0	139.601	19.9499	7207.26	1	165.2	21	1	0.0	0	1
0	1	139.601	19.9499	7207.26	1	165.2	21	1	0.0	0	1
1	0	139.601	19.9499	7207.26	1	165.2	21	1	0.0	0	1
1	1	139.601	19.9499	7207.26	1	165.2	21	1	0.0	0	1
TOTAL		554.405	79.7997	29329.04	1	660.9	21	1	0.0	0	1

DURATION : 364 DAYS TIME STEP : 7 DAYS INTERVALS : 51

Figure 6.6. Example time series dynamics of fauna biomass state variables and processes. ERU 0, ERU 1, ERU 2, ERU 3 represent highland, upland, lowland, and bottomland, respectively. X-axis is time in days. A. Mature female mule deer individual weight (kg), B. Mature female cottontail individual weight (kg), C. Mature female chipmunk individual weight (kg), D. Mature female coyote individual weight (kg), E. Mature female mule deer individual assimilation (kg), F. Mature female cottontail individual assimilation (kg), G. Mature female chipmunk individual assimilation (kg), H. Mature female coyote individual assimilation (kg), I. Mature female mule deer individual weight (kg), J. Immature female mule deer individual weight (kg), K. Juvenile female mule deer individual weight (kg), L. Mature male mule deer individual weight (kg), M. Immature male mule deer individual weight (kg), N. Juvenile male mule deer individual weight (kg), O. Mature female mule deer individual assimilation (kg), P. Immature female mule deer individual assimilation (kg), Q. Juvenile female mule deer individual assimilation (kg), R. Mature male mule deer individual assimilation (kg), S. Immature male mule deer individual assimilation (kg), and T. Juvenile male mule deer individual assimilation (kg).

Figure 6.6. (Continued)

Figure 6.6. (Continued)

Figure 6.6. (Continued)

Figure 6.6. (Continued)

Figure 6.6. (Continued)

Figure 6.6. (Continued)

Figure 6.7. Example time series dynamics of fauna population state variables and processes. ERU 0, ERU 1, ERU 2, ERU 3 represent highland, upland, lowland, and bottomland areas, respectively. X-axis is time in days. U-axis is number of animals. A. Total mule deer population, B. Total cottontail population, C. Total chipmunk population, D. Total coyote population, E. Juvenile female mule deer recruitment, F. Juvenile female cottontail recruitment, G. Juvenile female chipmunk recruitment, H. Juvenile female coyote recruitment, I. Total mule deer natural deaths, J. Total cottontail natural deaths, K. Total chipmunk natural deaths, L. Total coyote natural deaths, M. Total mule deer predation loss, N. Total cottontail predation loss, O. Total chipmunk predation loss, P. Total coyote predation loss, Q. Total mule deer dispersing population, R. Total cottontail dispersing population, S. Total chipmunk dispersing population, T. Total coyote dispersing population, U. Distance travelled by mature female mule deer (km), V. Distance travelled by mature female cottontail (km), W. Distance travelled by mature female chipmunks (km), X. Distance travelled by mature female coyotes (km), Y. Mature female cottontail population, Z. Immature female cottontail population, AA. Juvenile female cottontail population, BB. Mature male cottontail population, CC. Immature male cottontail population, DD. Juvenile male cottontail population, EE. Mature female cottontail natural deaths, FF. Immature female cottontail natural deaths, GG. Juvenile female cottontail natural deaths, HH. Mature male cottontail natural death, II. Immature male cottontail natural deaths, JJ. Juvenile male cottontail natural deaths, KK. Mature female cottontail predation loss, LL. Immature female cottontail predation loss, MM. Juvenile female cottontail predation loss, NN. Mature male cottontail predation loss, OO. Immature male cottontail predation loss, and PP. Juvenile male cottontail predation loss.

Figure 6.7. (Continued)

Figure 6.7. (Continued)

Figure 6.7. (Continued)

Figure 6.7. (Continued)

Figure 6.7. (Continued)

Figure 6.7. (Continued)

Figure 6.7. (Continued)

Figure 6.7. (Continued)

Figure 6.7. (Continued)

Figure 6.7. (Continued)

Figure 6.7. (Continued)

Figure 6.7. (Continued)

Thus, the minimum cohort capable of simulation is mature females (00).

Although some differences are indicated between ERUs in Table 6.6, much of the differences in response to ERU conditions are masked by the intermingling of animals between ERU and confounded by the two additional ERUs not shown.

The typical weights of mature females of each species are presented in Figs. 6.6A-D. Note that the scale is different for each species. The weights are fairly stable, except for chipmunks. Chipmunks die off in enormous numbers due to an error in the hibernation process, which does not provide for a buildup of body reserves prior to hibernation. Thus, most of the hibernating chipmunks die due to starvation (see Sec. 4.3.3.1). Fluctuations are more pronounced in the younger cohorts, as shown in Figs. 6.6I-N. The apparent sharp declines reflect an aging process by which older, and heavier, individuals mature to the next cohort. The graphs for the male cohorts, Figs. 6.6L-N, demonstrate the strong influence of the Brody growth function on predicted weights (see Fig. 4.25).

Assimilation is the net result of several consumption and foraging processes. It may be either positive (representing weight gain) or negative (representing weight loss), as shown in Figs. 6.6E-H. Again note that the scale is different for each species. Figs. 6.6O-T demonstrate the differences between mule deer cohorts. The assimilation graphs provide an interesting insight to the species responses to ERU conditions. Differing seasonal dynamics are exhibited between ERUs and between cohorts. Thus, during the spring and summer months, mule deer may prefer the new plant growth within the higher elevation ERUs, while during the winter months, these same ERUs are the least advantageous.

Total population dynamics for the four species are presented in Figs. 6.7A-D. Note that the scales are different for each species. The population graphs show a much greater difference in species' response to ERU conditions than did the biomass graphs. The more mobile species have a greater tendency toward stabilization and equalization between ERUs. Cottontail, which are fairly mobile, demonstrate a preference for the lower elevations, especially during the winter months. The crash of the chipmunk populations is due to starvation during hibernation, as previously mentioned. Cottontail cohorts were selected to illustrate inter-species population dynamics, Figs. 6.7Y-DD. Since cottontail breed throughout the warm months, there is a buildup of the juvenile cohort, which declines as winter conditions become more severe. Like typical weight, many of the sharp changes in population levels reflect an aging of a portion of the population to the next cohort. Thus, dramatic decreases in Fig. 6.7Z are offset by dramatic increases in Fig. 6.7Y.

Figs. 6.7E-H present the recruitment, or birth, of juvenile females into the population. Since birthrates are considered to be equal among the sexes, differences in the older cohorts generally reflect differences in mortality pressures. The negative values in these recruitment graphs represent juveniles which aged, or were recruited, into immature cohorts. Female condition does not affect the birthrate at present, so that differences between ERUs basically reflect differences in mature female population levels.

Natural death is primarily caused by starvation and exposure. Figs. 6.7I-L indicate that severe conditions vary both between ERUs and seasonally within ERUs. The majority of the natural deaths occur during the winter months. Figs. 6.7EE-JJ illustrate differential mortality of the cottontail cohorts.

All predation losses shown in Figs. 6.7M-P represent predation loss to coyotes. Although the coyote population is fairly consistent among ERUs, there are very significant differences in predation pressures due to habitat characteristics, such as cover. There is also a considerable increase of predation pressure during the seasons when animals are giving birth to young. The increased predation pressure on the younger cohorts is evident in Figs. 6.7KK-PP.

The dispersing populations of Fig. 6.7Q-T may be either positive (representing movement into an ERU) or negative (representing movement out of an ERU). Under favorable conditions, the populations tend to be more stationary, while as conditions worsen, there is a marked increase in the size of the dispersing population.

The distances traveled by individuals are fairly constant over time, as shown in Figs. 6.7U-X.

In summary, fauna populations exhibit definite seasonal preferences for different ERUs based upon various environmental conditions. This seasonal shift has important shale oil development implications if preferred habitats are reduced or access to them is hindered.

6.2.2 With Development

At this time, development effects have not been fully implemented in the model, thus, there has not been a simulation run involving development.

When a development simulation run is made, the results will be analyzed and described as in Sec. 6.2.1.

6.3 COMPARISON OF NON-DEVELOPMENT VS. DEVELOPMENT

This comparison is not possible at the present time for two reasons. First, an adequate baseline climate representing conditions of the Piceance Basin has not been available. Therefore, the simulation runs "without development" do not adequately represent the Piceance Basin dynamics. Second, as mentioned above, the development effects have not been incorporated into the model, so there have not been any "with development" simulations.

7. CONCLUSIONS AND GENERAL DISCUSSIONS

In this section we give some general conclusions about the shale oil development modelling activity and utility based on our experience of the last two years. We discuss some aspects of shale oil development impacts and then discuss in general limitations of data and models, research needs, and give general strategies of use of the model. Particularly, we give a specific set of recommendations towards the completion of the development and use of this model structure for assessing ecological and agricultural consequences of shale oil development.

7.1 PROJECTIONS OF FUTURE CONDITIONS WITHOUT SHALE OIL DEVELOPMENT

It is necessary to project what the future conditions of the ecological and agricultural systems of the Piceance Basin may be in the absence of the development of a shale oil industry, in order to develop projections of the scope and magnitude of the effects from such an industry. These projections are based upon a survey of current conditions and trends, experience in the region, and an understanding of the interrelationships between major components and processes.

In general, present conditions and trends should continue in the absence of a shale oil industry. Many of the natural systems exhibit drastic seasonal and annual fluctuations in composition, abundance and/or productivity in response to variations in climatic patterns and other external forces. Usually these fluctuations are offset or damped by reciprocal changes in other parts of the system, thus, the system as a whole exhibits a "dynamic equilibrium." The ecological systems in the Basin are also influenced by resource management policies, including vegetation manipulation, water storage projects and operation, livestock grazing, wildlife management, and other resource developments, such as coal. In addition to considering the effect of a shale oil industry per se, it is important to consider synergistic effects of these management policies. The Piceance Basin is a unique collection of many diverse, dynamic ecological systems under different management policies. Therefore, although present conditions and trends may be expected to continue, the future conditions will differ somewhat from present conditions, regardless of the development of a shale oil industry. The most significant changes will be associated with anticipated urban extension and changes in land use practices.

7.1.2 Climate and Air Quality

Air quality of the Basin will probably decline due to increased pollution associated with the local population growth and regional industrial development. The magnitude of this decline will depend upon the amount of growth and the effectiveness of air pollution controls. Climatic influences, such as inversions, may concentrate these effects in a few local areas, while the Basin as a whole experiences only minor changes.

Declines in air quality may affect local biotic communities. Natural plant communities will probably be less affected than agricultural fields, since species composition of the native communities may change to more

resistant species. Agronomic crops such as alfalfa and fruit trees, which are sensitive to SO_2 and other pollutants, could be adversely affected if moderate air pollution accompanies the population growth.

Wind blown dust from unpaved roads and other particulates will increase with the increased recreational activities of local residents.

7.1.3 Soils

Soils within the region will probably not change significantly, unless irrigation is added or other management practices are begun. Soil genesis is extremely slow in the region due to the low rainfall and sparse vegetation. As a result, the soils are fragile and are easily lost through wind and water erosion when disturbed.

Erosion will continue to be an important factor throughout the region, especially on sloping pinyon-juniper lands and along gulleys and washes. Soils in the sagebrush and mountain shrub types have a medium soil stability, while the aspen type has a high stability rating with little or no soil movement.

7.1.4 Vegetation

Except for changes in land use, only minor changes are expected in the natural plant communities. Many of the plant communities have reached a fairly stable condition, although not necessarily a climax condition. A notable exception is the vast acreages of pinyon-juniper and sagebrush which were chained for habitat improvement. These areas will progress through the slow successional changes from mountain shrub grassland to sagebrush pinyon-juniper woodland typical of secondary succession in the Basin.

Although some burning of rabbitbrush and greasewood is done to stimulate grass production in the bottomlands, these areas usually return to brush conditions within a few years. Grazing levels are generally low at the lower elevations so that grazing does not have a major effect on the vegetational composition.

Areas receiving irrigation, especially in poorly drained soils, will probably result in increased soil salinity levels. As these areas become too saline for pasture or agricultural production, they will be invaded by greasewood and halogeton. Ultimately, a salt desert community may replace the irrigated pasture.

7.1.5 Fauna

Deer and elk populations will probably remain fairly stable, however, the seasonal ranges could support population increases of both species. Black bear and mountain lion populations should increase slightly as their mortality factors are reduced in number and severity.

Populations of upland game, waterfowl, furbearers and varmints will, with a few exceptions, remain unchanged. Sage grouse populations will continue to decline as habitat, especially breeding habitat, is lost through range conversion programs.

Hunting pressure in the region, which is already quite high, will continue to increase even faster than the human population. With increasing numbers of hunters from outside the region and decreasing availability of habitat, game species will be forced into more stressful and demanding situations.

Highway fatalities, especially of mule deer, will also continue to increase as highway traffic volume increases.

The large number of rodents and relative openness of the vegetation should continue to make the region an important breeding and hunting area for raptors.

7.1.6 Agriculture

Irrigation practices and field drainage will probably be improved, resulting in less water being applied to the fields. With increased irrigation, substantial increases in crop production of wheat, alfalfa, and native grass pasture would occur. Also, some land presently cultivated for created wheat would be converted to other crops. Greater changes are expected in the agricultural lands along the Colorado River. Population growth in this area will create a greater local market for truck crops and lawn turf. This shift would be accompanied by a reduction in some row crops, such as corn, and a trend toward cleaner cropping of the fields.

7.1.7 Human Related

Even without shale oil development, the Piceance Basin region will continue to feel the effects of increased urbanization and industrialization. Although the increase in urban population will cause a loss of agricultural land, much of the population increase will occur within or near present urban areas. In the Upper Colorado Region, approximately 500 to 1000 acres of irrigated cropland are converted to urban and industrial use annually (Upper Colorado Region State-Federal Interagency Group 1971).

Increasing demands for recreation will continue to exert pressure on both the vegetation and fauna communities of the region. Although consumptive uses, such as wood cutting and hunting, will have the greatest effect, human harassment from all forms of recreation will become more important in the future. Increased use of snow mobiles may have drastic effects upon wintering mule deer and other animals.

Coal and natural gas development will continue to increase in the region. Although both industries will add to the urbanization, a greater impact may result from the increased accessibility to the "back country" as a result of the roads created during exploration and drilling. Depending upon the timing and location of these activities, there could be serious effects on local

wildlife which will probably result in a further withdrawal of the more reclusive species such as the mountain lion.

7.1.8 Summary

The Piceance Basin will continue to feel the effects of increased development, even in the absence of a shale oil industry. The region consists of large, relatively productive arid and semi-arid shrublands, and isolated highlands; most agriculture is conducted along the bottomlands along creeks and is primarily for livestock. As water becomes more available for irrigation, more land will be converted from rangeland use to agriculture. The region will continue to be important for hunting and grazing, though the quality of both is likely to decrease with increasing pressures and demands upon the natural systems. Regional population growth is likely to have the greatest effect through urbanization of range and farmland and through associated human activity. Although urban growth or industrialization may be restricted to one particular area, human activity extends throughout the region and has the potential to create drastic changes in the natural plant and animal communities. Recovery of these communities will require decades due to the fairly harsh climatic and soil conditions. Much more intensive management by all natural resource agencies and private developers will be required to maintain the quality and productivity of the natural and agricultural systems, even in the absence of a shale oil industry. With proper management, the region should support healthy natural plant and animal communities, productive range and farmland, and a certain level of urbanization and industrialization. Under improper management, the relatively fragile natural systems will deteriorate rapidly and be slow to recover.

7.2 PROJECTIONS OF FUTURE CONDITIONS WITH SHALE OIL DEVELOPMENT

The purpose and long-term goal of this activity is to make evaluations of the ecological and agricultural impacts of shale oil development. The emphasis has been on the northwestern Colorado situation. We defined early and submitted requests to other task forces on the general kinds of needed information required to calculate the ecological and agricultural impacts of shale oil development. These inputs serve as site characteristics and driving variable records to be used in the model. The driving variable records are of two main types, those of climatic features during the period of time for which the prediction is required and those related to shale oil development including effluents dispersed through the air over the landscape and through the water courses.

We received from another task force adequate information on a proposed scenario regarding a given rate and type of shale oil development. This scenario provided us information on the locations and types of industrial plants. We used this information in our conceptualization and formulation of the model structure.

We were not provided adequate driving variable records for either naturally occurring climatic fluctuations nor for shale oil development effluents, air-borne or water-borne. Without these records we can develop the model structure and in part test it and make implications as to what the impacts would be. We have done this. In this process we note there are

limitations in available data and models and we uncover research information needs. These are discussed below.

7.3 DATA LIMITATIONS

To formulate an ecosystem process in mathematical terms requires a rather precise understanding of the physical and physiological forces that together comprise the process. Often our knowledge of even the major processes is incomplete. The model is, therefore, based on the best, though partial, information available and, where data are lacking, on the most reasonable conceptualization of the process.

One of the possible limitations in the data is obtaining driving variable records for each ecological response unit. Unless driving variable data that can be associated with each of these units is obtained, the entire model must be driven by an overall average set of values.

The model can be operated only by specifying driving variable records, initial conditions, and the parameters used in the flow functions. "Poor guesses" at initial conditions of state variables will not greatly affect model output. However, parameter values for the flow functions may be quite important. The question arises then, can adequate "families" of parameter values for the flow functions be derived? For example, in the case of a parameter of maximum infiltration rate of water movement through a given soil, literature must be researched to determine how uniform such a parameter is for different soil series.

In conceptualizing the model and particularly the flow functions, it may be necessary to draw upon data for related groups of organisms to specify a specific species or group within the model. For example, if the model has a category of small mammals as a state variable, information may be available for related groups of small mammals from another region. These values could then be adapted to the small mammals in a given ecological response unit.

7.4 MODEL LIMITATIONS

All models are abstractions of real life. Therefore, some of the limitations are due to the process of simplification. The model is limited by general assumptions about the structure and function of the system being considered. It is limited in the present case particularly by the aggregation of plant and animal subsystems into ecological response units and the aggregation of system components into the selected state variables.

To be useful a model must be tractable. Even if complete data and comprehensive understanding of all the major ecosystem processes were available, because of the complexity of an ecosystem, sufficient computer storage and processing time would not be available to handle it. In addition, the more complete and precise the model representation, the more specific is the model to a particular geographic location and particular physical or climatic conditions. A high degree of specificity is not desirable when the model is intended to indicate general responses of such systems or to extrapolate to some future and only partially known conditions.

Ecological Response Units are conceptual generalizations of the habitats, defined as a system that responds in some unique fashion to system activities. It is recognized that there is variability among the different components of an ERU and, therefore, the response of the ERU will be based primarily upon the responses of dominant plant and animal species selected as representative. The model output, therefore, represents a generalized response for that segment of habitat. It is essential to generalize in this fashion in order to make the model practical, although the actual responses of the system components may vary.

Unfortunately, evaluation of the usefulness or truth content of an ecological simulation model is not currently based on a standard procedure. In fact, as Caswell (1976) shows, the whole concept of "validation" of ecological models is almost universally misconstrued by ecologists. The basic distinction is between theoretical models and predictive models. Validation of a theory is the problem of induction and Popper (1963) has shown that there is no valid technique for proving the truth of any theory via induction. Instead, we can corroborate our theories as they pass more and more stringent tests but this only increases our confidence and can never be absolute proof. In contrast, predictive models are judged as to usefulness based on how accurately they can predict aspects of the real world and from applying validation procedures appropriate for simulations of logical systems or other software.

