# LINKING THE FOREST-CENTERED ECONOMIC AND ECOLOGIC SYSTEMS OF WESTERN MONTANA: A PROBLEM ANALYSIS

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ABSTRACT

# LINKING THE FOREST-CENTERED ECONOMIC AND ECOLOGIC SYSTEMS OF WESTERN MONTANA: A PROBLEM ANALYSIS

By

Louis Walter Pompi

The Forest Service has accepted the recommendations of the President's Water Resources Council regarding multi-objectives in federal resource management. Multi-objective planning requires models much more comprehensive than heretofore available in management planning within the National Forest System. In expanding the planning process to include multi-objectives a large amount of difficulty has been experienced in attempts to link aspects of both the economic and ecologic systems of a region in a single planning model. In western Montana, with its forestry-based economic and ecologic systems, this problem is no less acute. In order to properly plan for the production of the array of goods and services from the forests of western Montana, it is necessary that plans be comprehensive and hence fully consider the internal linkages between these systems. Current planning models do not properly include these linkages.

The general objective of this research was to describe the procedures by which the forestry-based economic and eco-

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logic systems of western Montana could best be linked in a single analytical model. This general objective is more accurately defined in the following (summarized) specific research objectives:

1. To compile an annotated bibliography of literature on modeling economic-ecologic linkages.
2. To perform a comparative evaluation of alternative models for representing economic and ecologic systems in an integrated fashion.
3. To conceptualize how these linkages could best be modeled if there were neither data nor resource limitations. Types of questions that could be answered with and data requirements for this model are to be explored and defined.
4. To evaluate the structural appropriateness of the ideal model for representing the economic and ecologic systems of western Montana, and to describe modifications which might be necessary to achieve structural compatibility.
5. To assess the present availability, for western Montana, of secondary data required for operation of the structurally modified regional linkage model, and to describe any further modifications necessary to compensate for data inadequacies.
6. To compile a study plan that could serve as a feasible research guide for modeling the economic and ecologic systems of western Montana, relying entirely on data from secondary sources.

Standard library research procedures were used to compile an annotated bibliography of work related to modeling economic-ecologic linkages. This material was also organized into a literature review section for this report. The primary purpose of the review was to facilitate the identification of alternative approaches to modeling economic and ecologic systems in an integrated fashion. The outstanding finding associated with the literature search was the lack of empirical work in light of rather sophisticated conceptual development of available linkage models. Thus there are few guidelines available to potential users of these models to

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aid in implementing the models in specific regional and problem contexts. The major conclusion drawn from the review is that more research resources should be committed to empirical application and testing of existing conceptual models.

The comparative evaluation of alternative modeling approaches was designed to provide information necessary to proceed with conceptual development of the ideal model. The subjective evaluation considered four model types (identified in the literature) and eight evaluative criteria. The evaluation suggested that simulation models offered the most attractive approach to economic-ecologic modeling, followed by linear programming and input-output models. The fourth type--hybrid models--are composed of elements from two or more of the other three types. The large variety of potential configurations for this type precluded a full evaluation here.

Development of the ideal conceptual model could be accomplished only in very general terms. Essentially, the model uses an LP format for representing the economic system and simulation techniques for modeling the regional environment. The principal outputs of the LP submodel are the residuals discharge vectors which enter the environmental simulator as data. Linkages from the environment to the regional economic system are incorporated using a feedback devise which essentially monitors changes in the environment and enters these changes as constraints on the solution of the LP submodel. The ideal model provided a basis for evaluating the operational feasibility of an economic-ecologic linkage model in the study region.

Operational feasibility was evaluated in two stages: 1) evaluate structural appropriateness of ideal model for representing regional economic and ecologic systems, and 2) evaluate adequacy of western Montana's secondary data base for operationalizing the model. Considerations related to structural appropriateness included: 1) goals and objectives of client, 2) interfacing with other planning models and procedures, and 3) structure of western Montana economic and environmental systems. One major modification of the ideal model resulted from the structural analysis. The LP submodel was reformulated using I-0 techniques. An extensive survey of readily available secondary data (conducted using the data requirements for the structurally modified model as a guide) indicated that the reformulated linkage model can be only partially implemented in the region. The I-0 submodel can be implemented using technical coefficients from the State I-0 model and adjusted final demand estimates from this model. The matrix of environmental coefficients can be implemented but only a few of the cells contain entries. In addition, the environmental coefficients included are from other sources and thus not directly related to the study region. The environmental simulator can not be implemented with existing secondary data.

The last chapter of the report summarizes the progress made toward fulfillment of each research objective. It was conclu-

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concluded that the report itself can stand as a study plan that could serve as a feasible research guide for modeling economic-ecologic linkages in western Montana. Also included is a discussion of research needs. These needs include: 1) more empirical work designed to provide guidelines for implementing existing conceptual linkage models, 2) further conceptual refinement of the ideal model; especially the environmental submodel, and 3) investigation designed to improve the secondary data base for western Montana; particularly in the area of providing data sufficient for estimating the coefficients in the environmental matrix and the parameters associated with the environmental simulator.

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By

Louis Walter Pompi

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To Betsy and Danny

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# CHAPTER I

# INTRODUCTION

## Problem Statement

There has been growing concern that the scope of present resource management planning is too narrow. Re-evaluation of policies and procedures connected with such planning has resulted in the establishment and widespread acceptance of new planning guidelines. For example, the Forest Service has accepted the recommendations of the President's Water Resources Council regarding multi-objectives in federal resource management. According to a recent regional policy statement:

> By direction of the Chief, National Forest planning will be responsive to these multi-objectives. The multi-objectives are briefly:
>
> 1. To enhance National Economic Development (NED).
> 2. To enhance Regional Development (RD).
> 3. To enhance the quality of the environment (EQ).
>
> No one multi-objective has any inherently greater claim on land and water use than any other.[1]

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[1]U.S.D.A., Forest Service, "Guidelines for Development of Unit Plans," Working Draft II, Northern Region, Missoula, Montana, July, 1972, p. 8. It should be noted that new Water Resource Council guidelines have been developed. These new guidelines emphasize national economic and environmental priorities, while recommending that the regional impacts of programs initiated in pursuit of these goals be displayed and considered where appropriate. See Water Resources Council, Water and Related Land Resources: Establishment of Principles and Standards for Planning, Federal Register, XXXVIII No. 174 (Washington: U.S. Government Printing Office, 1973).

This statement reflects not only the traditional concern for economic flows of priced goods and services but, also, the more recently developed awareness of the importance of considering the environment and flows of non-priced goods and services in resource management decisions. A recent study has emphasized this problem:

> . . . generally, many environmental goods are not bought and sold in markets. As a result, the information (i.e., price and quantity sets desired by or acceptable to consumers) necessary to apply traditional economic analysis is lacking. This vastly complicates the difficulty of quantifying the tradeoffs between economic development and conservation of natural resourceswhich would result in the 'wisest' use of resources for the economy under scrutiny.[2]

Multi-objective planning requires models much more comprehensive than heretofore available in management planning within the National Forest System. Planning models in resource analysis have typically centered on commodity production, especially timber, with little emphasis on the impacts of such production on the environmental system. Conversely, rarely have such planning models considered the impacts of environmental change on commodity production, except in a very indirect manner. Indeed, it would seem that, in general, such planning models have concentrated almost exclusively on silvicultural practices and principles of production economics, while largely ignoring all regional

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[2]Eugene A. Laurent and James C. Hite, Economic-Ecologic Analysis in the Charleston Metropolitan Region: An Input-Output Study (Clemson, South Carolina: Water Resources Research Institute in cooperation with the South Carolina Agricultural Experiment Station, Clemson University, Report No. 19, April, 1971), p. 11.

off-forest impacts--both environmental and economic--of forest management decisions.

Unfortunately, it is often the case that pursuance of commonly recognized production-economic goals (and, quite possibly, adherence to traditionally prescribed silvicultural practices) may lead to a decline in environmental quality, which occurs because of the integral linkages between the economic and ecologic systems. In addition, myopic planning and management practices may also result in adverse impacts on the local or regional economy, particularly on such critical indicators as employment and income. It is important to note that such regional economic impacts are significant not only in terms of their magnitude, but, also, in terms of their distribution. That such off-forest economic impacts are to be expected is not surprising in light of the high degree of interdependence which characterizes most modern regional economic systems.

The importance of this issue of environmental quality in National Forest management planning may be illustrated by the now notorious case of the Bitterroot National Forest. Public concerns regarding environmental impacts of management practices, particularly clearcutting, on that forest have caused people throughout the Nation to question the legitimacy of Forest Service practices and planning.[3] This

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[3]For a detailed description of an investigation of the management practices on the Bitterroot National Forest, consideration of the many criticisms and allegations regarding these practices, as well as recommendations for improved

case as well as others has brought the appropriate range of management practices for commodity production into question, in view of the many environmental impacts. The importance of considering off-forest, regional economic impacts in National Forest management planning is adequately emphasized in the previously quoted regional policy statement.

In order to properly plan for the production of the array of goods and services from the Nation's forests, it is necessary that plans be comprehensive and hence fully consider the internal linkages between the economic and ecologic systems, and, also, the linkages between timber production on National Forest land and regional economic development. Current planning models do not properly include these linkages. For example, the Timber RAM model is currently used by a number of Forest Service timber management planners to assist in making the allowable cut decision.[4] This model considers the growth and yield characteristics of a region's forests, the accessibility of timber at the present and future time periods, and a range of alternative

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future management by a Forest Service Task Force see: U.S. D.A., Forest Service, "Management Practices on the Bitterroot National Forest," A Task Force Appraisal (Missoula, Montana: U.S.D.A., Forest Service, Region 1, 1970). See also, A. W. Bolle, et al., A Select Committee of the University of Montana Presents its Report on the Bitterroot National Forest (Missoula, Montana: University of Montana, 1970).

[4]For a description of this model, see Daniel I. Navon, Timber RAM . . . A Long-Range Planning Method for Commercial Timber Lands Under Multiple-Use Management (Berkeley, California: U.S.D.A., Forest Service, Research Paper PSW-70, Pacific Southwest Forest and Range Experiment Station, 1971).

silvicultural treatments. As currently applied, the model is used to calculate optimal non-declining allowable cuts in terms of maximizing the harvest of merchantable bio-mass. There are no linkages within the model which measure either the impact of timber cutting on the condition of the environment or, conversely, the constraints that non-timber environmental conditions will likely impose on timber cutting. In addition, Timber-RAM does not consider restrictions on non-land inputs to the production process. Also absent from this model is any explicit recognition of potential regional economic impacts of timber cutting decisions. The basic problem to which this study addresses itself is to investigate possibilities of developing methods to correct these deficiencies.

## The Study Region[5]

The western Montana region provides an excellent laboratory within which to conduct this investigation. The region has a forestry-based economy. Indeed, according to Johnson, ". . . something like 43 percent of total employment and 51 percent of total personal income in western Montana came, either directly or indirectly, from the wood

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[5]The study region consists of the following eight counties in western Montana: Flathead, Granite, Lake, Lincoln, Mineral, Missoula, Ravalli, and Sanders. This region is Montana Economic Study Region I, as defined by the Bureau of Business and Economic Research, University of Montana, Missoula, Montana. A map illustrating the location and extent of the region is provided in the appendix.

products industry."[6]

Land resources in the region are largely in the ownership of the Federal government, including the Kootenai, Flathead, Lolo, Bitterroot, and Deerlodge National Forests. Extensive Federal ownership of land by a single agency, the U.S. Forest Service, insures that the management practices of that agency will be important in terms of impacts on both the regional economy and, more recently recognized by the public, the regional environment. There are indications that such off-forest impacts of Forest Service management decisions are receiving increasing attention from forest managers and research personnel.

## Selection of the Study Region

The regional definition problem has been discussed at great length in the literature of various fields.[7] At one

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[6]Maxine C. Johnson, "Wood Products in Montana: A Special Report on the Industry's Impact on Montana's Income and Employment," Montana Business Quarterly, Vol. 10, No. 2 (1972), p. 11.

[7]See for example, Advisory Commission on Intergovernmental Relations, Multistate Regionalism (Washington, D.C.: U.S. Government Printing Office, April, 1972); Peter Haggett, Locational Analysis in Human Geography (London: Edward Arnold, Ltd., 1965); Karl A. Fox and T. Krishna Kumar, "The Functional Economic Area: Delineation and Implications for Economic Analysis and Policy," Papers and Proceedings of the Regional Science Association, XV (1965), pp. 57-85; M. B. Ullman and R. C. Clove, "The Geographic Area in Regional Economic Research," Regional Income, XXI, Conference on Research in Income and Wealth, National Bureau of Economic Research (Princeton, N.J.: Princeton University Press, 1957), pp. 92-94: Charles L. Leven, John B. Legler, and Perry Shapiro, An Analytical Framework for Regional Development Policy (Cambridge, Mass.: The M.I.T. Press, 1970); P. M. Lankford, "Regionalization: Theory and Alternative Algo-

time or another, geographers, demographers, sociologists, economists, regional scientists, and others have been occupied with this problem. Consequently, there has been a proliferation of suggestions regarding principles of regionalization and techniques for establishing regional schemes which incorporate these considerations.

A region may be defined quite precisely as a geographic area relevant for answering a specific question or set of questions. If a particular study is aimed at a single question then the regional definition problem is somewhat simplified in the sense that the researcher may consider a smaller set of criteria in defining his region or system of regions. When there are multiple questions to be answered, the relevant criteria will usually define regions which are not entirely consistent and the resulting conflicts must be resolved by compromise.

In this study, the relevant geographic area--its location and extent--is essentially dictated by the decision-making concerns of the client agency. Thus the regionalization process which, in many other research efforts, has proved tedious and consumptive of a large amount of research resources has been largely avoided. This does not imply that the problem of defining the proper region for investigation is not an important one. However, it is thought

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rithms," Geographical Analysis, I, No. 2 (April, 1969), pp. 196-212; and Harry W. Richardson, Regional Economics: Location Theory, Urban Structure, Regional Change (New York: Praeger Publishers, Inc., 1969), pp. 223-231.

advantageous to be able to conserve research resources, which always appear to be in short supply, and direct those scarce resources toward meeting the stated objectives of the study.

It is important to note, however, that the eight county western Montana region does satisfy several of the criteria traditionally applied to the regional selection problem (i.e., regionalization). Physically the region is as nearly homogeneous for many important characteristics (e.g., climate, soils, landforms, vegetation cover, etc.) as it is possible to achieve for a region of this size. Several publications describing the Montana economy have indicated that much of the economic activity in the region is associated either directly or indirectly with the forest products industries.[8] There is only one city--Missoula--thus minimizing the potential problems arising from a region exhibiting distinct urban and rural contrasts associated with multiple centers.[9] The boundaries of the region coincide with existing county boundaries and the region itself may be subdivided into smaller units (i.e., individual

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[8]For example: Bureau of Business and Economic Research, Montana Economic Study: Research Report (Missoula, Montana: University of Montana, School of Business Administration, 1970); and R. E. Benson et al., A Descriptive Analysis of Montana's Forest Resources: A Progress Report (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974).

[9]As of the 1970 Census of Population. This classification assumes the census definition of a city having a population of 25,000 inhabitants or more.

counties). This feature will facilitate data collection and the implementation of any policy decisions that might be made as a result of this study. Another important advantage of the study region related to planning and administrative considerations is the fact that the entire area is wholly within the jurisdiction of one administrative unit of the Forest Service (i.e., Region 1, Northern Region, National Forest System).

For any one variable that one may wish to investigate it may be possible to derive a unique regionalization. When one works with many variables, the final regionalization is ultimately a compromise to a variable degree. The overall objective of this study is to investigate procedures for linking two extremely complex systems in one analytical model. Thus the ideal region for such research, i.e., one possessing the necessary degree of homogeniety and one in which both the ecologic and economic systems are closed, probably cannot be defined. However the problems for which it is hoped that this study will help provide answers are ones which are right now being faced by a large number of both management and research personnel in many regions, ideal or not. It is felt, therefore, that the region upon which this study is based is not only relevant for the objectives of the study, but, also, that it represents as good a compromise on the difficulties of multi-purpose regionalization as one is likely to establish given the complexity of the problem at hand.

## Description of the Study Region

A detailed description of the economic and environmental systems of the western Montana region is not considered essential to the pursuit of the overall objective of the study. Indeed, the presentation of such a description would require a formidable amount of space and, it is felt, would distract the reader from the central emphasis of this research. Thus the description provided in this report is intended only as a general discussion of some major features of the economic and environmental systems of western Montana, and is placed in the Appendix B so as not to disturb the continuity of this chapter. It is thought that the description provided in the appendix adequately serves the purpose of providing the reader some general information on the context within which the study took place. The discussion is brief and is based on readily available information from secondary sources. At several points in the study (in pursuit of the more specific research objectives to be discussed below) it becomes necessary to have more detailed information on certain specific aspects of the region. When necessary, this information has been provided in the relevant sections of the paper.

The description of the study region is divided into three major sections covering the economic system, the physical setting, and the forest resource of western Montana. Discussion of the region's economic system emphasizes the two features which serve to distinguish it from that of other regions in the State, i.e., rapid economic growth and the transition from a predominantly agricultural economy to one dominated by manufacturing activities. The region's physical setting is described under the following topical headings: climate, topography, hydrographic features, soils, and flora and fauna. A discussion of western Montana's forest resource necessarily includes elements from both the economic and environmental systems of the region. In addition, the forest resource plays an extremely significant role in many of the activities taking place in western Montana and thus, it is felt, should be treated apart from the general descriptions of the economic system and physical setting. Topics treated in the discussion of the region's forest resource include: the forest land area and ownership pattern, the timber resource, the recreation resource , the range resource, the wildlife resource, the water resource, the mineral resource, and the timber economy.

## Objectives of the Study

The general objective of this study is to describe the procedures by which the forestry-based economic and ecologic systems of western Montana can best be linked in a single analytical model. This general objective has been further defined in terms of several more specific research objectives. These objectives are:

1. To compile an annotated bibliography of literature concerned with modeling the linkages between economic and ecologic systems.

2. To perform a comparative evaluation of alternative models for representing economic and ecologic systems in an integrated fashion.

3. To conceptualize how such a linking of economic and ecologic systems could best be developed if there were neither data nor resource limitations. Types of questions that could be answered with and the data requirements for such an ideal model are to be explored and defined.

4. To determine whether this ideal model is structurally appropriate for representing both the forest-centered economic and ecologic systems of western Montana, and to suggest any modifications which might be necessary to achieve structural compatibility.

5. To assess the present availability, for the western Montana region, of secondary data required for the operation of the structurally modified model, and to describe any further modifications which might be necessary to compensate for any inadequacies found to exist in the region's secondary data base.

6. To compile a study plan that could serve as a feasible research guide for linking the forest-centered economic and ecologic systems of western Montana, relying entirely on data from secondary sources.

The overall study objective and the first five specific objectives clearly indicate that the majority of this research can be characterized as a problem analysis. The final objective, i.e., development of a study plan, can be viewed as a culmination of the research undertaken in pursuit of the first five.

At this point it is worth noting, briefly, the continuity intended in the development of the research objectives listed above. The compilation of the annotated bibliography and the associated review of the literature is designed to provide a comprehensive knowledge of the state-of-the-art in modeling economic-ecologic linkages. This information is then used to define the alternative models for representing economic and ecologic systems in an integrated fashion. The alternatives are then evaluated through development and application of a set of evaluative criteria. The information generated by the comparative evaluation of alternative economic-ecologic models then forms the basis for conceptualizing an ideal linkage model.

Once formulated, the ideal conceptual model indicates the types of questions that could be answered through its application and the quantity and quality of data required to operationalize the model. The ideal conceptual model is then compared against the actual structure of the forest-centered economic and ecologic systems of the western Montana region and modified when appropriate. This represents the first step in adjusting the ideal model to conform with realistic considerations. An inventory is then made of the present availability, from secondary sources, of pertinent economic and ecologic data for the western Montana region. Data requirements for the structurally modified model are then compared against the inventory of available data for the region and the model is further modified to reflect the operational constraints imposed by the secondary data base. The study plan is essentially a description of the best model for linking the forest-centered economic and ecologic systems of western Montana which could be implemented in the region utilizing existing data available from secondary sources. The description of the currently feasible model includes a discussion of the location of the various secondary data sources.

## On Research Hypotheses and Models

The primary goal of a problem analysis is the identification of specific information needs.[10] Thus the problem analysis precedes and forms the basis for study planning. As already noted, a large portion of the research undertaken here involves problem analysis while the remainder of the study is devoted to the development of a detailed study plan. As such, this study has not investigated the validity of specific research hypotheses nor has it employed a specific model or set of models to accomplish its objectives. Rather, this study has followed various procedures that have made possible the development of a final study plan as the end product of the research effort.

It is worth noting that there has been some minor professional controversy as to the legitimacy of problem analysis as research. It is felt this topic has been adequately dealt with and the conflict satisfactorily resolved in a recent publication from a group of forestry researchers.[11] They conclude that, ". . . conducting problem analysis is a legitimate form of research in itself--although one not consciously and commonly practiced by many researchers."[12]

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[10] Carl H. Stoltenber, *et al.*, *Planning Research for Resource Decisions*, (Ames, Iowa: The Iowa State University Press, 1970), p. 32.

[11] *Ibid.*, pp. 32-34. [12] *Ibid.*, p. 33.

## Research Procedures

The procedures employed in this study vary by the specific objective being pursued. Thus it is most convenient to organize this discussion around each of these objectives in turn.

In compiling the annotated bibliography specified in the first research objective (and, also, in organizing the literature review contained in the following chapter) standard library research methods were used. Natural resource abstracting services of various types (e.g., Selected Water Abstracts) and other related publications such as the Journal of Economic Literature (formerly the Journal of Economic Abstracts) were consulted to provide literature citations of appropriate studies. The reference lists and bibliographies contained in the studies thus uncovered have been helpful in locating other relevant published and unpublished work. In addition, the Current Research Information System (CRIS) was searched for applicable in-progress research projects.

The comparative evaluation of the alternative models for representing economic and ecologic systems in an integrated fashion was completed in three stages. First, the information obtained from the literature search was processed to identify the alternative models currently being proposed for this purpose. Next, a set of evaluative criteria, reflecting those qualitative aspects of each model which are relevant to the goals and objectives of this study, was developed. Finally, the criteria were applied to each alternative model, thus identifying the pertinent merits and deficiencies of each and providing the basis for relative comparisons among these attributes.

The information obtained from the comparative evaluation formed the basis for conceptualizing the ideal model. The model is ideal in the sense that its development has not been constrained by realistic data or resource limitations. Developing an ideal conceptual model serves three purposes. First, it provides a standard from which to measure the performance of other, more realistic, models. Second, it serves as a guide to future data collection and processing activities since the ideal conceptual model defines the data requirements for providing the most detailed answers to the broadest range of questions given the state-of-the-art. Last, and perhaps most important, the ideal conceptual model provides a basis for analyzing the operational feasibility of economic-ecologic linkage models for the western Montana region.

It should be noted that the ideal conceptual model was developed not only in the absence of consideration of realistic data and resource limitations, but, also, in the absence of any association with a particular region or specific problem context. Thus the model developed is quite general (or, perhaps abstract would be a more appropriate term), and the questions it could help to answer and the data required for its operation are not related to a specific regional or problem context. Indeed, the overriding consideration at this stage of the research was whether a particular conceptual formulation accomplishes the most complete linkage of the economic and ecologic systems of a region. Analysis of the operational feasibility of the model for the western Montana region forms the basis for the fourth and fifth specific research objectives.

The fourth research objective requires that the ideal model be examined for structural appropriateness for the economic and ecologic systems of western Montana; and modified when necessary to achieve a high degree of compatibility. The procedures employed in pursuit of this objective include the definition of the essential structure of these regional systems and the design of necessary modifications. Major considerations in the pursuit of this study objective included the definition of the spatial structure of the regional systems and determination of the most appropriate conceptual formulation for dealing with this structure (e.g. whether a regional or interregional configuration is most appropriate); the development of a scheme of sectors which provide the most accurate description of the regional economy and environment; and the selection of the most meaningful levels of aggregation within each sector.

The next step in analyzing the operational feasibility of the model for the western Montana region is to investigate the availability of data required for its operation.

In this study the decision was made to require that all data considered be readily available from secondary sources. This decision reflects the desire to provide a system for linking the economic and ecologic systems of western Montana that can be immediately implemented in the region. Procedures followed in pursuit of this objective are rather straightforward. They involved an examination of the modified economic-ecologic linkage model to determine specific data requirements for its operation; a survey of the secondary data sources relevant for western Montana to determine data currently available; and the design of further modifications of the model to reflect the absence of necessary information inputs.

There were no specific procedures followed in pursuit of the last research objective. Rather, information obtained at each preceding stage of the study was organized so as to provide a description of the best set of currently feasible operational procedures for linking the forest-centered economic and ecologic systems of western Montana. In addition, a detailed description of available data (including location) necessary for implementing the model in the region, and the types of information that the feasible model could provide, is presented.

## CHAPTER II

## REVIEW OF THE LITERATURE[1]

### Purpose

The first specific objective of this research requires the compilation of an annotated bibliography of literature concerned with modeling the linkages between economic and ecologic systems. A comprehensive investigation has produced several references to research efforts of this type. This information has been organized into an annotated bibliography which is provided in the appendix. In addition, the same information is presented here in essay form primarily for the reader who prefers this to reading the annotated bibliography. Also, it is felt that a literature review chapter maintains the continuity of the report.

To date, progress in modeling economic-ecologic linkages has been hampered, in part, by the fragmentary nature of published work on the subject. The review of these diverse offerings presented here emphasizes the current level

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[1]An annotated bibliography of the works discussed in this chapter appears in the appendix. Much of the material presented in this chapter also appears in: Louis W. Pompi and Daniel E. Chappelle, "Toward More Comprehensive Forest Management Planning: Modeling Economic-Ecologic Linkages in a Regional Context," (Department of Resource Development, Michigan State University, 1974) (Mimeographed).

of achievement in this important area of research. It is felt that such an overview will serve not only to bring this research together, thereby facilitating comparative evaluation of accomplishments, but, also, to aid in the identification of those problems which have not as yet been successfully approached. As previously noted, the literature review is also a necessary first step in pursuit of the overall objective of this research effort. Specifically, it is designed to provide information required to complete a comparative evaluation of alternative modeling approaches.

## Scope of the Review

There arises the problem of boundaries, i.e., deciding which studies to include for presentation in this chapter. All studies of interest in this context may be arranged along a generalized continuum running from those which are entirely devoted to modeling ecological systems (or some segment thereof) to those studies which deal exclusively with modeling aspects of economic systems. Thus the choice of any segment of this continuum for examination is, at best, an arbitrary one. However, major concern here is for the problem of modeling linkages that exist between the two systems. Therefore, the decision was made to include only those published research efforts that focus exclusively, or nearly so, on the linkage problem. Studies that deal primarily with modeling either economic or ecologic systems but include only a superficial treatment of the linkage problem have been excluded from this review. In addition, this chapter includes a discussion of only those models of a general nature. Many research efforts have focussed on a single sector of the economy (e.g., steel production, coal mining, etc.), the wastes generated by such activities and their impact on the environment.[2] Such studies, though numerous and important, have not been treated here. Other studies have been primarily concerned with examining impacts of residuals on the assimilative capacities of a single sector of the environment (e.g., water, air, or land). These very detailed studies have also been excluded from this review. Finally, research efforts which focus on one or a few specific residuals or pollutants have been left out of this discussion. Such exclusions do not imply that the work reviewed here is superior to that omitted, rather, they were necessary to restrict discussion to a manageable number of publications and to focus on the specific study objectives.

Work reviewed in this chapter does not, in all probability, provide and exhaustive listing. However, it is

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[2]Several input-output studies have emphasized the forestry sector. See for example: Jay M. Hughes, "Forestry in Itasca County's Economy: An Input-Output Analysis," Miscellaneous Report 95, Forestry Series 4, Agricultural Experiment Station, University of Minnesota, 1970. However these studies have not incorporated environmental analysis. Other efforts have focussed on the wastes generated by forestry-related activities. An example of this type of study is: U.S. Department of the Interior, Industrial Waste Guide: Logging Practices (Portland, Oregon: Federal Water Pollution Control Administration, Northwest Regional Office, 1970).

thought to be highly representative of the current level of progress in this important model building area of research. It should also be noted here that treatment of individual studies in this review has been necessarily brief. It is hoped that the essence of each individual effort is adequately related in the discussion to follow.

## Modeling Economic-Ecologic Linkages

An extensive examination of the literature has revealed that efforts to include the analysis of environmental linkages in economic models are comparatively recent. In response to the urgency of the problem, a number of researchers have advanced conceptual models which deal with these issues. As is usually the case with relatively new areas of research, there have been fewer applied studies than there have been conceptual efforts. Though the nature of the problem indicates that several types of models might be profitably applied (e.g., input-output models,[3] linear programming models,[4]

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[3]For detailed descriptions of input-output analysis see: W. W. Leontief (ed.), Input-Output Economics (New York and London: Oxford University Press, 1965); and W. Miernyk, The Elements of Input-Output Analysis (New York: Random House, Inc., 1965).

[4]For detailed descriptions of linear programming techniques see: George B. Dantzig, Linear Programming and Extensions (Princeton: Princeton University Press, 1963); and Saul I. Gass, Linear Programming: Methods and Applications (New York: McGraw-Hill Book Co., Inc., 1958).

simulation models,[5] or a variety of hybrid types composed of elements from each of these three basic models), a large part of the work thus far concentrates almost exclusively on an input-output approach.

Wassily W. Leontief, the originator of input-output analysis, has proposed some procedures for extending his basic models for the purpose of analyzing environmental phenomena.[6] Essentially, Leontief incorporates pollution abatement activities into the transactions matrix of the static, open, input-output model. However, this approach makes no provision for examining waste outputs which necessarily flow from waste treatment processes. A central feature of the "environmental problem" is that nonmarket flows of materials and energy accompany the economic flows of goods and services from the market processes. Thus, it is important that all materials and energy flows be identified and linked to specific economic activities if a satis-

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[5]For a general discussion of simulation techniques and operations see Francis F. Martin, Computer Modeling and Simulation (New York: John Wiley and Sons, Inc., 1968). For applications to economic systems see T. H. Naylor, et al., Computer Simulation Experiments with Models of Economic Systems (New York: John Wiley and Sons, Inc., 1971); and for applications to ecological systems see Kenneth E. F. Watt, Ecology and Resource Management: A Quantitative Approach (New York: McGraw-Hill Book Co., Inc., 1968).

[6]W. W. Leontief, "Environmental Repercussions and the Economic Structure: An Input-Output Approach," Review of Economics and Statistics, LII, (August, 1970), pp. 262-271; and W. W. Leontief and Daniel Ford, "Air Pollution and the Economic Structure," Fifth International Conference on Input-Output Techniques, Geneva, January 11-15, 1971.

factory analysis of economic-ecologic interrelationships is to be accomplished.

An early effort to develop a conceptual model depicting economic-ecologic linkages was made by Isard and his associates at the Harvard University Graduate School of Design. This research has been documented in a recently published book[7] and in two shorter published articles.[8]

Isard's approach relies heavily on extension of input-output techniques to include environmental as well as economic phenomena. While the major emphasis in this work appears to be on the development of a conceptual model, there is also limited empirical content in the publications. An important feature of Isard's approach is the attempt made to include not only economic activities and their waste emissions but, also, ecological relationships and measurement of the impact of wastes upon ecological systems. An example of the ecological relationships is the rather detailed discussion of the food chain associated with cod production to be found in the book.

Isard uses this model to demonstrate how traditional methods of regional analysis can be supplemented with eco-

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[7]Walter Isard, et al., Ecologic-Economic Analysis for Regional Development (New York: The Free Press, 1972).

[8]Walter Isard, et al., "On the Linkage of Socio-Economic and Ecologic Systems," Regional Science Association Papers, XXI, (1968), pp. 79-99; and Walter Isard, "Some Notes on the Linkage of the Ecologic and Economic Systems," Regional Science Association Papers, XXII, (1969), pp. 85-96.

logical data to make comparative cost studies of alternative configurations of spatial development. In particular, the Isard model is applied to problems of alternative recreational developments in a marine environment. It should be noted that Isard experienced great difficulty in obtaining data necessary to quantify ecologic and ecologic-economic relationships. Thus many cells in what he terms the "General Interrelations Table: Ecologic-Economic Analysis" are not filled.[9]

An early effort to extend regional input-output models to the analysis of environmental problems is the conceptual model developed by John H. Cumberland.[10] This model recognizes that each disaggregated economic activity potentially results in environmental impacts which may be evaluated in terms of benefits and costs. In addition, emphasis is placed on the economic accounting system which could be developed from the interindustry sectorization within the model. This system highlights such welfare variables as regional per capita real income and government revenues and expendi-

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[9] Isard, et al., Ecologic-Economic Analysis for Regional Development, pp. 96-107.

[10] John H. Cumberland, "A Regional Interindustry Model for Analysis of Development Objectives," Regional Science Association Papers, XVII, (1966), pp. 65-94. See also: J. H. Cumberland, "Application of Input-Output Techniques to the Analysis of Environmental Problems," Fifth International Conference on Input-Output Techniques, Geneva, January 11-15, 1971; and "Environmental Implications of Regional Development," Canadian Economics Association and Canadian Council on Regional and Rural Adjustment, Winnipeg, November 12-14, 1970.

tures. It is suggested that these variables can be compared with the environmental impacts associated with alternative regional development strategies and programs. The model does not, however, offer an integrated procedure for performing such comparisons.

Building upon this initial work, Cumberland and his colleagues at the University of Maryland, in conjunction with the Maryland Department of State Planning, are currently implementing an economic-environmental model in order to provide decision-makers with a more comprehensive information base for both planning and policy analysis. The progress of this research to date has been documented in two recent publications. The first of these,[11] discusses the design of a state planning model for Maryland that emphasizes economic-ecologic linkages. The initial phase of the design study proposes development of a short-run model comprised of a static, 100-order, input-output model for the state of Maryland, environmental coefficients, and a state economic accounting system. The operation of this model will involve multiplying the Leontief inverse matrix by the matrix of final demands and then multiplying the result of this computation by the matrix of environmental coefficients. Thus the economic outputs will be estimated

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[11]John H. Cumberland, et al., Design for a Maryland State Planning Model with Economic-Environmental Linkages (Baltimore: Maryland Department of State Planning, 1972).

by input-output matrix equation:

$$(X) = (I-A)^{-1} \cdot (Y)$$

where:

(X) = matrix of gross outputs

$(I-A)^{-1}$ = inverse of the identity matrix (I) minus the matrix of input coefficients ($A_{ij}$'s)

(Y) = the matrix of final demand elements.

These gross outputs will serve as the inputs into the environmental linkages model. Environmental linkages will be estimated by using outputs from the input-output model as inputs to the environmental model such that:

$$(GR) = (X) \cdot (GRC)$$

where:

(X) = matrix of gross outputs

(GRC) = matrix of $grc_{ij}$

$grc_{ij}$ = gross residual coefficient relating residual j to gross output of industry i, $i = 1,\ldots,n;\ j = 1,\ldots,m$

(GR) = gross residuals.

Net emissions are similarly calculated, such that:

$$(NE) = (X) \cdot (NEC)$$

where:

(NE) = matrix of net emissions

(X) = matrix of gross outputs

(NEC) = matrix of net emissions coefficients.

This model involves the development of a waste classification system and will be used to make short-run forecasts of the total materials flow and waste generation created by the activity levels of the state economy.

The second part of the plan proposes the development of a long-run, dynamic, interregional, interindustry model to be used in conjunction with a state and local revenue and expenditure model, also proposed for development. The long-run model is to be used for medium and long-range forecasting and is to be operated in essentially the same way as the short-run model except that state and county gross outputs and state and local accounts will be estimated recursively using industry location equations to forecast regional supply and demand for each industry in the model instead of the static interindustry model. The plan also proposes the use of diffusion models to estimate impacts of projected waste residuals on the environment.

A journal article by Cumberland and Korbach, provides a more general discussion of the Maryland research on economic-ecologic linkages.[12] The stated purpose of this paper is to:

> . . . take some preliminary steps in the direction of providing local areas with an operational model and with appropriate sets of data which will permit them to compare the probable impacts of alternative programs of regional development and to compare the

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[12]John H. Cumberland and Robert J. Korbach, "A Regional Interindustry Environmental Model," Regional Science Association Papers, XXX, (1973), pp. 61-75.

> expected economic benefits with probable environmental and other costs of development.[13]

Included in this paper are discussions of the development of a state economic-environmental planning model, a theoretical model of the processes involved, an environmental accounting system upon which the model is based, and a summary of empirical results currently available.

In their model, Cumberland and Korbach assume linearity. Specifically, they assume that waste loads generated from particular production processes are directly proportional to the amount of economic output produced. An interindustry, input-output model similar to that developed in Cumberland's previous work is employed to generate expected levels of economic output from each sector of the regional economy. These empirical estimates are used to drive a waste-flow model. Seven specific waste flow equations comprise this model. The general form for these equations is:

$$P_{jk} = P_{ijk}X_i$$

where: $P_{jk}$ = amount of pollutant j in matrix k expressed in thousands of tons,[14]

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[13]Ibid., pp. 62-63.

[14]The term "matrix k" refers to seven separate matrices (one for each waste flow equation) of pollution coefficents by type and economic sector.

$P_{ijk}$ = pollution coefficient expressed in thousands of tons of pollutant _j_ in matrix _k_ per millions of dollars of output from industry _i_,

$X_i$ = output of industry _i_ in millions of dollars (from the interindustry model).