Confusion has arisen in the ecological literature due to a failure to distinguish between these two classes of models. Goodness of fit to ecological data is taken as the main criteria for model evaluation. The problem is that goodness of fit is necessary but not sufficient as a criterion for evaluation of a theory. We can accept a predictive model as being sufficiently accurate, but we can only fail to reject a theory.

The root dynamics model of Ares and Singh (1974) is a good example of the danger of failure to distinguish theory from curve fitting. Seven of their seventeen process equations are discontinuous functions. All are functions of time. Because they fit these functions to their data, they were able to get reasonable seasonal dynamics. The problem arises because they state that this model can (i) synthesize the available knowledge into a conceptual framework and (ii) indicate the critical rate processes. The fact that the data has been fit by a type of state variable model seems to indicate that explanation has taken place. However, a model with functions based entirely on time clearly does not explain the mechanisms involved. Changes in the system that are actually responses of the plant to changes in the environment are modelled as phenological functions, leading us to expect some sort of elaborate timing apparatus within the plant. A delay in spring due to a long winter or an early summer dry spell would yield data that could not be fit at all by this model. Thus, this model is based on a faulty conceptual framework if the intent is to explain rather than just fit the data. Mechanisms postulated by the model (many biological clocks) should be tested before the next step (discovering critical rate processes) is undertaken.

Many other examples could be given of ecological models with biologically uninterpretable parameters, unmeasurable state variables, or that are just untestable. If these models have prediction as their sole purpose there is no problem, but treating them as theories and drawing conclusions about the real

system from them is hazardous and obscures the distinction between a predictive model and a theoretical model. It will be shown below that these two types of models require very different tests of their "goodness."

Logical models are an additional type of model which must be treated before examining the evaluation techniques that are appropriate. Certain types of simulation models embody logical structures exclusively. Thus, a simulation of a mechanical telephone switching system, a chess playing computer program, and a simulator of a computer operating system all share the characteristics that they are logical operators and may perform their tasks exactly. This distinguishes them from any predictive or theoretical model which can only approximate reality.

The method used for evaluation of the quality, usefulness, or truthfulness of a simulation model will differ for each of the three model types discussed above. These are the ideal types proposed, but, most actual models are some combination of the three.

Testing a Logical Model. This type of model may be evaluated by the usual "validation" techniques extant in the computer science literature (Innis et al. 1977). Some of these models may be perfectly valid in the sense of no error in their predictions or operation. Others may have varying degrees of usefulness based on comparison with design specification (for example, a simulation of a computer operating system in action).

Testing a Theoretical Model. Before tests of the theory embodied by a simulation model are begun, the possibility of confounding sources of error should be examined. There are three main sources of possible error: inaccurate translation of the theory into mathematical form, coding errors, and failure of numerical techniques to calculate answers correctly. Due to the lack of mathematical sophistication in the field of ecology, it is not uncommon for a theory to be expressed in an inappropriate mathematical form. Templeton and Lawlor (1981) cite several examples of the "fallacy of the average" in the formulation of ecological optimization models. Clearly, conclusions about a theory should not be drawn from the results of an incorrectly formulated model. The other two types of error should be eliminated during the simulation verification process.

Once there is confidence that the model is correctly formulated and coded, it is possible to use the model to test the theory. However, as Caswell (1976) points out, it is not very useful to just generate a time series of state variables and reject or accept the whole model based on some statistical criteria of goodness of fit. Rather, the application of "strong inference" (Platt 1964) is required. This process involves

- i. devising alternative hypotheses,
- ii. devising a crucial experiment, the outcome of which will exclude at least one of the hypotheses,
- iii. carrying out the experiment, and
- iv. returning to (i), refining the problem further.

This process never ends because our theories never capture reality perfectly.

Testing Predictive Models. There can be no one method for testing the adequacy of predictive models because adequacy (credibility, validity) depends on the purpose of the project and the time and money constraints involved. These objectives define the ideal domain of applicability. The domain of applicability is the prescribed set of conditions for which the model is intended to match reality. Thus, one test criteria is how well the model covers the domain. There may be regions of the ideal domain that are covered poorly or not at all, but results in the region that is covered may still be useful to the user. It should be made clear to the user, however, what the realized domain is. Within the realized domain, various output variables may have different degrees of accuracy. Describing the extent of agreement between reality and the simulation is the establishment of the range of accuracy of the simulation.

7.5 RESEARCH NEEDS

With preliminary and continuing model runs, sensitivity analyses can be made to determine relative critical value levels of parameters. These analyses also lead to an assessment of priorities of information needed for interpreting the potential ecological and agricultural impacts of shale oil development.

7.5.1 Model Output as Guidance to Experimental Studies

Although a great deal of prior work has been done in the Piceance Creek Basin area, it was not done with a dynamic conceptual framework in mind. Several environmental baseline studies were conducted by shale oil companies and their consultants on different tracts in the Colorado, Wyoming, and Utah regions. Several broad reviews were also done by other consulting firms leading to information used in environmental impact statements. Under ideal conditions, these baseline studies and impact reviews should have been guided at the outset by a conceptual, and possibly a mathematical, model that would identify the most important ecosystem components and processes to measure. In planning a field study, there should be a great deal of thought given to which variables need to be collected in a coordinated manner in time and space. There should be a greater agreement in definition. This would be reflected in uniform maps, lists of important plant, animal, and abiotic components, and such considerations. This planning was not done in the past work.

In past work, many of the individuals collected large quantities of apparently useless data. Furthermore, there was a great imbalance in the quantity and quality of the data as well as an imbalance in the timing and spatial location of data. An example of such a data imbalance occurred in the C-b tract baseline studies. Almost 500 time series could be developed for dynamics of driving and state variables by analyzing the summary volumes, yet many important items were not measured. Haug and Van Dyne (1979) indicated some of the shortcomings of the baseline study:

Most of the items measured were variables. Little information was provided on process rates. No information was developed for factors influencing processes. Had the conceptual modelling activity been completed first, many of these information needs would have been identified, and baseline studies could have been more efficient, more focused, and better coordinated.

The present model includes a number of items for which broad guesses must be made. It was necessary in the short time interval available to make some crude approximation in some instances and go on to the next segment of work rather than devote the entire effort to a single part.

7.5.2 Field Data for Validation of Model Results

Uniform validation sets of data are needed from the field to improve model structure and functioning. Such uniform validation sets will require concurrent collection of driving variable data along with state variable data and selected rate process information. All the driving variables, but not all of the state variables need to be monitored.

Only selected rate processes can be monitored economically in the field. These can be compared against model calculations. Where these levels seem high, specific experiments can be set up to evaluate their impact on plant and animal systems. Many of these studies should be done with the species or groups (or closely related groups) found in the study region. In designing such controlled laboratory, greenhouse, growth chamber, or metabolism experiments, model output could be used as a guide. The experiments should be multi-variable rather than uni-variable. These controlled experiments then should also be conducted to provide results in functional form which could be incorporated into model structures.

7.6 STRATEGIES OF MODEL USAGE

Model output should be used with great caution. It is not superfluous to reemphasize that all models are simplified abstractions of reality.

There are two general steps in interpreting model output for reasonability. The first of these is to compare the projected seasonal dynamics of state variables and flows to that of previous experience. Thus, model output should be compared to the expected system dynamics as outlined in Section 2.2. Note, however, that each year is different. A check should be made to see if there is "internal consistency" in the dynamics of the different variables. For example, in the periods of time where the flow rate of standing live vegetation to standing dead vegetation is high, one should find a corresponding increase in the state variables for standing dead vegetation.

The second major way to interpret model output is not to rely on the result of one run, but instead to use several different runs. In general, it is desirable to impose a modelling experiment treatment in some quantitative scale. For example, a model could be run with increasing relative values of 1, 2, 3 and so forth. Results of the model run then could be plotted against those levels.

To be very useful, the model should be expanded to different ecological response units, both terrestrial and aquatic, and appropriate connections made between such units. Then it will be necessary to develop probable sets of driving variables. Different levels or types or scenarios should be constructed. It would be valuable if at least three different levels or scenarios were examined.

A set of model experiments should be designed and conducted. Designing a model experiment requires specifying (i) the specific driving variable records to be used, (ii) the initial conditions, and (iii) the parameter values. It also requires determining which measures or output from the model run will be used in the evaluation. The simulation should be made, summarized, and then discussed in a workshop.

There should be a continued search of information regarding the structure, parameterization, and outputs of the modelling effort. These should be tied back to monitoring on-going field investigations. Furthermore, periodic sensitivity analyses, both qualitative and quantitative, should be made of the model to derive information regarding research needs.

One strategy in making model experiments is as follows. A standard summary of simulation statistics is printed including the date of the simulation, initial simulation time, terminal simulation time, and the time steps used by the different submodels. It also specifies the different ecological response units incorporated, the specific driving variable set used and a definition of the model version. A specific table is developed which lists the state variables and their initial conditions. Another table lists the flows and the parameter values used in each flow calculation.

Outputs are summarized in several tabular and graphic ways. Standard tables are made for state variables, flows, intermediate variables, and output variables. These tables list each of the items by name and give their values at selected intervals. Simple descriptive statistics are calculated including the mean, standard deviation, sample size, and maximum and minimum values. The number of times each flow was greater than zero is also specified.

Standard graphs are made of the state variables, flows, output variables, and driving variables. Each graph plots the item against time. The graphs are done in such a way that they are readily reducible for use in reports and publications.

7.7 SOME SPECIFIC RECOMMENDATIONS REGARDING MODEL DEVELOPMENT AND USAGE

The project activity is incomplete. There has been insufficient time, funds, and inputs of data and information to complete the activity. This section gives some specific suggested tasks and procedures to complete and use the model for the original objective.

A workshop structure can be used to advantage in the remaining activities. These workshops would have participants selected from the resource management community, the biological science community, shale oil development industries, and state and federal regulatory agencies. Each workshop would have a specific purpose, a prior document or report circulated, and specific

follow up. These workshop activities would be meshed in time with the ecological and agricultural task force working group activities.

A workshop group needs to be assembled to examine the present model report. This report would serve as a focus for discussions. In effect, this workshop would be to conduct a "qualitative validation" of the model structure and its performance under the specified hypothetical climatic sequence used herein. In this workshop areas of improvement would be defined. Primary focus in this workshop would be on the dynamics of the state variables. The dynamics of the model variables would be judged against those summarized from the literature and presented herein and those from the personal experience of the workshop participants.

Given the outcome of the first workshop then a second workshop would be set up. The second workshop would seek new or modify existing flow functions and parameter values within the model structure. Note that the first workshop would focus on state variable dynamics. A second workshop would focus on the processes and flow functions. Also in the second workshop we would identify those needed field and laboratory monitoring measurements and research efforts to provide required information. An example of such follows.

Physiological studies should be undertaken with the main organism groups in the Piceance Basin to establish the basic physiological parameters for the ecotypes of the major species which exist there. At present the model must use parameters for ecotypes from Colorado, Oregon, Nevada, Wyoming or wherever else they can be obtained. For example, in the species Artemisia tridentata, big sagebrush, there is a great deal of genetic variation. The variation may be sufficiently great even within a species such as this that it makes validation difficult, results suspect, complicates tracing the sources of bias due to model parameters or descriptions of soil types and local climates.

As a second example we can consider the hydrological component from the model and the data relating to it. We have conceptualized an aquatic component but have not implemented it. The large particle concentration at each monitoring station should be measured to provide usable data. This measurement will enable the hydrology model to predict turbidity and mass transport, changing light intensities in the water and to show the effect of bank erosion and channel scouring. Furthermore, factors that must be measured and incorporated into the hydrology model include concentrations of nitrogen, oxygen, and phosphorus in stream water, water temperature and density. These factors have direct bearing on aquatic biota resident in the streams. The aquatic ecosystem component of the aquatic submodel requires studies of population numbers for the organisms present in the various trophic levels discussed earlier. Rates of reproduction, death, and migration along the stream also need to be known. The complexity or resolution of the aquatic ecosystem model can be reduced by the determination of the most important species present at each trophic level. Further, since the effect of complex organic compounds from shale oil on the Piceance Basin ecosystem is the major motive behind this modelling effort, information needs to be gathered regarding the incidents and concentration of organic compounds, such as, phenols, amines, and various wastes from the oil extraction process, in the streams.

These are but a few examples of specific monitoring or research measurements that need to be made. The second workshop, described above, would probably develop additional specifics.

Several activities need to be conducted concurrent with the two workshops noted above. One activity is the coding and parameterization of the aquatic submodel, which then needs to be incorporated within the terrestrial model and tested.

Another effort is securing valid driving variable sets for long-term runs. These are the climatic records and shale oil development impacts. The shale oil development impact records may need to be taken initially on a worst-case and best-case basis. The climatic records would need initially to cover a wet cycle, a dry cycle, and a normal cycle. A cycle might be in the order of 20 years.

A third effort is in software development. The statistical summarization package that takes output from the model runs and condenses it for ready interpretation needs to be incorporated with the model. Likewise, the graphical summarization must be incorporated. In the present case, the time-series graphs of the state variables or of the processes have been developed manually. Furthermore, extensive experiments should be conducted with the model. Thus response-function plots should be developed where integrated values of processes are plotted against levels of the treatment (or control variables) from the model experiment.

After the above activities and workshops are accomplished, there needs to be a further publication or report, similar to the present one. This report would document the revised and completed and tested total model and completed software.

A third workshop would then be held. The above report would be used as an input document and a major objective would be to define model runs and sensitivity tests for further experiments. For such model runs the definition of alternative shale oil development strategies would need to be included. For example, different rates of shale oil development (in terms of millions of barrels over a given time span), and types and locations of industrial plants (those that are in situ or those with aboveground retorts) would be compared. Secondly, the criteria for acceptance or rejection of the hypothesis that "there is no significant impact on ecological and agricultural systems of shale oil development" needs to be defined. Similarly, for sensitivity tests, parameter values are of key interest, what values they should be set at for various model runs and what would be the response function used to measure their impact need to be identified.

After this workshop, there would be a major effort of conducting the model runs and summarizing the findings into a final technical report.

A final workshop would be held to examine the final technical report, evaluate it, and interpret it. At this time a final executive report would be written. This report should be distributed widely to industry, regulatory agency, and other groups.

It is only with a plan similar to the above that full usage will be made of the model that has been developed to date.

8. LITERATURE CITED AND GENERAL BIBLIOGRAPHY

- Abeles, F. 1973. Ethylene in plant biology. Academic Press, New York. 301 pp.
- Abeles, F., and H. Heggstad. 1973. Ethylene: An urban air pollutant. J. Air Poll. Control Assoc. 23: 517-521.
- Abeles, F., L. Craker, and G. Leather. 1971. Abscission: The phytoherontological effects of ethylene. Plant Phys. 47:7-9.
- Allsman, P. T. 1968. Simultaneous caving and surface restoration system for oil shale mining. Quar. Colo. School Mines 63(4)857-870.
- Anderson, A. E., D. E. Medin, and D. C. Bowden. 1974. Growth and morphometry of the carcass, selected bones, organs, and glands of mule deer. Wildlife Mono. No. 39.
- Andrew, F. D., A. J. Gandolfi, and D. D. Mahlum. 1978. Development effects of synthetic fuel related materials in rats. Teratology 17(2):35A.
- Anonymous. 1978. Synthetic fuels: Oil shale, coal, and oil sands. Synthetic fuels 15(1):1-208.
- Ares, J., and J. S. Singh. 1974. A model of the root biomass dynamics of a shortgrass prairie dominated by blue grama (Boueloua gracilis). J. Appl. Ecol. 11:727-744.
- Armstrong, D. M. 1972. Distribution of mammals in Colorado. Monographs of the Museum of Natural History, Univ. Kansas 3:1-415.
- Arora, H. S., and T. Tamura. 1978. Physical/chemical characterization. Synthetic Fuels Program, Env. Sci. Div., Oak Ridge Nat. Lab., TN. Internal Document.
- Ashland Oil. 1976a. Oil shale tract C-b environment baseline program, Vol. 1. Regional and temporal setting. 221 pp.
- Ashland Oil. 1976b. Oil shale tract C-b detailed development plan and related materials, Vol. II. Summary of first year's environmental baseline programs and environmental setting. 522 pp.
- Ashland Oil, Inc. 1974 (a). Preliminary development plan for Colorado tract C-b. For the Bureau of Land Manage., U.S. Dept. of Interior. Ashland, KY. 47 pp.
- Ashland Oil, Inc. 1974 (b). Federal oil shale prototype leasing program tract C-b: Supplemental exploration plan. For the Conservation Div., U.S. Geological Survey. Ashland, KY. 46 pp.
- Ashland Oil, Inc. 1974-1976. First year environmental baseline program. Annual summary and trends depart. Denver, CO. 546 pp.

- Ashland Oil, Inc. 1976. Environmental monitoring programs for Tract C-b: Supplemental information. Unpublished document.
- Ashland Oil, Inc. 1978. Development monitoring program for oil shale tract C-b. Prototype Oil Shale Leasing Program for the U.S. Dept. of Interior, Grand Junction, CO. 169 pp.
- Ashland Oil, Inc., and Occidental Oil Shale Inc. (operator). 1976. Oil shale tract C-b: Environmental baseline program final report (Vol. I - V). C-b Shale Oil Venture for the U.S. Dept. of the Interior, Prototype Oil Shale Leasing Program.
- Aten, R. E., R. M. Alverson, R. W. Brooks, E. M. Cushing, and R. D. Johnson. 1978. Impact of energy development on ground water. J. of the Hydraulics Div., American Soc. of Civil Engineers 104(HY2):157-168.
- Atkinson, L. P., W. M. Dunstan, and J. G. Natoli. 1977. The analysis and control of volatile hydrocarbon concentrations benzene during oil bioassays. Water, Air, Soil Pollution 8(2):235-242.
- Atwood, M. T. 1974. Colony oil shale development, Parachute Creek, Colorado, p. 181-194. In Ayer, F. A. (ed.). Proceedings of Symposium on Environmental Aspects of Fuel Conversion Technology, St. Louis, MO.
- Auerbach, S. I. (director). 1979. Environmental Sciences Division annual progress report. Env. Sci. Div. Pub. #1280, Oak Ridge Nat. Lab., Oakridge, TN. 197 pp.
- Auerbach, S. I. 1975. Hearings on cost and effects of chronic low-level environmental pollution. Testimony presented to the subcommittee on environment and atmosphere, U.S. House of Representatives, 94th Congress First Session, Nov. 12, No. 49, Washington D.C., U.S. Gov't Printing Office. pp. 511-537.
- Axelrod, D. I. 1950. Evolution of desert vegetation in western North America. Carnegie Inst. Wash. Pub. 590, pp. 215-306.
- Balcomb, Kenneth C. 1968. Availability of water for oil shale development. In Proceedings of the fifth symposium on oil shale, Denver, Colorado. 2-3 May 1968. Quar. Colorado School of Mines. 63(4):109-112
- Bamberg, S. A. 1975. Approaches to large scale land reclamation in oil shale development. In Gary, J. H. (ed.). Proceedings of the environmental oil shale symposium, Colorado School of Mines. 9-10 October 1975. Quar. Colorado School of Mines. 70(4):95-104.
- Barrett, T. W., and H. M. Benedict. 1970. Sulfur dioxide. In Jacobson, J. S., and A. C. Hill (eds.). Recognition of air pollution injury to vegetation: A pictorial atlas. J. Air Poll. Control Assoc., Pittsburgh, PA.
- Barth, R. C. 1976. Saline and sodic spoils - What are they and how are they reclaimed? Mining Congress Journal, July, pp. 51-55.

- Battelle Memorial Institute. 1978. Pacific Northwest Laboratory annual report for 1978 to the DOE Assistant Secretary for Environment (Part 2). Richland, WA.
- Battelle, Pacific Northwest Laboratories (BPNL). 1972. Parachute Creek Valley diffusion experiments.
- Bauer, D. A., and G. A. Cresswell. 1975. Quality assurance for meteorological and air quality studies in support of the Rio Blanco oil shale project. In Gary, J. H. (ed.). Proceedings of the environmental oil shale symposium, Colorado School of Mines. 9-10 October 1975. Quar. Colorado School Mines 70(4):187-198.
- Bell, J. N. B., and W. S. Clough. 1973. Depression of yield in ryegrass exposed to sulphur dioxide. Nature 241:47-49.
- Benedict, H. M., and W. H. Breen. 1955. The use of weeds as a means of evaluating vegetation damage caused by air pollution. Proc. Nat. Air Poll. Symp. 3rd. p. 177.
- Bennett, J. H., and A. C. Hill. 1973. Inhibition of apparent photosynthesis by air pollutants. J. of Env. Quality 2(4):526-530.
- Bennett, J. H., and A. C. Hill. 1973. Absorption of gaseous air pollutants by a standardized plant canopy. J. Air Poll. Control Assoc. 23:203-206.
- Bennett, J. H., A. C. Hill, A. Soleimani, and W. H. Edwards. 1975. Acute effects of combination of sulphur dioxide and nitrogen dioxide on plants. Env. Poll. 9(2):127-132.
- Bennett, J., A. Hill, and D. Gates. 1973. A model for gaseous pollutant sorption by leaves. J. Air Poll. Control Assoc. 23:957-962.
- Berge, H. 1973. Sulfur dioxide and hydrogen fluoride emissions from the point of view of phytopathology. Meded Fac Landbouwwet Rijksuniv Gent 38(3, Part 2):1545-1548.
- Berg, W. A., and E. M. Barrau. 1973. Composition and production of seedlings on strip-mined spoils in northwestern Colorado. Paper presented at the Research and Applied Technology Symposium on Mined-Land Reclamation. Sponsored by the National Coal Association, Monroeville, Pa.
- Beychok, M. R. 1975. Environmental factors in producing supplemental fuels. Hydrocarbon Process 54(10):78-81.
- Bingham, E., and W. Barkley. 1977. Bioassay of complex mixtures derived from fossil fuels. Paper presented at US-USSR workshop on health effects of oil shale development.
- Biscoe, P. V., M. H. Unsworth, and H. R. Pinckney. 1973. Effects of low concentrations of sulfur dioxide on stomatal behavior in Vicia faba. New Phytol. 72:1299-1306.

- Blaisdell, J. P. 1958. Seasonal development and yield of native plants on the Upper Snake River plains and their relation to certain climatic factors. U.S. Dept. of Agric. Tech. Bull. No. 1190. Washington, D.C. 68 pp.
- Blaxter, K. L., E. W. Wainman, and J. L. Davidson. 1966. The voluntary intake of food by sheep and cattle in relation to their energy requirements for maintenance. *Animal Prod.* 8:75-83.
- Bleasdale, J. K. A. 1973. Effects of coal-smoke pollution gases on the growth of ryegrass (Lolium perenne L.). *Environ. Poll.* 5:272-285.
- Bogovski, P., and F. Vinkmann. 1977. Carcinogenicity of oil shale tars, some of their components and commercial products. Paper presented at US-USSR workshop on health effects of oil shale development.
- Bogovski, P., and H. Mirme. 1977. Cocarcinogenicity of phenols from estonian shale tars (oils). Paper presented at US-USSR workshop on health effects of oil shale development.
- Bond, H. W. 1980. Nutrient concentration patterns in a stream draining a montane ecosystem in Utah. *Ecol.* 60:1184-1196.
- Bonomo, F. 1974. Environmental effects of carbonaceous solid wastes from commercial oil shale operations, p. 133-186. *In* Siggia, S. and P. C. Uden (eds.). *Proceedings of Conference on Analytical Chemistry Pertaining to Oil Shale and Shale Oil*, Washington, D.C.
- Bonte, J., L. DeCormis, and P. Louguet. 1975. Effect of sulfur dioxide pollution on the degree of opening of Pelargonium x hortorum stomata. *C. R. Hebd. Seances Acad. Sci., Ser. D.* 280:2377-2380.
- Bowden, C. 1975. The impact of energy development on water resources in arid lands: Literature review and annotated bibliography. *Off. of Arid Lands Studies, Univ. of Arizona, Tucson.* 278 pp.
- Boyd, R. J. 1962. Study of deer losses on Colorado highways, p. 93-100. *In* *Quarterly Prog. Rep. Colo. Dept. Game and Fish, Denver* 10:1-137.
- Boyd, R. J. 1964. Study of deer losses on Colorado highways, p. 36-41. *In* *Game Res. Rep., Colo. Dept. Game, Fish and Parks, Denver* 4:1-69.
- Boyd, R. J. 1970. Elk of the White River Plateau, Colorado. *Colorado Division of Game, Fish, and Parks. Tech. Pub.* 25. 126 pp.
- Boyles, D. T. 1976. The loss of electrolytes from leaves treated with hydrocarbons and their derivatives. *Ann. Appl. Biol.* 83(1):103-113.
- Brady, N. C. 1974. The nature and properties of soils. 8th ed. McMillan Pub. Co., New York. 639 pp.
- Brandt, C. S., and W. W. Heck. 1968. Effect of air pollutants in vegetation, p. 401-443. *In* Stern, A. C. (ed.). *Air pollution, Vol. 1, 2nd ed.*, Academic Press, New York.

- Breymeyer, A. I. and G. M. Van Dyne (eds.). 1980. Grasslands, systems analysis and man. Cambridge University Press, Cambridge, United Kingdom. 950 pp.
- Brisley, H. R., C. R. Davis, and J. A. Booth. 1959. Sulphur dioxide fumigation of cotton with special reference to its effect on yield. Agron. J. 51:77-80.
- Brown, L. F., and M. J. Trlica. 1977. Interacting effects of soil water, temperature and irradiance on CO₂ exchange rates of two dominant grasses of shortgrass prairie. J. Appl. Ecol. 14:197-204.
- Brown, Richard (ed.). 1979. Health and environmental effects of oil shale technology: A workshop summary and panel reports for the Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies. Contract DOW/HEW/EPA-02 MTR-79W00136. Mitre Corporation, Metrek Division. 258 pp.
- Buckman, H. O., and N. C. Brady. 1969. The nature and property of soils. The Macmillan Co., New York. 653 pp.
- Bull, J. N., and T. A. Mansfield. 1974. Photosynthesis in leaves exposed to SO₂ And NO₂. Nature 250:443-444.
- Burge, J. R., and C. D. Jorgensen. 1973. Home range of small mammals: A reliable estimate. J. of Mammalogy 54:483-488.
- Burg, S. 1968. Ethylene, plant senescence and abscission. Plant Phys. 43:1503-1511.
- Burg, S., A. Apelbaum, W. Eisinger, B. Kang. 1971. Physiology and mode of action of ethylene. Hort Science 6:359.
- Burke, Hubert D. 1975. Wildlife and oil shale: A problem analysis and research program (Vols. I & II). Thorne Ecological Inst. for the U.S. Dept. of the Interior, Fish and Wildlife Service, Off. of Bio. Services. Boulder, CO. p. 112 and p. 131.
- Buron, A., and G. Cornic. 1973. Effect of sulfur dioxide on gas exchange in white mustard (Sinopsis alba). Bull. Soc. Voudoise Sci. Nat. 71:451-461.
- Cameron Engineers and Office of Energy, Minerals, and Industry. 1978. EPA program status report: Oil shale. Contract EPA-68-01-4337. Interagency Energy Env. Res. and Devel. Program Report, Washington, D.C. 29 pp. and Appendices.
- CampDresser & McKee Inc. 1978. Air quality impact assessment colony development operation. Final report. Wheatridge, CO. 44 pp.
- Canadian Journal of Plant Science. 1973. Vol. 53. Agricultural Institute of Canada.

- Carlson, L. W., and A. T. Cringan. 1975. Oil shale development and wildlife in northwestern Colorado. *Wildl. Soc. Bull.* 3:7-12.
- Carrier, R. 1977. Plant interactions. In Braumstein, H., E. Copenhaver, and H. Pfuderer (eds.). *Environmental health and control aspects of coal conversion: An information overview*, Vol. 2. Oak Ridge Nat. Lab. (Tennessee). ORNL/EIS-95.
- Caswell, H. 1976. The validation problem, pp. 313-325. In B. C. Patten (ed.). *Systems analysis and simulation in ecology*. Vol. IV. Academic Press, NY.
- Cataldo, D. A. 1978. Behavior of Tc and I in a Hanford soil and associated subsoil: Influence of soil aging on uptake by cheatgrass and tumbleweed. DOE Report PNL-2740, in review.
- Cataldo, D. A. 1978. Comparative availability of Cs and Sr for plant absorption from amended Rupert surface soil and associated subsoil: Influence of growth conditions. DOE report PNL-2741, in review.
- Cataldo, D. A., and R. E. Wildung. 1978. Soil and plant factors influencing the accumulation of heavy metals by plants. *Environ. Health Perspectives*.
- Cataldo, D. A., R. C. Routson, D. Paine, and T. R. Garland. 1978. Relationships between properties of Hanford soils and the availability of Cs and Sr for the uptake by cheatgrass and tumbleweed. DOE report PNL-2496.
- Cataldo, D. A., R. G. Riley, and W. E. Fallon. 1978. Physiological effects of oil shale water on plants. Paper presented at the ASA, CSSA and SSA Annual Meetings, Chicago, IL, 3-8 December.
- Cecil, C. B. 1974. Oil shale development: Some environmental considerations, p. 353-359. In Ayer, F. A. (ed.). *Proceedings of Symposium on Environmental Aspects of Fuel Conversion Technology*. St. Louis, MO.
- Cerniglia, C. E., and D. T. Gibson. 1977. Symposium on oil sand and oil shale. *American Chem. Soc. Div. of Fuel Chem. Prepr.* 22(3):209-216.
- Chappell, W. R., and D. D. Runnells. 1977. Toxic trace elements and oil shale production, p. 383-388. In *Proceedings of Univ. of Missouri Annual Conf. Trace Subst. of Env. Health*.
- Church, J. C. 1977. Annual review of selected mining research activities. Bureau of Mines, Washington, D.C. 79 pp.
- Cline, J. F., and G. M. Holter. 1978. The effect of soil affixants on germination, emergence, and growth of cheatgrass and Russian thistle. *Health Phys.* 35(2):409-411.
- Cline, J. F., and V. A. Uresk. 1978. Revegetation of disturbed grounds in the semi arid climate of southcentral Washington. *Health Phys.* 35(2):409-411.

- Clusen, Ruth. 1978. Introductory statement to the staff of the Office of Environment. Dept. of Energy, Office of the Secretary for Env. Washington, D.C. Unpublished document. 6 pp.
- Cole, G. W. (ed.). 1976. ELM: Version 2.0. Range Sci. Dept., Sci. Series No. 20, Colorado State Univ., Fort Collins. 663 pp.
- Colony Development Operation in Colorado. 1976. Final environmental impact statement: Proposed development of oil shale resources (Vol. I & II). For the Bureau of Land Manage., U.S. Dept. of the Interior. 238 pp. & 38 pp.
- Colony Development Operation (CDO). 1974. An environmental impact analysis for a shale oil complex at Parachut Creek, Colorado. Vol. I. 349 pp.
- Colorado Mining Association. 1978. Mining year book, 1978. Papers presented at the 81st Annual Meeting of the Nat. Western Mining Conf. and Exhibition, Denver, CO.
- Colucci, A. V. 1976. Sulfur oxides: Current status of knowledge. EPRI EA-316. Prepared by Greenfield, Attaway, and Tyler, Inc., San Rafael, CA, for The Electric Power Research Institute, Palo Alto, CA. (various paging).
- Connors, T. J., M. J. Schneider, R. G. Genoway, and S. A. Barraclough. 1978. Effects of acclimation temperature on plasma levels of glucose and lactate in rainbow trout, Salmo gairdneri. J. Experimental Zoology, accepted.
- Cooke, W. B. 1961. Pollution effects on the fungus population of a stream. Ecol. 42:1-18.
- Cook, C. Wayne. 1978a. Rehabilitation potential and practices of Colorado oil shale lands. Renewal Proposal Contract No. EY-76-S-02-4018, U.S. Dept. of Energy, Colorado State Univ., Fort Collins. 109 pp.
- Cook, C. Wayne. 1978b. Rehabilitation potential and practices of Colorado oil shale lands. Progress report for period 1 June 1977 to 31 May 1978. Contract No. EY-76-S-02-4018, Dept. of Energy. Colorado State Univ., Fort Collins. 268 pp.
- Cook, C. Wayne. 1979a. Rehabilitation potential and practices of Colorado oil shale lands. Progress report for period 1 June 1978 to 31 May 1979. Contract No. EY-76-S-02-4018, Dept. of Energy. Colorado State Univ., Fort Collins. 355 pp.
- Cook, C. Wayne. 1979b. Rehabilitation Potential and practices of Colorado oil shale lands. Renewal Proposal Contract No. EY-76-S-02-4018, U.S. Dept. of Energy, Colorado State Univ., Fort Collins. 355 pp.
- Cook, C. Wayne, R. M. Hyde, and P. L. Sims. 1974. Guidelines for revegetation and stabilization of surface mined areas in the western states. Range Sci. Dept., Sci. Ser. No. 16. Colorado State Univ., Fort Collins. 70 pp.
- Cook, Wayne C. (coordinator). 1974a. Surface rehabilitation of land disturbances resulting from oil shale development. Env. Res. Center, Tech. Rpt. Ser. No. 1. Colorado State Univ., Fort Collins. 255 pp.

- Cook, Wayne C. (coordinator). 1974b. Surface rehabilitation of land disturbances resulting from oil shale development: Executive summary. Env. Res. Center, Colorado State Univ., Fort Collins. 56 pp.
- Corbett, E. S., and R. P. Crouse. 1968. Rainfall interception by annual grass and chaparral, losses compared. USDA Forest Research Paper PSW-48. Pacific Southwest Forest and Range Exp. Sta., Berkeley, CA. 12 pp.
- Cotter, J. E. 1977a. Control technology for shale oil recovery processes: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-07-1881. TRW/DRI, Denver, CO.
- Cotter, J. E., and C. H. Prien. 1977b. Environmental analysis of oil shale operations: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-02-1881. TRW/DRI, Denver, CO.
- Cotter, J. E., C. H. Prien, J. J. Schmidt-Collerus, D. J. Powell, R. Sung, C. Habernicht, R. E. Pressey. 1977. Sampling and analysis research program at the Paraho Shale Oil Demonstration Plant: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-02-1881. TRW/DRI, Denver, CO. 71 pp.
- Cotter, J. E., D. J. Powell, and C. Habernicht. 1978. Sampling and analysis for retort and combustion gasses at the Paraho shale oil demonstration plant. Interagency Energy--Env. Research and Devel. Program report series. EPA Contract #68-03-2560. 44 pp.
- Coutant, C. C., and S. S. Talmage. 1975. Thermal effects. J. of Water Pollution Control Federation 47(6):1657-1711.
- Couturier, D. E., and E. A. Ripley. 1973. Rainfall interception in mixed grass prairie. Can. J. Plant Sci. 53:659-663.
- Craighead, J. J., and F. C. Craighead. 1969. Hawks, owls, and wildlife. Dover Publications, Inc., New York. 443 pp.
- Crawford, K. W., C. H. Prien, L. B. Baboolal, C. C. Shih, A. A. Lee. 1977. A preliminary assessment of the environmental impacts from oil shale development. Interagency Energy-Environment Research and Development Program Report. EPA Contract #68-02-1881. TRW/DRI, Denver, CO. 174 pp.
- Crecelius, E. A. 1978. Deposition rate of airborne particulate of elements on the Washington coast. Paper presented at the ASLO meeting, Victoria, Canada, 12-22 June.
- Cringan, A. T. 1974. Regional oil shale study. Environmental impact of prototype shale leases upon wildlife in Colorado, Piceance Creek Basin, Rio Blanco and Garfield counties, Colorado. Thorne Ecological Institute, Boulder, CO. 79 pp.
- Crocker, W. 1948. Growth of plants. Reinhold Publishing Corp., New York. 459 pp.