Each of the seven specific equations corresponds to a waste flow monitoring point and serves to estimate flow of waste materials at various places in the regional economy and environmental system, e.g., gross residuals, treated and untreated wastes, recycled waste, and waste discharged to environmental receptors (land, air, and water). The authors have derived empirical estimates of matrices of the seven pollution or waste coefficients ($P_{ijk}$) but these are not published in the paper.

In keeping with the operational focus of the research, Cumberland and Korbach discuss adaptions and uses, a sample application, and limitations of the model as well as a section on policy implications of regional environmental models. In particular, four limitations of the model are treated: 1) the linearity assumption; 2) the exclusion of residuals generated by the final consumption sector from the accounting framework; 3) the absence of coefficients for energy emissions such as heat, noise, and radiation; and 4) the use of national waste coefficients in a regional model.

A similar effort is the economic-environmental model developed by Elihu Romanoff which attempts to identify relationships between economic development and environmental impacts for a specific river basin.[15] Romanoff uses a static input-output model in conjunction with matrices for water supply and sewage removal. The model is partitioned into sub-areas and separate reaches of the river. Changes in water quality are related to alternative pollution abatement practices. The model makes use of feedback characteristics to emphasize that increased local activity and local efforts to adopt antipollution policies themselves generate increased economic activities which, in turn, add to the pollution load. Romanoff's methods make it possible to simulate regional growth and its impact on environmental quality since the model explicitly deals with general equilibrium relationships between geographic location, industry structure, and water quality.

Some of the most elaborate and comprehensive economic-ecologic models to date are those developed by Robert U. Ayres, Allen V. Kneese and their colleagues at Resources for the Future, Incorporated. The first published report of this research effort appeared in a paper by Ayres and Kneese.[16] The initial ideas offered in this article have

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[15] Elihu Romanoff, "The Interdependence of a Regional Economy and a River," Fifth International Conference on Input-Output Techniques, Geneva, January 11-15, 1971.

[16] Robert U. Ayres and Allen V. Kneese, "Production, Consumption and Externalities," American Economic Review, LIX, No. 7 (June, 1969), pp. 282-297.

since been refined and developed into a rather complete large-scale economic-ecologic conceptual model.[17] This work significantly contributed to the fundamental understanding of environmental problems by pointing out that matter is not destroyed but rather is changed in form, and thus a "materials balance approach" (i.e., materials discharged by the economic system must be approximately equal in weight to those that entered this system) is appropriate. Ayres and Kneese emphasize the fact that all production and consumption activities either directly or indirectly result in non-economic (i.e., extra-market) flows of materials and energy which are discharged into common property resources, thereby creating external diseconomies. The materials balance concept in combination with this notion of the pervasiveness of production and consumption externalities constitutes the essence of the environmental problem.

A static input-output model, extended to include intermediate consumption, forms the basis for an expanded model. The expanded model includes recycling and emphasizes externalities as physical exchanges which are not matched by market flows, thereby creating a divergence between private and social costs.

The model is then reformulated through development of an objective function and functional constraints to conform

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[17] Allen V. Kneese, Robert U. Ayres, and Ralph C. d'Arge, Economics and the Environment: A Materials Balance Approach (Baltimore: The Johns Hopkins Press, Inc., for Resources for the Future, Inc., 1970).

to a linear programming format. This model is designed to achieve Pareto optimality in each sector by fully accounting for all material flows and estimating environmental taxes on production and consumption necessary to equate marginal social benefits and marginal social costs.

Ayres and Kneese recognize that their model does not avoid certain conceptual difficulties which stem from the necessary assumptions of the model, such as the acceptance of existing income distribution and the existence of less than fully competitive markets. In addition, unrealistic assumptions concerning non-substitutability of environmental resources also create problems. Perhaps of even more concern to resource managers and planners are problems that would be encountered in implementing the Ayres-Kneese model. Among these problems are the need to simulate ecological relationships, high cost of acquiring essential data, and operational dependence upon knowledge of the utility functions of individuals. In addition, in order to generate prices for environmental services (i.e., to design a system of taxes, subsidies, or other forms of control) that would achieve Pareto optimality while retaining advantages of decentralized decision-making by both producers and consumers, accurate and complete information would be needed on materials balances and economic interdependencies.

A short paper by Converse criticizes the Ayres and Kneese model on grounds that it does not correctly account for individual waste residues from various production sectors.[18] Converse feels that a modest change would overcome this objection. He notes that in the usual production sectors of the Leontief input-output model, inputs are set by the output from that sector. However, in an extended model involving waste inputs to the environmental sector, the inputs are set by the outputs of other sectors. Converse finds that relationship absent from the Ayres-Kneese formulation. He suggests revising the model so that flow of waste residuals from each production sector to the environment is given by multiplying the ratio of the waste residuals to the non-waste commodity in that sector by the flow of non-waste commodity from that sector. In the original formulation the ratio of waste residuals to non-waste commodity is multiplied by the total mass of residuals discharged to the environment.[19]

Converse offers further modifications which he feels would allow one to account for the various types of waste residues from both production and consumption activities. He feels that the ". . . need for such detail is caused by the specific activities of the various residues ($CO_2$ is significantly different from CO).[20] Converse also notes that pollution treatment, while changing the composition of

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[18]A. O. Converse, "On the Extension of Input-Output Analysis to Account for Environmental Externalities," The American Economic Review, LXI, No. 1 (1971), pp. 197-198.

[19]Ibid., p. 197.

[20]Ibid., p. 198.

the waste residue, also increases the total amount of waste since treatment processes generate waste themselves. Hence any analysis that considers only the total amount of waste residue will be unable to evaluate pollution control measures.

Noll and Trijonis have also suggested modifications of the Ayres-Kneese model.[21] These modifications are essentially proposals for generalizing the Ayres-Kneese formulation to make it more realistic and applicable to pollution policy. Four specific extensions are suggested: 1) separating "residues" from "pollutants" and including the complex relations between these two catagories (much of which Noll and Trijonis claim is lost through the mass balance approach which neglects differences in the impacts of the various types of pollutants on the environment and public health and which ignores interactions among residuals and pollutants); 2) including pollution abatement as a final demand, sometimes in the form of a collective good and as a constraint on the production system; 3) freeing the fixed relationship between goods and consumer services by recognizing that in consumption, like production, opportunities exist for switching to different methods of producing "goods characteristics;"[22] and 4) correcting the equation

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[21]Roger J. Noll and John Trijonis, "Mass Balance, General Equilibrium, and Environmental Externalities," _The American Economic Review_, LXI, No. 4 (September, 1971), pp. 730-735.

[22]_Ibid._, p. 735.

representing the effect of pollution on production to avoid the necessity of pollution as an input that is implicit in the Ayres-Kneese model. Some of the changes proposed by Noll and Trijonis would involve introducing nonlinear equations into the Ayres-Kneese model thus complicating the investigation of mathematical conditions for equilibrium. However, Noll and Trijonis maintain that the introduction of ". . . such complexities are necessary if the model is to be relevant to pollution abatement planning."[23]

Clifford S. Russell and Walter O. Spofford, Jr., also associated with Resources for the Future Incorporated, have attempted to improve the operational capabilities of the Ayres-Kneese model for application to a particular region.[24] As in the Ayres-Kneese formulation, a static input-output model is used as a basis for constructing an environmental-economic linear programming model. The complete model emphasize three elements or component models (see Figure II.1): 1) a linear programming industry model that relates inputs and outputs of the various production processes and consumption activities at specified locations within a region, including unit amounts of types of residuals generated by the

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[23] Ibid.

[24] Clifford S. Russell and Walter O. Spofford, Jr., "A Quantitative Framework for Residuals Management Decisions," In Environmental Quality Analysis: Theory and Method in the Social Sciences, ed. A. Kneese and B. Bower (Baltimore: Johns Hopkins Press for Resources for the Future, Inc., 1972), pp. 115-179.

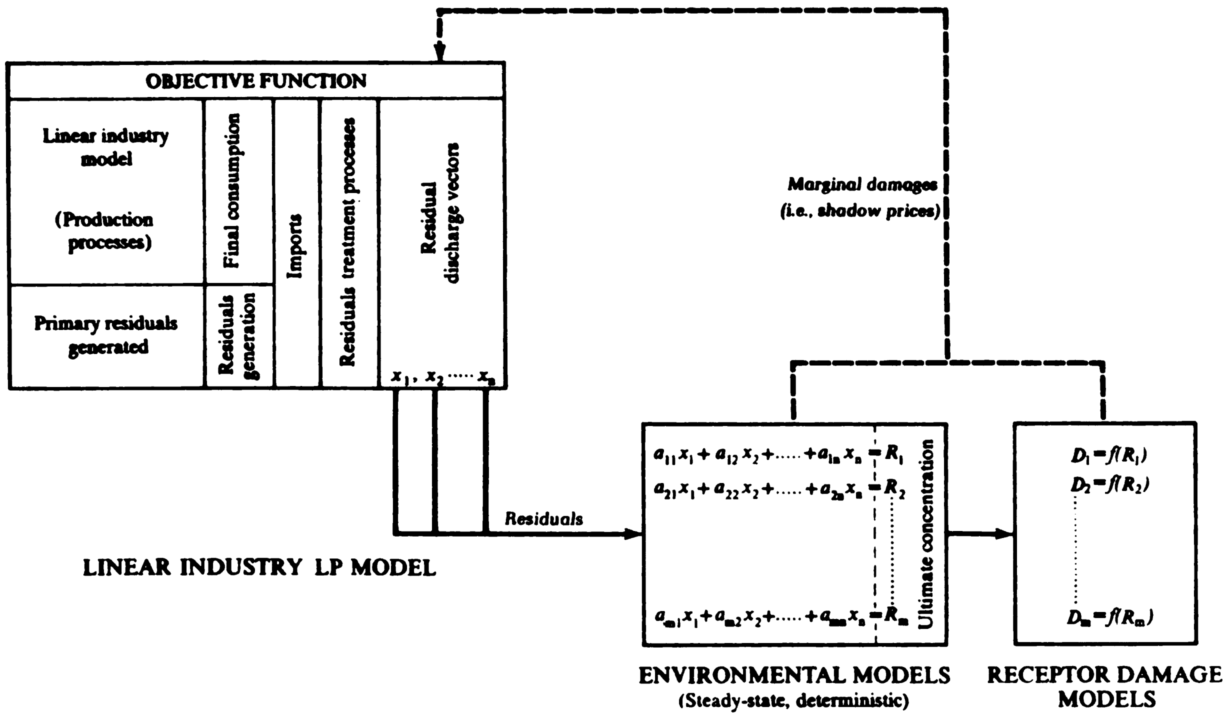


Figure II.1.--Schematic Diagram of the Russell-Spofford Residuals-Environmental Quality Planning Model

Source: C. S. Russell and W. O. Spofford, Jr., "A Quantitative Framework for Residuals Management Decisions," Environmental Quality Analysis: Theory and Method in the Social Sciences, ed. A. Kneese and B. Bower (Baltimore: Johns Hopkins Press for Resources for the Future, Inc., 1972), p. 123.

production of each product, costs of transforming these residuals from one form to another (e.g., gaseous to liquid in the scrubbing of stack gases), costs of transporting the residuals from one place to another, and cost of any final discharge-related activity such as landfill operations; 2) environmental diffusion models which describe the dispersion of various residuals through the biosphere after their discharge into the environment. Essentially, these models may be thought of as transformation functions operating on a vector of residual discharges and yielding another vector of ambient concentrations at grid points throughout the environment. Between discharge point and receptor locations, the residual may be diluted in the relatively large volume of air or water in the natural world, transformed from one form to another (as in the decay of oxygen-demanding organic material), accumulated or stored and, of course, transported to another place; 3) a set of receptor-damage functions relating residuals concentrations in the environment to resulting damages, whether these are sustained directly by humans, or indirectly through the medium of such receptors as plants or animals in which man has a commercial, scientific, or aesthetic interest. To simplify computational procedures associated with running their model, Russell and Spofford decided to view all relationships as linear functions. To work entirely with linear relationships they had to assume that: 1) the economic world is static so that time does not enter as a decision variable in the production model; 2) the relationships in the model are deterministic and steady state; 3) no interaction takes place between residuals; and 4) the environment cannot be modified to change its waste assimilation capabilities.

The model is run, essentially, in an iterative fashion. In the first iteration the linear programming model is solved with no restrictions or prices on the discharge residuals. The initial set of residual discharges generated by this first round are then entered as inputs to the environmental diffusion models and the resulting ambient concentrations enter as arguments in the receptor-damage functions. Ambient concentrations and damage values are then used to calculate marginal damages attributable to each residual discharge, i.e., change in total damages that would result if that discharge were changed by a small amount. These marginal damages are then applied as interim effluent charges on discharge activities in the industry model and that model is solved again (second iteration) for a new set of production, consumption, treatment, and discharge values.

Russell and Spofford intend to use their model to choose levels of production, consumption, treatment activities, and resulting damages that optimize a given regional economic objective. They suggest that, at least initially, this objective be maximization of regional economic efficiency. The general form of their objective function consists of six parts: 1) gross consumption benefits, i.e., total willingness to pay, B; 2) opportunity costs of traditional production inputs (including recycling, etc.), $C_p$; 3) residual treatment costs, $C_{RT}$; 4) costs of modifying the environment to reduce receptor damages, e.g., in-stream reaeration and low-flow augmentation, $C_{ME}$; 5) costs of final protective measures, e.g., water treatment facilities, $C_{FP}$; and 6) subsequent damages to man caused by ambient concentrations of residuals in the environment, D. Thus:

$$F = B(q_i,\ i=1,\dots,k_1) - C_p\ (q_i,\ i=1,\dots,k_1) - C_{RT}(w_i,\ i=1,\dots,k_2) - C_{ME}(s_i,\ i=1,\dots,k_3) - C_{FP}(R_i,\ i=1,\dots,k_4;\ y_i,\ i=1,\dots,k_4) - D(y_i,\ i=1,\dots,k_5)$$

where:

- $F$ = value of the objective function;
- $q_i$ = activity levels of $k_1$ production processes;
- $w_i$ = activity levels of $k_2$ residuals treatment processes;
- $s_i$ = activity levels of $k_3$ processes for modifying the environment;
- $R_i$ = ambient concentrations of residuals at $k_4$ receptor locations; and
- $y_i$ = ultimate ambient concentrations of residuals resulting in damages to receptors at $k_5$ locations.[25]

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[25]Subsequently, the objective function is revised to reflect other considerations. The last term in the revised equation then becomes: $DC(s_i,\ i=1,\dots,k_6; s_i,\ i=1,\dots,k_3)$, where DC represents the minimum of receptor damages plus costs of final protective measures and $x_i$ = activity levels of $k_6$ residual discharge activities (as in Figure II.1).

While this function is ordinarily nonlinear, the authors state that very often it is possible to transform a nonlinear function into a piecewise linear form. If the constraint set is also linear, the problem may then be solved as a standard linear programming problem.

Russell and Spofford provide an application of their model to a hypothetical region. This example serves to illustrate not only the usefulness of the procedure but, also, the amount and quality of data essential to its operation. The authors also note that it is likely that for the foreseeable future damage functions will be unavailable for the effects of most residuals that concern decision makers. They suggest that under these conditions one entirely respectable alternative is to calculate costs of meeting several different sets of standards on ambient concentrations. The decision on exactly which standard set should be selected involves, then, an implicit judgement, by the public or its elected or appointed representatives, on marginal benefits (i.e., reduction in damages), weighed against an explicit measure of costs. The authors concede, however, that when dealing with a number of residuals and of locations at which concentrations are constrained, the problem of choosing a relatively small number of alternative quality standards becomes rather difficult.

The methods of Russell and Spofford differ from those of Ayres and Kneese and their colleagues in three important respects: 1) the input-output and environmental dif-

fusion elements of the model can be run independently; 2) the model does not require a complete materials balance equality; and 3) separate river and air reaches are dealt with as in the approach employed by Romanoff.

A large continuing research effort is being conducted at Michigan State University under the direction of Herman Koenig (an electrical engineer and systems scientist) and William Cooper (a zoologist and systems ecologist). This study is perhaps unique in that a wide range of disciplines and interests is represented on the research staff. Indeed, a major theme of the project emphasizes the need for an eclectic approach to environmental problems.[26]

While the Michigan State project embraces a broad range of environmental topics, a growing awareness of the general concept that the externalities of agricultural production and materials processing activities in combination with the waste from consumption activities of a dominating human population are approaching and locally (i.e., regionally) surpassing the capacity of the environment to process

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[26]For a general discussion of the goals and objectives of this project see: H. E. Koenig (principal investigator), Ecosystem Design and Management, a research proposal submitted to Research Applied to National Needs, National Science Foundation, by the College of Engineering, College of Natural Science, and College of Agriculture and Natural Resources, Michigan State University, East Lansing, Michigan, 1971. See also: H. E. Koenig, W. E. Cooper, and J. M. Falvey, "Engineering for Economic, Social, and Ecological Compatibility," IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-2, (September, 1971), pp. 449-459.

them, has prompted efforts to identify linkages between the economic and ecologic systems. The nature of the research on this problem is well represented in a paper by Tummala and Connor.[27] In this "semi-tutorial" paper, methods are developed for a coordinated analysis of the mass-energy and economic characteristics of physical production processes. The approach taken is based on the concept of materials and energy balance. The model developed in this study is a modified classical input-output model. The slight modification involves reformulating labor as an energy cost, rather than a flow of services. By then considering labor as a nonrenewable resource (i.e., a manhour spent on a given task is lost forever), the authors feel that their model is made structurally more consistent with both ecological and physical constructs. This rather minor conceptual shift yields two other important advantages: 1) it sets the foundations for the direct application of well-developed theories in engineering (particularly network theory); and 2) it simplifies computation procedures by transforming fundamentally nonlinear economies of scale into additive terms which are shown to be mathematically tractable at all levels of analysis and aggregation. An example is provided showing the application of the models

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[27]Ramamohan L. Tummala and Larry J. Connor, "Mass-Energy Based Economic Models," a research report on Design and Management of Environmental Systems, submitted to Research Applied to National Needs, National Science Foundation, under Grant GI-20.

developed to a hypothetical situation having two material transformation processes connected by a transport network. The paper also contains some discussion of the policy implications of the study.

Eugene Laurent and James Hite have completed an economic-ecologic analysis of the Charleston, South Carolina metropolitan region in which the major focus was on empirical content.[28] Recognizing the need to expand regional planning in response to concern for environmental planning, the authors draw on previous conceptual research to build and run a model of a regional economic-ecologic system.[29]

Laurent and Hite develop a 31 sector economic input-output model based on the Leontief approach for the Charleston region. The general model is completed with the addition of an Isard-type economic-ecologic model, modified so that it can be applied empirically. The environmental matrix has a column for each endogeneous sector of the input-output matrix and 17 rows, each of which represent either a natural

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[28] Laurent and Hite, op. cit., pp. 1-89

[29] For example: J. C. Hite and E. A. Laurent, Economic Analysis and Environmental Goods (Washington: Coastal Plains Regional Commission, June, 1970), and J. C. Hite, "Water Resources Development and the Local Economy: Some Conceptual Considerations," Minutes of the Southern Regional Economists Workshop, Columbia, South Carolina, Attachment No. 5, February, 1969. See also: J. C. Hite and E. A. Laurent, "Empirical Study of Economic-Ecologic Linkages in a Coastal Area," Water Resources Research, VII, (October, 1971), pp. 1070-1078, and E. A. Laurent and J. C. Hite, "Economic-Ecologic Linkages and Regional Growth: A Case Study," Land Economics, XLVII, No. 1 (February, 1972), pp. 70-72.

resource input into the Charleston area economy or an emission from the economy into the environment. Coefficients in this matrix are positive for inputs and negative for emissions.

After collecting required data, the Leontief inverse of the input-output matrix is computed. The economic model is then linked to the environmental matrix by post-multiplying the environmental matrix by the inverse of the Leontief matrix. This operation yields what the authors label an "R-matrix" which has coefficients representing direct and indirect environmental impacts of each economic sector as it meets its portion of final demands. The authors then derive income multipliers from the input-output tables and divide these multipliers into the R-matrix. This operation yields what are termed resource-income or environmental-income multipliers, which are said to show the direct and indirect environmental linkages per dollar of local pecuniary income generated by the various economic sectors.

While this study provided no new conceptual insight, it is noted here because of its empirical content. Laurent and Hite have shown that models of economic-ecologic linkages can be profitably applied to regional planning problems. The paper also contains discussions of data sources, aggregation problems, and assumptions necessary for empirical application of the model.

Recent work by Ralph C. d'Arge and his colleagues at the University of California at Riverside has resulted in a series of working papers on the subject of environmental economics. Two of these papers are particularly relevant for the purposes of this paper. D'Arge and Kogiku begin by developing a simple model of waste generation based on the conservation of matter-energy principle with consumption behavior of the economy's inhabitants assumed to be predetermined.[30] Essentially, they model material and waste flows as being linearly related to total income measured in material units (e.g., tons of steel). The authors recognize that the assumption of linearity in this case is highly restrictive. Most important, it specifies an implied technology relating output to raw material inputs. In subsequent sections of the paper, the model is generalized to an "optimal control problem," where consumption and waste generation are allowed to be optimally regulated, and an attempt is made to integrate non-mutually exclusive processes of resource extraction and waste generation.[31] With each refinement the simple initial model becomes increasingly complex.

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[30]R. C. d'Arge and K. C. Kogiku, "Economic Growth and the Natural Environment," Program in Environmental Economics: Working Paper Series, Working Paper No. 1 (Riverside, California: University of California, Department of Economics, April, 1971).

[31]*Ibid.*, p. 2.

James E. Wilen notes that much more research is needed in defining environmental objectives, determining the nature of man-environment interaction, and devising sets of environmental quality indicators which measure the extent of that interaction.[32] In dealing with these questions in his paper, Wilen finds it useful to develop a model which is basically an extension of the materials balance approach. The basic model is extended so as to include an ecological system with corresponding linkages. The model employed is an input-output type model in which a vector of mass and energy inputs is transformed into what Wilen calls "Gross Ecosystem Product",[33] i.e., a measure of production which represents an ecosystem's ability to support life. In such a model, the earth's biosphere is viewed as containing, at any moment, a fixed amount of mass and potential energy from which both economic product and ecosystem product are produced. Production in both the economic and ecologic systems is thus linked by the mass-energy vector which enters both systems as an input. Wilen traces further linkages pertaining to residual flows and energy transfers between systems. Figure II.2 provides a schematic of the linkages involved in the Wilen model.

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[32] James E. Wilen, "Economic Systems and Ecological Systems: An Attempt at Synthesis," Program in Environmental Economics: Working Paper Series, Working Paper No. 10 (Riverside, California: University of California, Department of Economics, April, 1971).

[33] Ibid., p. 7.

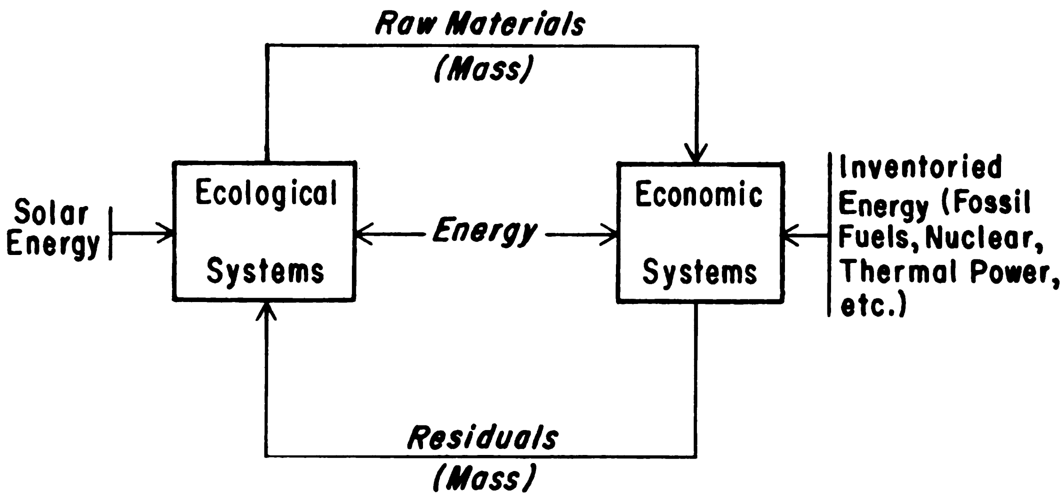


Figure II.2.--Schematic Diagram of Economic-Ecologic Linkages in the Wilen Model

Source: J. E. Wilen, "Economic Systems and Ecological Systems: An Attempt at Synthesis," Program in Environmental Economics: Working Paper Series, Working Paper No. 10 (Riverside, California: University of California, Department of Economics, 1971), p. 12.

A paper by Young P. Joun attempts to identify information requirements for various economic-ecologic models.[34] While Joun's paper provides no new conceptual insight regarding such models, it is noted here for its realistic appraisal regarding their potential for implementation. This paper would be of particular interest to planners who are considering applying these models to real-world situations. Lack of empirical work to date might lead one to believe that all models discussed in this section can be readily operationalized. Joun's evaluation quickly dispells such thoughts.

Joun classifies ". . . recent attempts to quantify social costs" into three categories: 1) those which attempt to measure "quality of life" and monitor changes in so-called "social indicators"; 2) those which attempt to introduce explicitly nonmarket variables into interindustry or ecological models and study environmental repercussions of economic growth or those which propose to build a social accounting system which includes a complete description of ecological chains and investigates interrelationships among them; and 3) those which attempt to construct a mathematical model which shows the consequence of a rapidly rising population on society and the natural environment.[35] Models

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[34]Young P. Joun. "Information Requirements for Socio-Economic Models," The Annals of Regional Science, V, No. 1 (June, 1971), pp. 25-32.

[35]*Ibid.*, p. 25.

discussed above correspond, generally, with Joun's second category.

Joun's paper contains a brief description of various socio-ecological models and their data requirements. Based on his research, Joun is able to reach several conclusions that are of particular interest here. First, he feels that there is an enormous gap between the need for data on the "quality of life" and actual supply of such data. Second, he concludes that conceptual model building, by identifying data requirements, delineates characteristics of statistical information systems that should be established for the purpose of closing this gap.

## Observations

It is obvious from the foregoing discussion that a rather large number of alternative procedures have been developed for modeling economic-ecologic linkages. One observation of particular interest here is the absence of any published work on modeling linkages between forest-centered economic and ecologic systems. While this does not stand as a criticism of either the research discussed in this paper or researchers in the fields of forest ecology, forest economics, forest management and policy, etc., it does indicate that there is much to be done if planning for forest management is to become more comprehensive. Research along these lines is also necessary if alternative management strategies are to be adequately tested before a choice is made for implementation.

Another interesting feature of the work completed to date on this problem is that in most economic-ecologic models, either the economic sectors or the sub-models representing the economic system are more fully developed than those portions dealing with the environment. Several factors might help to explain this difference. First, it should be noted that economics had been firmly established as an academic discipline and field of research for a much longer period of time than has the field of ecology as it is presently defined.[36] Therefore, theoretical structure and hence conceptual model building of a general nature in economics has received considerably more attention than these same topics in the science of ecology. Indeed, models of economic systems such as input-output analysis can be traced back as far as two centuries ago when Quesnay published the Tableau Economique, which recognized the existence of broad interrelationships within an economic system.[37] However, the real basis for most modern general equilibrium analysis is attributed to the work of Leon Walras. Walras was interested in simultaneous solutions to such questions as what is to be produced, how much is to be produced, and the transaction prices of all goods and ser-

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[36]It should be noted that ecology has been recognized as a specialized field of biology since the 1890's, though not, perhaps, as it is presently defined.

[37]Phillip C. Newman, The Development of Economic Thought (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1952), pp. 34-40.

vices at equilibrium. He developed a general equilibrium model of an economic system based on a series of simultaneous equations each of which represents a good or service produced by the system.[38]

In contrast, the presently defined field of ecology has, as noted previously, only recently emerged. Historically, topics encompassed by this field have been dealt with separately by researchers in many different disciplines (e.g., zoology, botany, geology, hydrology, meteorology, etc.). As one would expect, such fragmentation has hampered the development of general models of ecologic systems. Thus one finds that most models of economic-ecologic linkages are extensions of general equilibrium type economic models, and in one sense are simplifications of the grandiose general equilibrium models envisioned by Walras. In these models it is generally the case that the economic system is represented in more detail than is the ecologic system. In those conceptual models that have attempted to develop more detailed representations of ecologic system, the problem of identifying environmental sectors and describing interaction between these sectors has proved difficult.

In addition, it should be noted that the early development of general equilibrium theory in economics has provided a framework for data collection. The primary effort in

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[38] William Spiegal, The Development of Economic Thought (New York: John Wiley and Sons, Inc., 1952), pp. 581-591.

making the conceptual general equilibrium models operable in economic analysis has been the input-output technique which was initially developed by Leontief[39] and has subsequently undergone continuous development and application by Leontief and many others. The Federal government, state governments, and some local governments have sponsored data collecting activities to drive these input-output models. Consequently, both national and regional information systems have been developed, implemented, and operated on a sustained basis in the case of economic variables, but not for environmental variables. Thus data for operating models of economic systems are and have for some time been available in a well-organized, detailed format. Clearly, the availability of economic data has aided in the development of analytical models of economic systems, while the absence of such data for environmental systems has had the opposite impact on the development of ecological models.

Related to this discussion of model development is the dominance of the conceptual model in the literature of economic-ecologic linkages. There has been very little work of an empirical nature to date. Many of the studies discussed in the previous section do contain limited empirical content; but the primary focus is on conceptual modeling. This is probably due in part to the fact that interest in

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[39]W. Leontief, "Quantitative Input-Output Relations in the Economic System of the United States," The Review of Economics and Statistics, XVIII, (August, 1936), pp. 105-125.

economic-ecologic linkages is a rather recent development. Also, one could point to data requirements, both in terms of large quantity and high quality, for such models as a barrier to empirical analysis. At any rate, it is obvious that conceptual development of economic-ecologic models has proceeded well beyond empirical testing and problematic application of these models. The gap here is so large as to suggest that perhaps more research resources should be committed to this empirical work, even if these resources must be channeled away from further conceptual refinement. At present, it appears that there is sufficient conceptual development to allow resource managers opportunities to begin implementation of these models in response to real management decision problems.

The few attempts to use the models for empirical analysis have indicated that currently available data are inadequate for this purpose. In attempts to implement even the least detailed or simplest models, one is likely to confront severe problems in obtaining an adequate data base. Conceptual models provide a good description of the data required to quantify economic-ecologic linkages and an organizational framework for collecting such data. This suggests that a high priority need in this area is the improvement of data available to researchers, planners, and managers in the natural resources fields.

It is also interesting to note that most models developed to date have been designed primarily for application

in a regional context, (e.g., a metropolitan area, a watershed, a county or group of counties, a state, etc.). This is probably an attempt on the part of researchers to reduce the complexity of problems under study to a manageable level. However, this type of approach is quite appropriate since many important economic and environmental problems are of a primarily regional or local nature. The geographical distribution of such phenomena as environmental pollution and unemployment is often of greater importance than a general explanation of their occurrence. This importance of space (or location) as a factor in economic and environmental problems may necessarily lead one to a regional approach to a solution of these problems. In addition, it should be mentioned that while national economic models (e.g., national input-output models) have been used for some time, they have no counterparts in the ecologic system.

The review contained in the previous section indicates that, depending upon which type of model is employed, a variety of questions concerning both economic and ecologic impacts of resource management decisions can be answered in various degrees of detail. The fact that a number of alternative approaches exists suggests that a choice can be made from among these alternatives. If one is to make an informed choice, he must define in detail his objectives, including the specific questions for which he is seeking answers. Consideration here should not be restricted to defining which questions one would like to have answered, but rather, it should be extended to include an evaluation of the importance of having these answers or, conversely, of the costs of not having them.

## CHAPTER III

# A COMPARATIVE EVALUATION OF ALTERNATIVE MODELS FOR REPRESENTING ECONOMIC AND ECOLOGIC SYSTEMS

## Identifying the Alternative Models[1]

It is apparent from the foregoing literature review that at least four general types of models have been developed and offered as means for representing economic-ecologic linkages on a regional basis. Models based on the traditional static input-output (I-0) or interindustry model form the first group. In essence, the I-0 model involves manipulation of a matrix of coefficients representing some measure of the volume of transactions between different sectors of a regional or national economy. These sectors are often referred to as the processing or endogeous sectors and the payments (e.g., labor supplied by households) and final demands (e.g., government purchases) sectors which are exogenous. The solution of the model

[1]Much of the discussion in this section was adapted from: Louis W. Pompi and Daniel E. Chappelle, "Linking the Forest-Centered Economic and Ecologic Systems of Western Montana: A Progress Report," paper presented at the Economic Models for Management of Natural Resources Workshop, Big Sky, Montana, June 9-11, 1974.

yields estimates of the total requirements in terms of output from the processing sector necessary to meet a unit measure (e.g., one dollar) of the exogenously determined final demands. Several different types of multipliers can be computed from information contained in an I-0 solution. In general, multipliers have been used to estimate impacts on regional income and employment resulting from a given change in final demands.

Most modifications of the basic I-0 model to incorporate environmental linkages involve either addition of rows to the payments sectors and columns to the final demands sectors of the transactions table or multiplication of the direct and indirect coefficients matrix by a matrix of coefficients representing the amount of material each industry in the processing sector transmits to the local environment per unit of output from that industry (output here refers to economic or market output). If the model is to be further extended to account for those linkages existing between final consumption and the environment, this is usually accomplished by multiplying the final demands matrix by a matrix of coefficients representing the amount of residuals generated per unit of final consumption in each of the final demands sectors. Choice of methods depends to a large extent on the number of sectors involved and level of aggregation within each sector. These models yield estimates of the amount of materials (wastes or residuals) contributed to the environment by each of the processing sectors as it meets its portion of final demands and, if the model is so extended, provides estimates of residuals contributed by each of the final demands sectors in the process of consuming outputs of the processing sectors. Some multipliers may also be reformulated to provide environmental impact estimates. However, usefulness of these estimates is often dependant upon the degree to which the environmental sector is disaggregated in the model. In general, modified I-0 models yield estimates of flows of materials and energy from the processing and final demands sectors to the environment that result from meeting a given set of final demands for a region. Such models do not, generally, incorporate any measure of the capacity of the environment to assimilate these material or energy residuals.

A well formulated regional I-0 model will provide much useful information of environmental significance for a relatively reasonable data requirment. It also has the advantage of relative computational simplicity. However, many of the most critical limitations of the I-0 approach stem from this simplicity. One major limitation results from the static nature of the model. In holding the technical coefficients in the model constant, it is not possible to incorporate such variables as scale economies, changes in technology, productivity increases, price responses to changes in final demand, or any other influence which varies over time. Some of these difficulties can be overcome if the model is run in an iterative fashion, with appropriate changes in the coefficients being made before each iteration. However, such procedures involve more information and computation thus detracting from the simplicity aspect of the model.

Another limitation is the absence of any means of including a specific objective function or specific constraints of a functional nature in the model.[2] Thus, it is not possible to solve the I-0 model for a solution which optimizes on some criterion or set of criteria, nor is it possible to consider explicitly any resource limitations such as the waste assimilative capacity of the environment.

Another group of models includes those which use a linear programming (LP) format as their basis. To develop a comparable LP model, one must have all of the information necessary for I-0, plus an explicitly specified objective function and set of functional constraints. Thus the LP model generally requires more information (i.e., information related to the specification of the objective function and constraint set) and, even more important, explicit definition of societal goals and constraints. However, using this type of model has certain advantages. It is possible to account for substitutibility of resource inputs, a feature not associated with I-0. A very valuable feature of

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[2]It should be recognized, however, that the I-0 model does include the implicit objective function of developing the production scheme that exactly satisfies the exogenously determined final demands.

ese models is the ability to optimize (i.e., either maxi-
ze or minimize) a linear function subject to a set of
near constraints in the form of linear inequalities. Thus
eration of the model might yield a solution showing the
ximum amount of output that could be obtained from each
dustry in the region if all the functional constraints
hich might represent resource availability or environ-
ntal assimilative capacity) are to be met.

While it is a much more powerful model than I-0, the
model has certain limitations which in general stem from
s necessary assumptions. The assumption of linearity
mands that the ratios between any two inputs and between
y input and output are fixed and hence independent of
vel of production.[3] In addition, linearity means that
oduct prices are assumed constant and independent of out-
t. The linearity assumption, however, is not so restric-
ve as it might appear to be. It does not, for example,
quire that constant returns to a given variable factor
ld. Diminishing returns can be incorporated into the LP
del by specifying additional processes within a given
terprise. Scale economies may be dealt with in much the
me way, i.e., a process of size A may be distinguished
om one of a larger size B even though both require the

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[3]Robert Dorfman, Application of Linear Programming to
e Theory of the Firm (California: University of California
ess, 1951), p. 81.

same input mix. Also, nonlinear programming has been developed to handle cases where product prices are expressed as a function of output.

The assumption of additivity requires that the individual processes must be additive in the sense that when two or more are used their total product must equal the sum of the individual products.[4] This assumption means that no interaction between certain inputs can occur. If there is interaction then the entire combination must be treated as a single process. The additivity assumption also implies that the sum of inputs for each process is equal to the total resource requirement.[5]

As in the case of I-0 models, LP models are readily run on high speed electronic computers. Solution is accomplished via a variety of algorithms developed for this purpose. Perhaps the most popular computational procedure for solving LP models is called the simplex method, and was presented by George Dantzig of the U.S. Air Force operations research group. As noted previously, LP models, in general, require higher levels of both quality and quantity of data inputs than are required for I-0 formulations. In return for these higher information requirements, the researcher

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[4] Earl O. Heady and Wilfred Candler, Linear Programming Methods (Ames, Iowa: The Iowa State College Press, 1958).