- Cummins, K. W., J. R. Sedell, F. J. Swanson, S. A. Fisher, R. L. Vannote, G. W. Minshall, C. E. Cushing, and R. C. Petersen. 1978. Problems in evaluating organic matter budgets for stream ecosystems. *Hydrobiologia*, submitted.
- Cundell, A. M. 1977. The role of microorganisms in the revegetation of strip-mined land in the United States. *J. of Range Manage.* 30(4): 299-303.
- Cushing, C. E. 1978. Trace elements in a Columbia River food web. *Northwest Science*, accepted.
- C-b Shale Oil Venture. 1976. Tract C-b summary report #1-8. Submitted to Conservation Div., U.S.G.S. U.S. Dept. of Interior Prototype Oil Shale Leasing Program, Denver, CO.
- C-b Shale Oil Venture. 1976. Prototype oil shale leasing program, oil shale tract C-b environmental baseline program. Final report prepared for the U.S. Dept. of Interior.
- C-b Shale Oil Venture. 1978. Development monitoring program for oil shale tract C-b (supplementary information). Ashland Oil Co., Inc. and Occidental Oil Shale, Inc. (operator). 170 pp.
- Daines, R. H. 1968. Sulfur dioxide and plant response. *J. Occupational Medicine* 10:516-524.
- Dale, R. H., and J. B. Weeks. 1978. Hydrologic analysis of the U.S. Bureau of Mines underground oil-shale research facility site, Piceance Creek Basin, Rio Blanco County, Colorado. Water Resources Div., U.S. Geological Survey, Lakewood, CO. 35 pp.
- Davey, J. R. 1980. Energy flow dynamics of a desert grassland ecosystem. Ph.D. diss., Northern Arizona State Univ., Flagstaff, AZ.
- Davis, C. R. 1972. Sulfur dioxide fumigation of soybeans: Effect on yield. *APCA J.* 22:964-966.
- Davis, D. D., and H. D. Gerhold. 1976. Selection of trees for tolerance of air pollutants. Better trees for metropolitan landscapes Symp. Proc. USDE-Forest Service Gen. Tech. Rep. NE-22:61-66.
- Davis, D. D., and R. G. Wilhour. 1976. Susceptibility of woody plants to sulfur dioxide and photochemical oxidants: A literature review. Corvallis Environ. Res. Lab., Corvallis, Oregon. *Ecol. Res. Ser.* 71 pp.
- de Vries, D. A., and N. H. Afgan (eds.). 1975. Heat and mass transfer in the biosphere: Part 1, Transfer processes in the plant environment. Scripta Book Co., Washington, D.C. 591 pp.
- Delaney, Robert. 1965. The necessity of water storage for the oil shale industry. In Spear, S. W. (ed.). Second Symposium on Oil Shale, Denver, Colorado. 22-23 April 1965. *Quar. Colorado School of Mines.* 60(3):111-118

- Denevers, N., D. Eckhoff, S. Swanson, B. Glenne, and F. Wagner. 1978. Analysis of the environmental control technology for oil shale development. Coll. of Engineering, Utah Univ., Salt Lake City. 300 pp.
- DePuit, E. J., and M. M. Caldwell. 1975. Stem and leaf gas exchange of two arid land shrubs. *Amer. J. of Botany* 62:954-961.
- DePuit, E. J., and M. M. Caldwell. 1973. Seasonal pattern of net photosynthesis of artemisia tridentata. *Amer. J. Bot.* 60:426-435.
- Detling, J. K., and W. J. Parton. 1978. Primary producer submodel. In Ellis, J. E., and W. J. Parton (eds.). Impact of strip-mine reclamation practices: A simulation study. Nat. Res. Ecol. Lab., Colorado State Univ., Fort Collins.
- Deutscher, V. F. W. 1976. Proceedings of the International Symposium on Fossil Fuel Production and Water Resources. Deusseldorf, Germany. 470 pp.
- Development Engineering, Inc. 1978. Oil shale sampling and analysis review. Grand Junction, CO. Unpublished document. 8 pp.
- Dickson, E. M., R. V. Steele, and E. E. Hughes. 1976. Impacts of synthetic liquid fuel development: Assessment of critical factors. Analysis 76-129/2, SRI Project EGU-3505, Stanford Research Inst., Menlo Park, CA. 877 pp.
- Dietz, D. R., L. K. Barker, E. G. Hoffman, and R. L. Elderkin. 1978. Assessment of oil shale development: A problem in statistical design, p. 87-114. In Proceedings of the 1977 DOE Statistical Symposium, Richland, WA.
- DiToro, D. M., D. J. O'Connor and R. V. Thomann. 1971. A dynamic model of phytoplankton populations in the Sacramento-San Joaquin delta. *Advances in Chemistry Series*, p. 131-180. "Nonequilibrium systems in natural water chemistry."
- Dodd, J. L. 1980. Personal communication. Nat. Res. Ecol. Lab., Colorado State Univ., Fort Collins. (February, March, April).
- Dodd, J., W. Lauenroth, G. Thor, and M. Coughenhour. 1979. Effects of chronic low level SO₂ exposure on producers and litter dynamics, p. 384-477. In Preston, E., and T. Gullett (eds.). The bioenvironmental impact of a coal-fired power plant. EPA-600/3-79-044.
- Dougal, M. D. 1971. Snowmelt analysis in the Midwest and its role in water runoff and management. In Haugen, H. O. (ed.). Proceedings of the Snow and Ice in Relation to Wildlife and Recreation Symposium, Iowa Coop Wildlife Research Unit, Univ. of Iowa, Ames. 281 pp.
- Dreisinger, B. R., and P. C. McGovern. 1970. Monitoring atmospheric sulphur dioxide and correlating its effects on crops and forests in the Sudbury area, p. 11-28. In Linzon, S. N. (ed.). Impact of Air Pollution on Vegetation Conf., Ontario Dept. of Energy and Resource Manage., Toronto. 122 pp.

- DRI, Inc. 1977a. Applicable control technologies, Paraho oil shale process: Report on an assessment of environmental assessment from oil shale development. EPA Contract #68-02-1881. Denver, CO
- DRI, Inc. 1977b. Applicable control technologies, TOSCO II oil shale process: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-02-1881. Denver, CO
- Dugger, M. (ed.). 1974. Air pollution effects on plant growth. Amer. Chem. Soc., Washington, D.C.
- Dugger, W. M., Jr., O. C. Taylor, E. Cardiff, and C. R. Thompson. 1962. Stomatal action in plants related to damage from phototchemical oxidants. *Plant Phys.* 37:487-491.
- Dvorak, A. J., and B. G. Lewis. 1978. Impacts of coal-fired power plants on fish, wildlife, and their habitats. Argonne National Laboratory for U.S. Fish and Wildlife Service. DOE Contract #W-31-109-Eng-38. 257 pp.
- Dvorak, A. 1978. Impacts of coal-fired power plants on fish, wildlife, and their habitats. U.S. Fish and Wildlife Service. FWS/OBS-78/29.
- Eberhardt, L. L. 1978. Designing ecological studies of trace substances. In Adriano, D. C., and I. L. Brisbin (eds.). *Environmental chemistry and cycling processes*. CONF-760429.
- Eckert, R. E., Jr., and R. E. Kinsinger. 1960. Effects of Halogeton glomeratus leachate on chemicals and physical characteristics of soils. *Ecology* 41:764-772.
- Ecology Center. 1975. Desert biome: Ecosystem analysis studies. (Vol. 3) Report of 1974 Progress. U.S. International Biological Program, Utah State University, Logan. 414 pp.
- Ecology Consultants, Inc. (ECI). 1975. Parachute Creek environmental baseline program for Bechtel Corporation and Union Oil Company of California. Tech. Rpt. No. 267. October. 227 pp.
- Edwards, N. T., and M. R. Todd. 1978. Phytotoxicity. Synthetic Fuels Program, Env. Sci. Div., Oak Ridge Nat. Lab., Oak Ridge, TN. Internal Document.
- Ellis, J. E., and W. J. Parton. 1978. Impact of strip-mining reclamation practices: A simulation study. Nat. Res. Ecol. Lab., Colorado State Univ., Fort Collins for West. Energy and Land Use Team, Off. of Biol. Sci., Fish and Wildlife Serv., U.S. Dept. of Interior. 329 pp.
- Ellis, J. E., J. A. Weins, C. F. Rodell, and J. C. Anway. 1976. A conceptual model of diet selection as an ecosystem process. *J. Theor. Biol.* 60:93-108.
- Ely, Northcutt. 1967. The oil shale industry's water problems. Spear, S. W. (ed.). Fourth symposium on oil shale, Colorado School of Mines. 6-7 April 1967. *Quar. Colorado School Mines* 62(3):9-17.

- Epler, J. L. 1978. Energy related pollutants in the environment: The use of short-term tests for mutagenicity in the isolation and identification of biohazards. Presented at the Conference for Higher Plant Systems as Monitors of Environmental Mutagens, Marineland, FL.
- Epler, J. L., F. W. Larimer, C. E. Nix, T. Ho, and T. K. Rao. 1978. Comparative mutagenesis of test materials from the synthetic fuel technologies. *Mutation Res.* 53(2):185.
- Epler, J. L., T. K. Rao, and M. R. Guerin. 1977. Evaluation of feasibility of mutagenic testing of shale oil products and effluents. Paper presented at US-USSR workshop on health effects of oil shale development.
- Faller, N. 1970. Effects of atmospheric SO_2 on plants. *Sulphur Institute J.* 6:5-7.
- Felt, E. P. 1965. Plant galls and gall makers. Hafner Press, New York. 64 pp.
- Ferenbaugh, R. 1979. Effects of sulfur dioxide on the growth and productivity of the desert grass, Oryzopsis hymenoides, including a literature survey of the general effects of sulfur dioxide on vegetation. In Gaud, W. Environmental impact studies of the Navajo and Kaiparowits power plants. Environ. Impact Studies, Northern Arizona Univ., Flagstaff.
- Fetcher, N. 1977. Production of cold desert shrubs: A simulation model. Ph.D. dissertation, Colorado State Univ., Fort Collins. 205 pp.
- Ficke, J. F., B. Weeks, and F. A. Welder. 1974. Hydrologic data from the Piceance Basin, Colorado. Water Resources Basic Data Release No. 31, Colorado Dept. of Nat. Resources, Denver. 246 pp.
- Findley, J., M. D. Appleman, and T. F. Yen. 1974. Degradation of oil shale by sulfur oxidizing bacteria. *Appl. Microbiol.* 28(3):46-464.
- Finley, Robert B. Jr., D. E. Wilhelm Jr., and W. Caire. 1976. Mammals of the Colorado Oil Shale Region. U.S. Fish and Wildlife Laboratory. U.S. Fish and Wildlife Service. Unpublished document. 49 pp.
- Fireman, M., and H. E. Hayward. 1952. Indicator significance of some shrubs in the Escalante Desert, Utah. *Bot. Gaz.* 114: 143-155.
- Fischer, R. C. Colorado oil shale and water. In Gary, James H. (ed.). Proceedings of the seventh oil shale symposium, Colorado School of Mines. 18-19 April 1974. *Quar. Colorado School of Mines* 69(2):133-139.
- Flug, M., W. R. Walker, G. V. Skogerboe, and S. W. Smith. 1977. The impact of energy development on water resources in the Upper Colorado River Basin. Dept. of Agri. Engineering, Colorado State Univ., Fort Collins. 158 pp.
- Frere, M. H. 1975. Integrating chemical factors with water and sediment transport from a watershed. *J. Env. Qual.* 4:12-17.

- Frischknecht, N. C. 1975. Native faunal relationships within the pinyon-juniper ecosystem. In G. F. Gifford and F. E. Busby (eds.). The pinyon-juniper ecosystem: A symposium. Logan, Utah.
- Gandolfi, A. J., J. E. Lund, R. A. Renne, K. E. McDonald, and C. A. Shields. 1978. Response of rats to intratracheally administered oil shale dusts. *Toxicology Applied Pharmacology* 45(1):229.
- Gardiner, D. A. (compiler and ed.). 1977. Proceedings of the 1977 DOE statistical symposium, 26-28 October, p. 87-114. Pacific Northwest Laboratories, Richland, Washington. Oak Ridge National Lab., Oak Ridge, TN.
- Gardner, B. D., K. S. Lyon, and R. Tew. 1976. The effects on agriculture in Utah of water transfers to oil shale development. Dept. of Economics, Utah State Univ., Logan. 57 pp.
- Gardner, G. M. 1977. Comparison of energy analysis of oil shale, p. 173-212. In Odum, H. T. (ed.). Energy analysis of models of the United States: Annual report.
- Garland, J. A., and J. R. Branson. 1976. The mixing height and mass balance of SO_2 in the atmosphere above Great Britain. *Atmos. Environ.* 10:353-362.
- Garland, R. T., R. E. Wildung, and H. P. Harbert. 1978. Mobility of macroions, trace elements and organic components after application of irrigation water to lysimeters containing retorted oil shale. Paper presented at ASA, CSSA, SSA Annual Meetings, Chicago, IL, 3-8 December.
- Gaud, W. S. 1979. Environmental impact studies of the Navajo and Kaiparowits power plants. Final Report, June 1, 1975-May 31, 1976. Northern Arizona Univ.
- Gehrs, C. W. 1976. Panel discussion on liquid residuals from synthetic fuels production, p. 193-204. In Proceedings of First Symposium on Management of Residues from Synthetic Fuels Production. Denver Research Institute.
- Gehrs, C. W. 1977. Environmental implications of coal conversion technologies: Organic contaminants. Presented at Symposium on Energy and Env. Stress in Aquatic Systems. Augusta, GA.
- Gehrs, C. W. 1978. Zooplankton population response. Synthetic Fuels Program, Env. Sci. Div., Oak Ridge Nat. Lab., TN. Internal Document.
- Gehrs, C. W. and Wells. 1976. Chairman's summary on environmental transport and effects. In Proceedings of Symposium on Sampling Strategy and Emission Characterization from Synfuels Production. Lakeway, TX
- Gehrs, C. W., Parkhurst, and Shriner. 1978. Environmental testing. Presented at Symposium on Application of Short-term Bioassays in the Fractionation and Analysis of Complex Environmental Mixtures. Williamsburg, VA

- Giddings, J. M., and J. N. Washington. 1978a. Microcosm studies. Synthetic Fuels Program, Env. Sci. Div., Oak Ridge Nat. Lab., TN. Internal Document.
- Giddings, J. M., and J. N. Washington. 1978b. Algal assays. Synthetic Fuels Program, Env. Sci. Div., Oak Ridge Nat. Lab., TN. Internal Document.
- Giddings, J. M., B. T. Walton, Eddlemon, and Olson. 1978c. Transport and fate of anthracene in aquatic microcosms. Presented at Workshop on Microbiol Degradation on Pollutants in Marine Environments. EPA Sponsored. Pensacola Beach, FL
- Gilbert, P. F., O. C. Wallmo, and R. B. Gill. 1970. Effect of snow depth on mule deer in Middle Park, Colorado. *J. of Wildl. Manage.* 34:15-23.
- Gilbert, R. G., O. C. Wallmo, and R. B. Gill. 1970. Effect of snow depth on mule deer in Middle Park, Colorado. *J. Wildlife Manage.* 34:15-23.
- Gist, Clayton S., Rosielea Gash, F. D. Neelson, and Fred Weber. 1975. A simple method for evaluating alternatives to a proposed environmental alteration, its history, and an example of its use in oil shale development. In Gary, J. H. (ed.). Proceedings of the environmental oil symposium, Colorado School of Mines. 9-10 October 1975. *Quar. Colorado School Mines.* 90(4):29-74.
- Glass, N. R. (ed.). 1978. Environmental effect of increased coal utilization: Ecological effects of gaseous emissions. EPA-600/7-78-108. USEPA, Government Printing Office, Washington, D.C. 51 pp.
- Glass, N. R. 1978. Ecological effects of atmospheric deposition. EPA, ORD Decision Series, Energy/Environment EPA-600/9-78-022, October. p. 113-119.
- Glum, J. R. 1975. Oil shale and wildlife: What's it all about? In Gary, J. H. (ed.). Proceedings of the environmental oil shale symposium, Colorado School of Mines. 9-10 October 1975. *Quar. Colorado School Mines.* 70(4):147-152.
- Goehl, J. P., and J. W. Edde. 1978. Environmental effects of oil shale mining and processing, Part I: Fishes of Piceance Creek, Colorado prior to oil shale processing. Fisheries Research Center, Colo. Div. of Wildlife, Fort Collins. 22 pp.
- Gold, H., D. J. Goldstein, R. F. Probst, J. S. Shen, and D. Yung. 1977. Water Requirements for steam-electric power generation and synthetic fuel plants in western United States. Final Report. Water Purification Assoc., Cambridge, MA. 280 pp.
- Golley, F. B. 1961. Energy values of ecological materials. *Ecology* 42:581-583.
- Gordon, K. 1943. The natural history and behavior of the western chipmunk and the mantled ground squirrel. The College Press. Oregon State College, Corvallis, Oregon.

- Grant, W. E., and N. R. French. 1979. A simulation model representing the role of small mammals in grassland ecosystems. *Inter. Soc. for Ecol. Modelling J.* 1:91-117.
- Gray, S. L. 1974. Primary data on economic activity and water use in prototype oil shale development areas of Colorado: An initial inquiry. Dept. of Economics, Colorado State Univ., Fort Collins. 8 pp.
- Griest, W. H., and S. E. Herbes. 1978. Characterization of environmental distribution of polycyclic aromatic hydrocarbons in sediment and water in the vicinity of a coal coking plant. Presented at the Div. of Env. Chem., Amer. Chem. Soc., Anaheim, CA
- Guderian, R. 1977. Air pollution: Phytotoxicity of acidic gases and its significance in air pollution control. Springer-Verlag, Berlin. 127 pp.
- Hamilton, W. J., Jr. 1939. American mammals, their lives, habits and economic relations. McGraw-Hill Book Co., Inc., New York.
- Hansen, E. 1942. Quantitative study of ethylene production in relation to respiration of pears. *Bot. Gaz.* 103:543-558.
- Hansen, R. M., and B. L. Dearden. 1975. Winter foods of mule deer in Piceance Basin, Colorado. *J. Range Manage.* 28:298-300.
- Harbert, H. P. III, and W. A. Berg. 1978. Vegetative stabilization of spent oil shales: Vegetation, moisture, salinity, and runoff--1973-1976. Dept. of Agronomy, Colorado State Univ., Fort Collins. 169 pp.
- Harris, G. A. 1967. Some competitive relationships between Agropyron spicatum and Bromus tectorum. *Ecol. Mono.* 37:89-111.
- Harr, R. D., W. C. Harper, J. T. Krygier and F. S. Hsieh. 1975. Changes in storm hydrographs after road building and clear-cutting in the Oregon Coast Range. *Water Resources Research* 11:436-444.
- Haug, P. T. 1978. A systems approach to environmental assessment. *New Mexico Academy of Sci. Bull.* 18(1):9.
- Haug, P. T., and G. M. Van Dyne. 1977. A conceptual model for an integrated environmental analysis on Oil Shale Tract C-b. (Proceedings 20-21 March Oil Shale Development Symposium, Denver, CO).
- Heagle, A. S. 1973. Interactions between air pollutants and plant parasites. *Ann. Rev. Phytopathology* 11:365-388.
- Heck, W. W., and E. G. Pires. 1962a. Growth of plants fumigated with saturated and unsaturated hydrocarbon gases and their derivatives. *Texas Agric. Exp. Sta. Misc. Publ. No. MP-603.* 12 pp.
- Heck, W. W., and E. G. Pires. 1962b. Effect of ethylene on horticultural and agronomic plants. *Texas Agric. Exp. Sta. Misc. Publ. No. MP-613,* p. 3-12.

- Heck, W. 1973. Air pollution and the future of agricultural production, p. 118-130. In Naegele, J. Air pollution damage to vegetation. Advances of Chemistry Series 122. Amer. Chem. Soc.
- Heck, W., and C. Brandt. 1977. Effects on vegetation. In Stern, A. (ed.). Air pollution: The effects of air pollution, Vol. 2. Academic Press, New York.
- Heck, W., E. Pires, and W. Hall. 1961. The effects of a low ethylene concentration on the growth of cotton. J. Air Poll. Control Assoc. 11:549-556.
- Heil, R. D. 1976. Characterization studies of major soils found in proposed oil shale and coal development areas of northwest Colorado. EMRIA Report No. 23, Final Report 1 September 1976. Bureau of Land Manage. Contract No. 52500-CT5-1102, Colorado State Univ., Fort Collins. 220 pp.
- Heitschmidt, R. K., W. K. Lauenroth, and J. L. Dodd. 1978. Effects of controlled levels of sulphur dioxide on western wheatgrass in a southeastern Montana grassland. J. of Applied Ecol. 14:859-868.
- Herbes, S. E. 1977. Partitioning of polycyclic aromatic hydrocarbons between dissolves and particular phases in natural waters. Water Research 11:493-496.
- Herbes, S. E., and Beauchamp. 1978. Interaction of mixtures of two coal conversion effluent components (resorcinol and 6-methylquinoline) to Daphnia magna. Bulletin of Env. Contamination and Toxicology 17(1):25-32.
- Herbes, S. E., and G. R. Southworth. 1978. Abiotic and biotic process rate studies. Synthetic Fuels Program, Env. Sci. Div., Oak Ridge Nat. Lab., TN. Internal Document.
- Herbes, S. E., and Risi. 1978. Metabolic alteration and excretion of anthracene by Daphnia pulex. Bulletin of Env. Contamination and Toxicology 19(2):147-155.
- Herbes, S. E., and Schwall. 1978. Microbial transformation of polycyclic aromatic hydrocarbons in pristine and petroleum-contaminated sediments. Applied and Env. Microbiology 35(2):306-316.
- Herbes, S. E., G. R. Southworth, and C. W. Gehrs. 1976. Organic contaminants in aqueous coal conversion effluents: Environmental consequences and research priorities, p. 295-303. In Hemphill, D. D. (ed.). Trace substances in environmental health-x: A Symposium, Univ. of Missouri, Columbia.
- Herbes, S. E., Schwall, and Williams. 1978. Rate of microbial transformation of polycyclic aromatic hydrocarbons: A chromatographic quantification procedure. Applied and Env. Microbiology 34(2):244-246.
- Herbes, S. E., W. H. Griest, and G. R. Southworth. 1978. Field site evaluation of aquatic transport of polycyclic aromatic hydrocarbons. Oak Ridge Nat. Lab., TN.

- Herout, V., M. Luckner, and K. Mothes (eds.). 1976. Occurrence of chemically similar but functionally dissimilar metabolites in the plant and animal kingdom. *Nova Acta Leopoldina Supplementum*, No. 7, p. 441-444.
- Herreid, C. F., and B. Kessel. 1967. Thermal conductance in birds and mammals. *Comp. Biochem. Physiol.* 21:405-414.
- Hildebrand and Cushman. 1979. Toxicity of Gallium and Beryllium to developing carp eggs (Cyprinus carpio) utilizing copper as a reference. *Toxicology Letters*. Oak Ridge Nat. Lab., TN.
- Hildebrand, Cushman, and Carter. 1976. The potential toxicity and bio-accumulation in aquatic systems of trace element present in aqueous coal conversion effluents, p. 305-313. In Hemphill, D. D. (ed.). *Trace Substances in Env. Health: A Symposium*. Univ. of Missouri.
- Hillel, D. 1971. *Soil and water, physical principles and process*. Academic Press, NY. 288 pp.
- Hillel, D. 1977. Computer simulation of soil-water dynamics. *International Developmental Research Centre*, Hawaii. 214 pp.
- Hillhouse, R. A. 1968. The Federal Reserved Water Doctrine--application to the problem of water for shale oil development. *Land and Water Law Rev.* 3(1):75-102.
- Hill, A. C., and J. H. Bennett. 1970. Inhibition of apparent photosynthesis by nitrogen oxides. *Atmos. Environ.* 4:341-348.
- Hill, A. C., S. Hill, C. Lamb, and T. W. Barrett. 1974. Sensitivity of native desert vegetation to SO₂ and to SO₂ and NO₂ combined. *J. Air Poll. Control Assoc.* 24:153-157.
- Hill, G. R., and M. D. Thomas. 1933. Influence of leaf destruction by sulphur dioxide and by clipping on yield of alfalfa. *Plant Phys.* 8:223-245.
- Hinds, W. T., and J. T. Rotenberry. 1978. The relationship between mean and extreme temperatures in diverse microclimates. *Nature*, submitted.
- Hocking, D., and M. B. Hocking. 1977. Equilibrium solubility of trace atmospheric sulphur dioxide in water and its bearing on air pollution injury to plants. *Environ. Poll.* 13:57-64.
- Holland, L. M., D. M. Smith, and R. G. Thomas. 1977. Biological effects of raw and processed oil shale particles in the lungs of laboratory animals. Paper presented at US-USSR workshop on health effects of oil shale development.
- Holland, W. E. 1975. Mixing oil and water: The effect of prevailing water law doctrines on oil shale development. *Denver Law J.* 52(3):657-694.
- Holum, J. R. 1972. *Elements of general and biological chemistry*. John Wiley & Sons, Inc., New York. 578 pp.

- Hook, C. O. 1977. Oil shale research overview. Cameron Engineers, Inc., Denver, CO. EPA Contract. 79 pp.
- Hornbeck, J. W. 1972. Storm flow from hardwood-forested and cleared watersheds in New Hampshire. *Water Resources Research* 9:346-354.
- Howe, C. W., J. R. Kreider, and B. Udis. 1972. An economic analysis of the pollution problems in the Colorado River Basin: The upper main stem sub-basin. Univ. of Colorado, Boulder. 238 pp.
- Ho, C. H., B. R. Clark, and M. R. Guerin. 1976. Direct analysis of organic compounds in aqueous by-products from fossil fuel conversion processes: oil shale retorting, synthane coal gasification and char energy developemnt, coal liquefaction. *J. Env. Sci. Health, Part A: Environ. Sci. Eng.* 11(7):481-489.
- Hubbard, R. E., and R. M. Hansen. 1976. Diets of wild horses, cattle, and mule deer in the Piceance Basin, Colorado. *J. Range Manage.* 29:389-392.
- Huchabee, J. W., and D. M. Lucas. 1978. Terrestrial food chain research. Synthetic fuels program, Env. Sci. Div., Oak Ridge Nat. Lab., TN. (Internal Document)
- Hulbert, L. C. 1955. Ecological studies of Bromus tectorum and other annual brome grasses. *Ecol. Mono.* 25:181-214.
- Humphreys, W. F. 1979. Production and respiration in animal populations. *J. of Animal Ecol.* 48:427-453.
- Hutchinson, T. C., and L. M. Whitby. 1977. The effects of acid rainfall and heavy metal particulates on a boreal forest ecosystem near the Sudbury smelting region of Canada. *Water, Air, Soil Pollution* 7(4):421-438.
- Hutchins, J. S., W. W. Krech, and M. W. Legatski. 1971. Environmental aspects of a commercial oil shale company. In AIME report to Env. Qual. Conf., Washington, D.C.
- Innis, G. S. (ed.) 1978. Grassland simulation model. Ecological studies. Vol. 26. Springer-Verlag, NY. 298 pp.
- Innis, G. S., S. Schlesinger, and R. J. Sylvester. 1977. Model certification - varying views from different specialties, pp. 695-699. In Summer Computer Simulation Conference Proceedings.
- Ivory, T. M., W. R. Cody, B. B. Owen, and P. V. Morgan. 1975. Some autecological relationships of algae in the Piceane Creek Basin. In Gary, J. H. (ed.). Proceedings of the environmental oil shale symposium, Colorado School of Mines. 9-10 October 1975. Quar. Colorado School of Mines. 70(4):143-146.

- Jackson, L. P., R. E. Powlson, T. J. Spedding, T. E. Phillips, and H. B. Jensen. 1975. Characteristics and possible roles of various waters significant to in situ oil shale processing. *In* Gary, J. H. (ed.). Proceedings of the environmental oil shale symposium, Colorado School of Mines. 9-10 October 1975. Quar. Colorado School of Mines. 70(4):105-134.
- Jackson, R. D. 1972. On the calculation of hydraulic conductivity. *Soil Sci. Soc. Amer. Proc.* 36:380-382.
- Jacobsen, J. S., and A. C. Hill. 1970. Recognition of air pollution injury to vegetation: A pictorial atlas, Air Poll. Control Assoc., Pittsburgh, PA.
- Jacobson, J. S., and L. Colavito. 1974. The effect of sulphur dioxide on the phytotoxicity of ozone. *Plant Physiology Supplement.* 31 pp.
- Jaeger, H. J. 1977. Effect of phytotoxic air pollution of enzymatic activities and reactions [in German]. *Angew Bot.* 51(1-2):1-8.
- Jenkins, D., S. A. Klein, and R. C. Cooper. 1977. Fish toxicity of jet fuels, Part 1: The toxicity of the synthetic fuel JP-9 and its components. *Water Res.* 11(12):1059-1068.
- Jensen, K. R., and T. T. Kozlowski. 1975. Absorption and translocation of sulfur dioxide by seedlings of four forest tree species. *J. Environ. Qual.* 4:379-382.
- Jones, D., and C. Musgrove. 1975. Some considerations in monitoring low concentration air quality parameters. *In* Gary, J. H. (ed.). Proceedings of the environmental oil shale symposium, Colorado School of Mines. 9-10 October 1975. Quar. Colorado School Mines. 70(4):199-206.
- Kabe, W. 1976. Effects of sulfur dioxide on terrestrial vegetation. *Ambio.* 5:213-218.
- Karnowsky, D. F. 1977. Evidence for genetic control of response to sulfur dioxide and ozone in Populus tremuloides. *Can. J. For. Res.* 7:437-440.
- Katz, M. 1949. Sulfur dioxide in the atmosphere and its relation to plant life. *Ind. Eng. Chem.* 41:2450-2465.
- Katz, M., and A. W. McCallum. 1952. The effect of sulfur dioxide on conifers, Chapt. 8. *Proc. U.S. Tech. Conf. Air Poll.* p. 84-96.
- Katz, M., and G. A. Ledingham. 1939. Experiments on yield of barley and alfalfa. *In* Effect of sulphur dioxide on vegetation. Nat. Res. Council of Canada, Ottawa.
- Katz, M., G. A. Ledingham, and A. E. Harris. 1939. Carbon dioxide assimilation and respiration of alfalfa under influence of sulphur dioxide. *In* Effect of sulphur dioxide on vegetation. Nat. Res. Council of Canada, Ottawa.

- Kaushik, N. K. 1975. Decomposition of allochthonous organic matter and secondary production in stream ecosystems, p. 90-95. In Reichle, D. E., J. F. Franklin and D. W. Goodall (eds.). Productivity of world ecosystems. Fifth General Assembly Special Comm. IBP, Seattle, Washington. Nat. Acad. Sci., Washington, D.C.
- Kendeigh, S. C. 1969. Tolerance of cold and Bergmann's Rule. *The Auk* 86:13-25.
- Kendeigh, S. C. 1970. Energy requirements for existence in relation to size of bird. *The Condor* 72:60-65.
- Kersten, M. S. 1949. Thermal properties of soils. Engineering Exp. Sta. Bulletin, Institute of Technology, Univ. of Minn. 28 pp.
- Kilburn, J. S. 1978. Water purification with fragmented oil shale. Official Gazette of the United States Patent Office 975(4):1406.
- Kilburn, P. D. 1976. Environmental implications of oil shale development. *Env. Conserv.* 3(2):101-116.
- Kilburn, P. D., M. T. Atwood, and W. M. Broman. 1974. Oil shale development in Colorado: Processing technology and environmental impact in energy resources of the Piceance Creek Basin, Colorado, p. 151-164. In Murray, D. K. (ed.). Proceedings of the Field Conference of the Rocky Mountain Association of Geologists, Denver, Colorado.
- King, V. 1977. Morphological investigations of fibrogenic action of the estonian oil shale dust. Paper presented at US-USSR workshop on health effects of oil shale development.
- Kinsinger, F. E., and R. E. Eckert, Jr. 1961. Emergence and growth of annual and perennial grasses and forbs in soils altered by Halogeton leachate. *J. Range Manage.* 14:194-197.
- Kipling, M. D. 1976. Soots, tars, and oils as causes of occupational cancer. In Searles, C. E. (ed.). Amer. Chem. Soc. Monograph 73:315-323.
- Kirkby, W. A. 1949. Synthetic liquid fuels in the United States. *Fuel* 28:41-43.
- Kirkpatrick, L. W. 1974. Air pollution aspects of proposed oil shale development in northwestern Colorado. In Gary, J. H. (ed.). Proceedings of the seventh oil shale symposium, Colorado School of Mines. 18-19 April 1974. *Quar. Colorado School of Mines* 69(2)103-108.
- Kleiber, Max. 1961. *Fire of life*. John Wiley and Sons, Inc., NY. 454 pp.
- Klein, W. M., and J. G. Severson Jr. 1975. Sulfur in the environment. Missouri Botanical Garden in cooperation with Union Electric Company. St. Louis, MO. 189 pp.
- Klickoff, L. G. 1966. Competitive response to moisture stress of a winter annual of the Sonoran Desert. *Amer. Midland Naturlist* 75:383-391.

- Kohler, M. A., T. J. Nordenson, and W. E. Fox. 1955. Evaporation from ponds and lakes. Research Paper No. 38. Weather Bureau, U.S. Dept. of Commerce. Washington, D.C. 21 pp.
- Koppelaar, D., and S. E. Manahan. 1977. Formation of organo metallics and carcinogens in coal conversion processes and shale oil extraction, p. 279-286. In Proceedings Annual Conf. Trace Subst. Env. Health, Univ. Missouri.
- Kramer, Paul J. 1969. Plant and soil water relationships: A modern synthesis. McGraw-Hill Book Company, New York.
- Krebs, C. J. 1978. Ecology: The experimental analysis of distribution and abundance. 2nd ed. Harper & Row, New York. 678 pp.
- Kress, L. W., and J. M. Skelly. Prevention of significant deterioration of native ecosystems--allowable pollutant concentrations. Corvallis Environ. Res. Lab., Corvallis, OR. 81 pp. (in press)
- Krupa, S. U. 1976. Impact of air pollutants on terrestrial vegetation, p. 43-96. In Wood, F. A. (ed.). The role of disease in environmental and ecological management of national parks, Vol. 1. Ann. Rep. to Nat. Park Serv., US Dept. of Int. 221 pp.
- Kufeld, R. C. 1973. Foods eaten by the Rocky Mountain elk. J. Range Manage. 26:106-113.
- Kufeld, R. C., O. C. Wallmo, and C. Feddema. 1973. Foods of the Rocky Mountain mule deer. U.S. Dept. of Agric., Forest Serv. Research Paper RM-111. 31 pp.
- Lagerwerff, J. V. 1967. Heavy-metal contamination of soils, p. 343-366. In Brady, N. C. (ed.). Agriculture and the quality of our environment, 85 ed. Amer. Assoc. for the Advancement of Science, Washington, D.C.
- Lal, A., and B. S. Yadav. 1976. Effect of soil salinity on the occurrence of phyto parasitic nematodes. Indian J. of Mycology and Plant Pathology 6(1):82-83.
- Larcher, W. 1975. Physiological plant ecology. Springer-Verlag, New York. 252 pp.
- Larsen, R. I., and W. W. Heck. 1976. An air quality data analysis system for integrating effects, standards, and needed source reduction: Part 3. Vegetation Injury. J. Air Poll. Control Assoc. 26:325-333.
- Lasiewski, R. C., and W. R. Dawson. 1967. A re-examination of the relation between standard metabolic rate and body weight in birds. The Condor 69:13-23.
- Lavigne, R. J., and H. G. Fisser. 1961. Controlling western harvester ants. Mountain States Regional Publication No. 3.

- Lear, B. 1975. Phytotoxicity associated with bromide uptake in plants grown in soil fumigated with brominated hydrocarbons. *Nematropica* 5(2):24.
- Lechleitner, R. R. 1969. Wild mammals of Colorado: Their appearance, habits, distribution, and abundance. Pruitt Pub. Co., Boulder, Co. 254 pp.
- Lee, C. 1973. Models in planning. Pergamon Press, New York. 209 pp.
- Lewis, R. A., and A. S. Lefohn. 1976. Bioenvironmental impact of a coal-fired power plant. First Interim Report, Colstrip, Montana, December 1974. NTIS, Washington, D.C. 117 pp.
- Lewis, Robert A. and Carolyn W. Lewis. 1978. Terrestrial vertebrate animals as biological monitors of pollution. Contribution to the International Workshop on monitoring environmental materials and specimen banking. Berlin, German Federal Republic. 36 pp.
- Lewis, R. A. 1978. Environmental research plans and priorities of the Department of Energy: An address to the 7th Annual Conference of the NACC. U.S. Dept. of Energy, Off. of the Ass. Secretary for Env., Washington, D.C. In press. 20 pp.
- Lewis, W. M., Jr. and M. C. Grant. 1980a. Changes in the output of ions from a watershed as a result of the acidification of precipitation. *Ecol.* 60:1093-1097.
- Lewis, W. M., Jr. and M. C. Grant. 1980b. Acid precipitation in the Western United States. *Sci.* 207:176-177.
- Libera, W., H. Ziegler, and I. Ziegler. 1973. Stimulation of hill-reaction and CO₂ fixation in isolated spinach chloroplasts by low concentrations of SO₃. *Planta (Berl.)* 109:269-279.
- Linsley, R. K., M. A. Kohler, and J. L. H. Paulhus. 1949. Applied hydrology. McGraw-Hill Book Co., Inc., New York. 689 pp.
- Linzon, S. N. 1971. Economic effects of sulfur dioxide on forest growth. *J. Air Poll. Control Assoc.* 21:81-86.
- Linzon, S. N. 1978. Effects of airborne sulfur pollutants on plants, p. 109-162. In Nriagu, J. O. (ed.). Sulfur in the environment: Part II Ecological Impacts. John Wiley and Sons. 816 pp.
- Lipman, S. C. 1975. Union Oil Company revegetation studies. In Gary, J. H. (ed.). Proceedings of the environmental oil shale symposium, Colorado School of Mines. 9-10 October 1975. Quar. Colorado School of Mines. 70(4):165-180.
- Little, E. L. 1943. Common insects on pinyon (*Pinus edulis*). *J. New York Entomological Soc.* 51:239-252.
- Longhurst, W. M., H. K. Oh, M. B. Jones, and R. E. Kepner. 1968. A basis for the palatability of deer forage plants, p. 181-189. In Transactions of the 33rd North American Wildlife and Natural Resources Conference.
- Loucks, R. A. 1977. Occidental vertical modified in situ process for the recovery of oil from oil shale: Phase I, Summery Report, Nov. 1976 to Oct. 1977. Vol. II. Occidental Oil Shale, Inc., Grand Junction, CO. 42 pp.

- Loveless, C. M. 1967. Ecological characteristics of a mule deer winter range. Colorado Div. of Game, Fish, and Parks Tech. Pub. 20. 124 pp.
- Lunt, O. R. 1966. Sodium, pp. 409-432. In H. D. Chapman (ed.). Diagnostic criteria for plants and soils. Univ. of Calif., Div. of Agric. Sci., Riverside, CA.
- Lyon, J. L. 1979. Influences of logging and weather on elk distribution in western Montana. USDA Forest Service Research Paper INT-236.
- MacLean, D. C. 1975. Stickstoffoxide als phytotoxische Luftverunreinigungen. Staub-Reinhalt. Luft 35:205-210.
- MacLean, D. C., D. C. McCune, L. H. Weinstein, R. H. Mandl, and G. N. Woodruff. 1968. Effects of acute hydrogen fluoride and nitrogen dioxide exposures on citrus and ornamental plants of central Florida. Environ. Sci. Tech. 2:444-449.
- Majernik, O., and T. Mansfield. 1970. Direct effect of SO₂ pollution on the degree of opening of stomata. Nature 227:377-378.
- Malhotra, S. S. 1977. Effects of aqueous sulphur dioxide on chlorophyll destruction in Pinus contorta. New Phytol. 78:101-109.
- Malhotra, S. S., and D. Hocking. 1976. Biochemical and cytological effects of sulphur dioxide on plant metabolism. New Phytol. 76:227-237.
- Mandl, R. H., M. C. O'Neill, and L. H. Weinstein. 1974. The effect of ozone on the phytotoxicity of sulphur dioxide for alfalfa. Plant Physiology Supplement.
- Mansfield, T. A., and O. Majernik. 1970. Can stomata play a part in protecting plants against air pollution? Environ. Poll. 1:149-154.
- Marshall, J. K. (ed.). 1977. The belowground ecosystem: A synthesis of plant associated processes. Range Sci. Dept., Sci. Ser. No. 26. Colorado State Univ., Fort Collins. 351 pp.
- Masterson, W. L., and E. J. Slowinski. 1969. Chemical principles. W. B. Saunders Co., Philadelphia. 705 pp.
- McCree, K. F., J. H. Troughton. 1966. Non-existence of an optimum leaf area index for the production rate of white clover grown under constant conditions. In Plant Phys. 41:1615-1622.
- McDonald, A. 1974. Shale oil: An environmental critique. Center for Science in the Public Interest, Washington, D.C. 62 pp.
- McKean, W. T., and R. M. Bartmann. 1971. Deer-livestock relations of a pinyon-juniper range in northwestern Colorado. Colorado Game, Fish, and Parks Dept. Final Rpt. W-101-R. 132 pp.
- McKean, W. T., and W. T. Burkhard. 1978. Fish and wildlife analysis for the Yellow Jacket Project, July 1975 to January 1978. Prepared for the U.S. Bureau of Reclamation by the Colorado Div. of Wildlife. 543 pp.