[5] Daniel E. Chappelle, "A Primer on Linear Programming," A lecture presented to the graduate seminar in Forestry Economics, State University College of Forestry at Syracuse University, Syracuse, New York, 1962.

is rewarded with a more flexible model, and one which produces optimal solutions in terms of the specified objective function and constraints. However, it should also be noted that because of the very specific nature of the objective function and constraints, the LP model is less general than I-O models.

A third group of models is comprised of those emphasizing simulation techniques. Simulation models are, perhaps, the most flexible of all those currently being used to represent economic-ecologic linkages. They may range from the very simple to the extremely complex. They may be made quite general or tailored to a specific problem context. It must be noted, however, that simulation models are always "custom built" in the sense that library computer programs are not available to compute solutions. Specially designed computer languages to facilitate the implementation of computer-based simulation models have been developed, however, and are available for use in this regard (e.g., SIMSCRIPT, SIMULA, and DYNAMO). As with I-O approaches, simulation models by themselves are non-optimizing and thus require the user to make a value judgement concerning the "goodness" of alternative solutions generated. The flexible nature of simulation models makes it very difficult to discuss the associated advantages and disadvantages except in a very specific problem context.

Most simulation models adhere to a general structure containing four major elements:[6]

A. Components of the model - parts of the model for which behavior is to be explained (e.g., sectors in a regional model.

B. Variables

1. Exogenous

a. input variables - established outside the model and must be inputed (e.g., time trends).
b. Auxiliary variables - used to measure the impact of changing rates of both input and time variables on the status of the model.[7]
c. time variables - describe the time over which the behavior of the model occurs.[8]

2. Endogenous

a. status variables - (exogenous for the first step) describe the status of a component at any point in time.[9]
b. output variables - describe combined effects of input, auxiliary, time, and status variables.

C. Relations - define the way in which different variables in the model are related to one another.

1. Identities - "accounting or tautological statements which may be introduced for convenience."[10]

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[6]Pompi and Chappelle, "Toward More Comprehensive Forest Management Planning," p. 9.

[7]John E. Stahl, "Simulation as a Technique of Analysis," Regional Studies of Income Distribution, ed. W. B. Back and John E. Waldrop, Jr. (Baton Rouge, Louisiana: Louisiana State University, 1966), pp. 76-82.

[8]Ibid.

[9]G. H. Orcutt, "Simulation of Economic Systems," American Economic Review, I (No. 5), pp. 893-907.

[10]Ibid., p. 899.

2. Operating Characteristics - ". . . a relationship specific to a given component which specifies either an hypothesis or an assumption about how output variables of the component are related to its status and input variables."[11] This category of relations subsumes technical, behavioral, and institutional equations commonly found in an econometric model.[12]

D. Parameters - estimates of the degree of influence associated with the different variables in the model. Parameters are generally derived using statistical techniques.

Once the model has been constructed, it is run and the solutions compared to real-world observations. If the model produces reasonably good approximations of reality, it is said to have been validated. If it does not, then certain adjustments (e.g., changing the values of some of the parameters) are made and the model is operated again. The adjustment process is repeated until the model is validated.

Simulation models are generally solved recursively (i.e., the current status of the model depends upon the previous state), to yield two kinds of information; one type relating to levels of output variables and the other to rates of change in these variables. It is often desirable (or necessary) to add stochastic (random) variables to a simulation model to represent influences for which a parameter cannot be assigned.

Simulation models are best able to handle variables which change over time. They are easily manipulated mathe-

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[11] Ibid.

[12] Stahl, loc. cit.

matically and can take into consideration complex situations (e.g., nonlinearities and discrete data), but to gain these advantages the researcher must forego the optimization feature of LP models. For a given problem, simulation models generally require more detailed information inputs in order to generate results comparable to those which could be obtained if optimization models were applied. However, it should be recognized that simulation models are generally built in situations where LP models are not adequate.

Information requirements for simulation models are largely related to the degree of difficulty experienced in fitting parameter estimates and describing mathematically the necessary relationships. It is almost always necessary to make multiple runs of the model before it is possible to generalize about the trends indicated. This factor plus the fact that the model is tailored to a specific problem permitting almost no use of generalized computer programs, results in high programming costs and makes the simulation model quite expensive to develop and operate. Because of high information requirements and operation costs that would result if both economic and ecologic systems of a region were linked in one large simulation model, simulation techniques have been used most often in conjunction with other methods (e.g., linear programming) to model regional systems. Such models may be termed hybrid models and form the fourth major group of economic-ecologic models found in the literature.

Due to the large number of potential combinations of techniques that could be employed in developing a hybrid model, it is not possible to embark upon a general discussion of this class of models. Rather, each must be evaluated as a unique approach to a specific problem or group of problems. An example of this type of model would be one which uses and I-0 model to represent the regional economic system and quantify residual flows to the environment. These flows might then become input to a simulation model of the ecologic system of the region designed to determine the impact on environmental quality of a given change in output for the economic system.

## Criteria for Evaluation

There are, potentially, a large number of criteria that could be applied in evaluating the alternative approaches to modeling economic-ecologic linkages identified in the previous section. In order to narrow down this list and focus it more or less directly on the problem at hand, it was decided that the criteria employed in the comparative evaluation would emphasize the performance aspects of the models and, also, that they should reflect the goals and objectives of this study. Thus the list of eight criteria presented here is by no means a comprehensive one. Clearly, there are other features of the models discussed which might be relevant for evaluation in a different problem context.

It would be ideal if the comparative evaluation of the alternative economic-ecologic models could result in a quantitative measure of the appropriateness of each alternative. However, in order to accomplish this, it would be necessary to have a scheme of weights that would reflect not only the importance of each criterion relative to the others, but, also, the "score" of each alternative model on each criterion. Unfortunately, it was not possible to design such a weighting system; and, therefore, the comparative evaluation does not result in a quantitative measure of appropriateness.[13] It is possible, though, to rank the criteria subjectively, based on the degree to which each appears to reflect the goals and objectives of the research. In addition, subjective ranking of each alternative model on each criterion is possible when the actual evaluation is performed. However, it should be noted that this less than ideal system makes the results of the comparative evaluation somewhat arbitrary because alternatives do not have associated absolute quantitative measures of their appropriateness. In this section the criteria are developed and a rationale is given for each. In addition, the criteria are subjectively ranked and appear in order of decreasing importance.

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[13]The absence of a system of weights from this evaluation does not, of course, imply that one does not exist. Indeed, the task of resource managers in applying models as an aid to decision-making, is to define these weights so that the model eventually chosen will incorporate those features most appropriate for the particular problem at hand.

As stated previously, the overall objective of this study is to describe procedures by which the forestry-based economic and ecologic systems of western Montana can best be linked in a single analytical model. However, the primary objective of the comparative evaluation stage of the research is to provide information on the relevant attributes of the alternative models currently being used to represent regional economic and ecologic systems and the linkages that exist between these systems. This information then becomes input to the next phase of the research, i.e., conceptualizing the ideal economic-ecologic model. Thus, in developing evaluative criteria it was not necessary to insure that they reflected the specific aspects of this study. Put another way, the evaluative criteria did not have to incorporate considerations specific to forest-centered economic and ecologic systems or considerations specific to the western Montana region. Rather, the criteria developed were designed to reflect the relative performance of each model as it is used in representing economic and ecologic systems in general.

## Information Output

It is difficult to discuss the information output of a model without reference to the specific needs of the user. However, it is felt that since almost all models are developed and operated ultimately to provide information which is useful in some context, information generated by a particular

model should be a prime consideration in evaluating its performance. Thus the first criterion relates to the amount and quality of information generated when the model is applied in various real-world problem contexts. At this stage, it is not necessary to consider whether potential users are interested in total systems management or in making marginal improvements in managing those portions of the economic and environmental systems in which he has a high degree of influence. Similarly, it is not important at this stage to consider specific attributes (e.g., forest-centered, marine-centered, etc.) of the region with which one is ultimately concerned. Rather, one can assume that the model is to be used in a variety of regional and problem contexts, or, that it is to be used in the most demanding situation conceivable, and proceed to a general evalution of its information output. When it becomes necessary to discuss the operational feasibility of a model in a particular regional and/or problem context, it is then important to define those adjustments which will enable the model to better represent the more specific attributes associated with that problem and region. In this study, such fine tuning of the model forms the basis for two separate research objectives. The author's intent in this chapter is to try to identify the particular formulation which appears to offer the most complete representation of regional economic and ecologic systems in an integrated, comprehensive fashion.

The first element in the information output criterion is the quantity of information generated through operation of the model. In applying this criterion in the evaluation of a particular model, it is not intended that each bit of information output be counted or added up. Rather, an attempt is made to define scope of the information generated by the model. Such factors as whether the model provides only gross values for waste outputs from the economic system or provides additional information about diffusion of these wastes through the environment, are illustrative of what is meant by the scope or quantity of information output.

The second element in this criterion is the quality of the information provided by the model. An essential consideration here is the detail in which the model provides the information output. In evaluating certain aspects of a given model it might be possible to confuse the first element, i.e., the quantity or scope of the information output, with the second, i.e., the quality of the output. However, it is intended that the first element be interpreted generally as meaning scope or breadth of coverage and the second as meaning the detail or depth of coverage. Thus, for example, it is possible to have a model which provides a broad range of information but in highly aggregated form. Other considerations defining the quality element include, when applicable, the clarity of the information provided (i.e., is the information ambiguous or is it eas-

ily interpreted?), and the accuracy of the information output.

Under this criterion a model is generally considered superior if it provides information offering broader coverage and/or higher quality than the alternatives, especially if the data input requirements are equal to or less than those of the alternative formulations.

Data Input

The second most important evaluative criterion concerns both the quantity and quality aspects of the data requirements associated with the operation of each model under evaluation.[14] It is thought that while the information output of a model should be the prime consideration in evaluating its performance, certainly the data inputs required to obtain this information (what might be viewed as the cost of the information output) must be regarded in nearly the same light. Indeed, it would be ideal if quantitative measures of both data inputs and information outputs were available. Under these circumstances it would be possible to develop an efficiency ratio, i.e., output/input, which would clearly facilitate the comparative evaluation of alternative economic-ecologic models. Unfortunately it was not possible to achieve such sophistication in this effort.

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[14]It should be noted that in this report the term "quality" as applied to data requirements does not refer to quality in a statistical precision sense. Rather the term refers to the level of detail in data input necessary for operating a model.

As in the case of the first criterion, application of the data input criterion is expected to provide only a general appraisal of the relative requirements of each model. Thus it is not necessary to define in great detail each bit of information necessary to operate the model under evaluation. Rather, it is sufficient to know, in general, what types of data inputs are required and the level of detail necessary for the operation of each alternative model. It should be noted that an important aspect of the data input criterion involves the availability of the data necessary for operation. However, in the comparative evaluation, we are concerned only with relative requirements. The question of data availability must be treated in the context of a specific application of the model. In this study, data availability for the western Montana region is dealt with at a later stage. Specifically, the availability aspect is investigated in pursuit of the fifth research objective; and is discussed in Chapter VI.

Under this criterion a model is considered to be generally superior to the alternatives if it provides the same or higher levels of quantity and quality of information output for a smaller data input.

### Provision of Guidelines to Policy Questions

The third evaluative criterion involves the ability of the model to provide guidelines to policy questions in a form useful to decision-makers. While it is difficult to separate this aspect from the overall question of quantity and quality of information output, it is treated here, apart from the general information output criterion, to reflect more specifically the ultimate goal of developing a useful, operational economic-ecologic model. It should be recognized that for a model to have the capacity to provide useful guidelines to policy questions, it must also provide a rather broad range of reasonably high quality, useful information. Indeed, both the first and third criteria listed here may be viewed in a broader sense as different measures of the more general concept of information utility.

The essence of this criterion, as used here, is the degree to which the user has to exercise judgement in developing policy guidelines from the information output of the model. For example, if a particular model provides optimal solutions then as long as the user accepts all of the relationships built into the model (e.g., assumptions, constraints, objective function, etc.) as valid, the information generated through operation of this model can be translated directly into guidelines with little or no further interpretation and judgement on the part of the user. Of course this also implies that the user is satisfied with the specification of the model. Variables, or even relationships, which cannot be readily included in the model must be viewed as having little impact on the model's ability to accurately represent the real world situation being modeled. On the other hand, if the model generates a number of feasible solutions but does not provide information which distinguishes any particular one as "best", then the user must exercise considerable judgement in developing guidelines from the information output of the model. Another general consideration here is the extent to which information provided by the model enables the user to understand and, perhaps, manipulate the more critical relationships existing within the model.

In general, those models which facilitate development of policy guidelines are considered superior to those from which the derivation of such guidelines is, apparently, more difficult.

## Relevance of Necessary Assumptions

The fourth criterion involves an analysis of the relevance of the necessary assumptions of the model to realistic decision problems. Clearly, this criterion is designed to reflect another measure of the utility of the model under evaluation. If the assumptions (either explicit or implied) built into the model are violated in the real-world problem context in which the model is to be applied, than it is likely that operation of the model will yield inaccurate or, perhaps, even totally irrelevant information. Of course it is recognized that all models rest, to some extent, upon certain necessary assumptions. If this were not true, then models would not really provide much advantage over using the real world for study (certainly the models would be no less complex than reality). However, for any given problem context, certain assumptions are more acceptable or "easier to live with" than are others. In evaluating models proposed for representing regional economic and ecologic systems in an integrated fashion, it is necessary to examine at least the most critical of the assumptions necessary for each alternative model in order to determine which are likely to be violated when the model is implemented. In addition, it would be quite useful to have estimates of the impact of such violations on the quality of information generated by the model. It is felt, however, that such estimates would be quite difficult, if not impossible, to obtain without actually implementing each model in a particular problem context; and this procedure is thought to be beyond the scope of this paper.

Models with necessary assumptions that appear to be easiest to accomodate in real-world problem contexts are considered superior to those with assumptions that are more restrictive or more likely to be violated.

### Capacity for Dealing with the Temporal Dimension

The fifth evaluative criterion involves the capacity of the model to deal with the time dimension. This is rather straightforward in that it is usually quite easy to determine whether a particular formulation is static or dynamic. However, it can become more complicated since some models which are not initially developed to represent dynamic phenomena can be modified to do so. Thus another element of this criterion involves the question of whether the model can be modified to accommodate dynamic phenomena and, if so, what is the extent of the required modifications (including some consideration of the additional data inputs that would be necessary to operate the modified formulation).

This criterion is somewhat related to the policy guidelines criterion in that a dynamic model will facilitate the simulation of events as they occur over time. This feature would enable the user to test alternative configurations (particularly management strategies) to get some idea of the impact of each over time. Clearly such information would greatly assist decision-makers in development of policy guidelines, and thus, might also be viewed as an increase in the model's utility. Therefore, in general, models that facilitate representation of events or phenomena over time are ranked higher than those which do not appear to have this capacity, or those which require extensive modification for this purpose.

### Capacity for Dealing with the Spatial Dimension

The sixth criterion used in this study is the capacity of the model to deal with the spatial dimension. Actually, it is felt that, in evaluating the performance of economic-ecologic models, it is equally important to consider both the temporal and spatial capabilities. Thus the order in ich these two criteria have been listed does not, in this se, mean that one is regarded as being more important than e other.

One of the most significant aspects of what has come be known as the "environmental problem" involves the atial distribution of residuals. Indeed, in some cases is aspect is much more important than the temporal dis-ibution of these materials. In general, it is not so sy to characterize a model as spatial or non-spatial as it to determine whether the model is static or dynamic. wever, in many formulations it is possible to design modi-cations which will expand model capacity to include the atial dimension. For example, one can incorporate space the LP model by reformulating the model from a regional an interregional configuration. However it should be ted that such modifications are costly in terms of addi-onal data requirements. Essentially, then, in applying is criterion it is necessary to determine the extent to ich the model must be modified in order to enable it to present spatial phenomena. In general, those models which quire little modification in this regard are considered be superior to those which either cannot be modified or quire extensive modification before they are capable of equately representing the spatial aspects of the economic-ologic linkage problem.

## Generality

The seventh and eight criteria used in the comparative evaluation are designed to reflect the flexibility of the model under analysis. Both criteria are regarded, here, to be of equal importance, hence the order in which they are presented does not, in this case, imply that more weight is given to one than the other.

The seventh criterion relates to the extent to which the model can be generalized to a variety of problem situations, including different user goals and objectives and different regional contexts. The application of this criterion is purely subjective and perhaps, therefore, of limited value. However, it is felt that this particular aspect of the model, i.e., the scope of its applicability, is an essential consideration in determining its usefulness for solving problems and, as such, that an attempt--even a crude attempt--should be made to explicitly consider it.

## Specificity

The eighth criterion involves the facility with which the model under evaluation can be adapted to specific regional and/or problem contexts. While the seventh criterion is designed to account for the extent to which the model can be "stretched" to apply in a variety of different situations, this criterion is intended as a measure of the degree to which the model can be tailored to a specific situation. Essentially, this criterion is intended as a measure of the capabilities of the model for representing specific situations in sufficient detail to allow for meaningful analysis. Clearly, a model which provides only a very general representation of a problem situation will not be as useful as one which can provide more detailed information. It is equally clear that a model that can be applied to a variety of situations with little modification is preferable to one which does not possess this capability.

It should be recognized that the last two criteria presented here may be incompatible in the same formulation. For example, it is quite possible that to achieve a given level of generality in the design of a model, the designer has had to give up some of the capacity for representing specific situations in detail. In applying these two measures of flexibility, preference is given to models which rate high under both. If a case arose where a model is found to rate high on one criterion and low on the other, there is really no basis for choice. Under these circumstances the comparative evaluation would be considered to be inconclusive regarding these aspects and ranking of the model in question would be done on the basis of the remaining criteria. It should be noted that a quantitive weighting system would eliminate problems such as this one.

## Summary

The eight evaluative criteria employed in this research are designed to reflect the goals and objectives of this study. Thus they do not comprise an exhaustive listing of potentially significant attributes. The criteria used, in order of decreasing relative importance are:

1. Amount and quality of information generated when the model is applied in various real-world problem contexts.
2. Data requirements (both quantity and quality aspects) for operating the model.
3. Ability of the model to provide guidelines to policy questions in a form useful to decision-makers (e.g., does the model provide optimal solutions to problems?).
4. Relevance of the necessary assumptions of the model to realistic decision problems.
5. Capacity of the model to deal with the temporal dimension.
6. Capacity of the model to represent spatial phenomena (the fifth and sixth criteria are considered to be of equal importance).
7. Extent to which the model can be generalized to a variety of problem situations.
8. Facility with which the model can be adapted to specific problem situations (the seventh and eight criteria are designed as measures of the flexibility of the model under evaluation and are considered to be of equal importance).

## The Comparative Evaluation

In this section, a comparative evaluation of models offering alternative approaches to modeling economic-ecologic linkages is presented. It should be noted at the outset that this evaluation is not intended as a comprehensive analysis of the large number of attributes associated with each of the models under evaluation. Rather, it is an attempt to get some idea of the relative utility of each model for application to the problem at hand. As such, the comparative evaluation employs criteria that reflect the general objective of this study.

At this point, it is worth noting that the evaluative criteria used here do not include any which reflect concern for either forest-centered systems or the western Montana region specifically. It is felt that, in general, each of the four types of economic-ecologic models identified in the literature review are adaptable to both forest-centered regional economic and ecologic systems and to the western Montana region. The specific goal of the comparative evaluation is to provide information which will enable conceptual development of an ideal linkage model, where the adjective "ideal" here means development in the absence of any specific data or resource limitations or other considerations of a specific regional or problem context. Any modifications which might be necessary to accommodate specific attributes of forest-centered systems or the western Montana region are defined and discussed in pursuit of separate study objectives.

It is thought most useful to organize the comparative evaluation around the eight evaluative criteria. Thus in the sections to follow, the various types of models are compared under each criterion in turn. It should be noted that the fourth general type of model, i.e., the hybrid type, is not treated explicitly in this evaluation mainly because the large number of possible combinations precludes general comments here. However, some general observations about this type of model are made when appropriate and it should be recognized that hybrid models are largely composed of elements of the other three types and thus the attributes of this group derive from those associated with each of the component elements.

## Information Output

The first element in this criterion is the quantity or scope of information output. In general, I-0 and LP models provide the same types of information. As they are currently being used, both I-0 and LP provide a rather detailed representation of the regional economic structure and the level of interdependance within the regional economic systems. Indeed, the LP format provides everything that an I-0 formulation does (including information necessary to calculate multipliers) and, in addition, the LP model provides optimal solutions, indicates the existence of idle resources and the "value" of fully utilized resources. To date, both I-0 and LP have been used to provide estimates of residual outputs from the economic system. Use of these techniques to model the ecologic system has been very limited and thus they have not provided detailed information on the diffusion of residuals throughout the environment or on the impact of these residuals on environmental processes. In LP, it is possible to consider environmental capacities explicitly (through the use of constraints which reflect these capacities), while this is not possible in I-0 models.

Simulation models can be formulated to provide the same information that can be obtained from I-0 or LP models. In addition, the ecologic system and linkages between the economic and ecologic systems can also be represented in detail. Other advantages associated with models using simulation techniques include the facility with which alternative strategies can be tested using the model, and, perhaps more importantly, the relative ease with which the model's sensitivity to changes in input variables can be determined. However, the data input requirements for an integrated economic-ecologic simulation model would be quite large. Also, it should be noted that simulation models do not provide optimal solutions as do LP models. In general then, simulation models have the capacity to provide a broader range of information than either I-0 or LP models, but, also, require more data to provide this information. The second ranking model under this element would have to be the LP formulation by virtue of the optimal solutions generated through operation of this type of model. The I-0 model provides the narrowest range of information output of the three types discussed thus far. The hybrid type models would, in general, rank near the top under this element because they can be formulated to incorporate certain features of each of the other types.

The second element in this criterion is the quality of information output of the model, i.e., the detail in which the information is provided. Simulation models have the capacity to provide the most detailed information output, but again, this is usually accompanied by higher data input requirements. Both LP and I-0 have generally the same capacity to provide detailed information, though the optimal solutions provided by LP formulations could be regarded as more detailed in a sense. It is not possible to make a general statement about the quality of information generated by the hybrid type models since this would depend upon the particular formulation. However, such models have the potential to provide detailed information on a par with simulation models.

## Data Input

The second criterion is the data input required to operate the model. In general, both the quantity and quality aspects of data required to operate each model appear to increase as one moves from I-0 to LP to simulation to hybrid type models. Linear programming requires all of the data necessary to operate a comparable I-0 model and, in addition, it is necessary to have data related to the objective function and constraints. The data requirements for a simulation model are, for a given application, usually higher than for other models (though it should be noted that simulation models can handle lower quality data in the sense that various measurement scales, discontinuities, etc., can be entered). However it is difficult to discuss these requirements without reference to a specific problem context, since most of the data requirements stem from the need to describe, mathematically, the relationships within the model and, also, from the problem of estimating the necessary parameters. It is not possible to embark upon a general discussion of the hybrid group of models. The data requirements for this type of model vary according to the specific elements employed in a given formulation. As noted previously, there are a large number of possible combinations for this type of model. This precludes a general discussion of data requirements.

### Provision of Guidelines to Policy Questions

The third criterion is viewed as one measure of the utility of the model for the specific purpose of linking regional economic and ecologic systems. Essentially, the ability of the model to provide guidelines to policy questions is taken here to mean the extent to which users of the model must exercise judgment in developing guidelines from

the information output.

It is apparent that the LP model, with its optimal solutions, requires the least amount of user judgement in translating the information output of the model into policy guidelines. If, in a given application, the objective function accurately reflects the goals of the user and the constraints in the model are representative of those existing in reality, then the LP model will provide an optimal solution which can be translated directly into a set of policy guidelines. However it should be noted that the output of the LP model (or, for that matter, almost any model) would still have to be tempered by judgement because it is not possible to include all factors in the model. The I-0 model, which does not provide optimal solutions (except, of course, for the implicit objective function discussed previously), requires considerably more judgement on the part of the user before a set of policy guidelines can be developed from the information output of the model. While the simulation model does not provide optimal solutions, it is perhaps easier to develop policy guidelines from its information output than was the case with I-0 formulations. This statement is based primarily on the facility with which alternative strategies and configurations can be tested using simulation techniques. The hybrid type models appear to offer the best alternatives under this criterion. Using the hybrid type it is possible to combine, for example, LP with simulation to provide an

economic-ecologic linkage model which offers features of both types. In this case the simulation techniques would be used to generate data sets which might then be entered into the LP formulation. Such a configuration takes advantage of the flexibility associated with simulation and the ability of this type of model to operate on lower quality data, but, in addition, provides optimal solutions. Another example of the hybrid type model incorporates an economic I-0 model in conjunction with a simulation model of the regional environment. With residual discharges from the regional economic system (estimated in the I-0 portion) entering the environmental simulation, it is possible to estimate the impacts of alternative economic production strategies and hence develop policy guidelines for directing regional economic activity.

In general, it appears that the LP models or certain of the hybrid types provide information output which can be translated into policy guidelines with a minimum of user judgement being exercised in the process. Under this criterion, simulation models rank next followed by the I-0 approach.

## Relevance of Necessary Assumptions

The fourth evaluative criteria considers the relevance of the necessary assumptions of each alternative model for realistic decision problems. While it is not possible to identify and evaluate all of the assumptions necessary for

the operation of each model, it is important to consider, here, several of the potentially more restrictive ones.

The following assumptions are among those necessary for the operation of an I-O model:[15]

1. each commodity is supplied by a single industry or sector;
2. only one method is used for producing each commodity;
3. each commodity is homogeneous;
4. each industry or producing sector has only one primary output;
5. inputs purchased by an industry or sector are a function only of the level of output of that industry or sector (usually a linear function, of direct proportionality, i.e., constant input coefficients), thus the production functions in the model are linear;
6. no substitution among inputs in the production of any commodity is possible;
7. there are constant returns to scale, i.e., no internal economies or diseconomies of scale;
8. the total effect of carrying on several types of production is the sum of the separate effects (additivity), i.e., no external economies or diseconomies;
9. there is excess capacity in all processing units; and
10. there are no resource limitations.

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[15]The assumptions listed here are summarized from a series of lectures delivered by Daniel E. Chappelle during the period May 1-15, 1973, at Michigan State University, East Lansing, Michigan.

While all of the above assumptions clearly involve departures from reality, most do not appear to be so restrictive as to render the model useless for portraying economic-ecologic linkages.

There is, however, at least one assumption which has the potential to significantly restrict the utility of the model for this purpose. The linearity assumption contained within the I-0 format is quite unrealistic. Unfortunately, there is no way to avoid or "get around" this assumption. If one wishes to use an I-0 formulation then he must also accept the linear production functions specified within the model. It should be noted that the assumtpion of linearity may not provide as inaccurate a representation of production functions in the economic system as in the modeling of natural systems where such functions are notably nonlinear. Thus this assumption may be even more restrictive when I-0 formulations are used to model ecologic systems. However Isard notes that, ". . . many of the processes which are basic in the ecological system cannot be approximated in linear form . . ." and that, similarly ". . . many basic elements of the economic system cannot be represented in linear form."[16] So it is possible that the linearity assumption is equally restrictive when applied to the modeling of either system. Isard does conclude on a rather optimistic

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[16]Isard, _et al._, _Ecologic-Economic Analysis for Regional Development_, p. 95.

note, however, when he finds that ". . . it is often useful to record data as if they represented processes which do obey linear rules."[17] A related problem exists with the assumption that there is no substitution among inputs in the production of any commodity. This assumption prevents the model from providing an accurate representation of the complex interactions that occur between the various elements in the environment (in particular, those interactions which occur between residuals as they are diffused through the environment). However, current applications of I-0 techniques have received very limited use in the modeling of ecologic systems.[18] More often, they have been used only as a means of estimating residual flows to this system from the economic sectors. Thus these restrictive assumptions have not caused severe problems to date.

There are several special assumptions of linear programming models. Here, "special" refers to assumptions beyond those common to the usual optimization procedures. These are:[19]

1. the ratios between any two inputs and between any input and the output are fixed and hence independent of level of production (linearity).[20] Also, the prices received for products are assumed to be constant and independent of output.

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[17]Isard, _et al_., _loc. cit_.

[18]See for example: Isard, _et al_., _Ecologic-Economic Analysis for Regional Development_, pp. 56-90, and pp. 94-112.

[19]Chappelle, "A Primer on Linear Programming," pp. 2-3.

[20]Dorfman, _loc. cit_.

2. processes must be additive in the sense that when two or more are used their total product must equal the sum of the individual products (additivity).[21] This means that no interaction between certain inputs can occur. If there is interaction the entire combination must be treated as a single process. The additivity assumption also implies that the sum of the inputs for each process equals the total resource requirement.

3. all non-negative levels of input use and output are production possibilities (divisibility). Resources and products are assumed infinitely divisible.[22]

4. it is assumed that the number of alternatives and resource restrictions are finite (finiteness).

The assumptions associated with LP models are not as restrictive as they might at first appear to be. For example, the linearity assumption in LP (unlike that for I-0) does not imply that constant returns to a given variable factor hold. Diminishing returns can easily be incorporated into the LP model by specifying additional processes within a given enterprise. However, it should be noted that this modification increases data requirements of the model. Similarly, the assumption of additivity can be avoided through use of the non-linear programming techniques, but, again, one must pay for this modification to the basic structure with higher data requirements and a loss of mathematical simplicity. Another example involves the case where product prices cannot be assumed to be constant and independent of output. When, in a given application, it is

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[21]Heady and Candler, op. cit., p. 17.

[22]Heady and Candler, op. cit., p. 18.

necessary to express price as a function of level of output, curvilinear programming techniques are available to make this possible. It is apparent that some of the more restrictive assumptions associated with LP models can be circumvented through modifications (an option not available with I-0). Thus, under this criterion, it is clear that the LP model is superior to the I-0 model on the grounds that the assumptions associated with LP are not so binding as are those associated with I-0.

It is not possible to engage in a general discussion of assumptions involved in the operation of simulation models. Since simulation models must be tailored to a specific problem, there is no formal, general structure or general set of assumptions. Rather, assumptions are built into the model during the design stage and depend entirely upon that particular application. Thus each simulation model must be viewed as a unique approach to a specific problem and is, therefore, difficult to discuss out of this context. It should be noted that this flexibility suggests that one need not make any assumptions which would severly restrict use of the model providing he is clever enough to design a means for getting around the problem. On the basis of this observation, it is felt that the simulation model ranks higher than either I-0 or LP under this criterion.

The many potential configurations for the hybrid type models precludes a general discussion of the assumptions association with this group. It can be said, however, that the hybrid type models will require all of the assumptions normally associated with each of their component parts. For example, if an I-0 formulation is used in conjunction with a simulation model, then the resulting hybrid model will contain all of the necessary assumptions for I-0 plus any which have been built into the simulation component. This situation suggests that in most cases where hybrid type models are used, the user will likely have to accept a larger number of restrictive assumptions than if he had used simulation techniques in developing the entire model. Thus the hybrid type model appears to rank below the simulation approach under this criterion. However it is not possible to rank it relative to I-0 or LP except in the context of a specific application.

### Capacity for Dealing with the Temporal Dimension

The fifth evaluative criterion concerns the capacity of each model for dealing with the temporal dimension. Each of the types of models to be evaluated under this criterion has some capacity for incorporating temporal considerations, though for I-0 and LP models the standard form must be modified to achieve this capacity.

Though there has been considerable progress towards the development of a completely dynamic input-output system, such a model does not presently exist. Currently, it is possible to incorporate the temporal dimension in I-0 models only to the extent that one can estimate future technical coefficients and final demands. If an acceptable estimation procedure is available then one can derive estimates of the future values of these variables which can be inserted into the model in place of the current values. Thus the model can be operated iteratively, with new estimated values for the technical coefficients and final demands being introduced at each step, to provide an approximation of the dynamic processes involved in a regional economy, i.e., a comparative static approach.

There are a relatively large number of procedures available for modifying the standard LP model to incorporate dynamic elements. All of these procedures are more complex than was the case with I-0 models and thus cannot be discussed here.[24] However, it is sufficient, for the purpose here, to note that dynamic programming techniques are available and that they provide, in general, a better approximation of dynamic economic processes than that which is provided by the modified I-0 formulation discussed above. It should also be noted that dynamic programming techniques generally require higher levels of data inputs than the standard linear formulation. Another important problem arising when dynamic programming techniques are applied to realistic problems is that vast computer memories are re-

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[24]A general discussion of this topic is found in: Harvey M. Wagner, Principles of Operations Research: with Applications to Managerial Decisions (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1969).

quired to handle the computations involved. Of course, the modifications necessary to enable I-O models to handle dynamic phenomena also increase the data requirements of that type of model.

Simulation models can be described, generally, as methods for modeling reality and designing systems. As such, they are best suited to handle variables which change over time, i.e., recursive processes are integral to simulation techniques. Indeed, the only real limitations on the extent to which the temporal dimension can be incorporated into a given simulation model are the researcher's own creativity and cleverness and the data and resource constraints that he must operate under. In terms of capacity for incorporating the temporal dimension, the simulation model is clearly superior to both I-O and LP models.

Models in the hybrid group are composed of elements of models in the other three groups examined here. Thus the capacity of a hybrid model to deal with changes over time is essentially determined by the nature of its composite elements. For example, a hybrid model composed of elements from both linear programming and simulation could be more dynamic than a modified linear programming model. Clearly, the large number of potential combinations available in the development of a hybrid model precludes a general discussion of this group under this criterion. Therefore, it is not possible, here, to rank the hybrid class of models relative to the other types under consideration.

## Capacity for Dealing with the Spatial Dimension

The sixth criterion used in this evaluation involves the capacity of each model for representing the spatial aspects of a given problem. It should be noted at the outset that none of the model types under analysis in this chapter can be characterized as inherently spatial. Rather, each must be modified to some extent to incorporate spatial considerations.

In regional applications of LP models it is possible to incorporate the spatial dimension by subdividing the region under analysis into a number of subregions and reformulating the model from a regional to an interregional configuration. Using this procedure, the level of spatial detail achieved depends upon the number and size of subregions used, and is limited only by data availability and computer memory capacity. For example, a large region might be subdivided along county boundaries with each county thus forming a subregion. Under these circumstances the interregional model would only account for flows between counties. If, in a particular application, more detail is required, then a larger number of smaller subregions would have to be defined, e.g., one square mile grid cells. Obviously the data requirements increase as more subregions are defined since, for each subregion, all of the information necessary for one large model is required. It is also possible to spatially identify variables in the LP

model by attaching a subscript which refers to location. This is perhaps the simplest and least costly procedure available, requiring only that a system of location coordinates be devised. This procedure is possible with LP because the model deals with individual activities and not sectors (it should be noted that LP can include the case where activities are defined as sectors).

Input-output models may also be modified to incorporate the spatial dimension. The procedure followed is similar to the first one discussed for LP models. The region under analysis is first subdivided into the appropriate number of subregions. A transactions table for each subregion is then developed and the whole system of subregions is modeled using an interregional I-O formulation. Degree of spatial detail with this procedure depends upon the number and size of subregions used and the sectorization scheme employed. This procedure increases data requirements drastically because a transactions table must be developed for each subregion and in addition a complete set of trading coefficients reflecting trade between each sector in each subregion with all other sectors in all other subregions in the system must be derived.

Because of the minimal formal structure associated with simulation models and the resultant flexibility of such models, it is possible to build the spatial dimension into the model during the design phase. The flexibility associated with simulation models and the large number of different procedures available for modeling spatial phenomena using simulation techniques precludes a general discussion of this aspect.[25]

As was the case with several previously discussed criteria, it is not possible to embark upon a general discussion of the hybrid type model under the spatial criterion. It should be pointed out, however, that the capacity of a particular hybrid formulation to incorporate the spatial dimension is largely determined by the capacities of the component elements of the model.

The comparative evaluation under this criterion is rather inconclusive. Though each type of model under evaluation here can be modified or designed to incorporate spatial considerations, it is difficult to determine, in general terms, the problems encountered in doing so. Thus it is not really possible to rank the alternatives relative to this criterion. The comparative evaluation does suggest at least a tentative ranking with simulation models having the greatest spatial capabilities followed by LP and then I-0 formulations. However, it is clear that considerably more investigation, undertaken in greater depth,

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[25]It is possible, however, to provide references to some discussions of simulation as a spatial model. See for example: Barry M. Kibel, "Simulation of the Urban Environment," Commission on College Geography, Technical Paper No. 5 (Washington, D.C.: Association of American Geographers, 1972); and Peter Gould, "Spatial Diffusion," Commission on College Geography, Resource Paper No. 4 (Washington, D.C.: Association of American Geographers, 1969).

will need to be accomplished before a clearer picture of the relative attributes of each alternative model regarding spatial capabilities can be presented. It is felt that such research is beyond the scope of this effort.

## Generality

The seventh evaluative criterion is intended as a measure of the generality of the model. As such, it may also be viewed as a measure of one aspect of the utility of the model. It should be noted, that all of the models discussed here can be generalized to different problem and regional contexts, but that for some the process is much more expensive in terms of programming costs and increased data requirements than for others. Thus the concept of generality, as used here, means the degree of difficulty experienced in applying the model in different contexts.