- McKee, J. M., and S. K. Kuvckal. 1976. Energy and water requirements for an oil shale plant based on parako processes. In Gary, J. H. (ed.). Proceedings of the ninth oil shale symposium, Colorado School of Mines. 29-30 April 1976. Quar. Colorado School of Mines 71(4):49-64.
- McKell, C. M. 1978. Establishment of native plants for the rehabilitation of Paraho processed oil shale in an arid environment, p. 13-32. In The Reclamation of Disturbed Arid Lands. Univ. of New Mexico Press, Albuquerque.
- McNab, B. K. 1970. Body weight and the energetics of temperature regulation. J. Exp. Biol. 53:329-348.
- McNab, B. K. 1979. The influence of body size on the energetics and distribution of fossorial and burrowing mammals. Ecol. 60:1010-1021.
- Medin, D. E., and A. E. Anderson. 1979. Modeling the dynamics of a Colorado mule deer population. In Krumholz, L. A. (ed.). Wildl. Mono. No. 68, July.
- Meeuwig, R. O., E. L. Miller, and J. D. Budy. 1979. Estimating Pinyon and Juniper fuel and biomass from aerial photographs. USDA Forest Service, Res. Note INT-274.
- Menzie, C. M. 1972. Fate of pesticides in the environment. Ann. Rev. of Entomology 17:199-222.
- Meyer, L., and R. Nelson. 1975. Adequacy of regional atmospheric data for specific predictive purposes in the Piceavce Creek Basin. In Gary, J. H. (ed.). Proceedings of the environmental oil shale symposium, Colorado School of Mines. 9-10 October 1975. Quar. Colorado School Mines 70(4):207-222.
- Meyer, W. C., and T. F. Yen. 1976. Enhanced dissolution of oil shale by bio-leaching with thiobacilli. Appl. Env. Microbiol. 32(4):610-616.
- Middleton, J. T., E. F. Darley, and R. F. Brewer. 1958. Damage to vegetation from polluted atmospheres. J. Air Poll. Control Assoc. 8:9-15.
- Milchunas, D. G., M. I. Dyer, O. C. Wallmo, and D. E. Johnson. 1978. In-vivo/in-vitro relationships of Colorado mule deer forages. Colorado Div. of Wildl. Spec. Rep. 43.
- Miller, J. E., and P. B. Xerikos. 1979. Residence time of sulphite in SO₂ 'sensitive and tolerant' soybean cultivars. Environ. Poll. 18:259-264.
- Mitre Corporation. 1978. The impact of oil shale technology on health and the environment: An inventory of U.S. and privately sponsored research projects. Metrek Division. 200 pp.
- Montana Air Quality Bureau. M. D. Roach (dir.). 1978. Environmental Impact Statement -- Montana ambient air quality. Standards Studies. Helena, Montana.

- Morris, D. 1965. The mammals, a guide to the living species. Harper and Row. New York. 182 pp.
- Moses, R. J. 1966. Where is the water coming from? In Third symposium on oil shale, Denver, Colorado. 14-15 April 1966. Quar. Colorado School of Mines 61(3)23-32.
- Mudd, J. B. 1973. Biochemical effects of some air pollutants on plants, p. 31-47. In Naegele, J. A. (ed.). Air pollution damage to vegetation. Adv. in Chem. Ser. 122, Amer. Chem. Soc., Washington, D.C.
- Mudd, J. B. 1975. Sulfur dioxide, p. 9-22. In Mudd, J. B. and T. T. Kozlowski (eds.). Physiological Ecol. Mono. Series, Academic Press, Inc., New York. 383 pp.
- Mudd, J., and T. Kozlowski. 1975. Responses of plants to air pollution. Academic Press, New York. 383 pp.
- Muller, R. N., J. E. Miller, D. G. Sprugel, and H. J. Smith. 1977. Photosynthetic response of field-grown soybeans to fumigations with sulfur dioxide. In Radiological and Environ. Res. Division Ann. Rep., Argonne Nat. Lab. (ANL-77-65 Part III).
- Murray, J. J., R. K. Howell, A. C. Wilton. 1975. Differential response of 17 Poa pretensis cultivators to ozone and sulfur dioxide. Plant Disease Reporter 59:10.
- Myers, G. T. 1970. An investigation of deer-auto accidents, p. 403-437. In Game Res. Rep., Colo. Dept. Game, Fish and Parks, Denver. 7:287-455.
- Myers, G. T., and D. F. Reed. 1969. Deer-vehicle collisions in Colorado, p. 10. In Fourteenth Trans. Summer Conf. Central Mtns. and Plains Sec. of the Wildlife Soc. 18 pp.
- Naegele, J. A. 1974. Effect of pollution on plants, p. 82-100. In Sox, N. I. (ed.). Industrial Pollution, Van Nostrand Reinhold Co., New York.
- Nagy, J. G., D. L. Baker, J. A. Bailey, D. S. de Calesta, D. E. Reeder, and G. G. Schoonveld. 1974. Middle Park cooperative deer study. Physiology and prevention of deer starvation. Colorado Div. Wildl. Fed. Aid Project W-38-R-28. Final Rep. 554 pp.
- National Academy of Sciences. 1978. Sulfur oxides. Nat. Res. Council, Washington, D.C.
- National Air Pollution Control Administration (NAPCA). 1970a. Air quality criteria for sulfur oxides. AP-50. U.S. Dept. of Health, Education and Welfare. Washington, D.C.: Nat. Air Poll. Control Admin.
- National Air Pollution Control Administration (NAPCA). 1970b. Air quality criteria for carbon monoxide. AP-62. U.S. Dept. of Health, Education and Welfare. Washington, D.C.: Nat. Air Poll. Control Admin.

- National Air Pollution Control Administration (NAPCA). 1970c. Air quality criteria for hydrocarbons. AP-64. U.S. Dept. of Health, Education and Welfare. Washington, D.C.: Nat. Air Poll. Control Admin.
- National Air Pollution Control Administration (NAPCA). 1971. Air quality criteria for nitrogen oxides. AP-84. Washington, D.C.: Nat. Air Poll. Control Admin.
- National Air Pollution Control Administration (NAPCA). 1979. Air quality criteria for particulate matter and sulfur oxides. Vol. III. Welfare Effects. Environmental Protection Agency, Washington, D.C. (Draft).
- National Oceania and Atmospheric Administration. 1976. Environmental data and information service, Grand Junction Station. Compiles from National Climatic Center, Asheville, N.C. Vol. 81, Nos. 1-12.
- Naveh, Z., and S. Chaim. 1976. Phytotoxic effects of ozone sulphur dioxide and fluorides on sensitive cultivated plants. Israel J. of Botany 25(1/2):94.
- Nelson, Roger. 1975. Meteorological dispersion potential in the Piceavce Creed Basin. In Gary, J. H. (ed.). Proceedings of the environmental oil shale symposium, Colorado School of Mines. 9-10 October 1975. Quar. Colorado School Mines 70(4):223-227.
- Nielsen, D. G., L. E. Terrell, and T. C. Weidensaul. 1977. Phytotoxicity of ozone and sulphur dioxide to laboratory fumigated Scotch Pine. Plant Dis. Rep. 61(8):699-703.
- Nishimura, J. Y. 1974. Soils and soil problems at high altitudes, p. 5-9. In W. A. Berg, J. A. Brown, and R. L. Cuany (eds.). Revegetation of high altitude disturbed lands. Colo. State Univ., Environmental Resources Center, Information Series No. 10.
- O'Connor, J. A., D. G. Parberry, and W. Strauss. 1974. The effects of phytotoxic gases on native Australian plant species: Part 1, Acute effects of sulphur dioxide. Env. Pollution 7(1):7-23.
- O'Gara, P. J. 1922. Sulfur dioxide and fume problems and their solutions. In Fourteenth semi-annual meeting of the American Institute of Chemical Engineers. J. Ind. Eng. Chem. 14:744.
- Palekar, L. D., and D. L. Doffin. 1977. An experimental approach to the determination of pulmonary carcinogenic influences of shale oil effluents. Paper presented at US-USSR workshop on health effects of oil shale development.
- Parkhurst, B. R. 1978. Sublethal effects of contaminants on fish. Synthetic Fuels Program, Env. Sci. Div., Oak Ridge Nat. Lab., TN. Internal Document
- Parkhurst, B. R., A. S. Bradshaw, J. L. Forte, and G. P. Wright. 1978. Acute toxicity bioassays. Synthetic Fuels Program, Env. Sci. Div., Oak Ridge Nat. Lab., TN. Internal Document
- Parkhurst, B. R., A. S. Bradshaw, J. L. Forte, and G. P. Wright. 1978. Zooplankton. Synthetic Fuels Program, Env. Sci. Div., Oak Ridge Nat. Lab., TN. Internal Document

- Parton, W. J., J. S. Singh, and D. C. Coleman. 1978. A model of production and turnover of roots in shortgrass prairie. *J. of Applied Ecol.* 47:515-542.
- Paschin, Y. V., and L. M. Bakhitova. 1977. Mutagenic and carcinogenic properties of polycyclic aromatic hydrocarbons. Paper presented at US-USSR workshop on health effects of oil shale development.
- Patel, P. M., A. Wallace, and E. M. Romney. 1977. Effect of chelating agents on phytotoxicity of lead and lead transport. *Commun. Soil Sci., Plant Anal.* 8(9):733-740.
- Payne, G. F. 1974. Cover-weight relationships. *J. of Range Manage.* 27(5):403-404.
- Pearson, G. A. 1960. Tolerance of crops to exchangeable sodium. *Agric. Info. Bull.* 216. 4 pp.
- Pearson, G. A., and L. Bernstein. 1958. Influence of exchangeable sodium on yield and chemical composition of plants: II. Wheat, barley, oats, rice, tall fescue, and tall wheatgrass. *Soil Sci.* 8:254-261.
- Pellizzari, E. D. 1978. Identification of components of energy related wastes and effluents. Research Triangle Inst., Research Triangle Park, NC. 500 pp.
- Penman, H. L. 1948. Natural evaporation from open water, bare soil, and grass. *Proceedings of the Royal Society of London, Series A: Mathematical and Physical Sciences.* Vol. 193. Cambridge Univ. Press, London.
- Penning de Vries, F. W. T. 1972. Respiration and growth. *In* Rees, A. R., K. E. Cockshull, D. W. Hand, and R. G. Hurd (eds.). *Crop processes in controlled environments.* Academic Press, New York.
- Pfeiffer, F. M. 1974. Pollutional problems and research needs for an oil shale industry. EPA Tech. Series. Report EPA-660/2-74-067. 36 pp.
- Philip, R. P., and E. Yang. 1977. Alkaline potassium permanganate degradation of insoluble organic residues (kerogen) isolated from recently-deposited algal mats. *Energy Sources* 3(2):149-161.
- Platt, J. R. 1964. Strong inference. *Science* 146:347-353.
- Pojar, T. M. 1971. Deer-auto accident investigations, p. 275-318. *In* Game Res. Rep., Colo. Dept. Game, Fish and Parks, Denver 7:225-366.
- Popper, K. R. 1965. *Conjectures and refutations.* Harper and Row, N.Y. 417 pp.
- Pressey, R. E., and P. A. Westcott (eds.). 1979. EPA program status report: Oil shale, 1979 update. Contract R-806156. Denver Research Institute. Denver, CO. 39 pp. and appendix.

- Prien, C. H. 1977. An engineering analysis report on the Paraho Oil Shale Process: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-02-1881. DRI: Denver, CO.
- Prien, C. H., and T. D. Nevens. 1977. An engineering analysis report on the TOSCO II Oil Shale Process: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-02-1881. DRI, Denver, CO.
- Quale, T. R. 1973. The Colorado oil shale and its affects on the mule deer of the Piceance Creek Basin. Colo. State Univ. Special Studies Report. 14 pp.
- Quicks, H. E. 1951. Notes on the ecology of weasels in Gunnison, Colorado. Colorado J. Mammalogy 31:281-290.
- Rao, T. K., J. A. Young, A. A. Hardigree, W. Winton, and J. L. Epler. 1978. Analytical and biological analyses of test materials from the synthetic fuel technologies, Part 2: Extended genetic and biochemical studies with mutagenic fractions. Mutation Res. 54(2):185-192.
- Rasmussen, D. E. 1941. Biotic communities of the Kaibab Plateau. Ecological Monographs 11:229-275.
- Rasmussen, K. H., M. Taheri, and R. I. Kabel. 1975. Global emissions and natural processes for removal of gaseous pollutants. Water Air Soil Poll. 4:33-64.
- Ratsch, H. C. 1971. Heavy-metal accumulation in soil and vegetation from smelter emissions. EPA 660/3-74-012. Nat. Environ. Res. Center, Washington, D.C.
- Redente, E. F., and C. W. Cook. 1978. Reclamation studies on mined waste material from coal, limestone, and dolomite mining. Progress report for period 1 June 1977 to 31 May 1978. Range Sci. Dept., Reclamation Res. Lab., Colorado State Univ., Fort Collins. 37 pp.
- Redente, E. F., and J. P. Abbott. 1979. Reclamation studies on mined waste material from coal, limestone, and dolomite mining. Progress report for period 1 June 1978 to 31 May 1979. Range Sci. Dept., Reclamation Res. Lab., Colorado State Univ., Fort Collins. 39 pp.
- Reece, P. E. 1975. Autecology of three perennial grasses relative to microenvironmental modification following permanent defoliation of Wyoming big sagebrush. M.S. thesis, Oregon State Univ., Corvallis, OR. 136 pp.
- Reed, D. F. 1973. Investigation of one-way deer structures, p. 171-175. In Game Res. Rep., Colo. Div. Wildl., Denver 7:45-275.
- Reed, D. F. 1975. An evaluation of 8-foot (2.44 m) fence length required to prevent movements on or across high speed highways, p. 315-320. In Game Res. Rep., Colo. Div. Wildl., Denver 7:191-504.

- Richens, V. B. 1966. Characteristics of mule deer and their range in northeastern Utah. *J. Wildlife Manage.* 31:651-655.
- Richey, J. E. 1974. Phosphorus dynamics in Castle Lake. Diss., Univ. Calif. 160 pp.
- Ricklefs, R. E. 1967. Patterns of growth in birds. *Ibis* 110:419-451.
- Riehl, H. 1972. Introduction to the atmosphere. McGraw-Hill, Inc., New York. 516 pp.
- Riis, H. 1972. Effect of environmental factors on algae count in the main soil types of the Estorian-SSR. *Eesti NSV Tead Akad Toim Biol.* 21(3):199-206.
- Rio Blanco Oil Shale Project (RBOSP). 1976a. Progress reports 7 and 9. Gulf Oil Corporation-Standard Oil Company (Indiana).
- Rio Blanco Oil Shale Project (RBOSP). 1976b. Aquatic annual report for Rio Blanco Oil Shale Project. Aquatic baseline studies. Gulf Oil Corporation-Standard Oil Company (Indiana).
- Rio Blanco Oil Shale Project (RBOSP). 1977. Final experimental baseline report for Tract C-a and vicinity. Books 1 and 2. Gulf Oil Corporation-Standard Oil Company (Indiana).
- Rittenhouse, L. R., and F. A. Sneva. 1974. A technique for estimating big sagebrush production. *J. of Range Manage.* 30(1):68-70.
- Robinette, W. L., and J. S. Gashwiler. 1955. Fertility of mule deer in Utah. *J. Wildl. Manage.* 19(1):115-136.
- Robinette, W. L., J. S. Gashwiler, J. B. Low, and D. A. Jones. 1957. Differential mortality of sex and age among mule deer. *J. Wildl. Manage.* 21(1):1-15.
- Rocky Mountain Oil and Gas Association. 1975. Summary of industrial oil shale: Environmental studies and selected bibliography of oil shale environmental references. Oil Shale Committee, Denver, Colorado. 31 pp.
- Rogers, L. E. 1978. Analysis of invertebrate populations inhabiting the shrub-steppe region of southcentral Washington (Hanford Reservation), p. 83-93. *In* Kitchings, J. T., and N. E. Tarr (eds.). National environmental research park symposium: Natural resource inventory, characterization, and analysis. DOE report ORNL-5304.
- Rogers, L. E., and J. D. Hedlund. 1978. A comparison of small mammal populations occupying three distinct shrub-steppe communities in eastern Oregon. *Northwest Sci.*, submitted.
- Rogers, L. E., and N. E. Woodley. 1978. Invertebrate density and biomass distribution patterns in an old-field community in south-central Washington. *Northwest Sci.* 52(2):100-103.

- Rogers, W. L. 1975. The oil shale environmental advisory panel, the environment, and the federal program - past, present, and future. In Gary, J. H. (ed.). Proceedings of the environmental oil shale symposium, Colorado School of Mines. 9-10 October 1975. Quar. Colorado School of Mines 70(4):1-18.
- Rold, J. W. 1974. Colorado's involvement in solving environmental problems of oil shale development. In Gary, J. H. (ed.). Proceedings of the seventh oil shale symposium, Colorado School of Mines. 18-19 April 1974. Quar. Colorado School of Mines 69(2):85-91.
- Romney, E. M., A. Wallace, R. Wood, A. M. El-Gazzar, J. D. Childress, and G. V. Alexander. 1977. Role of soil organic matter in a desert soil on plant response to silver, tungsten, cobalt, and lead. Commun. Soil Sci., Plant Anal. 8(9):719-726.
- Rothfeld, L. B. 1975. Water and energy requirements for an oil shale industry, p. 81-105. In Proceedings of Conf. on Water Requirements for Lower Colorado River Basin Energy Needs. Univ. of Arizona, Tucson.
- Routson, R. C., and D. A. Cataldo. 1978. A growth chamber study of the effect of soil concentration and plant age on the uptake of Sr and Cs by tumbleweeds. Commun. Soil Sci. and Plant Anal. 9(3):215-229.
- Routson, R. C., R. E. Wildung, and R. M. Bean. 1979. A review of the environmental impact of ground disposal of oil shale wastes. J. of Env. Qual. 8(1):14-19.
- Routson, R. C., and D. A. Cataldo. 1978. Accumulation of Tc by tumbleweeds and cheatgrass grown on arid soils. Health Phys. 34:685-690.
- Routson, R. C., R. E. Wildung, and R. M. Bean. 1978. A review of the environmental impact of ground disposal of oil shale wastes. J. Environ. Qual., in press.
- Rowe, J. W., and D. B. McWhorter. 1978. Salt loading in disturbed watershed: Field study. J. of the Env. Engineering Div., American Soc. of Civil Engineers 104(EE2):323-338.
- Rue, L., III. 1978. The deer of North America. Crown Publishers, Inc., New York. 122 pp.
- Russell, C. P. 1932. Seasonal migrations of mule deer. Ecological Monographs 2:1-44.
- Sauer, R. H. 1978. A simulation model for grassland primary producer phenology and biomass dynamics. Ecological Studies 26:55-58.
- Sauer, R. H. 1978. Effect of removal of standing dead material on growth of Agropyron spicatum. J. Range Manage. 31(2):121-122.
- Sauer, R. H. 1978. Precipitation, harvesting and restoration on strip mine spoils. In Proceedings of the International conference on energy and ecosystems, Grand Forks, ND, 12-16 June.