The I-0 model is perhaps the most general of those under evaluation here. The structure of the I-0 model can be applied in a variety of problem and regional situations with little or no modification. Because of the highly specific nature of the objective function and constraints associated with LP models, it is clear that one loses generality in going from I-0 to LP. The simulation model is the least general model type under consideration. Simulation models must be tailored to the specific problem under investigation and therefore are not so readily adapted to different applications.

Here again, it is difficult to discuss the hybrid group of models in general terms. Depending upon the particular configuration used, the hybrid type is usually less general than I-0 but more easily generalized than a pure simulation model.

## Specificity

The last criterion involves the facility with which the model can be adapted to specific regional and/or problem contexts. It should be recognized that this is practically the opposite of the generality criterion, and, as one might expect, the models under evaluation rank in reverse order.

In general, simulation techniques are best suited for representing specific situations in great detail. Essentially, this attribute derives from the minimal formal structure associated with simulation models. Certain aspects of the structure of LP models enable the user to represent a particular problem situation in greater detail than with an I-0 formulation. For example, the objective function and constraints in the LP model must be specified by the user and can be designed to reflect certain unique aspects of a particular problem situation. In designing an I-0 model for application in the same situation, the user is essentially limited to the implied objective function contained in the model, i.e., to find the production scheme that will exactly satisfy the exogeneously determined final demands. Also, with I-0, the user does not have the option of specifying constraints which might reflect concerns specific to the particular problem context in which he is working. In addition, the LP model allows for substitution among inputs in the production process. This feature provides a capability for modeling specific situations in a level of detail not possible with I-0, and is likely to enable one to get at solutions to managerial questions more readily. It can be concluded, therefore, that under this criterion, LP models are superior to I-0 models. It is not possible to rank the hybrid type model without reference to a specific application and configuration. However, in general, such models would rank below the pure simulation approach under this criterion.

## Summary and Observations

The comparative evaluation discussed in this section is summarized in table III.1. It should be restated that the large number of potential combinations possible with the hybrid approach has precluded a general evaluation (and hence, relative ranking) of this type of model. On the basis of this admittedly subjective evaluation, it appears that the simulation approach offers the most attractive alternative to modeling economic-ecologic linkages in a regional context, followed closely by the LP type model with I-0 a distant third. It should be noted that these conclusions may be quite different depending upon the weights applied by a given analyst.

TABLE III. 1

RANKING OF EACH ALTERNATIVE MODEL TYPE ON EACH EVALUATIVE CRITERION[a]

| Criterion | Model Type | | |
|---|---|---|---|
| | Input-Output | Linear Programming | Simulation |
| Information Output | 3 | 2 | 1 |
| Data Input | 1 | 2 | 3 |
| Policy Guidelines | 3 | 1 | 2 |
| Assumptions | 3 | 2 | 1 |
| Temporal Dimension | 3 | 2 | 1 |
| Spatial Dimension | I[b] | I[b] | I[b] |
| Generality | 1 | 2 | 3 |
| Specificity | 3 | 2 | 1 |

[a]Rank: 1 = highest, 3 = lowest.

[b]I = inconclusive evaluation.

While the comparative evaluation may appear less than conclusive, it does strongly suggest the existence of distinct trade-offs. For example, both the quantity and quality of data required to operate each model appears to increase as one moves from I-O to LP to simulation to hybrid models. Of course, moving in this same direction also appears, in general, to provide increasingly detailed information and thus allows the researcher to answer not only questions which are more specific in nature but, also, a broader range of questions. The limited empirical content to be found in those studies reviewed in Chapter II indicates that currently available data are likely to be inadequate for implementing those models with the more demanding data requirements.

If a model is to be used as tool for management planning, a critical aspect of the model would be its capacity to incorporate the temporal dimension. If alternative management strategies are to be adequately tested via the model, then it must provide the researcher with a means of evaluating the various impacts of each strategy as they occur over time. Here again, the general rule appears to be that as models become more dynamic their appetite for more and better data increases.

A related aspect is the capacity of the model for incorporating the spatial dimension. This is particularly true if management planning is to fully consider the essence of environmental impacts of alternative management strategies.

While all of the models can be modified or designed to incorporate spatial phenomena, this is not accomplished without additional cost. Specifically, these costs involve any programming changes that would have to be made in the more or less standard programs available for operating the model and, more importantly, the increased data requirements made necessary by the modifications. Another interesting question is the extent to which each model is capable of incorporating, simultaneously, both the temporal and spatial dimensions. In the preceeding sections, the models were evaluated under each criterion separately, i.e., without regard for any possible interaction that might result if more than one criterion were applied simultaneously. However, this is not considered to be a serious deficiency since none of the attributes reflected in the criteria are considered to be mutually exclusive. For example, in the case of the temporal and spatial dimensions, the same model, e.g., an LP formulation, can be modified to incorporate both temporal and spatial phenomena. Of course such modifications will result in increases in both the quantity and quality aspects of the data required to operate the modified formulation, and, also, add different requirements for core capacity of the computing system used for operation. It can be concluded, then, that if a model ranks high under two different criteria when they are applied separately, it will also rank high if the two criteria are applied simultaneously.

In addition, there also appears to be a distinct association between the extent to which a model can be tailored.

to a specific regional and/or problem context and its data requirements and, to a lesser extent, computational complexity. Some models (e.g., input-output) are couched in very general terms and while they are useful tools for analyzing a wide variety of problems in almost any regional context, there are structural limitations which preclude their use for modeling specific regional systems in great detail. Modifications as would be necessary to tailor I-0 models to solve specific problems may be extensive and costly in terms of both time and data requirements.

On the other end of the scale, simulation models and certain of the hybrid types appear to offer maximum opportunity for detailed representation of regional systems. However, such models are not easily transferable from one problem or region to another, i.e., they are less general or more specific. While simulation techniques can provide the most detailed representation and, hence, the most detailed and specific information output, they also have associated with them the strictest data requirements (in terms of both quantity and quality where quality refers to level of detail). Thus, once again, it would appear that an increase in the quality and quantity of information output must be paid for in terms of increased data inputs.

If the comparative evaluation yields a general observation it is that it appears as though increases in the utility of the model (i.e., increases in the model's capacity to incorporate the temporal and spatial dimensions, the quality and quantity of information generated through operation of the model, its ability to provide guidelines to policy questions, and the flexibility of the model) will result in increases in both the quantity and quality of data required for operation. This is apparently an inescapable trade-off.

There are some definite limitations on the complexity that can be built into a model that are imposed by the quality of data inputs (apart from those limitations imposed by the formal structure of the model). When very complex models are run with poor quality data (i.e., data which have low precision in the statistical sense), the error that is propagated in the long chains of mathematical equations can be so large as to completely overshadow the numerical results and perhaps render them completely meaningless. The error resulting from imprecise data inputs is in addition confounded by numerical errors that propagate because of the computational processes used (i.e., round-off and truncation errors). Because of the error propagation processes noted above, many analysts (especially those concerned with urban models)[26] have suggested that researchers and decision-makers should construct simple mod-

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[26]See for example: William Alonso, "The Quality of Data and the Choice and Design of Predictive Models," Urban Development Models, Highway Research Board, Special Report 97, (Washington, D.C.: National Academy of Sciences, 1968), pp. 178-192.

els for policy analysis, thereby keying the model complexity to both the quantity of data available and the quality of those data.

# CHAPTER IV

## CONCEPTUALIZING THE IDEAL MODEL

The third objective of this study involves the conceptual development of an ideal model for linking regional economic and ecologic systems, including an assessment of data requirements for this model and definition of questions that the model could help answer. The model may be considered ideal in the sense that its development is not constrained by actual data or resource limitations or by reference to a specific regional or problem context. In addition to providing a basis for evaluating the operational feasibility of an economic-ecologic linkage model for the western Montana region, it is felt that the development of such an ideal model fills two more general roles. First, it provides a standard from which to measure the performance of other, less than ideal, models. Thus as restrictive conditions change or are relaxed, the ideal model developed here can serve as a guide to implementing the most useful and comprehensive model possible under the new circumstances (e.g., more funds, more personnel, better data, etc.). Second, the ideal model serves as a guide to future data collection and processing activities. In the absence of data and resource limitations, development of the ideal model proceeds so as to provide the most complete answers to the broadest range of questions, given the state of the art. In this sense it would be the "best" possible tool for the job at hand. Thus data requirements dictated by the ideal model can provide a framework for data collection and processing activities if these activities are to be designed to provide a maximum of useful information. Also, the ideal model can be used to determine the quantity and quality of data that are needed to provide "better" answers to regional decision-makers. It should be noted that development of the ideal model is accomplished not only in the absence of consideration of data and resource limitations, but, also, in the absence of any direct association with a particular region or problem situation. Thus the model developed is quite general and the questions that it can answer and the data required for its operation are not related to a specific application.

A major feature identified through the comparative evaluation of alternative models is the apparent trade-off existing between information output and data input, i.e., more and better information output is achieved by applying models with higher data requirements. As noted previously, however, the ideal model is conceptualized in the absence of such considerations as data and resource requirements. In the absence of such considerations, it is clear that LP and simulation models offer the most potential for modeling economic-ecologic linkages. The comparative evaluation also revealed that simulation models are best suited for modeling natural systems because the relationships in these systems are notably nonlinear. On the other hand, LP models are useful in modeling economic systems where the assumption of linearity is not so restrictive (or can be handled by increasing the number of activities included in the model) and where the optimal solutions generated by LP are perhaps most applicable. These considerations suggest that perhaps neither type of model (i.e., LP or simulation) is wholly appropriate for modeling regional economic and ecologic systems in an integrated fashion. Rather, the hybrid approach, wherein it is possible to combine some of the more attractive features of several types of models, appears to be most promising for this purpose.

## The Russell-Spofford Approach

Both the literature review and the comparative evaluation of alternative models indicate that much success (at least conceptually) has and can be achieved through the use of hybrid models for representing regional economic and ecologic systems and the linkages that exist between these systems. Currently, perhaps the most comprehensive and useful conceptual model available is the hybrid approach developed by Clifford S. Russell and Walter O. Spofford, Jr., at Resources for the Future, Incorporated.[1] Russell and Spofford employ a static input-output model as the basis for constructing an environmental-economic linear programming model. The complete model emphasizes three elements or component models (see Figure II.1, Chapter II): 1) a linear programming industry model that relates inputs and outputs of the various production processes and consumption activities at specified locations in a region, including unit amounts of types of residuals generated by the production of each product, the costs of transforming these residuals from one form to another (e.g., gaseous to liquid in the scrubbing of stack gases), the costs of transporting the residuals from one place to another, and the cost of any final discharge-related activity such as landfill operations; 2) environmental diffusion models which describe the fate of various residuals after their discharge into the environment. Essentially these models may be thought of as transformation functions operating on a vector of ambient concentrations at grid points throughout the environment. Between the discharge point and receptor locations, the residual may be diluted in the relatively large volume of air or water in the natural world, transformed from one form to another (as in the decay of oxygen-

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[1]Russell and Spofford, loc. cit. A summary discussion of this effort appears in Chapter II. Some of the discussion in this section is repeated from that found in Chapter II. This was felt necessary to maintain the continuity of this chapter.

demanding organics), accumulated or stored and, of course transported to another place; and 3) a set of receptor-damage functions relating concentration of residuals in the environment to resulting damages, whether these are sustained directly by humans, or indirectly through the medium of such receptors as plants or animals in which man has a commercial, scientific, or aesthetic interest. To simplify the computational procedures associated with operating their first-phase models, Russell and Spofford decided to view all relationships as linear. To work entirely with linear relationships they had to assume that: 1) the economic world is static so that time does not enter as a decision variable in the production model; 2) the relationships in the model are deterministic and steady state; 3) no interaction takes place between residuals, and 4) the environment cannot be modified to change its waste assimilation capabilities.[2]

The model is run, essentially, in an iterative fashion. In the first iteration the LP model is solved with no restrictions or prices on the discharge residuals. The initial set of residual discharges generated by this first round are then entered as inputs to the environmental diffusion models and the resulting ambient concentrations enter as arguments in the receptor-damage functions. The ambient concentrations and damage values are then used to calculate the marginal damages attributable to each residual discharge,

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[2]Russell and Spofford, loc. cit., p. 125.

i.e., the change in total damages that would result if that discharge were changed by a small amount. These marginal damages are then applied as interim effluent charges on the discharge activities in the industry model and that model is solved again (second iteration) for a new set of production, consumption, treatement, and discharge values.

## Economic System[3]

Russell and Spofford intend to use their model to choose levels of production, consumption, treatment activities, and resulting damages that maximize a given regional economic objective. They suggest that, at least initially, this objective should be maximization of regional economic efficiency. The general form of their objective function consists of six parts: 1) gross consumption benefits, i.e., total willingness to pay, $B_k$; 2) opportunity costs of traditional production inputs (including recycling, etc.), $C_p$; 3) residual treatment costs, $C_{RT}$; 4) costs of modifying the environment to reduce receptor damages, e.g., in-stream reaeration and low-flow augmentation, $C_{ME}$; 5) costs of final protective measures, e.g., water treatment facilities, $C_{FP}$; and 6) subsequent damages to man caused by ambient concentrations of residuals in the environment, D. Thus:

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[3]A detailed exposition of the linear programming model of production and residuals transformation, too lengthly for inclusion here, is found in Russell and Spofford, loc. cit., pp. 138-148.

$$F = B(q_i,\ i=1,\ldots,k_1) - C_p(q_i,\ i=1,\ldots,k_1) - C_{RT}(w_i,\ i=1,\ldots,k_2) - C_{ME}(s_i,\ i=1,\ldots,k_3) - C_{FP}(R_i,\ i=1,\ldots,k_4;\ y_i,\ i=1,\ldots,k_4) - D(y_i,\ i=1,\ldots,k_5)$$ [4]

where:

$F$ = value of the objective function;

$q_i$ = activity levels of $k_1$ production processes;

$w_i$ = activity levels of $k_2$ residuals treatment processes;

$s_i$ = activity levels of $k_3$ processes for modifying the environment;

$R_i$ = ambient concentrations of residuals at $k_4$ receptor locations;

$y_i$ = ultimate ambient concentrations of residuals resulting in damages to receptors at $k_5$ locations.[5]

While this function is ordinarily nonlinear, the authors state that very often it is possible to transform a nonlinear function into a piecewise linear form. If the constraint set is also linear, the problem may then be solved as a standard LP problem.

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[4] Russell and Spofford, loc. cit., p. 127.

[5] Subsequently, the objective function is revised to reflect other considerations. The last term in the revised equations then becomes: $DC(x_i,\ i=1,\ldots,k_6;\ s_i,\ i=1,\ldots,k_3)$, where DC represents the minimum of receptor damages plus costs of final protective measures and $x_i$ = activity levels of $k_6$ residual discharge activities (as in Figure II.1). Russell and Spofford, loc. cit., p. 130.

## Environmental Diffusion Models

The environmental diffusion models are used to describe the transportation, transformation and storage, throughout both space and time, of both energy and materials that have been disposed of in the environment as residuals from the production and consumption activities of man. Russell and Spofford use these models to specify the steady state ambient concentrations of residuals at various points in space (receptor locations) throughout the environment, given: 1) a set of residual discharge levels (from the LP model), and 2) a set of values for the environmental parameters, e.g., stream flow and velocity, water temperature, wind speed and direction, and atmospheric mixing depth. For their purposes (i.e., the desire to relate marginal damages to types and sources of residuals), Russell and Spofford need to be able to relate quantity of residuals discharged from a production or consumption activity in a region to its contribution to the total ambient concentration at a given receptor location. The authors refer to the general form of such models as transfer functions but note that under very special assumptions (i.e., deterministic, steady state model with noninteracting residuals) these transfer functions degenerate to constants and thus may be called transfer coefficients.[6] Here the ambient concentration of the

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[6]For an example of how one can actually evaluate the numerical value of these coefficients see, Russell and Spofford, <u>loc. cit</u>., pp. 148-150.

$k^{th}$ residual at any point in the region as a result of discharge from one source in the region may be expressed as:[7]

$$R^{(k)} = a^{(k)}X^{(k)}$$

where:

$R^{(k)}$ = ambient concentration of the $k^{th}$ residual;

$a^{(k)}$ = transfer coefficient for the $k^{th}$ residual; and

$X^{(k)}$ = rate of discharge of the $k^{th}$ residual.

In the case where a number of sources are discharging the same residual, the ambient concentration of this residual at a given receptor location may be determined by summing up contributions from all sources. Thus:

$$R^{(k)} = a_1^{(k)}x_1^{(k)} + a_2^{(k)}x_2^{(k)} + \ldots + a_n^{(k)}x_n^{(k)}$$

where the subscript represents the source.[8]

In the most general case it is possible to relate many receptor locations with all sources in the region. This relationship is conveniently expressed in matrix notation as:[9]

$$R = A \cdot X$$

where:

R is a vector consisting of elements $R_i$, i=1,..., m;

A is a matrix of transfer coefficients containing

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[7]Russell and Spofford, _loc. cit._, p. 150.

[8]Russell and Spofford, _loc. cit._

[9]Russell and Spofford, _loc. cit._, p. 151.

the elements $a_{ij}$, i=1,...,m, j=1,...,n, relating the ambient concentration at receptor location i to a unit discharge of a residual from source j; and

X is a vector of residual discharge levels (from the LP model) with elements $x_j$, j=1,...,n.

Russell and Spofford recognize that the environmental portion of their general model could employ a variety of formulations other than the transfer coefficient approach that they have chosen to follow. For example, complex diffusion-simulation models which trace in detail the path of residuals through the regional environment and keep track of concentrations over time could be developed, at least conceptually. However, it is unlikely that such models could be implemented with currently available data. Such models would incorporate the environmental parameters noted above in addition to a random element. Indeed, the authors suggest that whenever available, more comprehensive and detailed models of the regional environmental system (or parts thereof) should be substituted for their transfer coefficient approach.[10] In practice, however, the approach used in a given situation will depend upon data availability (both in terms of quantity and quality) and the specific questions for which one is seeking answers.

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[10]Russell and Spofford, loc. cit., p. 148.

## Modeling Residuals Damages

Perhaps the least developed portion of the Russell-Spofford model is that containing receptor damage functions. Such functions, in an ideal version of the model, would relate environmental damages per unit of time at each receptor location to ambient concentrations of residuals at each location (from the environmental models). However, the authors note that little is known about the form these damage functions should take. In discussing such functions Russell and Spofford admit that they are ". . . operating in a world in which very little is known about any actual damage functions. Indeed, it seems fair to characterize this section of the management problem as an enormous set of research needs."[11] Thus this portion of the Russell-Spofford model is left relatively open. The researcher is free to substitute the best available model for translating ambient concentrations of residuals into environmental damages.

In their discussion, Russell and Spofford outline a possible approach for a particular receptor location i. At any point in the iterative solution process a vector of ambient concentrations, $(R_i^{(k)})$ can be identified with location i. In addition, some set of human activities will be located at i, some of which will be affected by one or more of the k elements of $(R_i^{(k)})$. Russell and Spofford

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[11] Russell and Spofford, loc. cit., p. 152.

use the example of a suburban housing development at location i where some of the activities identified with this development could be characterized as household cleaning, housing maintenance, landscaping and gardening, and more generally, human existence. All of these activities are affected in some degree by atmospheric pollution. It might be possible to measure each of these effects, in dollar terms, as the increased cost of carrying on each activity. In the example used by Russell and Spofford, the damages associated with housing maintenance and $SO_2$ concentration, for instance, might be the increased cost of paint, labor, etc., necessary to keep houses at i at some specified state of repair and appearance when atmospheric moisture and sulfer dioxide mix to create a ". . . kind of perpetual acid bath."[12] Similarly, particulate fallout might increase the costs of house-cleaning, and concentrations of certain gases (e.g., nitrogen dioxide and hydrogen fluoride) could cause damage to trees and plants.

Russell and Spofford note that some of the activities taking place at this housing development (e.g., individual people eating, drinking, breathing, smelling, seeing, and hearing) are also affected by residuals concentrations, but that ". . . the damages associated with these direct effects are probably among the most difficult to quantify since there is virtually no point at which receptors bring their own judgements about the severity of conditions up against

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[12]Russell and Spofford, loc. cit., p. 153.

the measuring rod of money."[13] Russell and Spofford go on to discuss some less direct effects, notably health effects, of residual concentrations.

The authors next assume that a set of relations between damages and residuals concentrations for, say, stream DO, suspended solids, and chlorides; atmospheric $SO_2$, $NO_2$, and particulates; and for land pollution caused by accumulations of solid wastes, are known. We may then sum up damages at receptor location i associated with the ambient concentration of the $k^{th}$ residual (i.e., add up the individual activity damage functions associated with the $k^{th}$ residual at location i) to get a set of composite damage functions, one for each residual for that location. We may write this composite function as:[14]

$$DM_i^{(k)} = f(R_i^{(k)})$$

where: $DM_i^{(k)}$ = total damages at receptor location i associated with the ambient concentration of the $k^{th}$ residual.

Russell and Spofford note that if these composite functions are available for each of the M locations in the region, then the total regional damages associated with the $k^{th}$ residual ($D_T^{(k)}$) are:[15]

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[13]Russell and Spofford, loc. cit., p. 154.

[14]Russell and Spofford, loc. cit., p. 155.

[15]Russell and Spofford, loc. cit.

$$D_T^{(k)} = \sum_{i=1}^{M} DM_i^{(k)}$$

and the total regional damages from all k residuals ($D_T$) are given by:[16]

$$D_T = \sum_{k=1}^{K} D_T^{(k)}$$

In addition to the fact that for the most part relations between ambient concentrations of various residuals and damages to various activities cannot be adequately specified (thus leaving the functional forms undefined), one should also recognize that even if functional forms were specifiable, it is doubtful that current data are adequate to estimate parameters of such relations. Also, it should be noted that the Russell-Spofford approach to the problem of modeling environmental damages illustrates only one of several possible approaches. Perhaps an even more ideal model would incorporate the assessment of damages problem into the previously discussed environmental diffusion-simulation model. Of course, such modification would require not only the specification of individual damage functions as described by Russell and Spofford, but also, knowledge of interactions among residuals as they affect the environment. Thus additional parameters would have to be estimated, increasing the data requirements of the model.

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[16]Russell and Spofford, loc. cit.

## Computing Marginal Costs and Damages: the Final Link

The major objective of the Russell-Spofford approach is to provide a quantitative framework for residuals management decisions. Thus they find it necessary to compute, at each iteration, marginal costs and damages to the environment which are then returned to the LP model as prices on associated activities. At present, Russell and Spofford incorporate marginal damages associated with the discharge of residuals in the environment as "shadow prices" on the discharge of these residuals, since for the most part market prices do not exist.[17]

Russell and Spofford state that:

> When explicit analytical expressions are available for relating (a) ambient concentrations to the discharge of residuals, and (b) damages to ambient concentrations, expressions for the marginal damages are dervied by taking the appropriate partial derivatives of the total damage function. If enough simplifying assumptions are made, the desired analytical functions can usually be provided. However, there are some cases in which continuous analytical expressions are just not available. For some of these situations, simulation models for relating inputs to, and outputs from, the environment may be all we have to work with.[18]

When analytical functions are unavailable, Russell and Spofford suggest that marginal damages may be evaluated numerically. Thus for the $k^{th}$ residual discharged one would have to solve the environmental-damage models twice; once for the discharge vector $(x_1^{(k)}, x_2^{(k)}, \ldots, x_n^{(k)})$, and the

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[17]Russell and Spofford, <u>loc. cit</u>., p. 156.

[18]Russell and Spofford, <u>loc. cit</u>., pp. 156-157.

second time for a discharge vector including a small change in the quantity of one of the residuals discharged, i.e., $(x_1^{(k)}, x_2^{(k)} + \Delta x_2^{(k)}, \ldots, x_n^{(k)})$. Finding the difference between the total damages for these two vectors, $D_T(x_1^{(k)}, x_2^{(k)}, \ldots, x_n^{(k)}) - D_T(x_1^{(k)}, x_2^{(k)} + \Delta x_2^{(k)}, \ldots, x_n^{(k)})$, and dividing this difference by the difference in the quantity discharged, $\Delta x_2^{(k)}$, will provide a measure of the marginal damages for the $x_2^{(k)}$ discharge source (perhaps a pulpmill).[19] Russell and Spofford recognize that this method of computing marginal damages is lengthy and thus quite expensive.

If analytical functions are available then marginal damages can be expressed as the partial derivatives of total damages, $D_T$, with respect to each of the residuals discharged. This method yields the vector of marginal damages that is returned, at each iteration, to the industry model as shadow prices on the discharge of residuals to the environment.[20]

## The Ideal Model: A Modified Russell-Spofford Approach

Development of those portions of the Russell-Spofford model dealing with environmental diffusion and ambient concentrations of residuals, receptor damages, and computation

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[19] Russell and Spofford, _loc. cit._, p. 157.

[20] This method is discussed in detail in Russell and Spofford, _loc. cit._, pp. 157-159.

and feedback of marginal damages, has been constrained by certain practical considerations, the most important of which is availability of relevant data inputs. As noted previously, development of the ideal conceptual model in this research is not so constrained. In addition, Russell and Spofford attempted to present a general model which will provide a framework for residuals management decisions. The purpose here for developing a conceptual model is much more specifically defined, i.e., to provide a conceptual model which will form the basis for an analysis of the feasibility of linking the forest-centered economic and ecologic systems of western Montana in a single, comprehensive, integrated model. Thus, we are free to incorporate considerably more detail then would be possible if we required the ideal conceptual model to be of general applicability to a variety of regional contexts and systems.

Accordingly, it is felt that the economic portion (i.e., the industry LP model) of the Russell-Spofford model should be incorporated, with only minor modification, into the ideal conceptual model (see Figure IV.1). The modification indicated here requires that each element in the residuals discharge vector be spatially identified by the addition of a set of subscripts which refer to specific geographic locations. It is felt that such a modification will increase the utility of the information output of the model, especially with reference to questions of environmental impacts. Conceptually, this modification could be implemented by

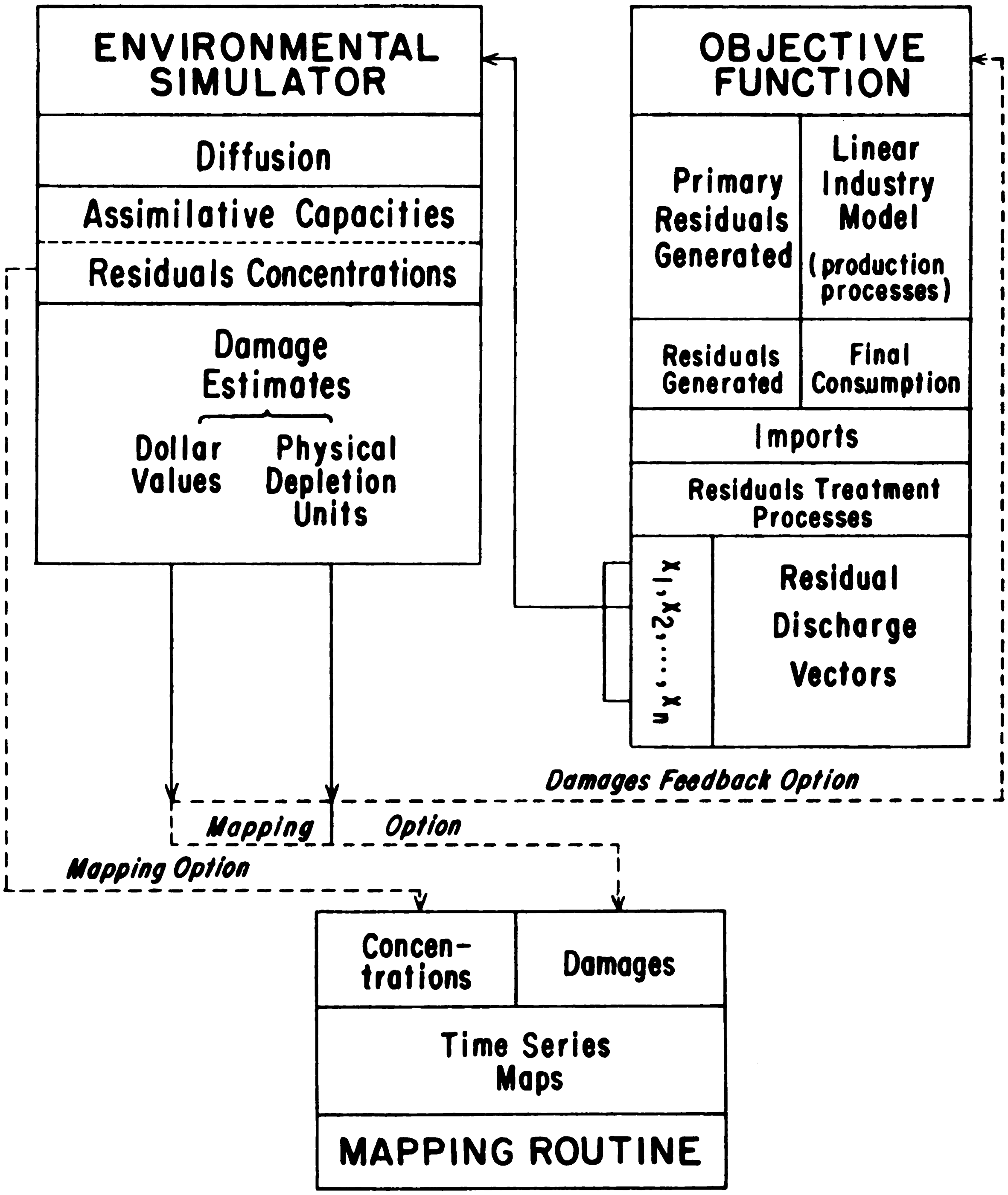


Figure IV.1.--Schematic Diagram of the Ideal Conceptual Model superimposing a fine grid on a map of the region in which the model is being applied. The location of the origin of each residual generated by the economic system might then be accurately identified by noting its coordinates from the grid. These coordinates could then be coded and translated into a set of subscripts which could subsequently be attached to each variable representing a residual discharge activity in the LP portion of the model.

The environmental portion of the ideal model is formulated as a single simulation model which receives as input the vector of residuals discharges (from the LP submodel) and traces the diffusion of these residuals through the regional environment, keeping track of the build-up (concentrations) of residuals at the various receptor locations (e.g., streams, lakes, landfills, urban areas, etc.) throughout the region. In addition, the environmental simulator estimates the damage caused by these concentrations to the various physical and biological entities located at each receptor by relating residuals loading to assimilative capacities. Conceptually, the simulation portion of the ideal model is designed to generate information about the spatial dimension involved in these processes, essentially making use of the grid coordinate system noted above. It is important to note that the portion of the environmental simulator dealing with diffusion of residuals throughout the regional environment and their concentration at various locations in this environment, is conceptualized as having stochastic elements. It is felt that modeling these processes using stochastic rather than deterministic techniques provides a more accurate representation of what actually happens in the real world, since many factors influencing diffusion and concentration of residuals are randomly distributed in both time and space thus making a deterministic approach inappropriate.

Output of the simulation submodel (specifically those values measuring current status of the environment including residuals concentrations and damage levels), labeled with a set of spatial coordinates, then enters as input to a computer mapping routine (perhaps one similar to SYMAP) so that a series of maps can be produced providing a graphic representation of the impacts over time and space.

The damage estimates from the environmental submodel are given in dollar terms (i.e., costs) if the damages are not related directly to the capacity of the environment to provide raw material inputs to the region's production system. An example of such damages would be any increase in the costs of home maintenance attributable to, say, concentrations of airborne residuals which might necessitate more frequent painting of these residences. If the damages are directly related to the capacity of the environment to provide raw material inputs to the production system then the environmental submodel estimates them in physical depletion units such as decreases in timber growth rates associated with concentrations of certain residuals at

specific locations. Damages which are not related directly to the provision of raw material inputs but for which it is not possible to assign dollar values, are also estimated in physical units.

For each round or iteration, the environmental submodel is conceptualized so as to estimate the damages caused at each receptor location by each residual discharged. The damages estimated in dollar terms are then converted to marginal values. This is accomplished, conceptually, by summing the damages attributable to a given residual for all locations and then dividing this total damage figure by the quantity of the residual discharged. The result is a marginal damages estimate (i.e., damages caused per unit of residual discharged), for each residual (causing dollar-cost damages) discharged by the economic system. An option is provided whereby these marginal damage estimates may be entered into the LP submodel on the next iteration as constraints on the objective function. Conceptually, these constraints are in the form of prices on those activities discharging the damaging residual.

The damages estimated in physical depletion units are summed (i.e., damages caused at each receptor location by a given residual are added) to yield a total damage estimate for each residual causing a decrease in the capacity of the environment to provide raw material inputs to the production system. These total damage estimates may also be entered in the LP submodel in the next round where they modify, directly, raw material input constraints.

As in the Russell-Spofford approach, one has the option of running the entire model in an iterative fashion. In addition, the model design allows one to evaluate the full extent of damages if damages from the previous iteration are not entered as constraints on the production and consumption systems in the current LP solution. Conceptually, this option is implemented in the model by including a provision for closing the damages feedback loop so that the damages constraints remain at their initial values through the entire run. Exercising this option is analagous to allowing environmental damages caused by residuals discharges to remain as externalities to the production and consumption processes, while not exercising the option is analagous to incorporating these factors in production and consumption decisions (i.e., internalizing the externalities).

It is recognized that the ideal conceptual model discussed here is presented in very general terms. This is particularly true of the environmental simulation submodel. It would, of course be preferable, if the entire conceptual model could be specified mathematically. However, it is felt that development of the conceptual model to this stage would require research resources far in excess of those allocated in pursuit of this specific study objective. There are indications that currently available data are grossly inadequate for operationalizing such a model in a regional context even if conceptual refinement had progressed to the stage where implementation was possible. It should be remembered, that development of an ideal conceptual model in this research serves two essential roles. First, the ideal model can be a blueprint for subsequent modeling efforts as well as a guide for future data collection and processing activities in the study region. Second, it provides a basis for evaluating the feasibility of an operational economic-ecologic linkage model for the western Montana region. Thus it is thought sufficient to conceptualize the ideal model in general terms so long as such a conceptualization serves the purposes for which it was intended. The conceptual model, as presented here, is thought to be adequate for these purposes.

## Kinds of Questions for Which the Ideal Model Would be Relevant

Quite obviously, there is a wide range of questions that could be answered if regional economic and ecologic systems could be as fully linked in an operational model as they are in reality. As problems, and hence questions, become more complex and detailed, the quantity and depth of information necessary for their solution increases. Ultimately, the kinds of questions that will, in practice, be asked of an economic-ecologic model will depend upon the nature of the decisions faced by various resource managers and research personnel. If, in the case of forest management, the decision-maker or researcher is interested in maximizing incremental growth of timber on a forest (or individual stand) he may be tempted to rely solely on silvicultural treatments to accomplish his goal. If he is unaware of (or chooses to ignore) the impacts of his decisions on the local environment and thus, perhaps indirectly, on the capacity of the environment to sustain timber growth, then an economic-ecologic linkage model will be of little use to him. Indeed, even a strictly economic formulation which provides information on regional economic impacts of timber production decisions will be irrelevant. In other words, if off-forest regional economic and environmental impacts are considered by the decision-maker to be factors external to timber production decisions then he will have no questions which could be answered by an integrated regional economic-ecologic model. Rather, he will be concerned entirely with silvicultural practices and, possibly, relevant principles from production economics. The other extreme is represented by the decision-maker who regards all potential impacts of each decision as worthy of some consideration. In this case there are no externalities and no regional model, no matter how comprehensive, will provide answers to all of the relevant questions (except insofar as the regional economic and ecologic systems are closed).

In general, questions that can be answered using regional economic-ecologic models can be classified into two very broad groups. The first group consists of those questions concerning regional economic impacts (direct, indirect, and induced) of changes in the economic system. For

example, an increase in the timber harvest from a given forest in a given year may have an influence on regional income and employment, industrial and commercial growth, tax expenditures and revenues, etc. The ideal model described above would provide adequate information, in the form of estimated impacts of the increased harvest on the important economic performance measures, to answer questions of this type. The second group of questions are those concerned with the regional environmental impacts of given changes in the economic system of a region. Here it might be useful to distinguish three levels or sub-groups of questions. The first sub-group is comprised of those questions about the amount of various residuals likely to be discharged as a result of a given change in the economic system. Included here are discharges of residuals from all economic activities, i.e., both production and consumption activities. Thus an increase in timber harvest will result in increases in solid wastes both directly (e.g., slash) and also indirectly (e.g., residuals from consumption processes). Such a change in the economic system may also result in increases in the amounts of various airborne residuals directly from increased harvest activities and indirectly as a result of probable increases in processing activities located in the region. Such information would be useful if one wanted to know, for example, how much additional waste treatment capacity would be required to accommodate a given change in the economic system. The ideal model would pro-

vide information to answer questions relating to amounts of residuals discharged. The amount of detail provided by the ideal model in this regard will depend upon the extent to which each production and consumption function is specified within the model. For example, information provided in terms of gross measures (e.g., tons of solid waste) would require a less detailed specification of household consumption activities than information provided in terms of more specific measures (e.g., tons of paper, tons of human waste, tons of aluminum, etc.). It should be obvious that, in the absence of data and resource restrictions, there is virtually no limit on the extent to which such relationships can be specified (except perhaps the limits set by human creative capacity). The "rub" as it were, comes when one tries to quantify such relationships.

The second sub-group of environmental questions involves those questions concerned with distribution and concentration of residuals discharged by production and consumption activities of the regional economic system. Such questions become particularly relevant when residuals discharge volume figures are insufficient for the problems at hand. There are many instances where knowledge of the spatial dimension of residuals is at least as important as knowing the amounts discharged into the regional environment. For example, an increase in the timber harvest on a forest in a given region may result in increased activity in the processing sector of the regional economy. Such in-

creased activity will, in the absence of changes in technology, result in an increase in airborne residuals. However, estimated amounts of these discharged residuals (e.g., solid particulates, $SO_2$, etc.) may not be enough to answer certain questions. If one is interested in knowing, for instance, how the discharge of these extra residuals will affect health, timber growth, home maintenance, etc., then he must know where the residuals go after they leave the smokestack. Are they widely dispersed over the region (thus in most cases diluting their strength) or do they tend to concentrate at discrete locations (thus increasing the potential for adverse effects)? If concentrations occur, then it may be desirable to know where and in what amounts. The ideal model described in the previous section has the capacity to provide answers to questions of this type. Once again, it should be noted that the completeness of such answers, as provided by the model, will depend on whether all relevant relationships have been specified in the model and on the level of detail incorporated into the specification of those relationships included.

The third level or sub-group of questions involve estimating actual impacts that the discharge, diffusion, and concentration of residuals (caused by a given change in the economic system) will have on the regional environmental system. If we find, for example, that airborne residuals tend to concentrate at various locations throughout a region (perhaps due to persistent meteorological patterns) then how much of a decrease in the rate of timber growth (if any) can we expect at various levels of concentration? At what levels of concentration of certain residuals is the capacity of various elements in the environment to process these residuals exceeded? For example, at what level of concentration will bio-chemical oxygen demanding (BOD) substances such as human wastes reduce the dissolved oxygen (DO) content of water in a given stream below the minimum content necessary to support, say, a trout population? The ideal model is designed to provide adequate information to answer such questions in a regional context, if relationships in the model are appropriately specified and all relevant relationships have been identified and included.

A fourth sub-group of questions can be identified, but does not fit well within our scheme of classification. Questions concerned with effects that environmental changes (caused by a given change in the regional economic system) will have on the regional economic system contain elements of both the economic and ecologic aspects. If one is considering a decision of whether or not to increase the timber harvest on a given forest by a specific amount, it is possible that he may not wish to consider off-forest effects. Thus, there would be no need to employ an economic-ecologic linkage model. On the other hand, before making the decision the analyst may want to estimate likely impacts of increased harvest on regional income and employment. Also, he may require at least some gross measures of the total amounts of various residuals that will be discharged into the regional environment as a result of increased harvesting. A much less complicated model (e.g., an input-output formulation extended to include environmental sectors) than the ideal conceptual formulation presented here would provide adequate information in this regard. However, use of the simpler model would leave the analyst in the position of having to make judgements as to the significance of this information (e.g., what does a .2% increase in regional income or a 100 ton increase in solid wastes in the region mean?). It is possible that he will want to know where the various extra residuals discharged as a result of the increased timber harvest go and whether or not they concentrate at certain locations within the region. Such questions could be answered by an economic-ecologic model somewhat less complex than the ideal formulation presented here (but more complex than an extended I-O formulation), but it would be necessary to model the ecologic system in some detail. Once again, the analyst must still exercise considerable judgement regarding the significance of such information. In addition, if he requires estimates of environmental changes (or damages) likely to be brought about by the diffusion and concentration of such residuals, then he must employ a complex model such as the ideal formulation conceptualized here. For example, the analyst may require an estimate of the possible decrease in the fish population caused by an increase in timber harvest. Such damages might be expected since a larger timber harvest almost certainly suggests both increased logging activity and increased processing activity. The increased processing activity may require additional labor, which suggests more people and higher levels of BOD substances in streams. This indicates a decrease in DO, perhaps to the point where a reduction in the fish population of the region occurs. In addition, the possibility of a decline in the fish population is increased due to the additional logging activity which could result in signficantly heavier sediment loads in the streams in the region. Clearly such information can be generated only by a model offering rather complete economic-ecologic linkages. However, the analyst must still exercise judgement as to the significance of a given decrease in the fish population relative to other impacts of the decision to increase timber harvest (e.g., higher regional income and employment, increased timber growth as a result of old-growth removal, increased levels of air pollution, etc.).

It is at this point that the fourth type of question might be asked. For example, one might want to know the impacts of a possible decrease in the fish population (an environmental change) on, say, regional income (an economic factor). Such information can be provided only if the model used for analysis contains feedback provisions wherein environmental changes can be translated into constraints on production and consumption activities. With inclusion of this final linkage in the model, the amount of judgement necessary on the part of the analyst is greatly reduced. If all relationships have been identified and appropriately specified in the model, then a complete display of the multiple regional impacts of the decision to increase timber harvest will be provided. The decision-maker or analyst having access to such information is thus free to exercise judgement in evaluating trade-offs defined by an examination of regional impacts. It might be said that the really essential decisions involve these basic trade-offs and that the ideal model is designed to provide sufficient information to adequately define them.

In summary, it appears that the ideal conceptual model presented above has the capacity to provide a great variety of information. The information output seems adequate for answering even the most detailed questions involving regional economic and ecologic impacts of resource management decisions. In addition, it should be noted that the LP formulation of the economic portion of the model provides the user with capacity to solve for an optimal solution providing he has specified a relevant objective function and set of constraints. It is felt that the kinds of questions that could be answered by the ideal conceptual model, if it were implemented in a given regional context, have been adequately identified here, though the discussion has been quite general.

## Data Requirements for Operationalizing the Ideal Model

Included as an essential element in the third research objective is a description of data requirements for operationalizing the ideal conceptual model in a regional context. The most important role of this objective is to provide a basis for evaluating the operational feasibility of economic-ecologic linkage models in the western Montana region. Given this purpose and the fact that limited research resources had to be allocated in pursuit of several study objectives, it was thought sufficient to conceptualize the ideal model in rather general terms. In addition, it should be remembered that development of the ideal conceptual model has not been constrained either by consideration of realistic data or resource limitations or of factors specific to a given regional and/or problem context. While this is compatible with the overall purpose for developing the model, it does complicate the problem of describing the data required for implementation. Therefore, while the presentation of the conceptual model provided in this chapter is thought adequate for its overall purpose, it is clearly not refined enough to allow for detailed definition of these data requirements. It is felt, however, that a general discussion of data requirements (i.e., one which explores the types of data required to implement the model, but does not specify each variable and parameter involved) will provide sufficient insight into the kinds of data required to allow for comparison with actual data availability in the study region, or, for that matter, to allow for a general evaluation of any relevant data system. In addition, the discussion of data requirements presented in this section could be translated into a set of guidelines for future data collection and processing activities. Clearly, then, a general description of the data requirements for the ideal model adequately serves the intent of this third research objective.

It should also be noted that a more detailed description of data requirements would require not only that the conceptual model be completely specified, i.e., all equations must be noted in explicit form, but, also, that the entire description be compiled with reference to a specific application. It is felt that such a detailed specification of the conceptual model is not within the scope of this research effort. One other consideration in the decision to couch the data requirements description in general terms was the huge amount of space that would be necessary to list each and every bit of information necessary to operate the conceptual model described in this chapter.

For almost any application (i.e., nearly all regional and/or problem situations) certain general types of information input will be required to operate the ideal model. Considerations specific to a given application may be reflected in differences within each catagory both in terms of quantity and quality of data required, but, in general, a number of data catagories are essential for operation in virtually all situations. The sections to follow describes these general data requirements. It should also be noted that the following discussion assumes that the user has clearly defined his problem and is able to state explicitly his goals and objectives for using the model.

## The Economic System

The ideal conceptual model emphasizes some economic goal as the objective function of the LP portion of the model, with environmental considerations being reflected in the constraint set. Thus the first kind of data necessary for operationalizing the economic portion of the model is that necessary to define the objective function and non-environmental constraints. The discussion of the tentative objective function used in the Russell-Spofford model is an example of the kind of data necessary here, though specific requirements will vary with the exact form chosen for this function.[21] The non-environmental constraints (in the form of linear inequalities) reflect, in general, either limits on the production sector or restrictions applicable to consumption activities. Some of the constraints are non-negativity constraints wherein it is required simply that each activity in the model not be allowed to go below zero, i.e., it is not possible to produce or consume negative amounts

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[21]See Russell and Spofford, loc. cit., pp. 126-127, and p. 130.

of a good. No data are necessary in defining these constraints. Other constraints are needed to limit demand for goods from the system and to represent availability of raw material inputs to the production processes. Also, constraints representing minimum production requirements must be established. Those constraints setting upper and/or lower limits on activities in the model will have non-zero values on the right hand side and thus data are necessary to establish these values.

It should be noted that constraints reflecting availability of production inputs from the environmental system must be set initially at some value. However, as the model is run through each iteration, some of these constraints will be modified on the basis of feedback information on environmental damagesestimated by the environmental simulator. Thus data are necessary to provide realistic estimates of the initial availability of each of the raw material production inputs considered in the model. The number of inputs actually considered and the designation of those to be modified by the damage estimates of course depends upon the particular application and, hence, on the objectives of the user.

Other information is necessary to define the activities that are to be incorporated in the model. This is similar to the problem of deciding which sectors to include in a regional I-O formulation. One must have rather detailed information on the structure of the regional economy if all of the relevant activities are to be included. It should be noted that both production and consumption activities must be specified. Related to this topic is the problem of defining residuals that are to be considered for a given application in the model (e.g., is the model going to consider, say, fly ash as a residual or will it break fly ash into its chemical components and consider each component as a separate residual?). Part of the answer of course depends upon the objectives of the user. However, much of the answer lies in the detail to which the environmental system is represented in the model (e.g., are the environmental sectors specified in the model as, say, air, water, and land, or is a more detailed sectorization appropriate?). Regardless of the particular specification ultimately employed for the residuals to be considered, the user will require data related to this problem before an informed decision can be made in this regard.

In addition to the data noted above, it is also necessary to have a matrix of coefficients defining the relationships existing among activity levels for all activities included in the model. Essentially these coefficients are analagous to the direct and indirect coefficients associated with I-0 formulations. They are measures of the interdependence which exists among the economic activities of a region. Thus it is necessary to have data which will allow one to define, for example, how many units of output from activity A are necessary to produce a unit of output from activity B; or how many production units from which production activities are necessary to support a unit of some given consumption activity (e.g., perhaps one person consuming a specified bundle of goods for one day). These coefficients are the most essential to the operation of the economic portion of the model, and, as pointed out in the literature, are often the most difficult pieces of information to obtain empirically.

Another type of coefficient necessary for the matrix noted above, relates the activity levels of each producing and consuming activity to the discharge of residuals. Thus data are needed that will enable the user to define, for example, the amount of BOD substances that will be discharged per unit of economic output from, say, a pulpmill. Another example would be data sufficient to define the quantity of CO (carbon monoxide) released into the regional atmosphere per unit of some specified consumption activity (e.g., heating one home for one month).

Essentially, then, data requirements for operationalizing the economic portion of the ideal conceptual model (i.e., the LP submodel) are similar to those for operationalizing any I-O formulation, with some additions. Data requirements for standard I-O models are well documented in the literature[22] and, therefore, it is not thought

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[22]See for example: Leontief, Input-Output Economics, and Miernyk, loc. cit.

necessary to discuss them in detail here. The additional data required for the economic submodel are related to the definition and specification of an objective function and set of constraints and to the determination of residuals discharge coefficients. Also, inclusion of consumption activities in the ideal model increases the data requirements over those normally associated with a standard LP or I-0 formulation. However, additional data made necessary by this expansion (i.e., that necessary to determine the coefficients relating consumption activities in the model to each other and to production activities) are similar in form to the data required by the standard formulation.

## The Environmental System

The environmental portion of the ideal conceptual model is conceptualized in more general terms than is the economic portion. This is essentially the case because the economic model uses a technique (i.e., LP) which has substantially more formal structure associated with it than does simulation. It is, therefore, difficult to discuss data requirements for this portion of the model in the absence of any reference to a particular application and, hence, more detailed specification of the environmental simulator. However, a general discussion similar to the one provided in the previous section is possible.

First, data related to regional environmental structure are necessary to enable users to define appropriate environmental sectors and to locate those points throughout the environment that should be designated in the model as receptor locations. It should be noted that receptor locations are, in general, defined by both the spatial structure of regional economic activity and environmental factors. The choice of both an evnironmental sectorization scheme and receptor locations depends, also, to a large extent upon the goals of the user.

Without a more detailed specification of the form of equations in the environmental simulator (remembering that a more detailed specification would require reference to a specific problem context or application), it is not possible to identify each necessary parameter. However, to simulate the diffusion of residuals through the various environmental sectors, certain data are essential though, again, requirements vary depending upon how residuals and environmental sectors are defined within the model. If, for example, the environmental sectors are defined as land, water, and air, then data related to air temperature, wind speed and direction, turbidity, precipitation, and other atmospheric phenomena are essential to defining the parameters for the diffusion of airborne residuals. Also necessary are stochastic variables representing probabilities of occurance for certain meteorological phenomena or combinations of phenomena. Large amounts of data are required to determine values for these variables.

For the water sector (e.g., lakes, streams, ground water, etc.), data related to water temperature, depth, volume, velocity (in the case of streams), and a number of other phenomena are necessary to define parameters in the equations for the diffusion of waterborne residuals. Again, stochastic variables and the associated data are necessary here. Similarly, parameters necessary for modeling diffusion of solid wastes can be determined only if data related to elevation, slope, precipitation, wind speed and direction, etc., are available.

It should be noted that data related to both the temporal and spatial aspects of the environmental phenomena included in the model are essential. Thus it is necessary to have data related to, for example, the temporal distribution of stream volume (e.g., high-flow and low-flow periods) and the spatial distribution of this phenomenon (e.g., upper reaches of a stream vs. lower reaches). Also, stochastic variables associated with the environmental simulator are related to both the temporal and spatial dimensions of the diffusion problem. Thus the probability of a given phenomenon (e.g., heavy rainfall) or combination of phenomena occurring at a given point in time and at a particular location in the region must be incorporated. Clearly, fixing of these probabilities requires data of both a temporal and spatial nature.

In summary, depending upon the specification of the diffusion portion of the environmental simulator, the parameters defined within this portion of the model can be estimated only through analysis of relevant data. It is apparent that data requirements for implementing this portion of the model are rather large.

The diffusion portion of the environmental simulator is conceptualized as providing a tabulation of the concentrations of various residuals at locations throughout the regional environment. If this is to be accomplished with an operational model, then the model must contain parameters related to the assimilative capacity of the environmental phenomena at each location. Apparently, in many cases knowledge of the process by which the environment assimilates certain residuals is rather incomplete. Thus it is questionable whether appropriate variables can even be specified much less data obtained for the estimation of certain of these parameters. However, to be fully operational, the model must contain parameters representing these assimilative capacities and thus part of the data requirements for the environmental portion of the model are related to the problem of estimating these parameters.

Another set of relationships within the environmental portion of the ideal model are those which estimate damages caused by concentrations of residuals at various locations throughout the regional environment. These damages are conceptualized in two different forms. First, as physical depletion units (if they directly affect the quantity or quality of raw material inputs to the region's production system), for example the decrease in usable timber associiated with a decline in timber growth caused by the concentration of certain residuals at specific locations. Second, damages may be estimated in terms of dollar costs (if they do not directly affect input availability), for example the increase in dollars spent per unit of fish caught by sport fishermen resulting from a decline in the fish population of a stream caused by high residuals concentrations.

The number and actual specification of these damage relationships depends upon the objectives of the user in a given application of the model and are, therefore, defined only in this context. However, it is clear that each relationship of this type included in an operational model will involve the estimation of parameters for its equation. As with many of the data requirements for the ideal conceptual model, it is difficult to discuss, in general terms, the kinds of data necessary to operationalize this portion of the model.

The ideal conceptual model also contains a provision for entering the damage estimates from the environmental simulator into the LP industry model as constraints on the solution of that submodel. Those environmental damages that are estimated in physical depletion units are entered so as to modify directly the raw material production input constraints. This is accomplished, conceptually, by subtracting the amount of the damage (e.g., 5,000 cubic feet of timber) from the initial quantity available (i.e., the value on the right hand side of that production input constraint at the begining of the current round). Thus availability is reduced by the amount of the damage and the value of the objective function on the next round is constrained by this modified availability value. Clearly, no additional data are required to return these damage estimates to the LP submodel.

Damages estimated in dollar terms (and converted to marginal values) are returned to the LP submodel and are entered as prices on residuals discharge activities. The price constraints are intially set at zero (i.e., for the first round or iteration) and are subsequently modified by residuals discharge prices returned at each iteration from the environmental simulator. Again, no additional data, beyond that necessary to calculate the damage estimates, are needed to return the dollar value damages to the LP submodel.

Although this discussion of data requirements for the ideal model is quite general, it is felt that the discussion provides an adequate description of the scope of these requirements. In addition, the discussion identifies at least the essential general catagories of data necessary to operationalize the ideal model. Thus it is felt that the foregoing description of data requirements fulfills the intent of this research objective.

CHAPTER V

# MODELING ECONOMIC-ECOLOGIC LINKAGES IN WESTERN MONTANA: AN EVALUATION OF OPERATIONAL FEASIBILITY

It is worth noting again that the conceptual model described in the preceeding chapter is ideal in that its development was not constrained by consideration of realistic data or resource limitations or, by reference to a particular regional and problem context. However, the general objective of this research is to describe the procedures by which the forest-centered economic and ecologic systems of western Montana can best be linked in a single analytical model. Thus, it is necessary to compare the ideal conceptual formulation with the western Montana region to determine what modifications, if any, are necessary before the model can be operationalized in the region. Stated another way, it is necessary to evaluate the operational feasibility of the ideal conceptual model for the western Montana region.

In this research, two broad areas of consideration are identified as being particularly relevant to the question of operational feasibility. First, it is necessary to consider the structural appropriateness of the conceptual model for application in the region; and to make modifications, if necessary, to achieve structural compatibility between the model and the regional systems of western Montana. Second, analysis of the secondary data base for the western Montana region is necessary to determine whether this base is adequate for operationalizing the structurally modified model, again making any modifications necessary to compensate for deficiencies (if any are found to exist) in available data. These two areas of concern form the basis for two separate research objectives in this study (i.e., objectives four and five as described in Chapter I). However, both of these research objectives are treated here in a single chapter because each is a component of the more general goal of evaluating the operational feasibility of the ideal conceptual model for western Montana.

## An Evaluation of Structural Compatibility

Clearly, there are many considerations which could be investigated if a detailed and comprehensive evaluation of the structural appropriateness of the ideal conceptual model for application in the study region is to be accomplished. It should be remembered, however, that the ideal model has been conceptualized in rather general terms, hence precluding an extremely detailed evaluation. Therefore, it is felt that the analysis of the model's structural appropriateness for representing the regional economic and ecologic systems of western Montana must also be concerned with the broader aspects of the problem, i.e., the analysis should highlight the more critical areas wherein structural incompatibilities are most likely to arise. For the purposes of this study, two general areas of inquiry have been identified as particularly relevant in this regard. The first area relates to the goals and objectives of potential users of an economic-ecologic linkage model in the region while the second involves analysis of the actual structure of the two regional systems. It is felt that any major structural modifications that might be required in the ideal model will be identified within these two areas of concern.

## Goals and Objectives of Users

Ideally, the conceptual model should be evaluated on the basis of its compatibility with the goals and objectives of all potential users in the region. However, it is important to recognize at the outset that this study is strongly client-oriented. While it is hoped that the results of the research will be useful to a broad spectrum of people and groups (both in western Montana as well as outside of the region), the research was definitely designed with a specific client in mind--the Forest Service. Thus not only time and resource constraints, but, perhaps more importantly, obligations to a specified client, have served to limit evaluation of this aspect of structural compatibility to the goals and objectives of that client. It is felt that within the context of this study this comparatively narrow evaluation is not only adequate, but preferable to a broad-based analysis including all potential users.

As the largest owner and manager of forest land in the State, it is difficult to deny the significance of the impacts that Forest Service decisions will have on the western Montana region. Essentially, the Agency's interest in studies such as this one is that of increasing its capabilities for evaluating off-forest regional impacts of forest management decisions. This interest is, however, somewhat different from that which has motivated the development of most currently available economic-ecologic linkage models, including the conceptual model proposed by Russell and Spofford. In general, such models were developed to pursue the ultimate goal of total systems management. Such management would necessarily involve a high degree of control over the regional economic system to avoid adverse environmental effects of residuals over-production or excessive depletion of raw materials. Even on the regional level it is doubtful that such control can, in fact, be exercised in a society with a long tradition of opposition to concepts of centralized planning and direction of economic activities. Certainly such control is not presently being exerted by the Forest Service even in those regions with forest-based economic and ecologic systems since governing units represent all segments of the population and this is reflected in the rules and regulations imposed by these units. Indeed, total systems management is most likely not even a long range goal of the agency or for that matter any other branch of the Federal government. Rather, it appears that the agency's main concern in using economic-ecologic linkage models is in making better informed decisions relating to the allocation of the resources over which it does exercise some control, either directly or indirectly.

Two features make the ideal conceptual model described in the preceeding chapter particularly useful for pursuing the goal of total systems management. First, the linear programming format which provides the capacity to optimize some regional objective function subject to a set of constraints means that solutions generated by the model yield information on the most efficient allocation of resources for pursuing the specified regional objective. Second, the damage estimation and feedback portions provide the model with the capacity to essentially monitor activity in the environmental system and automatically adjust the activity in the economic sectors to conform with the specified regional constraints.

If the actual goal of the user is not one of total systems management then the ideal conceptual model as it is presently formulated may provide more information then can be used. This is clearly wasteful since, as noted in a previous section of this report, increased information output from a model is achieved only by increasing the quantity and/or quality of data inputs. In addition, the ideal model presented here requires that some regional objective function be specified and optimized. It is the opinion of this author, that the maximization of, for example, regional income (or, perhaps, minimization of some measure of regional costs) is not the realistic goal of the Forest Service in making use of an economic-ecologic linkage model in the western Montana region. Of course, in forest-centered regions the agency does have available various instruments to influence regional decision-makers, and, consequently, may well be interested in such worthy objectives. However, recognition of its limited control over many of the factors which determine regional economic performance suggests that adoption of so broad a goal would be impractical. Indeed, pursuit of such a broad, unrealistic goal might even reduce, significantly, the agency's effectiveness regarding the discharge of its legal responsibilities, particularly where regional objectives conflict with National goals.

To bring the information output of the model more in line with the goals and objectives of the Forest Service, it is felt that the economic portion of the ideal model should be reformulated from an LP configuration to an I-O format. It should be noted that this structural modification not only makes the model more compatible with the specific problem context here, but, also, results in a significant reduction in the amount of data required to operationalize the model in the study region. In addition, since the I-O formulation contains no provision for a constraint set, the feedback option is eliminated from the modified version of the model. With the elimination of the feedback option, the model is no longer able to provide automatic adjustment of processing activities in the economic system to compensate for changes in the regional environment. Such adjustments must now be made exogenously and involve manipulation of final demand values and technical coefficients in the I-O model. While this does reduce the power of the model somewhat, it is felt that this reduction does not detract from the model's capacity to provide information useful to the client. It is felt that the modifications suggested thus far will reduce the number of problems encountered in implementing the model in western Montana, and, at the same time, preserve much of the capacity of the model to generate information relevant to the regional concerns of the Forest Service.

With the modifed model it is possible for the agency to translate its management decisions into dollar or quantity values and evaluate impacts of these decisions on the regional economic and ecologic systems. Thus, for example, impacts on regional income and employment can be calculated (i.e., via multiplier analysis) but the user is not constrained by the necessity of optimizing on some specific criterion. Under these circumstances, the user is free to exercise considerable judgement as to the weight such impacts are to have in the decision-making process.

### Structural Modification of the Ideal Model in Response to User Goals and Objectives

Reformulation of the economic portion of the ideal model using I-O techniques employs essentially the same procedures as those followed by Laurent and Hite in developing their economic-ecologic linkage model for the Charleston Metropolitan region.[1] Figure V.1 illustrates a simplified version of this portion of the model. Matrix A is a standard interindustry input-output matrix. Each element in the matrix is a coefficient (usually called a direct or technical coefficient) representing the amount (measured in dollar values) of the output of the row industries required to produce one dollar's worth of gross output by the industry heading the column.[2] Thus, $a_{aa}$ is the amount of output from Industry A required to produce one dollar of gross output from A. Likewise, $a_{ab}$ is the amount of output from Industry A required to produce one dollar of gross output from B. The G matrix shows the amount (in physical units) of various types of inputs (imports) from the ecologic system required to produce one dollar's worth of gross output from the industry sectors in the A matrix. Thus, $g_{1b}$ is the amount of environmental in-

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[1] Laurent and Hite, <u>Economic-Ecologic Analysis in the Charleston Metropolitan Region</u>, <u>loc. cit</u>.

[2] It should be noted that the households sector, normally exogenous, is endogenous in the structurally modified economic submodel. This is done to incorporate some aspects of consumption activities in the region.

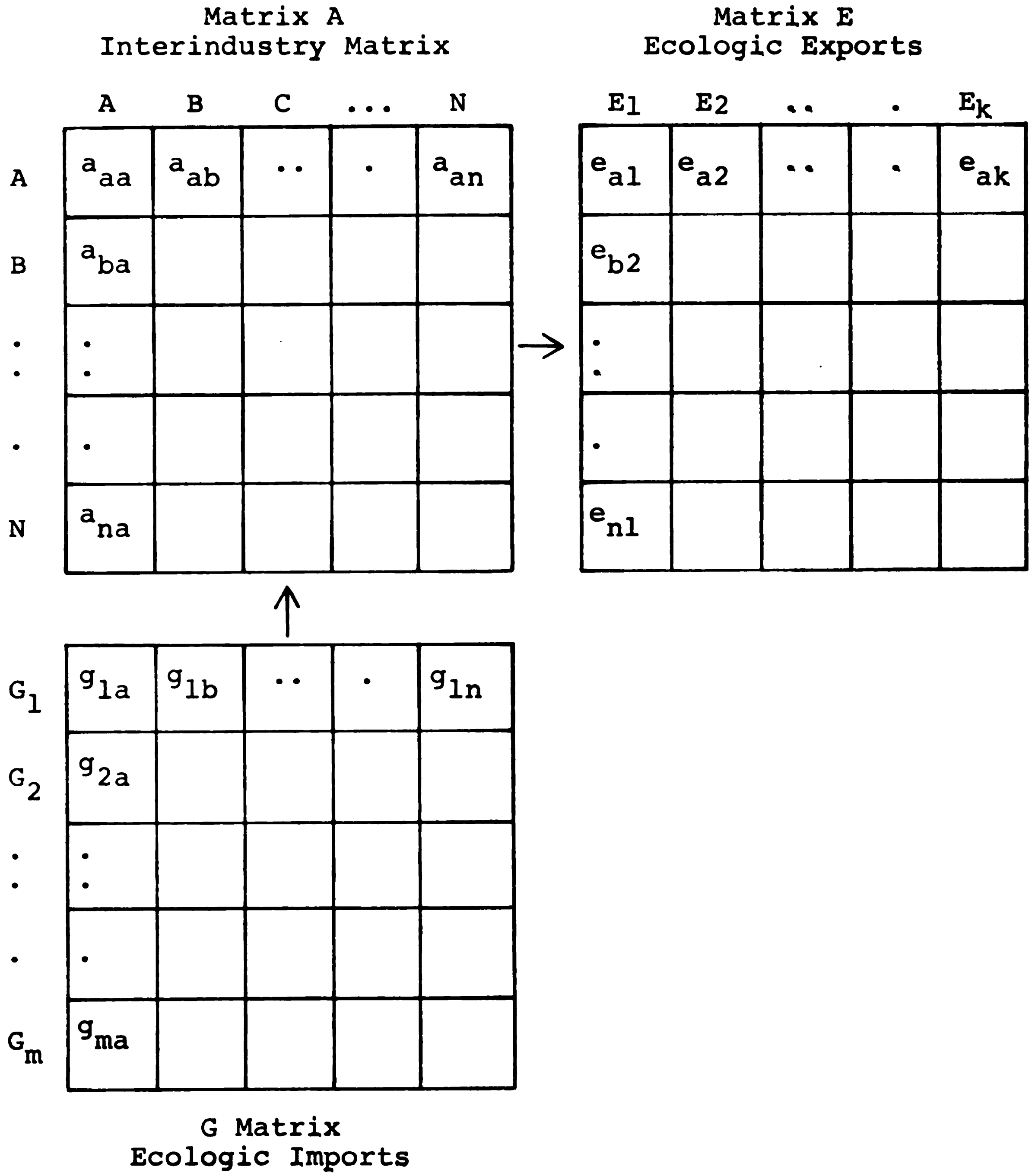


Figure V.1.--A Simplified Illustration of the Laurent and Hite Economic-Ecologic Model

Source: E. A. Laurent and J. C. Hite, Economic-Ecologic Analysis in the Charleston Metropolitan Region: An Input-Output Study (Clemson, South Carolina: Water Resources Research Institute in cooperation with the South Carolina Agricultural Experiment Station, Clemson University, Report No. 19, April, 1971), p. 16.

put (for example, cooling water) necessary to produce one dollar of gross output from Industry B. The E matrix is analogous to the G matrix, but it represents exports of residuals to the environment from the various industries in the processing sector. Thus, if, for example, $E_1$ is $SO_2$, then $e_{a1}$ is the amount of this residual exported to the environment for each one dollar of gross output from sector A.

It is useful to further modify this formulation by eliminating one of the environmental matrices. It is possible to view the export of residuals to the environment as negative imports. Thus the elements in the E matrix may be given negative signs and included in the G matrix. This creates a new matrix which can be labeled G'. The elements in the environmental (i.e., G') matrix can be referred to as direct environmental coefficients. While the operational significance of this modification is not immediately obvious, it does facilitate mathematical manipulation of the model without any loss of information.[3] It should be noted that the reformulated economic submodel is a system of linear processes and does not avoid any of the limitations and assumptions associated with such configurations.

It is easier to explain the mathematical derivation of the reformulated economic submodel if reference is made to an expanded illustration as shown in Figure V.2. If a ma-

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[3]Laurent and Hite, Economic-Ecologic Analysis in the Charleston Metropolitan Region, p. 17.

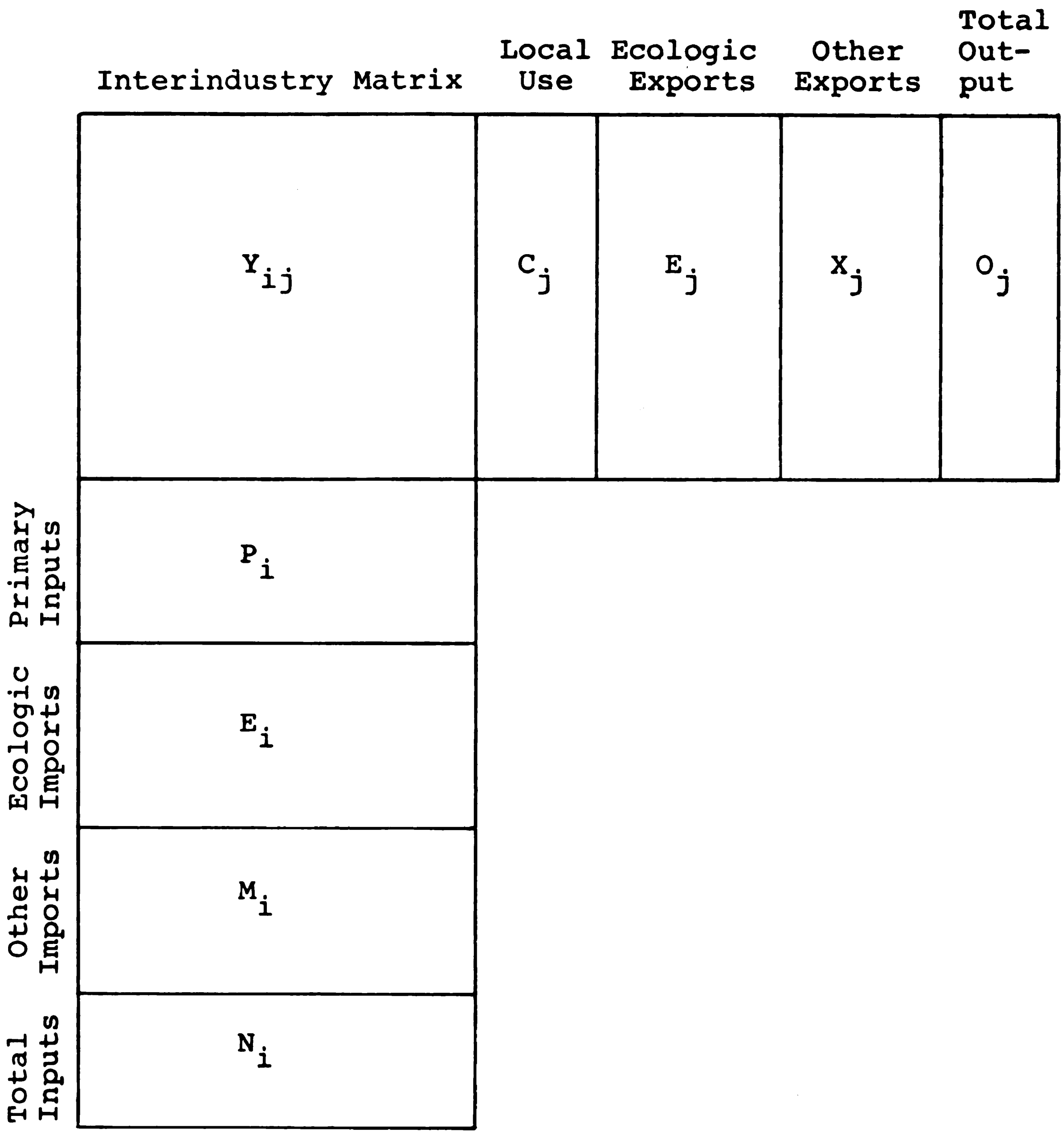


Figure V.2.--Expanded Illustration of the Laurent and Hite Model

Source: E. A. Laurent and J. C. Hite, Economic-Ecologic Analysis in the Charleston Metropolitan Region: An Input-Output Study (Clemson, South Carolina: Water Resources Research Institute in Cooperation with the South Carolina Agricultural Experiment Station, Clemson University Report No. 19, April, 1971), p. 19.

trix of technical coefficients (A matrix) is not already available or cannot be derived from a National table, then it is necessary to construct a transactions table from empirical data. Matrix Y (Figure V.2) represents the processing sector of such a table, while $C_j$, $E_j$, and $X_j$ are all part of the final demand sector. Likewise, $P_i$, $E_i$, and $M_i$ combine to form the payments sector.

Solution to the modified economic submodel involves computing technical coefficients to obtain the A matrix (Figure V.1) in such a way that the elements of matrix A are equal to:

$$A_{ij} = \frac{Y_{ij}}{O_j}, \quad (i,j = 1,2,3,. . .,n)$$

where: $A_{ij}$ = any element of matrix A,

$Y_{ij}$ = elements of matrix Y,

$O_j$ = total output of sector groups.

Thus industry group j in order to produce a dollar of gross output needs to purchase $A_{ij}$ of input from industry group i, and employ $P_i/O_j$ units of primary inputs, $E_i/O_j$ of environmental imports, and import $M_i/O_j$ of economic inputs from outside the region.

To estimate the total effect, i.e., the direct effect resulting from succeeding rounds of buying and selling activities between the different industry groups in the region, plus indirect effects, of a one dollar increase in the output of a given sector it is necessary to compute what is often called the Leontief inverse of the A matrix, noted as $(1-A)^{-1}$.[4] Once the Leontief inverse matrix is calculated, the total effect of local users (i.e., households and other elements of final consumption within the region) on the sector groups is obtained by the following: $C_j(1-A)^{-1}$. The total effect of the outside region is: $X_j(1-A)^{-1}$. Likewise, the total effect of the ecologic system is $E_j(1-A)^{-1}$.

While it is conceptually useful to visualize the model in this way, it is not actually empirically derived in this manner since dollar values for environmental exports are difficult to obtain.[5] In addition, it is mathematically more expedient to enter all environmental goods (both imports and exports) in a single matrix. Thus the environmental linkages are actually quantified by post-multiplying the environmental matrix (G') by the Leontief inverse matrix. Therefore:

$$(G')\ (1-A)^{-1} = (R)$$

where: (R) is a matrix of direct and indirect coefficients representing the environmental impact, in physical units, of each economic sector.

To generate the residuals output values required for operation of the environmental simulator, it is necessary

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[4]The procedure for calculating this matrix is outlined in Miernyk, op. cit., pp. 141-147.

[5]Laurent and Hite, Economic-Ecologic Analysis in the Charleston Metropolitan Region, p. 20.

to multiply the gross output value of each sector by the appropriate negative coefficients in the R matrix. Thus, for example, if 10 residuals and 15 economic sectors have been included in the model, the gross output from each sector will be multiplied by each of 10 coefficients in the R matrix to yield 150 residual output values. The flows from the environment to the economic system can be quantified using a similar procedure. Here the gross output values for each sector are multiplied by the corresponding positive coefficients in the R matrix. The residuals output values obtained from the I-O portion of the model are then entered into the environmental simulator where the diffusion and concentration of the residuals are monitored, and damages and marginal damages are estimated and evaluated.