- Saunders, B. C. 1976. The state of Utah water-1975. Utah Div. of Water Resources, Salt Lake City. 72 pp.
- Schiff, J. A., and R. C. Hodson. 1973. The metabolism of sulfate. *Ann. Rev. Plant Phys.* 24:381-414.
- Schiffrin, J. F., T. A. Orav, T. Kudrev, I. Ivanova, and E. Karanov (eds.). 1975. Comparative study of the effect of growth stimulators obtained from Bulgarian and Estonian oil shale, p. 748-755. *In* Proceedings of the 2nd International Symposium, Sofia, Bulgaria, 21-24 October. *Illus.* Bulgarian Academy of Sci.
- Schmidt-Collerus, J. J. 1974. Disposal and environmental effects of carbonaceous solid wastes from commercial oil shale operations. Annual Report No. 1, Denver Research Institute, Colorado. 269 pp.
- Schramel, M. 1975. Influence of sulfur dioxide on stomatal apertures and diffusive resistance of leaves in various species of cultivated plants under optimum soil moisture and drought conditions. *Bull. Acad. Pol. Sci., Ser. Sci. Bio.* 23:57-63.
- Schultz, T. W., and J. N. Dumont. 1977. Cytotoxicity of synthetic fuel products on *tetrahymena-pyriformis*, Part 1: Phenol. *J. of Protozoology* 24(1):164-172.
- Schultz, T. W., J. N. Dumont, and L. M. Kyte. 1978. Cytotoxicity of synthetic fuel products on *tetrahymena-pyriformis*, Part 2: Shale oil retort water. *J. of Protozoology* 25(4):502-509.
- Schwall, and S. E. Herbes. 1978. Methodology determination of rates of microbial transformation of polycyclic aromatic hydrocarbons in sediments. Presented at ASTM sediment microbial activity and biomass symposium. Ft. Lauderdale, Florida.
- Segal, W., and R. Hamilton. 1976. Microbiological parameters of spent oil shale. *Abstr. Annu. Meet. Amer. Soc. Microbiol.* 76.
- Sellers, W. D. 1965. Physical climatology. Univ. of Chicago Press, Chicago. 272 pp.
- Severson, J. G., Jr. 1975. Sulfur and higher plants. *In* Sulfur in the environment. Missouri Botanical Garden, St. Louis.
- Sharma, M. L., and D. J. Tongway. 1973. Plant induced soil salinity patterns in two saltbush (*Atriplex*) communities. *J. Range Manage.* 26:121-125.
- Sheldon, J. K., and L. E. Rogers. 1978. Grasshopper food habitats within a shrub-steppe community. *Oecologia* 32:85-92.
- Shih, C. C., C. H. Prien, T. D. Nevans, and J. E. Cotter. 1976. Technological overview reports for eight shale oil recovery processes: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-02-1881. TRW/DR1. Denver, CO. Pre-publication copy. 111 pp.

- Shriner, D. S. 1976. Research needs related to air pollution from coal conversion processes. Presented at AIChE 82nd Annual Meeting. Atlantic City, NJ.
- Shriner, D. S. 1978. Atmospheric transport. Synthetic Fuels Program, Env. Sci. Div., Oak Ridge Nat. Lab., TN. Internal Document.
- Shriner, D. S., and S. B. McLaughlin. 1978. Gaseous effects research. Synthetic Fuels Program, Env. Sci. Div., Oak Ridge Nat. Lab., TN. Internal Document.
- Shriner, D. S., S. B. McLaughlin, and Baes. 1979. Character and transformation of pollutants from major fossil fuel energy sources. ORNL/TM-5979. Oak Ridge Nat. Lab., TN.
- Sibbald, A. R., T. J. Maxwell, and J. Eadie. 1979. A conceptual approach to the modelling of herbage intake by hill sheep. *Agri. Systems* 4:119-134.
- Sij, J. W., and C. A. Swanson. 1974. Short-term kinetic studies on the inhibition of photosynthesis by sulfur dioxide. *J. Environ. Qual.* 3:103-107.
- Siler, W. 1979. A competing-risk model for animal mortality. *Ecol.* 60:750-757.
- Silviera, D. J., T. R. Garland, and R. E. Wildung. 1978. Characterization of retorted oil shale leachate in laboratory studies. In *Agronomy abstracts*, ASA, SSA and CSSA Annual Meetings, Chicago, IL, 3-8 December.
- Sims, P. L., and E. F. Redente. 1977. Rehabilitation potential and practices of Colorado oil shale lands. Dept. of Range Sci., Colorado State Univ., Fort Collins. 4 pp.
- Skelly, J. M., and R. C. Lamb. 1974. The diagnosis of air pollution damage to plants. Va. Coop. Ext. Serv., Pub. No. 568. 16 pp.
- Slawson, G. C. Jr. 1979. Groundwater quality monitoring of western oil shale development: Identification and priority ranking of potential pollution sources. Contract #68-03-2449 for Env. Protection Agency, Off. of Research and Devel., Las Vegas, NV.
- Slawson, G. C. Jr., and T. F. Yen. (eds.). 1979. Compendium reports on oil shale technology. Contract #EPA 600/7-79-039 General Electric Company--TEMPO, Santa Barbara, CA. 203 pp.
- Smith, W. H. 1974. Air Pollution - effects on the structure and function of the temperate forest ecosystem. *Environ. Poll.* 6:111-129.
- Sommers, L. E., R. E. Wildung, and C. M. Gilmour. 1978. The effects of water potential on decomposition processes in soil. In *Abstracts of the ASA, CSSA, and SSA Annual Meetings*, Chicago, IL, 3-8 December.
- Southworth, G. R. 1979. The role of volatilization in removing polycyclic aromatic hydrocarbons from aquatic environment. *Bulletin of environmental contamination and toxicology*.

- Southworth, G. R. 1977. Transport and transformation of anthracene in natural waters: Process rates studies. Presented at ASTM 2nd Annual Symposium on Aquatic Toxicology. Cleveland, OH.
- Southworth, G. R., Beauchamp, and Schmieder. 1979. Bioaccumulation potential of polycyclic aromatic hydrocarbons in Daphnia pulex. Water Research. Oak Ridge Nat. Lab., TN.
- Southworth, G. R., J. J. Beauchamp, and P. K. Schmieder. 1978. Biological accumulation potential and acute toxicity of synthetic fuels effluents in fresh water biota Aza Arenes. Env. Sci. Tech. 12(9):1062-1066.
- Spakhova, A. S., and L. A. Ryazantseva. 1978. Damage to some trees by sulphur dioxide [in Russian]. Res. Institution for Genetic Selection. Fiziol Rast (Mosc.), Voronezh, USSR 25(2):407-409.
- Sparks, Felix L. 1974. Water prospects for the emerging oil shale industry. In Gary, J. H. (ed.). Proceedings of the seventh oil shale symposium, Colorado School of Mines. 18-19 April 1974. Quar. Colorado School of Mines 69(2):93-101
- Spencer, J. D., and B. Linville. 1974. U.S. Bureau of Mines Energy Program, 1973. Morgantown Energy Research Center, Morgantown, WV. 80 pp.
- Sprugel, D. G., J. E. Miller, P. B. Xerikos, and N. J. Smith. 1979. Effects of chronic sulfur dioxide fumigation on development yield and seed quality of field-brown soybeans: Summary of 1977 and 1978 experiments, p. 1-10. In Radiological and environmental research division annual report. Ecol. Jan.-Dec. 1978. Argonne Nat. Lab., Argonne, Illinois. Prepared for the USDOE Contract W-31-109-Eng-38.
- Srivastava, H. S., P. A. Jolliffe, and V. C. Runeckles. 1975a. The effects of environmental condition on the inhibition of leaf gas exchange by NO_2 . Canadian J. Bot. 53:475-482.
- Srivastava, H. S., P. A. Jolliffe, and V. C. Runeckles. 1975b. Inhibition of gas exchange in bean leaves by NO_2 . Can. J. Bot. 53:466-474.
- Standard Oil Co. of Indiana, and Gulf Oil Corporation. 1974. Prototype oil shale leasing program, Colorado Tract C-A: Preliminary development plan. Whiting Oil Corp., Denver, CO. 114 pp.
- Standard Oil Co. of Indiana, and Gulf Oil Corporation. 1977. Final environmental baseline report for Tract C-a and vicinity: Rio Blanco Oil shale project. Book 1 and 2. Denver, CO.
- States, J. B. 1975. Quantitative baseline definition for terrestrial ecosystems at oil shale tract C-a. In Gary, J. H. (ed.). Proceedings of the environment oil shale symposium, Colorado School of Mines. 9-10 October 1975. Quar. Colorado School of Mines 70(4):135-141.
- Steinhardt, I., G. G. Fox, and W. E. Marlatt. 1976. Modeling the uptake of SO_2 by vegetation. USDA For. Serv. Ga. Tech. Rep. RM32:209-213.

- Stetler, L. H. 1979. Inventory, food habits, and trace element levels of selected fauna of Colorado's oil shale region. (Abstract of dissertation). In Natural Resources Newsletter. Colorado State Univ. Cooperative Extension Service, Fort Collins 7(9):5.
- Stewart, D. R. 1912. Oil shales of the Lothians: Part III, Chemistry of the oil shales, p. 163-166. In Mem. Geological Survey, Scotland, Great Britain.
- Stoddard, L. A., A. D. Smith, and T. W. Box. 1975. Range management. McGraw-Hill, New York. 532 pp.
- Sturges, D. L. 1977. Soil water withdrawal and proof characteristics of big sagebrush. *Amer. Midland Nat.* 98:257-274.
- Sturm, M. 1978. MAW contents of an eocene horse propaleotherium out of the oil shale of Messel near Darmstadt, West Germany. *Cour Fourschungsinst Senckenb* 30:120-122.
- Swain, R. E., and A. B. Johnson. 1936. Effect of sulfur dioxide on wheat development. *Ind. Eng. Chem.* 28:42-47.
- Tamm, C. O., and A. Aronsson. 1972. Plant growth as affected by sulphur compounds in polluted atmosphere. A literature survey. Research Notes No. 12. Royal College of Forestry, Stockholm.
- Tanner, J. T. 1966. Effects of population density on growth rates of animal populations. *Ecol.* 47:733-745.
- Taylor, O. C. 1973. Acute responses of plants to aerial pollutants, p. 9-20. In Naegele, J. A. (ed.). Air pollution damage to vegetation. *Advances in Chemistry Series 122*, Amer. Chem. Soc., Washington, D.C.
- Taylor, O. C. 1974. Air pollution effects influenced by plant-environmental interaction. In Dugger, M. (ed.). Air pollution effects on plant growth, *ACS Symp. Ser. 3*, Amer. Chem. Soc., Washington, D.C.
- Taylor, O. C., and D. C. MacLean. 1970. Nitrogen oxides and the peroxyacyl nitrates, pp. E1-E5. In Jacobson, J. S., and A. C. Hill (ed.). Recognition of air pollution injury to vegetation: a pictorial atlas. Air Poll. Control Assoc. and Nat. Air Poll. Control Admin., Pittsburgh, PA.
- Taylor, O. C., and F. M. Eaton. 1966. Suppression of plant growth by nitrogen dioxide. *Plant Phys.* 41:132-135.
- Taylor, O. C., C. R. Thompson, D. T. Tingey, and R. A. Reinert. 1975. Oxides of nitrogen, p. 122-139. In Mudd, J. B. and T. T. Kozlowski (eds.). Responses of plants to air pollution. Academic Press, New York.
- Taylor, O. C., W. M. Dugger, Jr., E. A. Cardiff, and E. F. Darley. 1961. Interaction of light and atmospheric photochemical products (smog) within plants. *Nature* 192:814-816.

- Taylor, W. P. 1956. The deer of North America. Wildlife Management Institute. Washington, D.C. 479 pp.
- Templeton, A. R., and L. R. Lawlor. 1981. The fallacy of the averages in ecological optimization theory. *Am. Nat.* 117:390-393.
- Terwilliger, C. Jr., C. W. Cook, and P. L. Sims. 1974. Ecosystems and their natural and artificial rehabilitation, p. 67-97. In Cook, C. W. (ed.). Surface rehabilitation of land disturbances resulting from oil shale development. Final Report, Phase I. Colorado State Univ., Fort Collins. 259 pp.
- Thomas, J. M. 1978. A qualitative/quantitative procedure for assessing the biological effects of waste heat on economically important populations. In Proceedings of the Second Waste Heat Management Conference, Miami Beach, FL, 4-6 December.
- Thomas, J. R. 1974. Environmental challenges to fossil fuels, pp. 79-89. In Pacific Southwest Energy and Minerals Conference, Dept. of Interior, Denver, CO.
- Thomas, M. D. 1956. The invisible injury theory of plant damage. *J. Air Poll. Control Assoc.* 5:205-208.
- Thomas, M. D., and G. R. Hill. 1937. Relation of sulphur dioxide in the atmosphere to photosynthesis and respiration of alfalfa. *Plant Phys.* 12:309-383.
- Thomas, M. D., and G. R. Hill, Jr. 1935. Absorption of sulfur dioxide by alfalfa and its relation to leaf injury. *Plant Phys.* 10:291-307.
- Thomas, M. D., and R. H. Hendricks. 1951. Effect of air pollution on plants, p. 233-278. In Air pollution. World Health Organization Monograph Ser. No. 46, New York, Columbia Univ. Press.
- Thomas, M. D., and R. H. Hendricks. 1956. Effect of air pollution on plants, p. 1-44. In Magill, P. L., et al. (eds.). Air Poll. Handbook, New York.
- Thomas, M. D., R. H. Hendricks, L. C. Bryner, and G. R. Hill. 1944. A study of the sulphur metabolism of wheat, barley and corn using radioactive sulphur. *Plant Phys.* 19:227-244.
- Thomas, M. D., R. H. Hendricks, T. R. Collier, and G. R. Hill. 1943. The utilization of sulphate and sulphur dioxide for the sulphur nutrition of alfalfa. *Plant Phys.* 18:345-371.
- Thomas, R. E., D. M. Whiting. 1977. Annual and seasonal precipitation probabilities. Envir. protection tech. series. Robert S. Kerr Envir. Res. Lab., Ada, OK. 51 pp.
- Thorne Ecological Institute. 1973. An environmental reconnaissance of the Piceance Basin: A report on the completion of Part I, Phase One of the environmental inventory, analysis, and impact study. Regional Oil Shale Study. Boulder, CO. 150 pp.

- Thorne Ecological Institute. 1974. Environmental impact analysis of prototype oil shale leases: Piceance Creek Basin (Vol. 12-27). Regional Oil Shale Study. Boulder, CO.
- Thorne Ecological Institute. 1975. Wildlife and oil shale: A problem analysis and research program (Vol. I & II). Coordinated by H. D. Burke. Under contract to: U. S. Dept. of Interior, Fish and Wildlife Service, Office of Biological Services. 112 & 131 pp.
- Thornley, J. H. M. 1976. Mathematical models in plant physiology. Academic Press, NY. 318 pp.
- Tiedeman, J. A. and C. Terwilliger, Jr. 1978. Phyto-edaphic classification of the Piceance Basin. Range Sci. Dept., Sci. Series No. 31. Colorado State Univ., Fort Collins. 265 pp.
- Tingey, D. T., L. Bard, and R. W. Field. 1978. The relative sensitivity of selected plant species to several pollutants, singly and in combination. In The bioenvironmental impact of a coal-fired power plant, 3rd interim report, Colstrip, Montana. 521 pp.
- Tingey, D. T., R. A. Reinert, J. A. Dunning, and W. W. Heck. 1971. Vegetation injury from the interaction of nitrogen dioxide and sulfur dioxide. *Phytopathol.* 71:1506-1511.
- Tingey, D., R. Field, and L. Bard. 1976. Physiological responses of vegetation to coal-fired power plant emissions, p. 100-111. In The bioenvironmental impact of a coal-fired power plant, Second Interim Report, Colstrip, Montana. EPA 600/3-76-013.
- Tischendorf, Wilhelm. 1963. An evaluation of infiltration theory and methods. Colorado State Univ., Fort Collins. M.S. thesis. 85 pp.
- Treshow, M. 1970. Environmental and plant response. McGraw-Hill Book Co., Inc., New York. 422 pp.
- TRW, Inc. 1977. Environmental sampling of the Parano oil shale retort process at Anvil Points: Executive briefing. Denver, CO. 17 pp.
- TRW, Inc. 1977a. An evaluation of control technologies for treating oil shale wastewaters: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-02-1881. Denver, CO.
- TRW, Inc. 1977b. Trace elements associated with oil shale and its processing: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-02-1881. TRW/DRI, Denver, CO.
- TRW, Inc. 1977c. An engineering analysis report on the Occidental modified in Situ process: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-02-1881. Denver, CO.
- TRW, Inc. 1977d. An engineering analysis report on the Union retort B process: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-02-1881. Denver, CO.

- TRW, Inc. 1977e. An engineering report on the Lurgi retorting process for oil shale: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-02-1881. Denver, CO.
- TRW, Inc. 1977f. Evaluation of air pollution control equipment to oil shale recovery processes: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-02-1881. Denver, CO.
- TRW, Inc. 1977g. Impact assessment of particulates emitted from four different oil shale plants: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-02-1881. Denver, CO.
- TRW, Inc. 1977h. Management of solid waste residuals from oil shale recovery processes: Report on an assessment of environmental impacts from oil shale development. EPA Contract #68-02-1881. Denver, CO.
- Tueller, P. T., C. D. Beeson, R. J. Tausch, N. E. West, and K. H. Rea. 1979. Pinyon-Juniper Woodlands of the Great Basin: Distribution, flora, vegetal cover. USDA Forest Service, Research Paper INT-229.
- Turbas, E. and V. Kiis. 1971. Comparison of the effectiveness of cement kiln flue dust and various powdered shale ashes and their granules in field experiments. USSR SB Nauchn. Tr. Est. S-KH Akad 73:128-145.
- Tyler, G. 1972. Heavy metals pollute nature, may reduce productivity. *Ambio* 4:52-59.
- Udis, B., C. W. Howe, and J. F. Kreider. 1973. The interrelationship of economic development and environmental quality in the Upper Colorado River Basin: An interindustry analysis. Univ. of Colorado, Boulder. 651 pp.
- Uggla, E. 1959. Ecological effects of fire on north Swedish forests. Almquist and Wiksell, Stockholm. 18 pp.
- Uhlman, D. 1975. Hydrobiology. John Wiley and Sons, Chichester, England. 313 pp.
- United States Department of the Interior (USDI). Bureau of Sport Fisheries and Wildlife. 1973. Relative indices of predator abundance in western United States. S. B. Linhart, Coordinator. Denver Wildlife Research Center, Denver, Colorado. 37 pp.
- Univ. of Colorado. 1977. Trace elements in oil shale. Progress Report, 1 June 1976 to 31 May 1977. 97 pp.
- Unsworth, M. H., P. V. Biscoe, and H. R. Pickney. 1972. Stomatal responses to sulfur dioxide. *Nature* 239:458-459.
- Utter, S. 1976. Oil shale research and development: A Bureau of Mines program, p. 286-287. In Morgan, J. D. (ed.). Proceedings of the Second Annual UMR-MEC Conference on Energy. Rolla, MO.