This major structural modification is not accomplished without some significant problems. First, it should be noted that with I-0 techniques, the only way to spatially identify the residuals output values is to define the sectors so that each sector represents only one discharge source (e.g., a single firm). At higher levels of aggregation the residuals outputs of each sector are likely to originate from a number of spatially dispersed sources. For example, the forest products sector in a forestry-based region may contain a large number of firms located throughout the region each of which exports $SO_2$ to the regional ecologic system. Hence, under these circumstances, it would not be possible to pinpoint sources of the gross output of $SO_2$ contributed by the forest products sector. This problem, which is really one of minimizing the aggregation error, may be handled in a number of ways. In a given application, it might be possible to define the economic sectors in enough detail so that each sector is a point source of one or more residuals. If this is not possible, one option available to the user is to assign source locations throughout the region. This is, essentially, a regionalization (or sub-regionalization) problem involving analysis and judgement to determine which geographical locations would best approximate the actual points at which various residuals generated by each economic sector enter the regional environment. Of course, it is also possible to disregard the environmental simulator portion of the model altogether and use only the information output of the I-0 submodel for policy analysis and decision-making. If, as suggested previously, the client is primarily interested in estimating regional economic impacts and environmental impacts in terms of gross residuals output, then this last option may well be the most appropriate one. Of course it should again be recognized that without the environmental simulator, the actual changes in the regional environment caused by the discharge of residuals from the economic system will have to be evaluated exogenously. While such side calculations clearly depend upon the judgement and expertise of the user, it should be remembered that this same judgement and expertise is also built into an operational environmental simulator. Indeed, it is possible that estimating environmental changes resulting from the discharge of residuals exogenously may be the better approach since the user has the flexibility to treat each estimate individually. Under such circumstance, one is not locked into the specific estimating procedures specified in the model, and can readily adjust the procedures used to reflect changing conditions or unique attributes of specific problems.

Another problem arising from this first reformulation of the model involves the lack of capacity for representing consumption activities in the model. One adjustment that has been made to help offset this deficiency is to include the households sector in the model as an endogenous sector. Thus coefficients in the households row of the Leontief inverse matrix represent the amount of servies supplied by households (i.e., essentially labor) required to produce one dollar's worth of economic output from each of the column sectors. Likewise, the households column coefficients in this matrix represent estimates of the amount of commodities purchased from each processsing sector to produce a one dollar increase in consumption by households. The G' matrix necessarily includes coefficients representing "purchases" from the environment (environmental imports) and "sales" to the environment (environmental exports) resulting from a one dollar increase in consumption by the households sector. Including the households sector in the endogenous portion of the model, therefore, enables the user to quantify, in rather general terms, the linkages between final consumption in the region and the regional ecologic system. These linkages cannot in practice, however, be so precisely defined as is possible in the ideal conceptual model.

## Interfacing with Other Planning Models and Procedures

Another goal-related consideration which might indicate structural changes in the model is the necessity to integrate an operational regional economic-ecologic linkage model with other planning models and procedures already in use by the Forest Service. As noted in Chapter I, the agency currently has available a model to aid in making the allowable cut decision on National Forests. The model, i.e., Timber Resource Allocation Model (Timber RAM), utilizes an LP formulation to optimize allowable cut on a forest for a given time period as specified by the user. If use of this model continues to increase it is difficult to ignore the possibility of a future desire to link Timber RAM with an operational linkage model for application in the western Montana region.

As it is currently being used, the Timber RAM model generates optimal allowable cut for individual forests. It does not consider either the impact of timber cutting on the condition of the environment or, conversely, the constraints that nontimber environmental conditions might impose on timber cutting. Likewise, the Timber RAM model contains no explicit recognition of potential regional economic impacts of timber cutting decisions. An economic-ecologic linkage model in the western Montana region could prove quite valuable in supplementing the information generated by Timber RAM. Also, some of the economic and ecologic impacts not directly considered in the Timber RAM model could be evaluated if the two models were integrated in a regional context.

At present, it appears as though no further structural modifications of the linkage model are necessary to facilitate integration with Timber RAM. The allowable cut generated by Timber RAM can be entered into the linkage model as an exogenous final demand value for the appropriate sector (i.e., the wood industries sectors). The model can then be solved for the residuals output values and these values can be entered either into the environmental simulator or directly into the decision process. In addition, the linkage model can provide estimates of the quantities of other natural resource inputs that will be required as a result of the change in the allowable cut.

A second related aspect here involves what might be called the requirements approach to management planning. For any given period of time, the Nation has a set of basic timber requirements. In general, the requirements must be met either from domestic production or foreign imports. That portion of timber requirements to be met from domestic sources can be subdivided into regional quotas. Thus, using this approach, it is possible to establish for the western Montana region a timber output goal which represents the specific portion of National timber requirements to be supplied from forests in the region. While the Timber RAM model can provide information on the technical (i.e., silvicultural and perhaps production economics) feasibility of meeting these regional quotas, it does not consider the broader set of constraints involving environmental impacts and regional economic development criteria. However, Forest Service decision-makers are required to consider these aspects in their planning and management functions.[6] Therefore, an operational economic-ecologic linkage model would be useful in that it could aid in providing a broader based estimate of the overall feasibility of meeting regional quotas. In addition, the information generated through operation of a linkage model would help in providing a display of the regional economic and ecologic impacts which could result from supplying these quotas from the region's forests.

Such considerations do not suggest any additional structural modifications to the proposed linkage model. The model, as modified to this point, is capable of accomodating the requirements approach to management planning. The linkage here is accomplished using the same procedure as was

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[6]U.S.D.A., Forest Service, Framework for the Future: Forest Service Objectives and Policy Guides (Washington: U.S. Government Printing Office, 1970), pp. 1-13.

described for linking Timber RAM with the economic-ecologic model. The regional quotas may be entered into the linkage model as final demands on the wood industries sectors. Operation of the model will provide not only the information necessary to identify economic and environmental impacts of meeting these demands, but, also, information that would help in identifying total demands on the regional environment as a supplier of raw material inputs. This second type of information is obtained by multiplying gross output for each endogenous sector by the appropriate positive coefficients in the R matrix. Thus additional information on the feasibility aspect is provided by this approach.

### Representing the Economic and Ecologic Systems of Western Montana

The second general area of inquiry relating to the analysis of structural compatibility involves the actual structure of the regional systems of western Montana. As noted previously, this is the second general area of concern which may necessitate structural modifications of the ideal model.

Perhaps the first question that should be answered here is whether the fact that both the economic and ecologic systems of the region are forest-centered precludes use of the linkage model as it has been formulated to this point. It is felt that this aspect is not a factor since the I-0 techniques used for modeling the economic system are quite general and can accommodate a broad range of applications while the environmental simulator can be designed to reflect any unique features that might exist for a given application. Rather, the fact that the regional systems are forest-centered will only be a factor if it prevents the user from defining economic and environmental sectors for the region under analysis.

## Economic Sectors of Western Montana

The choice of an appropriate scheme of sectors to adequately represent the regional economic system is a difficult one. If the sectors reflect too high a level of aggregation then many of the important linkages and interdependencies existing within the regional economy will not be represented in the model. On the other hand, disaggregating the sectors provides a more accurate and detailed representation of interdependence but at the same time results in higher data requirements. The level of aggregation ultimately chosen must enable the model to generate information that is useful in solving regional-scale problems. It is important to remember that the focus of this research is to identify economic-ecologic linkage procedures which are currently feasible in western Montana and can be operationalized with the existing secondary data base. Thus, the choice of sectors, while considering the aggregation problem, should reflect to a large extent these more practical concerns. To this end, it was thought to be appropriate to make use of any existing work involving sectorization of the Montana economy.

The Montana Input-Output Model[7]

There have been two I-0 models developed for the Montana economy. The original Montana I-0 model was developed by Theodore A. Hoff during the period 1968 to 1969.[8] Hoff used 1963 as the base year for his model which relied entirely on secondary data, primarily from U.S. Census sources. The original model separates the Montana economy into 17 sectors, 12 of which are endogenous. Each sector in the Hoff model is a consolidation of sectors from the U. S. model. Table V.1 provides a listing of the endogenous and exogenous sectors in the Hoff model and shows the correspondence between the Montana sectors and those in the National model.

In 1971, Donald O. Mitchell updated the 1963 Montana I-0 model to the base year 1967.[9] Mitchell's effort also relied entirely on secondary data. In updating the Hoff model, Mitchell essentially estimated output totals for each sector then scaled the 1963 transactions matrix, column by column, based on those totals unless his data indi-

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[7]The history and development of this model is somewhat confusing. Some of this confusion may be due to a lack of documentation, but, it is felt that most is due to the unavailability of existing documentation.

[8]Theodore A. Hoff, "An Analysis of Interdependence in the Montana Economy: An Input-Output Study" (unpublished Ph.D. dissertation, Dept. of Economics and Agricultural Economics, Montana State University, 1969).

[9]Donald O. Mitchell, "An Updated Input-Output Study of Montana" (unpublished Master's thesis, Dept. of Economics and Agricultural Economics, Montana State University, 1971).

TABLE V.1

CORRESPONDANCE OF MONTANA AND U.S. SECTORS:
1963 MONTANA INPUT-OUTPUT MODEL

| Montana Sectors | | U.S. Sectors | |
|---|---|---|---|
| 1. | Livestock & Livestock Products | 1.1 | Livestock & Livestock Products |
| 2. | Crops | 2.1 | Other Agricultural Products |
| 3. | Food & Kindred Products | 3.1 | Food & Kindred Products |
| 4. | Lumber & Wood Products | 4.1 | Lumber & Wood Products, Except Containers |
| 5. | Manufacturing | 5.1 | Apparel |
| | | 5.2 | Household Furniture |
| | | 5.3 | Paper & Allied Products |
| | | 5.4 | Printing and Publishing |
| | | 5.5 | Chemicals & Selected Chemical Products |
| | | 5.6 | Petroleum Refining & Related Products |
| | | 5.7 | Rubber & Miscellaneous Plastics Products |
| | | 5.8 | Leather Tanning & Industrial Leather Products |
| | | 5.9 | Stone & Clay Products |
| | | 5.10 | Primary Nonferrous Metals Manufactures |
| | | 5.11 | Heating, Plumbing & Structural Metal Products |
| | | 5.12 | Other Fabricated Metal Products |
| | | 5.13 | Construction, Mining & Oil Field Machinery |
| | | 5.14 | Machine Shop Products |
| | | 5.15 | Other Transportation Equipment |
| | | 5.16 | Scientific & Controlling Instruments |
| | | 5.17 | Miscellaneous Manufacturing |
| 6. | Transportation & Public Warehousing | 6.1 | Transportation & Public Warehousing |
| 7. | Communications & Public Utilities | 7.1 | Communications, except Radio & T.V. |
| | | 7.2 | Radio & T.V. Broadcasting |
| | | 7.3 | Electric, Gas, Water & Sanitary Services |

TABLE V.1 (cont'd.)

| Montana Sectors | | U.S. Sectors | |
|---|---|---|---|
| 8. | Real Estate, Finance, & Insurance | 8.1 | Finance & Insurance |
| | | 8.2 | Real Estate |
| 9. | Mining | 9.1 | Nonferrous Metal Ores Mining |
| | | 9.2 | Coal Mining |
| | | 9.3 | Crude Petroleum & Natural Gas |
| | | 9.4 | Sone & Clay Mining and Quarrying |
| | | 9.5 | Chemical & Fertilizer Mining |
| 10. | Services | 10.1 | Hotels, Personal & Repair Services, except Autos |
| | | 10.2 | Business Services |
| | | 10.3 | Research & Development Services |
| | | 10.4 | Automobile Repair & Services |
| | | 10.5 | Amusements |
| | | 10.6 | Medical, Educational Services |
| 11. | Trade, Wholesale & Retail | 11.1 | Wholesale & Retail Trade |
| 12. | Construction, Maintenance | 12.1 | Construction, Maintenance |
| 13. | New Construction | 13.1 | New Construction |
| 14. | State & Local Government | 14.1 | State & Local Government |
| 15. | Federal Government | 15.1 | Federal Government |
| 16. | Households | 16.1 | Households |
| 17. | Imports | 17.1 | All sectors in the U.S. model that did not exist in the Montana economy. For example, Tobacco Manufactures. |

Source: Theodore A. Hoff, "An Analysis of Interdependence in the Montana Economy: An Input-Output Study" (unpublished Ph.D. dissertation, Dept. of Economics and Agricultural Economics, Montana State University, 1969), p. 146.

cated otherwise. The Mitchell model employs 12 endogenous and four exogenous sectors. The reduction in number of sectors from the original model was accomplished by aggregating the Construction, Maintenance (12) and New Construction (13) sectors in the Hoff model.

In 1973, the Montana I-0 model was modified to provide a more accurate representation of the economy.[10] This modification was most likely made to reflect the increasing importance of the lumber and wood products industries in the State's economic system. At this time, the Lumber and Wood Products sector included in both the Hoff and Mitchell formulations was disaggregated into a Logging sector and a Sawmills and Wood Processing sector. The sectors and subsectors used in the current version of the Montana I-0 model are listed in Table V.2.

A brief examination of available Census data and limited field observation lead to the conclusion that all sectors currently included in the State I-0 model are also active in the region. However, the relative importance of these sectors is different from the State to the regional economic systems. In general, then, the scheme of sectors used in the State model provides an accurate breakdown of

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[10]The exact circumstances surrounding this modification could not be ascertained. However, Haroldsen states that the modification was accomplished by Gene Lewis at Montana State University. See: Ancel D. Haroldsen, "Adapting an Input-Output Model for Use in Estimating the Impact of a Recreational Development: The Case of Big Sky, Montana", Paper presented before the Workshop on the Use of Models in Resource Management Planning, Big Sky, Montana, June 9-11, 1974, p. 2.

TABLE V.2

SECTORS AND SUBSECTORS OF THE MONTANA ECONOMY:
CURRENT MONTANA INPUT-OUTPUT MODEL

| | Endogenous Sectors | | Subsectors |
|---|---|---|---|
| 1. | Livestock & Livestock Products | a) | Cattle & calves |
| | | b) | Sheep & lambs |
| | | c) | Hogs |
| | | d) | Dairy products |
| | | e) | Wool |
| | | f) | Poultry products |
| | | g) | Other Livestock products |
| 2. | Crops | a) | Wheat |
| | | b) | Barley |
| | | c) | Other feed grains |
| | | d) | Seed crops |
| | | e) | Other crops |
| 3. | Food & Kindred Products | a) | Meat products |
| | | b) | Dairy products |
| | | c) | Grain mill products |
| | | d) | Sugar |
| | | e) | Beverages |
| | | f) | Miscellaneous |
| 4. | Logging | a) | Logging camps |
| 5. | Sawmills & Wood Processing | a) | Sawmills and planning mills |
| | | b) | Mill work products |
| 6. | Manufacturing | a) | Furniture and fixtures |
| | | b) | Paper and allied products |
| | | c) | Printing and publishing |
| | | d) | Chemicals and allied products |
| | | e) | Petroleum and coal products |
| | | f) | Stone, clay and glass products |
| | | g) | Primary metal industries |
| | | h) | Fabricated metal products |
| | | i) | Machinery, except electrical |
| | | j) | Transportation equipment |
| | | k) | Miscellaneous manufacturing |
| 7. | Transportation & Public Warehousing | a) | Rail carriers |
| | | b) | Truck carriers |
| | | c) | Airlines |
| | | d) | Miscellaneous transportation |
| | | e) | Public warehouses |
| 8. | Communications & Public Utilities | a) | Public communications |
| | | b) | Electric & gas services |
| | | c) | Radio & T.V. broadcasting |

TABLE V.2 (cont'd.)

| | Endogenous Sectors | | Subsectors |
|---|---|---|---|
| 9. | Real Estate, Finance, & Insurance | a) | Real estate services |
| | | b) | Financial services |
| | | c) | Insurance except government |
| 10. | Mining | a) | Primary metals mining |
| | | b) | Crude petroleum and natural gas |
| | | c) | Non-metallic minerals mining |
| 11. | Other Services | a) | Public lodging |
| | | b) | Personal services |
| | | c) | Miscellaneous business services |
| | | d) | Auto services |
| | | e) | Miscellaneous repair services |
| | | f) | Amusement and recreation services |
| | | g) | Legal services |
| | | h) | Medical services |
| | | i) | Oil and gas field services |
| 12. | Other Trade | a) | Wholesale trade |
| | | b) | Retail trade |
| 13. | Construction | a) | Residential construction |
| | | b) | Non-residential construction |
| | | c) | Non-building construction |
| | | d) | Residential maintenance |
| | | e) | Non-residential maintenance |
| | | f) | Non-building maintenance |
| | **Exogenous Sectors** | | **Subsectors** |
| 14. | Households | a) | Wages and Salaries |
| | | b) | Proprietor Income |
| | | c) | Property income |
| 15. | State & Local Government | a) | Montana State Government |
| | | b) | County, city, and the local government units |
| 16. | Federal Government | a) | Federal Government |
| 17. | Imports | a) | Imports |

Source: Correspondence with Ancel D. Haroldsen, Montana State University, Bozeman, Montana, July 10, 1974.

the regional economy, especially since the forest related portion has been included as two sectors rather than just one. It is felt that use of this scheme of sectors will enable the user to generate information that is detailed enough to be useful at the regional level. Also, the sectors do not reflect so fine a breakdown as to present insurmountable data problems. Representing the western Montana economy with the 17 sectors from the State model does not involve any structural modification to the overall linkage model as described thus far.

### The Environmental System

The economic portion of the linkage model, as formulated to this point, requires that imports from and exports to the regional environment be specified. The environmental simulator, on the other hand, has no formally expressed structure which would require that environmental phenomena be represented in a particular way. Rather, the environmental portion of the model must be designed for a particular application. In other words, it is felt that the economic-ecologic linkage model is flexible enough to incorporate the structural features of the western Montana environment, at least at the level that they are to be modeled using this approach, and hence no structural modification of the model is necessary for application in the region.

In defining the imports from (i.e., natural resource inputs) and exports to (i.e., residuals) the regional environment the essential consideration is one of including all substances likely to have a significant impact on both the output from the economic system and the natural processes of the ecologic system in the region. There have been few empirical studies to provide guidelines for identifying these substances. However, on the assumption that the ecologic structure of one large region is similar to that of nearly any other large region at a fairly high level of aggregation, the work of Laurent and Hite does provide some assistance. In their Charleston study, Laurent and Hite suggest 16 substances which represent either a natural resource input into the Charleston area economy or an emission from the economy into the regional environment.[11] The substances and the unit of measurement for each are listed below:

(1) Particulates (lbs.)
(2) Hydrocarbons (lbs.)
(3) Sulfer Dioxide (lbs.)
(4) Gaseous Fluoride (lbs.)
(5) Hydrogen Sulfide (lbs.)
(6) $CO_2$ (lbs.)
(7) Aldehydes (lbs.)
(8) $NO_2$ (lbs.)
(9) Domestic Water (gals.)
(10) Cooling Water (gals.)
(11) Processing Water (gals.)
(12) Total Water Intake (gals.)
(13) Discharge Water (gals.)
(14) 5 Day BOD (lbs.)
(15) Suspended Solids (lbs.)
(16) Solid Waste (lbs.)

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[11] Laurent and Hite, Economic-Ecologic Analysis in the Charleston Metropolitan Region, p. 52.

Careful comparison of the industrial structure of the Charleston region with that of western Montan indicates that the two are quite similar. Though the Charleston model contains 23 endogenous sectors and the Montana model only 13, it should be noted that many of the Charleston sectors are disaggregations of sectors included in the Montana model. This suggests that some sectors are more important in the Charleston economy than in the Montana economy, but all sectors identified for the Charleston model are also active in the Montana economy. Another empirical study linking regional economic and ecologic systems in an integrated model has been accomplished by Kenneth J. Roberts and R. Bruce Rettig for Clatsop County, Oregon.[12] Clatsop County is a mountainous, coastal region with more than 90 percent of its land area in forests.[13] Roberts and Rettig describe the economic structure of the region with 16 endogenous sectors. The Clatsop County sectors correspond quite closely with those included in the Montana model indicating that the economic structures of Clatsop County and Montana are very similar. The Roberts and Rettig study also includes estimates of some environmental coefficients showing the quantities of natural

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[12] Kenneth J. Roberts and R. Bruce Rettig, "Linkages Between the Economy and the Environment: An Analysis of Economic Growth in Clatsop County Oregon," paper presented at the Economic Models for Management of Natural Resources Workshop, Big Sky, Montana, June 9-11, 1974.

[13] *Ibid.*, p. 2.

resource inputs to and waste outputs from the regional economic system per dollar of gross output from each economic sector. Roberts and Rettig consider 14 environmental substances in their model. The list of substances included for the Clatsop County study is similar to that employed by Laurent and Hite. The one substance included in the Clatsop County study which is not found in the Laurent and Hite list is organic nitrogen, measured in pounds. Roberts and Rettig point out that data inadequacies prohibited the development of direct linkages between the discharge of organic nitrogen and the economic sectors in the model, except for the fish processing sector.[14] It would appear, therefore, that the absence of a significant amount of this type of activity in the study region suggests that organic nitrogen need not be added to the list of environmental substances for implementing the linkage model in western Montana. Accordingly, it is felt that in implementing the linkage model in the study region, the list of environmental substances provided by Laurent and Hite can be used as a starting point in constructing the matrix of direct environmental coefficients (i.e., the G' matrix).[15]

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[14] Ibid., p. 14.

[15] Of course, the user has the option of specifying any set of substances for consideration in the model. However, it should be recognized that data will be necessary to estimate the direct coefficients associated with each substance included. It is felt that the flexibility of the model in

To tailor the model more closely with the study region, it is necessary to emphasize the residuals produced by forest-related economic activities. Cummins suggests that wood wastes are generated in three primary processes--timber harvesting, product manufacturing, and the natural forest life cycle.[16] He indicates that only about one-third of the forest's mass is removed by the harvest of timber.[17] The residue from the harvest consists of nearby shrubs and small conifers (destroyed in the harvesting process), branches, twigs, foilage, stumps, broken stems, cull, and stems left in the forest that are considered too small to be processed profitably.[18] If these residues are burned on-site, they will be reduced to ash which, over time, re-enters the nutrient cycle of the forest stand. Airborne residuals from this burning (with the exception of carbon

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this regard is desirable since it seems quite likely that application to different problems will require consideration of different environmental substances. It should be noted that other systems of environmental sectors and classifications of substances have been developed. For example, a more elaborate classification of residuals is discussed in John H. Cumberland, *et al.*, *op. cit.*, pp. 10-31.

[16]Leo K. Cummins, "Disposal of Wood Wastes," *Forest Land Use and the Environment*, ed. Richard M. Weddle (Missoula, Montana: Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana, 1972), p. 125.

[17]*Ibid.*, p. 129.

[18]*Ibid.*, p. 127.

monoxide) are accounted for in the list of substances noted above. Thus it is felt that carbon monoxide (CO) should be added to the list of environmental substances to be included in the western Montana model.

Cummins notes that ". . . prescribed fire is generally ineffective in reducing stems larger than four inches in diameter to ash,"[19] and, also, that ". . . in current practice, stems less than about seven inches in diameter,"[20] are left in the forest because they are considered too small to process profitably. Thus, those stems left behind which cannot be readily reduced to ash may be considered as solid waste and hence no addition to the list of environmental substances is necessary to account for these residuals. If the residue from timber harvesting is not burned, natural decomposition will, over a much longer period of time, reduce it to essential nutrients. However, for the most part this residue, especially the larger pieces, can be viewed as solid waste.

Cummins states that an ". . . efficient, modern lumber mill can transform 44 percent of a debarked commercial sawlog into lumber products, 54 percent into commercially valuable by-products (i.e., chips, sawdust, and shavings), and only 2 percent into unusable residue waste."[21] He also notes, however, that ". . . unfortunately, many saw-

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[19] Ibid., p. 127. [20] Ibid., p. 129.

[21] Ibid., p. 131.

mill operations do not achieve the high efficiency made possible by modern technology," with poor manufacturing facilities and improper management reducing the yield of usable products by as much as 40 percent.[22]

The unusable waste residue from lumber mills (the amount depending upon technology employed and management skills) can be accounted for in the model as a component of solid waste or, if it is burned, the residuals produced can be accounted for in the list of substances provided above. Bark is the major unusable waste residue from the processing of sawtimber.[23] According to Cummins, there are 36 cubic feet of bark per thousand board feet, Scribner log scale.[24] Several economic uses have been discovered for this residue, including bark as an agricultural aid in the form of mulch or animal bedding, fuel, extender for resins, resins for plastics, tannins, waxes, ingredients for explosives, rubber, paint, asphalt tile, drilling mud, water conditioner, flotation agents, pharmaceuticals, and particle board.[25] However, Cummins notes that the cost of shipping bark is the primary factor limiting its beneficial use.[26] Thus it remains, in most cases, as waste residue from the lumber production process and is either disposed of as solid waste, or, more often, burned in boilers to

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[22]_Ibid_. [23]_Ibid_., p. 134. [24]_Ibid_., pp. 134-135.

[25]_Ibid_., p. 135. [26]_Ibid_.

produce steam. Airborne residuals generated when the bark is burned can be accounted for in the list of substances suggested for inclusion in the western Montana model.

The utilization of lumber by-products (i.e., residue from sawmills which can be used in the manufacture of other products), ". . . generates additional wastes, some of which can also be put to beneficial use."[27] Wood has four major components: extractives, ash-forming minerals, lignin, and cellulose.[28] In using lumber by-products for the production of other commodities, ash-forming minerals are rarely separated out and hence become waste only when the by-products (e.g., chips, sawdust, etc.) are burned in the manufacturing process. Extractives, including fatty acid, resins, hydrocarbons, tannins, etc., are used in the production of wood turpentine and alcohol. When the extractives are removed from lumber by-products, the remaining substance can be considered solid waste if its not used in another process or burned. According to Cummins:

> Cellulose, in its two forms, makes up approxmiately 70 percent of wood. Alph-cellulose is the basis for manufacturing such products as paper, explosives, synthetic textiles, and plastics. Hemi-cellulose, a residue from the manufacture of paper, is an ingredient of adhesives, ethyl alcohol, methyl alcohol, tall oil, turpentine, textiles, and plastics.[29]

Wastes generated in these various manufacturing processes

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[27] Ibid., p. 134.

[28] U.S.D.A., Forest Service, Wood Handbook No. 72 (Washington: U.S. Government Printing Office, 1955).

[29] Cummins, loc. cit., p. 134.

can be accounted for in the list of substances suggested for inclusion in the western Montana model. Lignin, which constitutes about 28 percent of coniferous wood, is another residual of the pulping process.[30] Cummins notes that disposal of this material is a major problem.[31] This suggests that lignin should be added to the list of environmental substances to be employed in implementing the linkage model in the study region.

The third major source of wood waste is the natural forest life cycle. Cummins notes that natural processes can inhibit forest growth.[32] Thus, unmanaged or poorly managed forests fall prey to nature's destructive forces resulting in a waste of resource potential.[33] Fire, wind, disease, insects, animals, and old age, can create areas having the appearance of clearcuts in some forests. Such processes, however, do not represent linkages between the regional economic and ecologic systems and thus do not create the need for consideration of additional substances for inclusion in the environmental matrix of an operational linkage model in western Montana. Rather, these processes represent intra-environmental transactions which should be included in an environmental simulation model.

On the input side, the importance of the wood products industry in the study region suggests that wood should be

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[30]Cummins, loc. cit. [31]Cummins, loc. cit.

[32]Cummins, loc. cit., p. 136. [33]Cummins, loc. cit.

added to the list of environmental substances included in an operational linkage model for western Montana. Thus, it is felt that three substances--wood, lignin, and carbon monoxide (CO)--should be added to the list of environmental substances provided by Laurent and Hite for inclusion in an operational linkage model for the study region, if the appropriate linkages between the environment and forestry-related economic activities are to be properly included. In addition, it should be noted that additional substances can be easily added to the list as use of the model indicates that they are critical or necessary, providing data are available to establish the environmental coefficients relating each sector to the new substance.

## Summary

The evaluation of structural compatibility has indicated only one major structural modification in the ideal conceptual model. That change involved reformulating the economic submodel using I-0 techniques in place of the LP formulation. A simplified version of the model suggested for implementation in the western Montana region is shown in Figure V.3. The format for the initial transactions matrix for the western Montana economy is illustrated in Figure V.4. It should be noted that this matrix is based on the 17 sectors as described previously and the sector numbers in the figure correspond to those shown in Table V.2. The matrix of technical coefficients (A matrix) is a

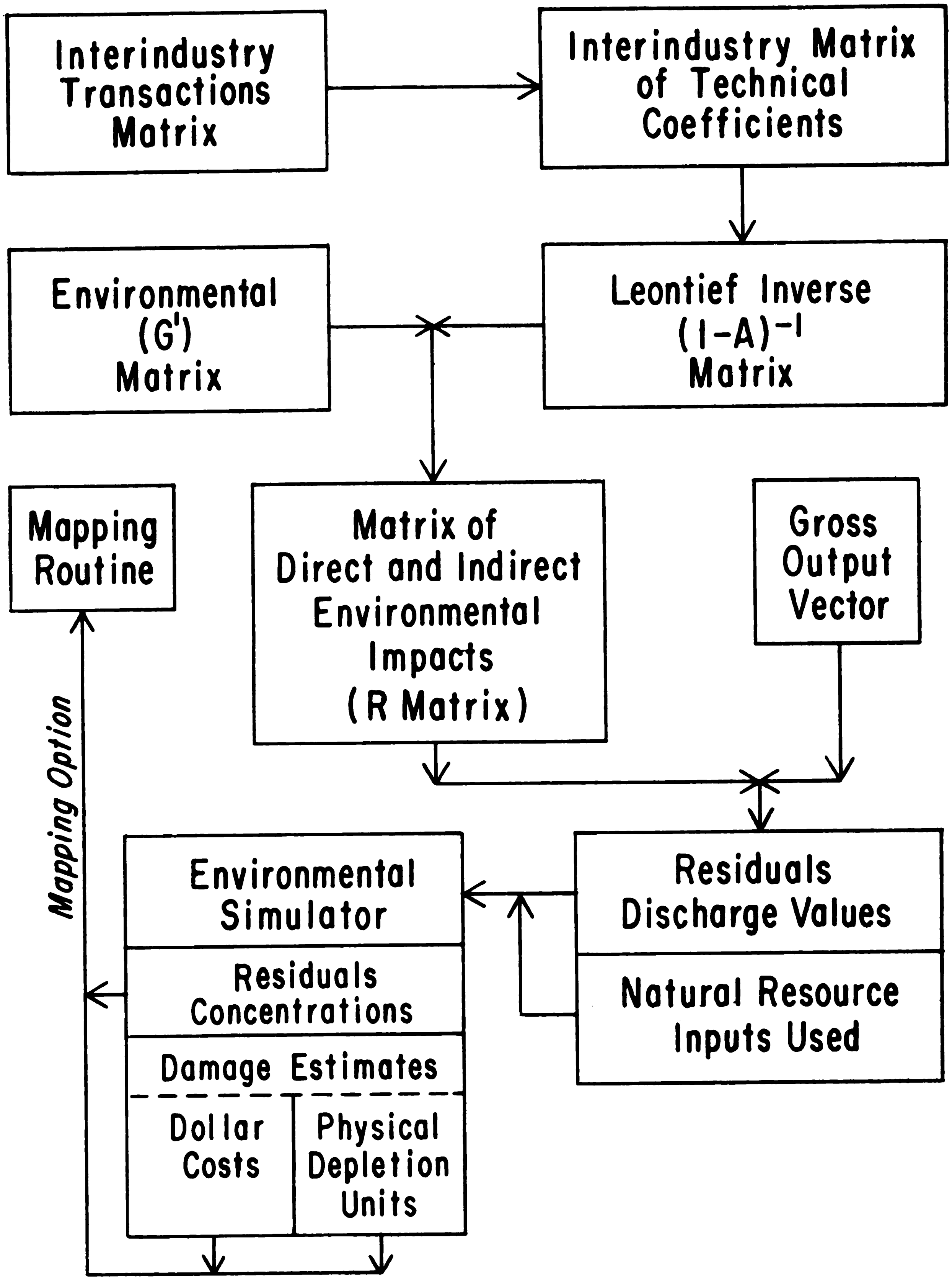


Figure V.3.--Simplified Version of Structurally Modified Economic-Ecologic Linkage Model

PROCESSING SECTORS (Endogenous Consuming Sectors) — FINAL DEMAND SECTORS (Exogenous Consuming Sectors)

| | Inputs (Purchases) \ Outputs (Sales) | Sector 1 | Sector 2 | Sector 3 | Sector 4 | Sector 5 | Sector 6 | Sector 7 | Sector 8 | Sector 9 | Sector 10 | Sector 11 | Sector 12 | Sector 13 | Sector 14 | Sector 15 | Sector 16 | Sector 17 | Total Gross Output |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PROCESSING SECTORS (Endogenous Producing Sectors) | Sector 1 | | | | | | | | | | | | | | | | | | |
| | Sector 2 | | | | | | | | | | | | | | | | | | |
| | Sector 3 | | | | | | | | | | | | | | | | | | |
| | Sector 4 | | | | | | | | | | | | | | | | | | |
| | Sector 5 | | | | | | | | | | | | | | | | | | |
| | Sector 6 | | | | | | | | | | | | | | | | | | |
| | Sector 7 | | | | | | | | | | | | | | | | | | |
| | Sector 8 | | | | | | | | | | | | | | | | | | |
| | Sector 9 | | | | | | | | | | | | | | | | | | |
| | Sector 10 | | | | | | | | | | | | | | | | | | |
| | Sector 11 | | | | | | | | | | | | | | | | | | |
| | Sector 12 | | | | | | | | | | | | | | | | | | |
| | Sector 13 | | | | | | | | | | | | | | | | | | |
| | Sector 14 | | | | | | | | | | | | | | | | | | |
| PAYMENTS SECTORS (Exogenous Producing Sectors) | Sector 15 | | | | | | | | | | | | | | | | | | |
| | Sector 16 | | | | | | | | | | | | | | | | | | |
| | Sector 17 | | | | | | | | | | | | | | | | | | |
| | Total Gross Inputs | | | | | | | | | | | | | | | | | | |

Figure V.4.--Format for I-O Transactions Table for Western Montana

14 by 14 matrix since these coefficients are calculated only for processing (endogenous) sectors. It should be remembered that for the economic-ecologic linkage model, the Households sector (exogenous in the State table) is included in the endogenous portion of the model to gain some capacity for incorporating local consumption activities in the model.

Figure V.5 illustrates the format for the environmental matrix (G' matrix) using the economic sectors and environmental substances suggested in previous sections. In this figure, the list of substances includes carbon monoxide, lignin, and wood, which were added to the original Laurent and Hite list. Also, Figure V.5 includes the Households sector as an endogenous sector. The remaining elements in the model have been discussed previously and need no further explanation.

## Inventory of Secondary Data

The second general area of concern in evaluating the operational feasibility of an economic-ecologic linkage model in the study region involves the adequacy of the region's secondary data base for supporting operation of the structurally modified model. In this section it is most convenient to divide the model into sections and treat each portion in turn.

### The Interindustry Input-Output Model

The data requirements for implementing the interindustry I-O submodel are fairly obvious. The user must be

| Endogenous Economic Sectors in the Western Montana Model / Environmental Substances (i.e., inputs from or outputs to the regional environment) | Livestock and Livestock Products | Crops | Food and Kindred Products | Logging | Sawmills and Wood Processing | Manufacturing | Transportation and Public Warehousing | Communications and Public Utilities | Real Estate, Finance, and Insurance | Mining | Other Services | Other Trade | Construction | Households |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Particulates (lbs.) | | | | | | | | | | | | | | |
| 2. Hydrocarbons (lbs.) | | | | | | | | | | | | | | |
| 3. Sulfer Dioxide (lbs.) | | | | | | | | | | | | | | |
| 4. Gaseous Fluoride (lbs.) | | | | | | | | | | | | | | |
| 5. Hydrogen Sulfide (lbs.) | | | | | | | | | | | | | | |
| 6. Carbon Dioxide (lbs.) | | | | | | | | | | | | | | |
| 7. Carbon Monoxide (lbs.) | | | | | | | | | | | | | | |
| 8. Aldehydes (lbs.) | | | | | | | | | | | | | | |
| 9. Nitrogen Dioxide (lbs.) | | | | | | | | | | | | | | |
| 10. Domestic Water (gals.) | | | | | | | | | | | | | | |
| 11. Cooling Water (gals.) | | | | | | | | | | | | | | |
| 12. Processing Water (gals.) | | | | | | | | | | | | | | |
| 13. Total Water Intake (gals.) | | | | | | | | | | | | | | |
| 14. Discharge Water (gals.) | | | | | | | | | | | | | | |
| 15. 5 Day BOD (lbs.) | | | | | | | | | | | | | | |
| 16. Suspended Solids (lbs.) | | | | | | | | | | | | | | |
| 17. Solid Waste (lbs.) | | | | | | | | | | | | | | |
| 18. Wood (cu. ft.) | | | | | | | | | | | | | | |
| 19. Lignin (lbs.) | | | | | | | | | | | | | | |

Figure V.5.--Format for Environmental (G') Matrix for Western Montana Model able to fill either the cells in the transactions matrix or the cells in the matrix of direct (i.e., technical) coefficients. If it is necessary to construct a transactions table then data are required to establish the volume of trade that occurred between each processing (endogenous) sector and every other processing sector in a specified time period. Also required are data sufficient to determine the volume of transactions occurring between each processing sector and each final demand and payments (exogenous) sector. Total gross output for any sector is then obtained by summing across the row in the transactions table associated with that sector. Likewise, the total gross outlay for a sector, i.e., total value of inputs or purchases by that sector, is obtained by summing down the column associated with that sector.

The literature on I-O analysis, especially those studies that have attempted empirical research, indicates that, in general, data necessary for constructing an initial transactions matrix are not readily available from secondary sources. This is particularly true at the regional level where (due mainly to aggregation problems) a rather large amount of primary data must be assembled for this purpose.[34]

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[34] It should be noted that at the state level, the recently available outputs of the Harvard Economic Research Project may be of help in this regard. This work is published as a series entitled, Multiregional Input-Output Analysis, edited by Karen R. Polenske. The volumes in this series contain a presentation of the complete multiregional I-0 model developed by the Project, and additional explanations of other parts of the data assembly. Included are

In the western Montana region, it was not possible to locate data from secondary sources sufficient to construct a transactions table having the format illustrated in Figure V.4, for the regional economic system.

If a transactions table cannot be constructed then an option open to the user involves the use of technical coefficients "borrowed" from other sources. Using this method, it is still necessary to have data sufficient for estimating final demands and payments for each processing sector. In general, regional models developed in this way employ one of several procedures available for deriving a small area (i.e., regional) model from a larger base model (e.g., a state or even national model). These reduction techniques are necessary to adjust the technical coefficients from the base model so that they reflect, more accurately, the interdependence existing in the regional economy under investigation. Schaffer and Chu have identified and discussed sever-

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state estimates of 1947, 1958, and 1963 final demands and outputs, employment, and payrolls; state estimates of 1963 interregional trade flows; and 1970 and 1980 state projections of final demands, outputs, and interregional trade. The fourth volume in the series: Karen R. Polenske, et al., State Estimates of Technology, 1963 (Lexington, Massachusetts: D. C. Heath and Company, 1974), contains an explanation of the assembly of 1963 technology data and state estimates of those data. It should be noted, however, that the outputs of the Project were not incorporated in this research since they are provided at the state level and this research is concerned with a substate region. Also, there was available an operational I-O model for Montana which was chosen as the base model for developing the regional model. Since the Montana model is for the base year 1967 and the most recent Polenske estimates are for 1963, the Project outputs did not provide relevant information for this research.

al available reduction procedures.[35]

Reduction procedures are described in detail in the references cited. Thus the discussion here is brief and emphasizes the data requirements for operationalizing each procedure. The first of these reduction techniques is called the simple location quotient method. The location quotient is computed as:

$$LQ_i = \frac{x_i/x}{X_i/X},$$

where: $x_i$ = regional output (or total gross output) of industry (or sector) i,

$x$ = total regional output (or total regional gross output),

$X_i$ = national (or base economy) gross output of industry i, and

$X$ = total national (or base economy) gross output.

If, $LQ_i = 1$, then this indicates that the region is self-sufficient in the industry in question, i.e., it has its "proper share" of that industry.[36] If it is assumed that other industries appear in the region in the same proportions as in the base economy, then the location quotient can be

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[35] William A. Schaffer and Kong Chu, "Nonsurvey Techniques for Constructing Regional Interindustry Models," The Regional Science Association Papers, XXIII (1969), pp. 83-101. See also: Sterling H. Stipe, "A Proposal and Evaluation of a Regional Input-Output Modeling System," (unpublished Ph.D. dissertation, review draft, Dept. of Agricultural Economics, Michigan State University, 1975), and W. I. Morrison and P. Smith, "Nonsurvey Input-Output Techniques at the Small Area Level: An Evaluation," Journal of Regional Science, XIV (April, 1974), pp. 1-14.

[36] Schaffer and Chu, loc. cit., p. 85.

used to derive regional coefficients from the base coefficients. If, $LQ_i$ is greater than or equal to one, then it is assumed that the regional coefficient--$a_{ij}$--is equal to the base model coefficient--$A_{ij}$.[37] If, $LQ_i$ is less than one, the regional technical coefficient--$a_{ij}$--can be determined as:

$$a_{ij} = LQ_i \cdot A_{ij}.$$

With the information obtained thus far, the authors go on to describe a procedure for deriving a regional transactions table.

Schaffer and Chu indicate that this method is grossly deficient.[38] For example, it can not be concluded with certainty that if $LQ_i$ is greater than or equal to one, there is a surplus of output (over regional needs) from industry i in the region, or that regional production is inadequate to supply regional needs when $LQ_i$ is less than one. Schaffer and Chu conclude that the simple location quotient method provides satisfactory results only if the regional industry structure resembles closely the base economy industrial structure.[39] To operationalize this technique it is necessary to have data sufficient to estimate the regional output of each industry and total regional output. It is assumed that base economy output of industry i and total

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[37] Schaffer and Chu, loc. cit.

[38] Schaffer and Chu, loc. cit., p. 86.

[39] Schaffer and Chu, loc. cit.

base economy output can be obtained from the base model being reduced.

A modification of the simple location quotient method to improve results has been suggested by Tiebout and is referred to by Schaffer and Chu as the purchases-only location quotient method.[40] Using this method, the location quotient is computed as:

$$LQ_i' = \frac{x_i/x'}{X_i/X'} ,$$

where the prime indicates that the summation of total base model gross output--X'--and total regional gross output--x'--include only the outputs of those industries which purchase from industry i. Substituting $LQ_i'$ into the simple location quotient method described above yields basically the same formulations for determining regional technical coefficients. Also provided is a procedure for deriving a regional transactions matrix from this information. Schaffer and Chu find that they cannot conclude that the purchases-only approach yields better estimates than the simple approach.[41] To operationalize this approach, data are necessary for estimating $x_i$ ( regional gross output of industry i) and x' (total regional gross output of all industries in the region purchasing from i). Other information necessary to operationalize the technique is assumed available from the base model.

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[40] Schaffer and Chu, loc. cit.

[41] Schaffer and Chu, loc. cit., p. 87.

Another modification of the location quotient approach yields what Schaffer and Chu refer to as the cross-industry quotient approach.[42] This quotient compares the proportion of base output of selling industry i in the region to that for purchasing industry j and is computed as:

$$CIQ_{ij} = \frac{x_i/X_i}{x_j/X_j},$$

where: $x_j$ = output of regional purchasing industry j, and

$X_j$ = output of base economy purchasing industry j.

If, $CIQ_{ij}$ is greater than or equal to one, then $a_{ij}$ is assumed equal to $A_{ij}$ for cell ij. This interpretation rests on the assumption that if output of industry i is larger than that of industry j in the region, then regional industry i can provide all of the output required by regional industry j. It should be noted that this computation must be performed for each cell in the $a_{ij}$ matrix while use of the simple or purchases-only approaches requires that only one quotient be computed for each industry or sector in the endogenous portion of the model. If, $CIQ_{ij}$ is less than one, then $a_{ij}$ is computed as:

$$a_{ij} = CIQ_{ij} \cdot A_{ij}.$$

The authors also describe a method for deriving a regional transactions table from the information assembled thus far. Schaffer and Chu do not conclude that this procedure is

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[42]Schaffer and Chu, loc. cit.

superior to those discussed above.[43] To operationalize this technique it is necessary to have data sufficient for estimating the gross outputs of industries in the region.

The authors note that location quotient techniques require balancing corrections.[44] Balancing of the regional transactions matrix derived using either the simple or purchases-only location quotient techniques is accomplished as:

$$e_{ij} = A_{ij} \cdot x_j \text{ or } x_{ij} = A_{ij} \cdot LQ_i \cdot \frac{x_i}{(x_i - e_i)} \text{, whichever}$$

is greater, where $e_{ij}$ = exports from industry i outside the region. Schaffer and Chu find that after these adjustments are made, the transactions tables derived with each procedure are identical. This happens because the input requirements of regional industries are completely satisfied and the remaining output of a selling industry is exported or the regional gross flows, $x_{ij}$, for a row are computed as a constant proportion of base economy gross flows, $X_{ij}$, (but less than required) for that row and exports are zero.[45]

In addition, the authors note that the cross-industry quotient procedure may yield negative exports and gross flows might have to be adjusted.[46] The pool and iterative techniques discussed below are self-balancing.

One of the pool techniques is called the regional com-

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[43]Schaffer and Chu, loc. cit., p. 88.

[44]Schaffer and Chu, loc. cit., p. 94.

[45]Schaffer and Chu, loc. cit.

[46]Schaffer and Chu, loc. cit., p. 95

modity balances approach.[47] Regional commodities balances are derived following these steps:

1. estimate value of output for each industry in the region--$x_j$;

2. multiply regional industry outputs by base model technical coefficients to get the total inputs required from other industries to support each regional industry at its current level of output--$r_{ij}$,

$$r_{ij} = x_{ij} \cdot A_{ij};$$

3. estimate final-demand vectors as the region's shares of base economy final-demand vectors,

$$c_{if} = Y_{if} \cdot \frac{y_f}{Y_f} ,$$

where: $c_{if}$ = estimated regional final demand for product i by sector f,

$Y_{if}$ = base economy final demand for product i by sector f,

$Y_f$ = total base economy final demand for sector f, and

$y_f$ = total regional final demand for sector f;

4. sum the elements in each row to obtain the total regional requirements (production and consumption) of product i,

$$r_i = \sum_j^s r_{ij} + \sum_f^t c_{if} ,$$

where: $r_i$ = total regional requirements of product i;

5. subtract total regional requirements from total regional production--$x_i$--to obtain the net surplus (deficit), or commodity balance--$b_i$--for each industry,

$$b_i = x_i - r_i .$$

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[47] Schaffer and Chu, loc. cit., p. 88.

When the above steps have been followed, the result is a table showing total regional demand for products without a designation of sources of supply, but indicating whether we should expect the region to export or import each product.[48]

Once obtained, these regional commodity balances can be extended to construct a regional technical coefficient matrix. One such method is referred to by Schaffer and Chu as the supply-demand pool technique.[49] First, base model coefficients ($A_{ij}$) and estimates of total gross regional output ($x_j$) are used to derive initial cell entries for a table of total input requirements as in steps 1, 2, and 3 above. Commodity balances for each industry i are then computed as the difference between input requirements and regionally produced supply (steps 4 and 5 above). Where $b_i$ is positive, the regional technical coefficients ($a_{ij}$) are set equal to the base model coefficients ($A_{ij}$). Where $b_i$ is negative, regional coefficients are computed as:

$$a_{ij} = A_{ij} \cdot \frac{x_i}{r_i} .$$

Thus where regional requirements exceed regional production, i.e., imports are necessary, the base coefficients must be adjusted to reflect this difference. Also provided are procedures for deriving a regional transactions table.

Schaffer and Chu note that this pool procedure allocates regional production, where adequate to regional

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[48]Schaffer and Chu, loc. cit., p. 89.

[49]Schaffer and Chu, loc. cit.

needs.[50] Where regional output is inadequate, however, the technique allocates to each regional purchasing industry j its share of regional output i, based on the needs of the purchasing industry itself, relative to total needs for output i (i.e., $x_{ij} = x_i \cdot r_{ij}/r_i$).[51] To operationalize the supply-demand pool procedure, data sufficient to estimate total regional final demand for each final demand sector--$y_f$, and total regional production (i.e., total regional gross output) for each industry--$x_i$, must be assembled. The other values necessary are obtainable from the base model.

One variation of this technique has been proposed by Kokat[52] and is discussed by Schaffer and Chu as the modified supply-demand pool approach.[53] This modification results in a slight change in the procedure allocating insufficient regional production.[54] This approach is summarized in the following steps:

1. compute input requirements on the basis of base model technology and estimates of regional output,

   $$r_{ij} = x_j \cdot A_{ij} ;$$

2. compute total regional demand for goods, excluding exports--$e_i$, using the final demand matrix for the

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[50]Schaffer and Chu, loc. cit., p. 90.

[51]Schaffer and Chu, loc. cit.

[52]R. G. Kokat, The Economic Component of a Regional Socioeconomic Model, IBM Technical Report 17-210 (IBM, Inc.: Advanced Systems Development Division, December, 1966).

[53]Schaffer and Chu, loc. cit., pp. 90-92.

[54]Schaffer and Chu, loc. cit., p. 90.

region under investigation ($y_{if}$),

$$r_i = \sum_j^s r_{ij} + \sum_f^t y_{if} \text{ ; and}$$

3. compute commodity balances,

$$b_i = x_i - r_i \ .$$

Where $b_i$ is positive, $a_{ij} = A_{ij}$. Where $b_i$ is negative, a regional transactions matrix is calculated. First imports ($m_{ij}$) are computed as:

$$m_{ij} = \frac{r_{ij}}{r_i - y_i} \cdot (r_i - x_i),$$

where: $y_i$ = total regional final demand for product i.

Regional transactions are then computed as:

$$x_{ij} = r_{ij} - m_{ij},$$

where $x_{ij}$ = volume of transactions between regional industry i and regional industry j. The regional technical coefficients are then computed from the derived transactions matrix ($x_{ij}$) in the usual fashion:

$$a_{ij} = x_{ij}/x_j.$$

Schaffer and Chu note that the modified supply-demand pool method simply adjusts the supply-demand pool procedure to account for a predetermined final demand. To operationalize this procedure, it is necessary to assemble data sufficient to estimate regional output for each industry, the regional final demand matrix ($y_{if}$), and the total regional final demand for each product produced in the region--$y_i$, (this can be obtained, if the regional final demand matrix

has been estimated, by:

$$y_i = \sum_f^t y_{if}).$$

Schaffer and Chu have developed a technique which incorporates several of the above described devices but also employes an iterative procedure to redistribute regional sales allocated initially on the base economy sales pattern.[55] The technique, referred to as the Regional Input-Output Table (R-I-O-T) Simulator, not only assumes that the base economy production technology applies at the regional level, but, also, attempts to distribute regional production according to both the base economy sales pattern and regional needs.[56]

The iterative procedure involves the following steps:

1. compute required inputs--$r_{ij}$--for producing estimated regional output--$x_j$--for each industry as:

   $$r_{ij} = x_j \cdot A_{ij} ,$$

   and estimate regional final demand--$c_{if}$--as a proportion of base economy final demand:

   $$c_{if} = \frac{y_f}{Y_f} \cdot Y_{if} ;$$

2. distribute regional sales from each industry to every other industry ($d_{ij}$) initially by the base economy distribution pattern:

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[55]Schaffer and Chu, loc. cit., p. 92. See also: W. A. Schaffer and K. Chu, "Application of the Regional Input-Output Table Simulator: A Provisional Interindustry Model of Atlanta," Discussion Paper 6, A Program in Regional Industrial Development, Georgia Institute of Technology, June, 1968, mimeographed.

[56]Schaffer and Chu, "Nonsurvey Techniques," loc. cit.

$$d_{ij} = x_i \cdot \frac{X_{ij}}{X_i} ,$$

and distribute regional sales from each industry to each final demand sector ($dy_{if}$) also according to the base economy pattern:

$$dy_{if} = x_i \cdot \frac{Y_{if}}{X_i} ;$$

3. compare requirements with allocations for each industry to determine surplus allocation to cells ($z_{ij}$):

$$z_{ij} = d_{ij} - r_{ij} ,$$

compare requirements with allocations for each final demand sector to determine surplus allocation to cells ($zy_{if}$):

$$zy_{if} = dy_{if} - c_{if} ,$$

construct for each row i a pool of surplus available for reallocation ($POOL_i$) such that:

$POOL_i$ = sum of all positive $z_{ij}$ and $zy_{if}$ ,

construct for each row i a pool of needed reallocations ($NEEDS_i$) such that:

$NEEDS_i$ = sum of all negative $z_{ij}$ and $zy_{if}$ ;

4. allocate sales to industries with exportable surpluses, i.e., for industries where $POOL_i$ is greater than ($-NEEDS_i$) by assuming that the actual regional transaction between industry i and industry j is equal to the estimated transaction:

$$x_{ij} = r_{ij} ,$$

that the actual regional final demand for product i by regional final demand sector f is equal to the estimated final demand for product i by sector f:

$$y_{if} = c_{if} ,$$

and computing the exportable surplus--$e_i$--as a remainder:

$$e_i = POOL_i + NEEDS_i ;$$

5. reallocate regional sales of industries with outputs insufficient to meet regional needs, i.e., for industries with $POOL_i$ greater than zero and less than or equal to $(-NEEDS_i)$, where $z_{ij}$ is positive or zero assume:

$$x_{ij} = r_{ij} \text{ , and}$$

$$y_{if} = c_{if} \text{ ,}$$

where $z_{ij}$ is negative:

$$x_{ij} = d_{ij} + POOL_i \cdot \frac{d_{ij}}{x_i} \text{ , and}$$

$$y_{if} = dy_{if} + POOL_i \cdot \frac{dy_{if}}{x_i} \text{ ,}$$

and repeat, iterating until $POOL_i$ diminishes to zero. The result of this iterative procedure is to spread the surplus regional output among industries on the basis of relative need.[57]

6. exports and imports are computed as:

$$m_{ij} = r_{ij} - x_{ij} \text{ ,}$$

if $m_{ij}$ is positive then regional production requirements exceed regional outputs and $m_{ij}$ is an estimate of imports necessary to maintain regional production, if $m_{ij}$ is negative, then outputs exceed requirements indicating a surplus available for export.

Values generated with the above procedure, i.e., $(x_{ij})$ and $(y_{if})$ are then used to construct a regional transactions matrix from which can be derived the regional $a_{ij}$ matrix. To operationalize the Schaffer-Chu iterative procedure, it is necessary to assemble data sufficient to estimate output from each industry in the region and total regional final demand by each final demand sector. It should be noted that

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[57]Schaffer and Chu, "Nonsurvey Techniques," p. 93.

there are other reduction techniques available,[58] but it was felt that their presentation here is not necessary.

Schaffer and Chu have constructed interindustry models based on five of the above described techniques (i.e., both location quotient methods, the cross-industry quotient method, the supply-demand pool technique, and the iterative procedure), for Washington State for 1963. These models were constructed using the 1958 transactions table for the U.S. and survey-determined industry outputs as program inputs. The derived transactions tables were compared with an actual Washington State table to provide what the authors term a "limited test of acceptability" for each technique.[59]

To compare the regional technical coefficients estimated with each reduction technique, with the survey-based coefficients, the authors computed chi square for each column in the technical coefficients matrix for each reduction method, taking the survey-based coefficients as true values. Schaffer and Chu note that while the results are weak, they are also fairly consistent.[60] They conclude that the test provides no reason to reject the hypothesis

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[58]See for example: Morrison and Smith, loc. cit. and E. M. Lofting and P. H. McGauhey, Economic Evaluation of Water, Part IV: An Input-Output and Linear Programming Analysis of California Water Requirements, Water Resources Center Contribution No. 116 (Berkely, California: University of California, Sanitary Engineering Research Laboratory, August, 1968).

[59]Schaffer and Chu, "Nonsurvey Techniques," p. 94.

[60]Schaffer and Chu, "Nonsurvey Techniques," p. 95.

that the methods tested can yield technical coefficients which are the same as the survey-based coefficients for only seven of the 23 industries in the Washington State model.[61] The results of the test show the location quotient procedures (after balancing) and the cross-industry quotient technique as the most successful, followed by the iterative procedure and the pooling technique.

In Montana, a State I-0 model is available for the base year 1967. It is possible to use this as the base model and follow one of the available reduction procedures to derive a regional model. However, the survey of the secondary data base for western Montana indicates that existing data from published sources are inadequate for fully implementing any of the reduction techniques described above. To operationalize any of these procedures it is necessary to have accurate estimates of regional gross output for each endogenous sector. Data supporting independent estimates of these values could not be assembled for the region. Apparently, then, the only option available to the user is to use the technical coefficients from the State model directly (i.e., unadjusted) in the regional model. In transferring these coefficients directly, it is doubtful that they will provide an accurate interpretation of the interdependence existing in the regional economy. However, it is felt that this procedure does provide a reasonable

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[61] Schaffer and Chu, "Nonsurvey Techniques," loc. cit.

first approximation of this interdependence. Also, it should be noted that if the user has access to unpublished data relevant to the adjustment procedures or, if such data become available from published sources in the future, the State coefficients can be adjusted to provide a more accurate representation of regional economic interdependence.

The primary purpose in using the linkage model in western Montana is to focus upon the linkages that exist between the regional economic and ecologic systems so that regional impacts of changes in the economic system can be identified. In most cases, these changes will involve increases or decreases in the output of one or more of the regional economic sectors. Such changes can usually be entered into the model as changes in final demand. When used in this way, the model is essentially being employed as a forecasting tool. Estimates of payments values for each endogenous sector are not necessary for operating the model since the linkage model emphasizes the output side of the economic system. Thus, it is thought sufficient to assume that economic inputs to the regional production system from exogenous sectors will be forthcoming. Raw material inputs to the economic system from the regional environment are accounted for in the environmental matrix (G').

In the regional model as it is presently formulated, there are three exogenous final demand sectors (i.e., Exports, State and Local Government, and Federal Government), since Households has been incorporated in the endogenous portion of the table. Thus any final demand for the output of a given processing sector must be allocated among these three sources. This obviously increases the information required for operationalizing the model since the allocation must be based on relevant data. It should be noted that the number of sectors chosen to represent final demand in an I-0 model is somewhat arbitrary, with the number actually chosen dependent upon the level of detail required in the model's information output. It is possible to combine final demand from all sources into a single composite or aggregate final demand sector (column). Thus if data are not available to allocate final demand for commodities produced by the regional economic system among the three sources specified in the model, these three sources can be combined so that final demands are included in one column (i.e., total final demand). This is not accomplished without some loss of information, since aggregating final demand from all sources means that one can no longer determine the contribution of each source. However, the information loss resulting from this aggregation procedure is minimized if the Households sector is included in the endogenous portion of the model.

In operating the linkage modelin the study region, it is likely that the interests of the Forest Service will be generally confined to analyzing the impacts of changes in final demand for lumber and wood products. It is felt that, in general, such changes will not need to be allocated among the various sources of this final demand. Therefore, to operationalize the I-0 submodel, it is necessary to estimate final demand, from all sources, for each of the 14 endogenous sectors, i.e., to collapse final demand into a single column and fill each element in this column. Once these estimates are obtained, it is possible to determine the total gross output from each processing sector necessary to satisfy these final demands. This is accomplished by first multiplying each row of the matrix of direct and indirect coefficients, i.e., the $(1-A)^{-1}$ matrix, by the estimated final demand value for that row. This yields another matrix of the same size as the Leontief inverse matrix. The next step is to sum the columns of this matrix to obtain the new total gross output figures. These total gross output values can then be used to determine the total amount of imports from and exports to the regional environment necessary to meet the specified final demands.

This research has indicated that data, currently available from secondary sources, on the eight-county western Montana region are not sufficient to support independent estimates of the final demand figure for each of the endogenous sectors in the regional model. There are, however, ways to circumvent this problem, but they do not provide the accuracy necessary for certain types of analysis. If the model is to be used primarily for simulating the impacts of changes in the final demand figures for one or more sectors, then any set of final demands will be sufficient. The validity of this statement is based on the assumption of linearity which is inherent in I-O formulations. For example, if the Forest Service needs to determine the regional economic and environmental impacts of, say, an increase in the allowable harvest from the region's forests of one million cubic feet, then the initial run of the model can be made using an arbitrary set of final demands to yield an equally arbitrary set of total gross output values for each sector. These gross output values become the basis for evaluating the impacts of the change in timber harvest. This is accomplished by interpreting the one million cubic feet increase in the harvest as an increase in the final demand for output from the logging sector equal to that amount (if the user assumes that the entire increase will be sold). Thus, one million cubic feet (or, more accurately, the market value of that amount of wood) can be added to the arbitrary final demand figure for the logging sector. A second run of the model using this adjusted final demand vector yields a new gross output vector. Subtracting the first (arbitrary) gross output vector from the second yields the change in the gross output of each sector attributable to the one million cubic foot increase in final demand for the logging sector. The vector of values representing the change in gross output for each sector is then multiplied by the matrix of direct and indirect environmental impacts, i.e., the R matrix, to yield the residuals discharge and natural resource input values attributable to the change in allowable harvest.

If interest is not confined to relative changes then a set of final demand estimates that more accurately represent actual final demands on the regional economic sectors is necessary. One procedure for obtaining such estimates involves adjustment of the State final demand values. Final demand values for each of the State processing sectors can be obtained from Mitchell's thesis.[62] Essentially, this procedure requires the assumption that a relatively constant portion of final demands associated with each State processing sector is supplied by the corresponding sector in the regional economy. The procedure, then, is to estimate this proportion using surrogate measures such as employment, number of establishments, value of products sold, receipts for services rendered, value of shipments, etc. Basically, the reasoning employed is as follows. If, for example, establishments in the manufacturing sector of the regional economy account for, say, 25 percent of the total value of shipments associated with the State manufacturing sector, then it is assumed that the regional sector supplies approximately 25 percent of the final demands made upon the State manufacturing sector. Hence, multiplication of the State sector final demand value by .25 yields an estimate of final demands made upon the corresponding regional sector.

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[62]Mitchell, op. cit., p. 65.

Confidence in this estimating procedure varies according to the particular measure used in calculating the adjustment ratio. For example, use of some value-of-output measure (e.g., sales, receipts, value of shipments) is perhaps a better surrogate than the more indirect measures (e.g., employment, number of establishments) that could be used. Unfortunately, value measures are not always reported in a form usable at the regional level. In the case of western Montana, U.S. Census reports in conjunction with the Montana Economic Study supply adequate information to support this procedure; but do not provide usable value measures for each sector.

The first step in the estimation procedure involves summing the final demand from each of the three sources specified in the State model (i.e., Exports, State and Local Government, and Federal Government) to obtain a total final demand figure for each endogenous sector in the State model. These total final demand values are then multiplied by the adjustment ratios which are computed based on the surrogate measures as described below.

Census information is available to establish the value of livestock and livestock products and value of crops sold for the State and on a county basis.[63] The county values can be summed to yield an aggregate value for the region.

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[63] U.S. Department of Commerce, Bureau of the Census, <u>1964 Census of Agriculture</u> (Washington: U.S. Government Printing Office, 1964), Vol. I, Part 38, Table 5, Characteristics of Commercial Farms: 1964, pp. 246-251.

Thus, the final demand values for the Livestock and Livestock Products and Crop sectors of the regional model can be estimated using value measures and the procedure outlined above.

The Census also provides data on total receipts for selected services for the State and individual counties.[64] Six of the nine services included in the Other Services sector of the State and regional models are represented in this data base. It is felt that this representation is sufficient to yield an adequate estimate of final demand for the Other Services sector of the regional model based on a value measure.

The final demand value for the Other Trade sector of the regional model can also be estimated using value measures from the Census. This sector combines both wholesale and retail trade. For retail trade, the Census provides data on total sales for all retail trade establishments in the State and in each county.[65] The same information is provided for all wholesale trade establishments.[66]

The Montana Economic Study reports that in 1966, total earnings from mining for the State amounted to $59,000,000,

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[64] U.S. Department of Commerce, Bureau of the Census, <u>1967 Census of Business</u> (Washington: U.S. Government Printing Office, 1967), Vol. V, Part 2, Chapter 28, Table 3, Counties; Cities of 2,500 Inhabitants or More: 1967, pp. 8-9.

[65] Ibid., Vol. II, Part 2, Chapter 28, Table 3, Counties; Cities of 2,500 Inhabitants or More: 1967, pp. 8-9.

[66] Ibid., Vol. IV, Chapter 28, Table 4, Counties; Cities of 5,000 Inhabitants or More: 1967, pp. 8-9.

while for the western Montana region these earnings totaled $1,253,000.[67] It should be noted that the regional total excludes data for Lincoln and Ravalli Counties, which were withheld to avoid disclosure. However, the six counties included in the regional figure are sufficient to make this total representative. Thus, final demand for the Mining sector of the regional model can also be estimated with value measures.

The Study also provides total earnings figures for the construction industry at both the State and regional level. In 1966, total earnings from contract construction for the State amounted to $102,000,000 and for the region the total was $18,130,000.[68] Thus, using the percentage of total earnings from construction contributed by the regional construction sector it is possible to estimate the final demand for this sector.

Final demand for the Real Estate, Finance, and Insurance sector of the regional model can also be estimated via the procedure described above using earnings data from the Montana Economic Study. According to the Study, earnings from these industries in 1966 totaled $54,000,000 for the State and $8,550,000 for the region.[69] It should be noted

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[67]Bureau of Business and Economic Research, op. cit., Part 2, Vol. 1, Chapter 2, p. 33.

[68]Bureau of Business and Economic Research, op. cit., Part 2, Vol. 2, Chapter 4, p. 3.

[69]Bureau of Business and Economic Research, op. cit., Part 2, Vol. 3, Chapter 5, p. 41.

that the earnings figure for the region excludes data for Granite and Mineral Counties which were withheld to avoid disclosure. It is felt, however, that exclusion of these data does not distort the percentage value enough to render it useless for estimating final demand for the regional Real Estate, Finance, and Insurance sector.

Usable value measures for estimating final demand for each of the next four sectors in the regional linkage model (i.e., Food and Kindred Products, Manufacturing, Transportation and Public Warehousing, and Communications and Public Utilities), could not be obtained from secondary sources. The Montana Economic Study does provide earnings data but the industry groupings for which these data are assembled do not match the groupings represented in the sectors of the regional or State models. The Census provides relevant value measures for appropriate industry groupings, but, unfortunately, these data are not disaggregated to the county level. Thus, the Census information cannot be used to calculate regional values. For these four sectors, then, it is necessary to rely on less direct surrogate measures (e.g., employment or number of establishments), for estimating the final demand values for the regional linkage model.

It is felt that employment data, if available in usable form, provide a better surrogate measure than number of establishments. At a given level of technology, employment (i.e., number of persons employed in a given sector) bears a more or less direct relationship to the output of each sector. If, for each sector, the technology can be assumed to be nearly the same at both the State and county (or regional) levels, then the ratio of employment in a given State sector to employment in the corresponding regional sector can be used to estimate the proportion of final demand for the output from the State sector that is supplied from the regional sector. It is felt that number of establishments data bear a less direct relationship to sector output because the measure does not take establishment size into account. For example, if the State sector in question contains 100 establishments and the corresponding regional sector contains 20, then it can be said that the region contains 20 percent of the establishments in the State sector. However, if the regional establishments are all relatively small compared to those for the rest of the State, it is clearly inaccurate to reason that the regional sector supplies 20 percent of the final demands made upon the State sector.

The Census provides data sufficient for estimating the final demands for output from the Food and Kindred Products, Manufacturing, Transportation and Public Warehousing, and Communications and Public Utilities sectors using either employment[70] or number of establishments[71] measures. Thus

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[70] U.S. Department of Commerce, Bureau of the Census, 1970 Census of Population (Washington: U.S. Government Printing Office, 1970), Vol. 1, Part 28, Chapter C, Table 123, Industry of Employed Persons and Occupation of Experienced Unemployed Persons for Counties: 1970, pp. 216-220; and Table 55, Industry of Employed Persons by Race, for Urban and Rural Residents: 1970, pp. 129-130.

[71] U.S. Department of Commerce, Bureau of the Census, 1967 Census of Manufactures (Washington: U.S. Government

the user is free to choose between these two surrogate measures in estimating the final demand values for these regional sectors.

The 1967 transactions table contained in Mitchell's thesis does not incorporate the recent disaggregation of the Lumber and Wood Products sector into two separate sectors--Logging and Sawmills and Wood Processing--which are included in the regional linkage model. However, Haroldsen has indicated that an adjusted transactions table for 1967 does incorporate this modification and is currently available.[72] Thus, this information appears to be available though it could not be obtained for inclusion in this report. With the final demand values obtained for these two State sectors from the adjusted table, it is possible to use the procedure outlined above to derive estimates of final demand for the corresponding regional sectors.

In the regional linkage model, the Households sector is included in the endogenous portion of the table. Thus it is necessary to estimate final demand for the output of this sector. The transactions table for the 1967 State I-0 model (from Mitchell) provides information sufficient for calculating the final demand value associated with the State House-

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Printing Office, 1967), Vol. III, Part 1, Chapter 27, Table 9, Distribution of Establishments by Employment Size Class and Major Industry Group for Counties: 1967, pp. 7-10.

[72] Correspondence with Ancel D. Haroldsen, Montana State University, July 10, 1974. As noted previously, this modification was accomplished in 1973 at Montana State University by Gene Lewis. Documentation of this change could not be obtained by the author.

holds sector (exogenous in that model).[73] Thus, the regional final demand value for that sector can be estimated using the procedure outlined above. It is felt that the most appropriate surrogate measure to use in this context is population. Use of an adjustment ratio based on population implies the assumption that households in both the State and the region are equally productive. In 1970, the population in the State totaled 694,409; while the regional population in that year was 157,428 (see Table I.1, Chapter I). Thus the region accounts for 22.7 percent of the total State population. Multiplication of the final demand value obtained from the State transactions table for the Households sector by .227, yields an estimate of final demand for the corresponding regional sector.

To this point, it is apparent that the interindustry submodel of the regional linkage model can be operationalized in the western Montana region. Essentially, the procedure for implementing this portion of the model involves use of technical coefficients from the State I-0 model. In addition, final demand estimates for each endogenous sector in the regional model are derived by adjusting the estimates of final demand associated with each endogenous sector in the State model.

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[73]Mitchell, loc. cit.

The Environmental Matrix

The environmental matrix (i.e., G' matrix), as formulated for the regional linkage model, contains coefficients relating the amounts (in physical units) of 19 environmental substances (rows) that are either imported from or exported to the regional ecologic system for each one dollar's worth of gross output from each of the 14 endogenous sectors in the interindustry portion of the economic submodel.

An examination of published reports on empirical research designed to estimate coefficients of this type indicates that such efforts have met with only limited success. For example, Laurent and Hite developed an environmental matrix consisting of 16 rows (representing 16 environmental substances) and 28 columns (representing 28 endogenous economic sectors).[74] Of the 448 cells in this matrix, the authors were able to fill only 91 using largely secondary information; but, also, supplementing this information with surveys when possible.

In most studies reviewed, the development of an environmental matrix was either the central focus of the research or one of only two or three major research objectives. In this study, this was not the case. As a problem analysis, the intent of this research was to cover as much of the problem as possible. Unfortunately, when limited research resources are employed in this manner, some of the topics

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[74]Laurent and Hite, Economic-Ecologic Analysis in the Charleston Metropolitan Region, pp. 52-55.

covered cannot be treated in depth. Indeed, it is felt that development of an environmental matrix for the western Montana region would, alone, support a large and intensive research effort involving several researchers and considerable research resources.

An exhaustive search of obtainable published sources has been carried out as part of this research effort. This search has indicated that existing secondary data are not sufficient for estimating any of the direct environmental coefficients in the G' matrix for the study region. The bluntness of this statement is perhaps tempered somewhat by the circumstances surrounding this study. The two most significant circumstances involve the large distance between the study region and the home-base of the researcher, and the researcher's lack of familiarity with western Montana. Limited travel funds made possible only one short trip to the region; and this trip was a multi-purpose one with a small amount of time budgeted for field research. In addition, lack of familiarity, on the part of the researcher, with the study region (especially its data sources and resource people), meant that identification of potentially useful data sources (including published but little used sources) was difficult without actually being in western Montana. Thus it is entirely possible (or perhaps even quite likely) that data sufficient for estimating several of the regional environmental coefficients are available from secondary sources, both published and unpublished, that could not be identified in this research.

Though it was not possible to fully operationalize this portion of the model in western Montana at the present time, the conceptual development and structural modification already accomplished does provide a useful framework for future data collection and processing activities in the region. It is possible, to some extent, to implement this portion of the model, if the user can accept as valid the use of coefficients derived either from other research efforts focussed on different regions or on certain specific aspects of the linkage problem.

A complete survey of such studies is clearly beyond the scope of this research. It is possible, here, only to note that this option is available to the user in implementing the linkage model and to cite some examples. While this does not provide an adequate base for implementing the entire environmental matrix, the examples noted do identify some of the necessary coefficients. As mentioned previously, other linkage models have been operationalized, at least initially, with only a few of the cells in the environmental matrix filled.[75] Indeed, Laurent and Hite suggest that it is legitimate to operate the model on this basis but caution that in those ". . . cases where blank cells should have

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[75]It should be noted that in post-multiplying the environmental (G') matrix by the inverse, i.e., $(1-A)^{-1}$, matrix all of the cells in the resultant R matrix will have an entry. This is true even for those sectors which did not show a direct ecologic linkage in the G' matrix. This results from the economic interdependence among sectors in the interindustry model.

numbers, but presently do not, there will be a bias introduced into the estimates of the environmental impacts of economic activities and this impact will be understated."[76] However, it is felt that use of coefficients obtained from other studies will provide a basis for operationalizing the environmental matrix portion of the linkage model until more adequate information is available.

It should be noted that the coefficients in the environmental matrix involve certain assumptions. Perhaps the most important is the assumption of linearity. The structure of the I-0 model makes necessary the assumption that the same amount of natural resource inputs or residuals outputs are associated with each dollar of gross output from a given economic sector whether it is the first dollar or the one millionth dollar. Clearly this assumption is unrealistic in certain cases. For example, emissions from the heating unit of a plant may remain constant for any positive level of output since the facilities must be heated whether the plant is producing at capacity or at only 50 percent of capacity. However, in many other cases the linearity assumption is not nearly so inadequate.

Direct use, in the western Montana linkage model, of environmental coefficients estimated on the basis of data relevant to other regions, implies the additional assumption that technology and/or consumption activity is the same be-

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[76]Laurent and Hite, Economic-Ecologic Analysis in the Charleston Metropolitan Region, pp. 56-57.

tween the two places. Undoubtedly, this assumption is more realistic in some cases than in others; but if coefficients for the western Montana model are to be derived in this way, the user must be ready to accept this discrepancy.