- U.S. Bureau of Land Management. 1979. Proposed development of oil shale resources by the Colony Development Operation in Colorado, Vol. 1 and 2, Final statement. U.S. Dept. of Interior, Washington, D.C. IX-79 and X-38 with appendices A-1-1 through A-6-1.
- U.S. Bureau of Land Manage. 1979. Proposed Superior Oil Company land exchange and oil shale resource development: Draft environmental statement. Denver, CO. 105 pp.
- U.S. Bureau of Mines. 1973. A summary of significant results in mining metallurgy and energy. Dept. of Interior, Washington, D.C. 112 pp.
- U.S. Bureau of Mines. 1975. A summary of significant results in mining, metallurgy, and mineral economics. Dept. of Interior, Washington, D.C. 123 pp.
- U.S. Bureau of Reclamation. 1977. Tables from the progress report No. 8: Quality of water, Colorado River Basin, January 1977. Nine tables and an environmental analysis worksheet.
- U.S. Department of Energy, Department of Health, Education, and Welfare, and the Environmental Protection Agency. 1978. Workshop on the health and environmental effects of oil shale technology. Elvin Jones and Assoc., Denver, CO. Unpublished document. 52 pp.
- U.S. Department of Interior. 1973. Final environmental statement for the prototype oil shale leasing program. Vol. 1: Regional impacts of oil shale development. Washington, D.C. 750 pp.
- U.S. Energy Research and Development Administration. 1977. Oil shale - FY 1977 environmental development plan. Washington, D.C. 35 pp. and appendix.
- U.S. Environmental Protection Agency. 1971. Mount Storm, West Virginia - Gorman, Maryland, and Luke, Maryland - Feyser, West Virginia Air Pollution Abatement Activity. 67 pp.
- U.S. Environmental Protection Agency. 1973. Effects of sulfur dioxides in the atmosphere on vegetation. Report No. EPA-R3-73-030. Nat. Environ. Res. Centr. USEPA, Raleigh, NC 43 pp.
- U.S. Environmental Protection Agency. 1976. Diagnosing vegetation injury caused by air pollution. Hicks, D. R. (ed.). EPA Cont. Pub. No. 68-02-1344.
- U.S. Environmental Protection Agency. 1977. Airborne particles. Rep. No. EPA-600/1-77-053. Env. Health Eff. Series. 555 pp.
- U.S. Forest Service. 1968. Rainfall interception by annual grass and chaparral . . . losses compared. U.S.D.A. Forest Service Research Paper PSW-48. Pacific Southwest Forest and Range Exp. Sta., Berkeley, California. 12 pp.

- U.S. Geological Survey. 1974. Federal oil shale prototype leasing program, Tract C-b, Supplemental Exploration Plan. U.S. Geological Survey, Lakewood, CO. 53 pp.
- U.S. Geological Survey. 1976. Hydrologic studies by the U.S. Geological Survey in oil-shale areas of Colorado, Utah, and Wyoming. U.S. Geological Survey, Lakewood, CO. 88 pp.
- U.S. Geological Survey. 1978. Assessing the environmental effects of oil shale development: Monitoring guidelines. U.S. Geological Survey Conservation Div., Area Oil Shale Office, Grand Junction, CO. Unpublished document. 21 pp.
- U.S. Geological Survey, Conservation Division. 1974. Summary of workshop on modelling deer-forage-timber relations, Nacogdoches, TX, 3-5 December 1974. Area Oil Shale Office, Grand Junction, CO. Unpublished document. 37 pp.
- U.S. Soil Conservation Service. 1951. Soil survey manual. U.S.D.A. Handbook No. 18. Soil Survey Staff. U.S. Govt. Printing Off., Washington, D.C. 503 pp.
- U.S. Soil Conservation Service. 1960. Soil classification, a comprehensive system. 7th Approximation (supplements issued March 1967, Sept. 1968). Soil Survey Staff. 265 pp.
- U.S. Soil Conservation Service. 1971. National engineering handbook, Sec. 4: Hydrology. Soil Survey Staff. U.S. Govt. Printing Off., Washington, D.C. 114 pp.
- Van Dyne, G. M., and P. T. Haug. 1977. Oil shale tract C-b environmental baseline program final report, Volume V: System interrelationships. Published by C-b Shale Oil Venture (Ashland Oil, Inc., and Occidental Oil Shale, Inc.), Denver, Colorado. xv + 285 pp. + 9 foldout charts.
- Van Haut, H. and H. Stratmann. 1961. Die analyse von Schwefeldioxydwirkungen auf Pflanzen in laboratoriumsversuch. Staub 21(2):52-56.
- Van Wijk, W. R. 1963. Physics of plant environment. North-Holland Publishing Co., Amsterdam. 382 pp.
- Van Wormer, J. 1964. The world of the coyote. J. B. Lippencott Co., New York.
- Veldre, I. A. 1963. Toxicological characteristics of shale waste waters, p. 55-59. RYB. KHOZ. NNUTR. VODYEMOV LATV. SSR.
- Veldre, I. A. 1969. Efficiency of water pollution control in shale-processing combines. Hygiene and Sanitation 34(12):413-417.
- Veldre, I. A., and Kh. Ya. Yanes. 1977. Toxicological studies of shale oils, some of their components and commercial products. Paper presented at US-USSR workshop on health effects of oil shale development.

- Veldre, I., K. Norman, V. Saliev, K. Simm, S. I. Yesaar, and H. Annus. 1977. A study of the toxicity of generator shale oil [in Russian]. *Eesti NSV Tead Akad Toim Biol.* 26(2):91-95.
- Verlaque, M. 1976. Impact of thermal pollution from the Martigues-Ponteau plant on macrophyte benthos [in French]. *Stn. Mar. End.*
- Vins, B., and R. Mrkva. 1973. The diameter increment losses of pine stands as a result of injurious immissions. *Acta Univ. Agric-Brno, Ser. C* 42:25-46.
- Vories, K. C. 1974. A vegetation inventory and analysis of the Piceance Basin and adjacent drainages. W. State Coll. of Colorado, Gunnison. M.S. thesis. 243 pp.
- Vosamae, A. 1977. Carcinogenicity studies of estonian oil shale soots. Paper presented at US-USSR workshop on health effects of oil shale development.
- VTN Colorado, Inc. 1975. Environmental baseline data collection and monitoring program: Federal prototype 0.7 shale leasing program Tracts U-a and U-b White River Shale Project. Denver, CO.
- VTN Colorado, Inc. 1977. White River Shale Project, Final environmental baseline report: Federal lease tracts, U-A and U-B, Vol. 2.
- VTN, Colorado, Inc. 1976. First year environmental baseline report. Federal prototype oil shale leasing program. Tracts U-a and U-b, Utah. White River Shale Project. Denver, Colorado. Vols. 1 and 2.
- Wagner, F. H. (project director). 1975. Desert biome: Ecosystem analysis studies. Vol. 3. US IBP Program Report of 1974 Progress. Ecology Center, Utah State Univ., Logan. 414 pp.
- Walters, C. J., and F. Bunnell. 1971. A computer management game of land use in British Columbia. *J. of Wildl. Manage.* 35:644-657.
- Walton, B. T. and E. G. O'Neill. 1978. Reproductive toxicology. Synthetic fuels program. Env. Sci. Div., Oak Ridge Nat. Lab., TN. Internal Document.
- Ward, J. C., and S. E. Reinecke. 1972. Water pollution potential of snowfall on spent oil shale residues. Dept. of Civil Engineering, Colorado State Univ., Fort Collins. 62 pp.
- Ward, R. T., R. L. Dix, and W. Slauson. 1978. Suitability of native shrubs and forbs for shrubland restoration design: Their possible genetic variability and community relationships, p. 85-121. In Cook, C. Wayne. 1978. Rehabilitation potential and practices of Colorado oil shale lands. DOE Contract EY-76-S-02-4018. Colorado State Univ., Fort Collins.

- Ward, R. T., R. L. Dix, and W. Slauson. 1979. Suitability of native shrubs and forbs for shrubland restoration design: Their possible genetic variability and community relationships, p. 85-121. In Cook, C. Wayne. 1979. Rehabilitation potential and practices of Colorado oil shale lands. DOE Contract EY-76-S-02-4018. Colorado State Univ., Fort Collins.
- Ward, R. T., W. Slauson, and R. L. Dix. 1974. Natural vegetation in the landscape of the Colorado oil shale region, p. 30-66. In Cook, C. W. (ed.). Surface rehabilitation of land disturbances resulting from oil shale development. Final Report, Phase I. Colorado State Univ., Fort Collins. 259 pp.
- Warner, M. L., C. D. Becker, W. T. Hinds, and R. H. Sauer. 1978. Impacts of ecosystems. In The impact of increase coal consumption in the Pacific Northwest, p. 8.1-8.22, National Coal Utilization Assessment, DOE Report BNWL-RAP-21.
- Watt, K. E. 1968. Ecology and resource management. McGraw-Hill Book Co., New York. 450 pp.
- Weast, R. C. (ed.). 1968. Handbook of chemistry and physics. The Chemical Rubber Co., Cleveland, Ohio.
- Weaver, G. D. 1973. Environmental hazards of oil-shale development - Summary report and recommendations. Ph.D. Thesis, Johns Hopkins Univ., Baltimore, Md. 65 pp.
- Weeks, J. B. 1976. Ground water problems with oil shale mining in the Piceance Basin. Water Spectrum 8(1):8-14.
- Weeks, J. B. 1978. Digital model of ground-water flow in the Piceance Basin, Rio Blanco and Garfield counties, Colorado. Water Resources Div., Geological Survey, Lakewood, CO. 108 pp.
- Weeks, J. B., G. H. Leavesley, F. A. Welder, and G. J. Saulnier, Jr. 1974. Simulated effects of oil shale development on the hydrology of Piceance Basin, Colorado. U.S. Geological Survey Professional Paper #908. 84 pp.
- Welder, F. A., and G. J. Saulnier, Jr. 1975-76. Geohydraulic data from twenty-four test holes drilled in the Piceance Basin, Rio Blanco County, Colorado. U.S. Geological Survey, Lakewood, CO. 132 pp.
- Wellburn, A. R., O. Majernick, and F. A. M. Wellburn. 1972. Effects of SO₂ and NO₂ polluted air upon the ultrastructure of chloroplasts. Environ. Poll. 3:37-49.
- Welty, J. C. 1975. The life of birds. 2nd edition. W. B. Saunders, Co., Philadelphia. 623 pp.
- Wheeler, R. M. and F. B. Salisbury. 1980. Gravitropism in plant stems may require ethylene. Sci. 209:1126-1128.

- Whitaker, G. A., and R. H. McCuen. 1976. A proposed methodology for assessing the quality of wildlife habitat. *Ecol. Modelling* 2:251-272.
- White, K. L., A. C. Hill, and J. H. Bennett. 1974. Synergistic inhibition of apparent photosynthesis rate of alfalfa by combinations of sulfur dioxide and nitrogen dioxide. *Environ. Sci. and Tech.* 8:574-576.
- White, M. D. 1974. Legal problems in the acquisition of suitable water supplies for oil shale operations in western Colorado, p. 12-21. In *Water Resources Problems Related to Mining: Proceedings No. 18.*
- Wiegert, R. G. and P. C. Fraleigh. 1972. Ecology of Yellowstone thermal effluent systems: Net primary production and species diversity of a successional blue-green algal mat. *Limnology and Oceanograph* 17:215-228.
- Wildlife Management Institute. 1973. Transactions of the thirty-eighth North American Wildlife and Natural Resources Conf. Wildlife Manage. Institute, Washington, D.C. 525 pp.
- Wildung, R. E. 1978. Significance of environmental pathways in pollutant toxicology. Paper presented at the Intra-Science Symposium on trace metals in health and disease, Santa Monica, CA, 29 November.
- Wildung, R. E. et al. 1978. Terrestrial effects of oil shale development and development of chemical reactions, stability, and transport model of oil shale process wastes in soil, p. 6.1-6.15. Pacific Northwest Lab. Annual Report for 1977 to DOE Asst. Sec. for Env., Part 2. Battelle Pacific Northwest Lab., Richland, WA.
- Wilhour, R. G. 1975. EPA, Corvallis Environ. Res. Lab. (unpublished data).
- Winsor, D. B. 1975. Endangered Species: Their implication in oil shale development. In Gary, J. H. (ed.). Proceedings of the environmental oil shale symposium, Colorado School of Mines. 9-10 October 1975. Quar. Colorado School of Mines 70(4):153-157.
- Woodward-Clyde Consultants. 1975. Biological baseline studies: Federal oil shale lease Tract C-b. Prepared for Atlantic Richfield. 1975-1976. 190 pp.
- Woodward, T. N. 1973. An evaluation of deer-proof fence length required to prevent deer movements on or across high speed highways, p. 197-202. In *Game Res. Rep.*, Colo. Div. Wildl., Denver. 7:45-275.
- Woolhiser, D. A. 1973. Hydrologic and watershed modeling - State of the art. *Trans. Amer. Soc. Agric. Engineers* 16:553-559.
- Wunder, B. A. 1975. A model for estimating metabolic rate of active or resting mammals. *J. Theor. Biol.* 49:345-354.
- Wymore, Ivan F. 1974. Water requirements for stabilization of spent shale. Colorado State Univ., Fort Collins. Ph.D. dissertation. 137 pp.

- Wymore, I. F., W. D. Striffler, and W. A. Berg. 1974. Water requirements for stabilizing and vegetating spent shale in the Piceance Basin, p. 228-255. In Cook, C. W. (ed.). Surface rehabilitation of land disturbances resulting from oil shale development. Final Report, Phase 1 Colorado State Univ., Fort Collins. 259 pp.
- Yeager, L. E. (ed.). 1970. Deer-vehicle accidents, p. 17-19. In Colorado Game Res. Review 1969. Colo. Dept. Game, Fish and Parks, Denver. 35 pp.
- Yeager, L. E. (ed.). 1972. Deer-vehicle accidents, p. 4-5. In Colorado Game Res. Review 1970-71, Colo. Dept. Game, Fish and Parks, Denver. 49 pp.
- Young, M. A. 1979. Effects of ozone on wheat: A computer model. (Abstract of thesis). In Natural Resources Newsletter. Colorado State Univ. Cooperative Extension Service, Fort Collins 7(9):5.
- Zahn, R. 1961. Wirkungen von Schwefeldioxid auf die Vegetation, Engelbrisse aus Begassungsversuchen. Staub 21, 56-60.
- Zahn, R. 1963. Investigations on plant reaction to continuous and/or intermittent sulfur dioxide exposure. Staub 23:334-352.
- Zar, J. H. 1968. Standard metabolism comparisons between orders of birds. Condor 70:278.
- Ziegler, I. 1972. The effect of SO_3 on the activity of ribulose-1, 5-diphosphate carboxylase in isolated spinach chloroplasts. Planta 103:155-163.
- Ziegler, I. 1973. Effect of sulphite on phosphoenolpyruvate carboxylase and malate formation in extracts of Zea mays. Phytochemistry 12:1027-1030.
- Ziegler, I. 1974. Malate dehydrogenase in Zea mays: Properties and inhibition by sulfite. Biochem. Biophys. Acta 364:28-37.
- Ziegler, I. 1975. The effect of SO_2 pollution on plant metabolism. Residue Rev. 56:79-105.
- Ziegler, I., and W. Libera. 1975. The enhancement of CO_2 fixation in isolated chloroplasts by low sulfite concentrations and by ascorbate. Z. Naturforsch. 30c:634-637.
- Zinke, P. J. 1967. Forest interception studies in the United States, p. 137-161. In Sopper, W. E., and H. W. Ludd (eds.). Forest Hydrology. Pergamon Press, NY.
- Ziskind, R. and D. Hausknecht. 1976. Health effects of nitrogen oxides. EPRI 571-1A. Prepared by Science Application, Inc., El Segundo, CA, for the Electric Power Research Institute, Palo Alto, CA. 39 pp.

DISTRIBUTION

No. of
Copies

No. of
Copies

OFFSITE

A. A. Churm
DOE Patent Division
9800 South Cass Avenue
Argonne, IL 69439

2 DOE Technical Information Center

H. Ash
U.S. Department of the Interior
Building 67, Room 820-A
Denver Federal Center
Denver, CO 80225

G. Bierman
Science Applications, Inc.
1710 Goodridge Drive
McLean, VA 22101

A. C. Bishard
Colorado Department of Health
4210 E. 11th Avenue
Denver, CO 80220

W. R. Chappell
University of Colorado
P.O. Box 136
Denver, CO 80202

J. A. Coleman
Office of Environmental
Assessments
Mail Stop E-201/Gtn
Washington, DC 20545

Mark Ethridge
American Petroleum Institute
Policy Analysis Group
2101 L Street, N.W.
Washington, D.C. 20037

B. Harney
Office of Shale Resource
Applications
Technology Assessments Division
U.S. Department of Energy
Washington, DC 20545

R. Heistand
Development Engineering, Inc.
Box A
Anvil Point
Rifle, CO 81650

L. M. Holland
Los Alamos National Laboratory
P. O. Box 1663
Los Alamos, NM 87545

P. W. House
Office of Environmental
Assessments
U.S. Department of Energy
Washington, DC 20545

C. Mangeng & R.K. Lohrding
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos, NM 87545

J. Merino
TOSCO
P.O. Box 814
Vernal, UT 84078

G. Miller
U.S. Geological Survey-AOSO
131 No. 6th, Suite 300
Grand Junction, CO 81501

15 G. J. Rotariu
Technology Assessments Division
Mail Stop E-201/GTN
U.S. Department of Energy
Washington, DC 20545

A. Rudolph
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201

R. D. Shull
Regional Impacts Division
Mail Stop E-201/Gtn
U.S. Department of Energy
Washington, DC 20545

No of
Copies

W. E. Siri
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

T. Surles, M. F. Torpy,
and L. Habeggar
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

T. Thoem
Office of Energy, Region VII
Environmental Protection Agency
1860 Lincoln
Denver, CO 80295

R. E. Thomason
Occidental Oil Shale, Inc.
P.O. Box 2999
Grand Junction, CO 81501

J. W. Skiles
Department of Range Science
Colorado State University
Ft. Collins, CO 80523

No. of
Copies

E. R. Williams
Regulatory Analysis Division
Mail Stop E-201/Germantown
U.S. Department of Energy
Washington, DC 20545

ONSITE

DOE Richland Operations Office

H. E. Ransom

16 Pacific Northwest Laboratory

W. J. Bair
D. L. Brenchley
K. R. Chase
J. S. Fruchter
5 S. Marks
B. E. Vaughan
R. E. Wildung
J. N. Zachara

1 Technical Information Library
2 Publishing Coordination (KC)
1 Economics Library