Laurent and Hite provide empirical estimates of some direct environmental coefficients for 16 substances and 28 economic sectors based on research in the Charleston Metropolitan Region.[77] Unfortunately, the industry groupings in the Laurent and Hite sectors seldom match, exactly, those employed in the western Montana linkage model. Indeed, only two of the sectors--Food and Kindred Products and Households--are a close enough match to be used directly in the regional model. Laurent and Hite estimated direct environmental coefficients for the Food and Kindred Products sector and the following environmental substances: Domestic Water, Process Water, Total Water Intake, Discharge Water, and 5 Day BOD.[78] For the Households sector of the Charleston model, coefficients are estimated for: Domestic Water, Total Water Intake, Discharge Water, 5 Day BOD, and Solid Waste.[79] Some of the Charleston sectors represent consolidations of the industry groupings in two or more of the western Montana sectors, while others are disaggregations of certain western

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[77]Laurent and Hite, Economic-Ecologic Analysis in the Charleston Metropolitan Region, pp. 52-55.

[78]Laurent and Hite, Economic-Ecologic Analysis in the Charelston Metropolitan Region, loc. cit.

[79]Laurent and Hite, Economic-Ecologic Analysis in the Charleston Metropolitan Region, loc. cit.

Montana sectors. It might be possible to either disaggregate the Laurent and Hite coefficients or aggregate them for use in the western Montana linkage model, but this procedure would likely yield somewhat arbitrary results.

The empirical study conducted by Roberts and Rettig for Clatsop County, Oregon, provides estimates for some direct environmental coefficients.[80] The environmental matrix developed in this study considers 14 environmental substances and 30 economic sectors. Of the 420 cells in this matrix, only 95 have been filled. In adapting the work of Roberts and Rettig to the western Montana model, one faces the same problem (i.e., mismatched industry groupings) as was experienced with the coefficients estimted by Laurent and Hite. Three of the Oregon sectors appear to be compatible with those defined for the western Montana model.[81] These sectors are: Manufacturing, Construction, and Households. For the Manufacturing sector, direct environmental coefficients have been estimated for Process Water, Water Intake, Water Discharge, and Solid Waste.[82] For the Construction sector, Roberts and Rettig have estimated coefficients for Process Water, Water Intake, and Water Discharge.[83] Coefficients for Domestic Water, Water Intake, Water Discharge, Suspended Solids, and Solid Waste have been estimated for the House-

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[80]Roberts and Rettig, op. cit., pp. A8-A10.

[81]Roberts and Rettig, loc. cit.

[82]Roberts and Rettig, loc. cit.

[83]Roberts and Rettig, loc. cit.

holds sector.[84] One sector from the Roberts and Rettig paper, while not an exact match for any of the western Montana sectors, might be useful in implementing the linkage model in the region. Roberts and Rettig have estimated direct environmental coefficients for a Lumber sector for the following environmental substances: Particulates, Domestic Water, Cooling Water, Process Water, Water Intake, Water Discharge, 5 Day BOD, Suspended Solids, and Solid Waste.[85] As was the case with the Charleston area model, the Clatsop County effort contains some sectors which are disaggregations of the sectors in the western Montana model. Thus the possibility exists for combining these sectors to obtain coefficients for use in the western Montana linkage model.

It is felt that to be really effective, the regional linkage model should incorporate an environmental matrix having most, if not all, of the cells filled. Also, the performance of the model is greatly improved if these coefficients are estimated with data specifically related to the western Montana region. This suggests that a high priority information need is the assembly of data sufficient for estimating these coefficients. It is felt that such data can be assembled only through a survey of western Montana industries using the environmental matrix developed in this report as a guide. Each cell in the matrix defines a re-

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[84]Roberts and Rettig, loc. cit.

[85]Roberts and Rettig, loc. cit.

gional economic sector and an environmental substance. A survey of the regional industries contained in that sector which asks for information concerning the usage of that substance (if the industry uses it as a raw material input) or discharge of the substance (if it is a residual from that industry's productive process) per dollar of final output, should provide data sufficient for estimating the coefficient associated with that cell.

## The Environmental Simulator

Time and other research resources allocated for this investigation have not been sufficient to allow for development of the environmental simulation portion of the linkage model to a stage where data requirements for this submodel can be defined in detail. Based on the general requirements for this submodel discussed in Chapter III, the secondary data base for western Montana does not appear to be adequate to support operationalization of this portion of the model. It is felt, however, that considerably more conceptual development is necessary before the environmental simulator can even be considered for implementation in the region. Thus, at the present time, this portion of the model may be viewed as a very generalized conceptualization, not yet ready for implementation; and one for which the secondary data base associated with most regions is likely to be inadequate for operationalization. It should be noted that the present development of this submodel is sufficient to serve as a blueprint for further work as well as a set of guidelines for future data collection and processing activities in the study region.

With the elimination of the environmental simulator from an operational linkage model in the western Montana region, the ability to evaluate, within the model, the impacts of residuals discharges on the regional ecologic system is lost. The environmentally relevant output from the operational linkage model is contained in the R matrix. The values in this matrix, when multiplied by the gross output values for each economic sector, yield values representing the direct and indirect environmental impacts that result from meeting a specified set of final demands. At present, it is apparent that the significance of these impacts (i.e., residuals output and natural resource usage) in terms of environmental quality, will have to be evaluated by the user. Judgement will also be required in defining what adjustments, if any, are necessary in the economic system of the study region to preserve a given level of environmental quality.

## Summary

### The Operationally Feasible Linkage Model

The evaluation of the secondary data base for the western Montana region has indicated that only a portion of the structurally modified conceptual model can be operationalized at the present time. While this is far from an ideal situation, it should be recognized that circumstances existing in the real world are seldom ideal for the pursuit of most scientific investigation. At present, the interindustry portion of the economic submodel can be implemented in western Montana. The procedure uses coefficients from the State I-0 model and adjusted final demand estimates based on State figures.

The environmental matrix can be operationalized, but it should be noted that few of the cells in this matrix will be filled. In addition, those direct environmental coefficients that are used have been estimated from data relevant to other regions. While this procedure will likely yield inaccurate results when the model is operated in the study region, it is felt that these results will still represent an improvement over information currently available to decision-makers and planners in western Montana.

It was not possible within the limitations imposed upon this research to proceed with the conceptual development of the environmental simulator submodel to the point where a detailed analysis of the data required for operating this portion could be made. Therefore, an accurate evaluation of the operational feasibility of the environmental simulator could not be accomplished at this time. However, based on the general discussion of data requirements for this portion of the ideal conceptual model and the survey of the data base that has been accomplished, it is likely that, at present, this base would not support the simulation portion of the linkage model even if a conceptually complete formulation were available. The elimination of this portion of the linkage model implies that the actual impacts on environmental quality of variations in the regional economic system must be evaluated exogenously. Thus considerably more user judgement is necessary in conjunction with the operational linkage model than was required with the ideal formulation. In addition, it should be noted that in by-passing the environmental simulator, one loses the capacity to map the environmental impacts. With the currently feasible linkage model, it is possible to map only the gross residuals discharges accounted for in the model.

Operation of the feasible model involves the following steps:

1. construction of a table of direct or technical coefficients (i.e., A matrix) from the State I-0 model;
2. calculation of the Leontief inverse, $(1\text{-}A)^{-1}$;
3. construction of the environmental matrix (G'), using coefficients from other studies and estimates of coefficients based on any available, but unidentified, data relevant to the study region;
4. post-multiplication of the environmental matrix (G') by the inverse matrix, i.e., $(G')\cdot(1\text{-}A)^{-1} = (R)$, to yield the matrix of direct and indirect environmental impacts (R);
5. multiplication of each element in the R matrix by the gross output value of the appropriate sector (from the interindustry portion of the model) to yield gross residuals discharge and natural resource input values.

Information Output of the Feasible Model

Though the economic-ecologic linkage model which can be operationalized on currently available data from secondary sources in western Montana is considerably less powerful than the ideal conceptual model, it does, nevertheless, provide a significant amount of useful information output. Operation of the model yields: 1) a matrix of direct and indirect coefficients representing the total expansion of output in all industries as a result of the delivery of one dollar's worth of output outside the processing sectors by each sector, (i.e., the direct and indirect effects of changes in final demand); 2) the gross output necessary from each sector to meet the exogenously specified set of final demands; 3) a matrix of direct and indirect coefficients representing the direct and indirect changes in imports of natural resource inputs and exports of residuals resulting from an increase of one dollar in the external sales of each exogenous sector; and 4) gross residual output and resource input values necessary for each sector to meet its portion of the given set of final demands.

The feasible model is particularly relevant for evaluating off-forest regional economic impacts. Indeed, all of the various sectoral multipliers associated with I-0 models can be computed from solutions for the feasible western Montana model.[86] Included are type I income and employment

[86]For a discussion of impact or multiplier analysis in an I-0 context see: Harry W. Richardson, Input-Output and Regional Economics (London: Weidenfeld and Nicolson, 1972)

multipliers, which reflect only the direct and indirect changes in income and employment resulting from an increase of one dollar in the output of all the industries in the processing sectors. It is also possible to calculate Type II income and employment multipliers which take into account the direct and indirect effects indicated by the I-0 model plus the induced changes resulting from increased consumer spending.

The I-0 portion of the model also provides information useful in describing structural interdependence in the regional economic system. In addition, I-0 models have been used as a forecasting tool to simulate future patterns of economic activity in the region.[87]

The environmentally relevant information output of the regional linkage model consists essentially of estimates of natural resource inputs used and residuals discharged in meeting a given set of final demands. Clearly, users may also calculate changes in these values resulting from changes (either actual or proposed) in the final demand for the output of one or more of the endogenous economic sectors. The operationally feasible model does not, unfortunately, pro-

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pp. 31-52. See also Miernyk, op. cit., pp. 42-55; Werner Z. Hirsch, "Interindustry Relations of a Metropolitan Area," The Review of Economics and Statistics, XLI (November, 1959), pp. 360-369; and Frederick T. Moore and James W. Petersen, "Regional Analysis: An Interindustry Model of Utah," The Review of Economics and Statistics, XXXVII (November, 1955), pp. 368-381.

[87]For a discussion of I-0 as a forecasting tool see: Miernyk, op. cit., pp. 31-41.

vide information sufficient for evaluating impacts of imports from and exports to the regional environment on the quality of that environment. As noted previously, this problem must currently be dealt with outside of the linkage model.

The table of direct and indirect environmental coefficients (R matrix) provides the user with information which will aid in identifying those sectors where changes in the level of economic activity are associated with major environmental impacts. High positive (natural resource input) coefficients indicate sectors which use a large amount of environmental goods in their production or consumption processes. Similarly, low negative (residuals discharge) coefficients indicate sectors which export large quantities of various residuals to the environment as a result of production or consumption activities. This information is particularly useful because it is often difficult to identify those sectors having major environmental impacts. For example, it is possible for a given sector to have few obvious (direct) linkages with the regional environmental system yet still be a major cause of environmental pollution. This can happen if the sector in question has strong links with (i.e., purchases the output of) other sectors which do discharge a large quantity of residuals. Thus, when one considers both the direct and indirect impacts associated with a given sector, this sector may indeed by found to have major impacts on the regional environment when examination of only the direct impacts of the economic activity in this sector led to the opposite conclusion.

It is felt that the range of questions for which the operationally feasible model is relevant is significantly smaller than was the case for the ideal conceptual model. Perhaps the greatest reduction in information output can be attributed to the loss of the environmental simulator from the operationally feasible model. Thus, questions concerned with the diffusion and concentration of residuals in the regional environment cannot be dealt with in the operational model. Also, the operational model does not provide information which would allow the user to evaluate the actual impacts on environmental quality of the residuals discharged to the environment by the regional economic system. These considerations must, at present, be evaluated exogenously It should be noted, however, that the environmentally relevant information that can be provided by the operationally feasible model (i.e., the estimates of changes in natural resource usage and residuals output associated with specified changes in the economic system), is essential to an overall evaluation of environmental impacts of resource management decisions.

Another feature associated with the ideal conceptual model which could not be retained in the operationally feasible model, is the feedback loop through which environmental damages can be entered into the economic submodel as constraints on future activity in the economic system. Thus, the feasible model does not generate information directly applicable to questions concerning the impacts of regional environmental changes on the economic system.

Despite its deficiencies when compared with the ideal model, it is felt that the feasible model can provide essential inputs for decisions by planners and administrators concerned with the economic development of the western Montana region and with maintaining regional environmental quality. It would seem that the model would be particularly useful to the Forest Service in its land use and management planning functions in the region. If the model is used primarily as a forecasting tool, it can provide simulated data on changes in regional income and employment likely to result from alternative forest management strategies. In addition, the feasible model can provide information which could be quite helpful in the development of the environmental impact statements required of the Forest Service under both the National Environmental Protection Act (NEPA) and internal administrative rules. In this context, the feasible model can be especially useful in identifying which sectors of the regional economy are likely to be impacted (in terms of an increase or decrease in the output of that sector) by Forest Service decisions; and, further, whether those sectors so effected have a linkage with the regional environmental system (in terms of usage of natural resource inputs or discharge of residuals). Thus, the feasible model does provide a means of estimating the changes (direct and indirect) in the volume of natural resource materials used and the volume of residuals discharged, likely to result from different management strategies.

It should be recognized that the operationally feasible model is only a first attempt at implementing an economic-ecologic linkage model in the western Montana region. As conditions change (i.e., better data become available, more research resources are committed) it is still possible to move in the direction of the ideal conceptual formulation.

# CHAPTER VI

## SUMMARY AND CONCLUSIONS

This study was initiated in an atmosphere of enthusiasm and anticipation and its completion has, it is felt, produced much useful information. However, it has probably identified (and, it is hoped, illuminated) more questions and problems than it has answered or solved. Such results, as indicated by the specific research objectives outlined at the beginning of this report, were not totally unexpected. Indeed, it is felt that a careful examination of the research objectives defined for this study leaves the impression that each would, by itself, support a major research effort. Under these circumstances, it has been difficult to pursue, comprehensively, all of the research objectives within the confines of a small scale study.

It should be remembered that the study was designed as a problem analysis. The function of this type of research is to clarify problems and identify specific research needs, rather than to provide definitive answers to specific questions. It is felt that this study has achieved some measure of success toward this goal. In summarizing the achievements, disappointments, and conclusions of the research described in this report, it is most convenient to treat each objective individually. In addition, a separate section is devoted to a discussion of what are felt to be significant research needs that have been identified at various stages of this study.

## The Annotated Bibliography

An annotated bibliography of literature concerned with linking economic and ecologic systems has been compiled and is presented in the Appendix. The primary purpose in compiling this bibliography was to facilitate the identification of alternative approaches to modeling economic and ecologic systems in an integrated fashion. This knowledge was essential input to the comparative evaluation of the various models. In addition, it was felt that a comprehensive review of the literature would provide a concise report on the state of the art in this important modeling effort. Such reports are periodically necessary particularly in an area where relevant research crosses disciplinary lines. It is felt that the annotated bibliography (and literature review chapter), provided in this report not only satisfies the first research objective, but, also, provides the information that it was intended to identify.

The outstanding finding associated with this literature search is the lack of empirical research in light of the rather sophisticated conceptual development of economic-ecologic linkage models. It is obvious that conceptual development of these models has proceeded well beyond empirical testing and problematic application. Indeed, the gap here is so large as to suggest that perhaps more research resources (including competent researchers) should be committed to this empirical work, even if these resources must be channeled away from further conceptual refinement.

As a result of this gap, one very critical problem facing potential users of economic-ecologic linkage models is the lack of guidelines to implement the various formulations. In some cases, conceptual development has proceeded in such a way that it is extremely difficult, if not impossible, to determine the specific data requirements for operationalizing the model. Not only does this difficulty hinder empirical application of a given conceptual model, but, also, it prevents development of improved data and information systems necessary for implementation.

The literature review also revealed that, in general, for most linkage models either the economic sectors or the submodels representing the economic system are more fully developed than those portions relating to the ecologic system. Clearly, this discrepancy is more damaging when the model is applied to certain problems than in other applications. However, overall, the problem does not appear to be so severe as to limit utility of such models in a rather broad range of applications (i.e., problem and/or regional contexts).

Examination of the limited empirical content found in the literature reviewed indicates that, in general, current data systems will not support operation of comprehensive linkage models. This is particularly true in a regional context and for the more elaborate models. In addition, literature indicates that data problems are most severe in the case of modeling the ecologic system. It might be pointed out that this study tends to support this last observation.

Perhaps the most significant conclusion that can be drawn from research in pursuit of the first study objective is that more attention should be directed toward operationalizing existing conceptual models. The need for more detailed guidelines directed toward potential users of linkage models makes further conceptual refinement somewhat superfluous.

## Comparative Evaluation of Alternative Linkage Models

The second research objective requires completion of a comparative evaluation of alternative linkage models. The rationale for performing this evaluation was to provide information to be used in conceptualizing an ideal linkage model. The evaluation presented in this report was completed in three stages. They were:

1. identify alternative models,
2. develop evaluative criteria, and
3. evaluate alternatives.

It is felt that the evaluation performed in this research effort, though couched in rather general terms, satisfies the requirements of this objective. That is, the evaluation provided information necessary to proceed with the next phase of the study--conceptualizing the ideal model--but is not offered as a definitive treatment of the subject.

Four general types of models were identified in the literature and considered in the comparative evaluation. They are:

1. input-output (I-0) models,
2. linear programming (LP) models,
3. simulation models, and
4. hybrid type models.

The fourth type (i.e., hybrid models) is an open catagory containing all models which employ various combinations of techniques associated with the first three types.

Evaluative criteria were developed for application in the comparative analysis. Though it was recognized that a large number of model attributes could be considered relevant for a comparative evaluation depending upon the goals of such an evaluation, the following eight criteria were included for consideration here:

1. Information Output - the amount and quality of information generated when the model is applied in various real-world problem contexts;
2. Data Input - the quantity and quality of data required to operate the model;
3. Provision of Guidelines to Policy Questions - the ability of the model to provide guidelines to policy questions in a form useful to decision-makers;

4. Relevance of Necessary Assumptions - the relevance of model assumptions to realistic decision problems;
5. Capacity for Dealing with the Temporal Dimension - determine whether the model is essentially static or dynamic and the extent of any modifications that might be necessary to incorporate the temporal dimension;
6. Capacity for Dealing with the Spatial Dimension - determine what modifications, if any, are necessary to facilitate the representation of spatial phenomena;
7. Generality - a measure of flexibility; the extent to which the model can be generalized to a variety of problem applications; and
8. Specificity - a second measure of flexibility; the facility with which the model can be adapted or tailored to specific regional and/or problem contexts.

The criteria listed above are in order of decreasing relative importance except that the fifth and sixth criteria are considered to be of equal importance as are the seventh and eighth criteria. It is felt that the criteria developed, while not providing an exhaustive listing of potentially significant attributes, do adequately reflect the goals and objectives outlined for this research.

The comparative evaluation of alternative approaches to modeling economic-ecologic linkages involves a subjective application of each criterion to each alternative model. The evaluation is not only quite subjective, but, also, very general. The aim was to provide a rank-ordering of the alternatives and not a quantitative measure of the utility of each model. It should also be noted that the very large variety of potential formulations associated with the hybrid type of model precluded a general evaluation, and hence relative ranking, of this group. The results of the evaluation are summarized in Table III.1. In general, the comparative evaluation suggests that the simulation approach offers the most attractive approach to modeling economic-ecologic linkages in a regional context. However, this finding is somewhat tentative since the evaluation did not include, directly, the hybrid type model. It is felt that such models, which can incorporate features associated with each of the other types of models, may be more appropriate in any given situation.

The one general conclusion that can be drawn from the comparative evaluation is that increases in the utility of a model (i.e., increases in the model's capacity to incorporate the temporal and spatial dimensions, the quality and quantity of information generated through operation of the model, its ability to provide guidelines to policy questions, and the flexibility of the model) will result in increases in both the quantity and quality of data required for operation. At present, it is apparent that this tradeoff is unavoidable.

## Conceptualizing the Ideal Model

The third research objective requires the conceptualization of an economic-ecologic linkage model that is ideal in the sense that its development is not constrained by either data or resource limitations. In addition, the types of questions that could be answered with and the data requirements for such a model are explored and defined. The rationale for developing the ideal conceptual model is twofold. First, the ideal model provides the basis upon which subsequent modifications can be made to yield an operational linkage model for the western Montana region. Second, it can serve not only as a guide to future data collection and processing activities, but, also, as a blueprint for subsequent modeling effots in the region. It is felt that, in general,the conceptual model presented in this report fulfills the intent of this objective, though development of some portions of the model has progressed further than others. The ideal conceptual model is illustrated in Figure IV.1.

The ideal conceptual model suggested here is a modified version of an economic-ecologic linkage model developed by Clifford S. Russell and Walter O. Spofford, Jr. As such, it is most appropriately classified as a hybrid type since it employs both simulation and LP techniques. The model includes a linear programming economic submodel, which incorporates a regional economic objective function and both economic and environmental constraints. The principal outputs of the economic submodel are the residuals discharge vectors which give the quantity of various residuals exported to the environment for optimal levels of economic activity in the region. Of course the model also yields the pattern of economic activity which optimizes the regional objective function subject to the constraints. In addition, information provided by the LP submodel can be reorganized to yield a rather complete display of regional economic impacts resulting from changes in the level of production (e.g., multipliers).

The residuals discharge vectors enter as input to the environmental submodel (i.e., environmental simulator), which is conceptually designed to trace the diffusion of these residuals and monitor residuals concentrations at various receptor locations throughout the regional environment. In addition, the environmental simulator compares concentrations to environmental assimilative capacities and computes damage estimates in either physical units or dollar terms. The damage estimates are then converted to marginal values. It should be noted that the environmental simulator is conceptualized in extremely general terms. More detailed conceptual development, while obviously necessary, would require research resources in excess of those available for this study.

The conceptual linkage model also contains a provision

for mapping the output of the environmental simulator. Variables which can be entered into the mapping program include residuals concentration values, damage estimates, and marginal damage estimates. It is felt that the maps generated are essential output of an economic-ecologic linkage model because they represent the most convenient means of portraying the spatial aspects of the phenomena being modeled.

In addition, the ideal conceptual model provides a feedback option which is essentially the linkage from the environmental system back to the economic system. Marginal damages estimated with the environmental simulator can be entered into the LP submodel where they serve to modify the relevant constraints. Thus environmental changes are monitored and these impacts can automatically be taken into account on the next iteration of the economic submodel.

The model is run in an iterative fashion with each iteration spanning a time period specified by the user. Thus the entire linkage model can be viewed as simulating activity within each regional system and the interaction between these systems occurring over time.

The investigation discussed in the fourth chapter of this report indicates the range of questions for which the ideal model is relevant. It can be said that, in general, the ideal formulation has the capacity to provide a great variety of information. It is felt that this information output is adequate for answering even the most detailed questions involving regional economic and ecologic impacts. The conceptual model provides optimal solutions for the economic system, and, also, generates the information necessary to estimate regional economic impacts of changes in this system, including spatial aspects of these impacts. The environmental submodel provides information relevant to problems ranging from a determination of gross residuals output of the economic system to estimating the damages caused by these residuals at various locations throughout the regional environment. It is felt that, given the state of the art, the ideal conceptual model formulated here provides the capacity for dealing with perhaps the broadest range of questions possible in a single analytical model.

Data requirements for operating the ideal conceptual model are extremely large. In addition, the literature appears to indicate that such data are largely unavailable from secondary sources. This is particularly true at the regional level of aggregation and/or for the availability of the environmental data involved.

Data requirements for the economic LP submodel are not difficult to identify. It is felt that the discussion of these requirements presented in the fourth chapter of this report, though couched in general terms, is adequate to allow for a comparison with the secondary data base for the study region. The research resources allocated for this study did not permit conceptual development of the environmental submodel to the point where data requirements could be defined in other than extremely general terms. Thus development of this portion of the model did not progress far enough to fully meet the intent of this research objective.

## Evaluating Structural Compatibility

The next step in the research process for this investigation was to compare the ideal conceptual model with conditions existing in the western Montana region in order to evaluate the operational feasibility of the model in the region. The fourth research objective (i.e., evaluation of the structural appropriateness of the ideal model for representing the economic and ecologic systems of western Montana in an integrated fashion) is one of two designed to evaluate operational feasibility. Thus the rationale for including this objective is that it represents the first step toward formulating an operational linkage model for the western Montana region. It should be remembered that this is, in fact, the overall objective for this research. It is felt that the evaluation of structural compatibility discussed in this report includes those aspects most critical in the specific problem context of this research. It may be concluded that the evaluation performed fulfills the intent of the fourth study objective, but, clearly, does not provide a comprehensive treatment of the subject.

The evaluation of structural compatibility discussed in Chapter V incorporates a limited number of considerations. This was done to restrict the analysis to areas most likely to necessitate structural modifications. One general area of inquiry relates to the goals and objectives of potential users of a linkage model in the region. Recognizing that this study was oriented toward a specific client, this portion of the evaluation considered, directly, only those goals and objectives associated with the Forest Service. In general, it was felt that the ideal model was appropriate in applications where the overall objective was total systems management. However, this was not thought to be the primary objective of the Forest Service in using a linkage model in the region. Instead it would seem that the Agency's main concern here is in having more information related to the various regional impacts (both economic and environmental) that might result from management decisions involving resources over which it does exercise some control. Consequently, it was decided to reformulate the linkage model to make it structurally more compatible with goals and objectives of the Forest Service.

The reformulated linkage model incorporates an interindustry I-0 format for representing the regional economic system. While this results in the loss of the optimization feature associated with LP formulations, it also results in a considerable reduction in the amount of data required to operationalize the model. The I-0 formulation incorporates an environmental matrix in addition to the interindustry tables. This matrix contains coefficients representing the quantities of various substances that are either imported from or exported to the environmental system for each one dollar of final sales by each of the endogenous sectors in the industry portion of the model. The linkage is actually accomplished by post-multiplying this environmental matrix by the Leontief inverse of the A matrix associated with the industry model to yield a matrix of direct and indirect environmental coefficients (R matrix).

Gross residual output values are then calculated by multiplying the gross economic output value of each sector by the appropriate (negative) coefficients in the row of the R matrix associated with that sector. Similarly, imports from the environment to the economic system (i.e., natural resource inputs) are calculated by multiplying the positive coefficients in the appropriate row of the R matrix by the gross economic output value for each endogenous sector. The residual output values then enter the environmental simulator submodel.

A second aspect of the user goals and objectives criterion involves the potential for linking the economic-ecologic model with other planning models and procedures currently in use by the Forest Service. Two specific examples are considered--the Timber RAM model and the requirements approach to management planning. The analysis indicates that no further structural modifications to the linkage model are necessary to interface with other models and procedures.

The second general area of concern related to structural compatibility involves the actual structure of the western Montana economic and ecologic system. While the evaluation here indicates no further structural modifications, the discussion does suggest a scheme of economic sectors and environmental substances for use in the regional linkage model. The structurally modified model is illustrated in Figure V.3.

## Evaluating the Secondary Data Base

The fifth research objective is designed to explore a second aspect of the question of operational feasibility. Specifically, this objective requires an assessment of the present availability, for the western Montana region, of secondary data required for the operation of the structurally modified model; and, in addition, a description of any further modifications which might be necessary to compensate for any inadequacies found to exist in this data base. This objective is included because it is felt that data availability is perhaps the most binding constraint that one is likely to face in implementing economic-ecologic linkage models in a regional context. The evaluation performed here is considered adequate for the specific purpose for which it was intended. However, various factors combined to preclude a really comprehensive analysis of the region's secondary data base. Among the more critical factors, the time and funds (particularly funds for travel and field observation) allocated for the study and the distance between the study region and researcher's home base were particularly limiting. Under these circumstances it was difficult to identify sources of secondary data for the region, and, in addition, often more difficult to obtain

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the information once located. In general, efforts to locate and obtain data relevant to the economic portions of the linkage model were more successful than those directed toward the acquisition of environmental data.

Evaluation of the secondary data base for the study region indicated that only a portion of the structurally modified conceptual model could be operationalized at the present time. Data currently available from secondary sources are adequate to support the operation of the inter-industry portion of the economic submodel in the region. Essentially, operation here depends upon technical coefficients from the Montana State I-0 model and adjusted final demand estimates based on State figures.

The environmental matrix portion of the economic submodel can be operationalized in western Montana, but very few of the cells in this matrix could be filled. In addition, the cells that are filled contain coefficients that were estimated on the basis of data not related directly to the study region.

As noted previously, the conceptual development of the environmental simulator portion of the linkage model did not reach the stage where data requirements could be defined in detail. Thus this portion was not actually ready for implementation even if the regional data base were adequate for this purpose. However, based on the general discussion of these requirements and experience with the region's data base, it appears as through a refined conceptual model could not be implemented at the present time on existing secondary data. Therefore, the operationally feasible model does not include the environmental simulator portion. The absence of this submodel implies that the actual impacts on environmental quality of various activities in the regional economic system must be evaluated exogenously since the operationally feasible model provides only gross residual output and natural resource input values. Thus considerably more user judgement is necessary in conjunction with the operational model than would have been required with the ideal conceptual formulation.

In general, it can be concluded that the linkage model which can be operationalized in the region on the existing secondary data base is significantly less powerful than the ideal formulation. However, the ideal formulation was developed in the absence of consideration of realistic constraints such as data availability and resource limitations. Such circumstances are seldom, if ever, found in reality. In the western Montana region, it was not possible to obtain data, related specifically to the region, to support the operation of any portion of the structurally modified linkage model. Those portions which can be implemented at present must rely on information not related directly to western Montana.

Though the operationally feasible model is less comprehensive and certainly less powerful than the ideal formulation, it is felt that it does have the capacity to provide essential inputs for decisions by planners and administrators concerned with economic development and maintenance of environmental quality in the western Montana region. To put this effort in its proper perspective, one should view it as an initial attempt at a solution to a very complex problem. The feasible model can provide useful information, and, in addition, the research leading up to development of the feasible model does provide guidelines for further investigation. More complex models which might be implemented in the future are likely to be more comprehensive and powerful than the currently feasible model. As such, they will likely permit a much larger number of the linkages existing between the regional economic and ecologic systems to be quantified. Such models would provide more detailed information output and, in addition, would incorporate a more complete range of considerations (e.g., diffusion and concentration of residuals, damage estimation, and impacts of environmental changes on the regional economic system), most of which must be evaluated exogenously using the currently feasible model. While these more comprehensive models would not eliminate the need for user judgement (or perhaps the term "management discretion" is more appropriate here), they would clearly provide an improved basis for this judgement.

If it were possible to incorporate into an operational model all of the cumulative experience and "savvy" of the many competent decision-makers in both the public and private sectors, then perhaps this loss would be small. However, (perhaps fortunately) current technology does not provide us with the means to integrate such heuristic features. Thus it appears that leaving adequate opportunity for human judgement, while providing a maximum of useful information may ultimately be the best way to achieve more satisfactory resource management decisions.

## Compiling a Study Plan

The final research objective for this study is to compile a study plan that could serve as a feasible research guide for linking the forest-centered economic and ecologic systems of western Montana relying entirely on data from secondary sources. Though not in standard form, it is felt that this report (especially the first five chapters) represents such a plan. The report contains a description of the problem and problem context; a discussion of procedures; a review of the pertinent literature; and a description of the systematic procedure by which alternative approaches are evaluated, an ideal approach (model) is conceptualized, and then adjusted to reflect realistic limitations associated with the study region, to yield an operationally feasible economic-ecologic linkage model for western Montana. Clearly, the information contained in this report could serve as a feasible research guide for linking the economic and ecologic systems of the region. Indeed, it is felt that the report contains enough information to allow for immediate implementation of an operational model in western Montana, in addition to providing guidelines for future efforts aimed at improving the capabilities of this initial model. Thus it can be concluded that the development of this report satisfies the final research objective.

## The General Objective

The general objective of this research was to describe the procedures by which the forestry-based economic and ecologic systems of western Montana could best be linked in a single analytical model. This objective was derived from the notion that current planning models did not properly include the linkages existing between resource management decisions and the regional economic and ecologic systems. Thus this study was designed to help make these planning models more comprehensive, thereby providing a broader range of information inputs to management decisions. Though each of the specific objectives derived from this overall goal have been pursued with varying degrees of success, it is felt that the inforamtion generated by this research as a whole has contributed significantly to the achievement of the general objective of the study.

## Identification of Research Needs

Perhaps the critical reader will regard this entire report as a statement of research needs. Indeed, given the scope and complexity of the problem under investigation here, such a statement would in itself represent a contribution. Many research efforts on a variety of topics have been devoted to achieving a more comprehensive and accurate definition of a particularly difficult problem. If the research undertaken here has served to clarify the many aspects of the general economic-ecologic linkage problem, then it has been more successful than one could have anticipated under the circumstances. Actually, it is felt that the study has been moderately successful in the realm of restating and clarifying the problem of providing more comprehensive information to decision-makers on regional economic and environmental impacts of resource management decisions. In addition, however, the research here is thought to provide information that is more specific and directly useful. Reference here is to that information provided in this report which is directly applicable to the western Montana region. In conclusion then, it is felt that the research described here has produced results which, for the most part, have applicability to both the regional specific problem and the more general problem.

Many of the specific research needs noted below have been anticipated in earlier sections of this report. However, they have been restated here for the sake of the reader's convenience. In addition, it should be noted that not all of these needs are related directly to the western Montana region. Rather, the discussion to follow attempts to cover all areas that this research has indicated as being potentially fertile ground for future research efforts. Of course the discussion in this section is not intended as an exhaustive listing of research needs either for the general problem of modeling economic-ecologic linkages or for the more specific problem of modeling these linkages in the study region.

## The State of the Art

The literature surveyed in the course of this study has indicated that conceptual development of economic-ecologic linkage models has proceeded well beyond empirical application and testing of these models. Clearly, there is a need for more empirical research to help correct this deficiency. If such research is not undertaken in the very near future, it is likely that the rather elegant conceptual models already formulated will remain practically useless for decision-makers and analysts in natural resource management fields. In the absence of more explicit and detailed guidelines for implementation it will be very difficult, if not impossible, for these professionals to operationalize the various models to their advantage. Thus, while the more exciting, and perhaps professionally rewarding, research seems to be that directed toward further conceptual development and refinement of new as well as existing approaches to modeling economic-ecologic linkages, it appears as though the real pay-off in terms of useful information output will result from empirical research designed to operationalize existing formulations.

Literature also indicates the absence of research directed toward modeling forest-centered economic and ecologic systems with an integrated model in a regional context. This deficiency is not thought to be nearly as serious as that noted above since the conceptual models developed to date are quite general and can be applied in a variety of situations. However, it does indicate that the whole question of economic-ecologic modeling is not receiving much attention from forest scientists and managers. More of this type of research, particularly empirical efforts, is needed if management plans for the Nation's forests are to reflect consideration of off-forest economic and environmental impacts.

Literature reviewed in this study also revealed that, in general, current data systems (particularly at the substate, regional level) do not support the operation of many of the existing conceptual linkage models. As noted previously, data limitations are more severe for the environmental system than for the economic aspects. Research is needed to determine the feasibility (especially cost) of acquiring necessary data at appropriate levels of aggregation. This problem will be simplified somewhat as experience with empirical application of the various models accumulates and makes definition of data requirements more explicit. Of course, research directed toward the development of more adequate data systems is also very much needed.

The analysis described in this report attempted to evaluate the comparative advantages of several different types of models currently being used for representing economic and ecologic systems in an integrated fashion. However, resources allocated for this study had to be divided to enable pursuit of other research objectives in addition to the comparative evaluation. Thus this portion of the analysis was not comprehensive or detailed enough to provide a definitive statement of the relative attributes of the alternative models examined. Clearly, though, there is a real need for research which investigates this aspect of the linkage problem in greater depth. In particular, studies which apply the various models to a test problem and then provide quantitative analysis of the results of each application would be useful. Also, more information is needed concerning what was labeled here as the hybrid type of linkage model. It is important that a more detailed evaluation of the large variety of possible approaches included in this group be undertaken, if a truly complete statement of relative utility is to be produced.

## The Ideal Conceptual Model

A portion of this study was devoted to the development of a conceptual model which was to be ideal in the sense that the development was not constrained by consideration of realistic data or resource limitations. As noted previously, it is felt that while the conceptual model developed here is quite general (especially the environmental simulation portion), it is adequate for the purpose for which it was intended. However, it is clear that considerably more refinement is necessary before the entire conceptual model can be seriously considered for implementation in a specific regional context. Thus one very essential research need, identified during the course of this study, is the further refinement and more detailed description of the ideal conceptual model outlined in this report. This research should also include an attempt to define, more precisely, data requirements for operating the ideal model, particularly those requirements associated with the environmental portion of the model.

### The Western Montana Region

The research completed here has indicated that a really complete statement of the goals and objectives for using an economic-ecologic linkage model in the western Montana region is absent. While this may not define a research need, per se, it does represent a significant information deficiency. Such a statement is essential if the many approaches to modeling these linkages are to be evaluated for potential application in the region. If the goals and objectives are left vague then the possibility exists that a more elaborate, and hence costly, model will be implemented when, in fact, a simpler approach would have provided adequate information. Conversely, under the same circumstance the potential exists for spending time, money, and effort in implementing a linkage model in the region, only to discover that the model does not provide adequate information to solve problems confronting the user.

One very obvious research need, alluded to in earlier sections of this report, concerns the lack of data necessary for operating an economic-ecologic linkage model in western Montana. Indeed, this research appears to indicate that the region's secondary data base is not adequate for fully implementing even the less elaborate modeling approaches. Thus , the model suggested for implementation as a result of this research can be operationalized only partially because of incomplete data. In addition, much of the data used for this purpose does not relate specifically to western Montana but, rather, to the State as a whole or to other regions for which similar studies have been done.

In general, this deficiency can be corrected only when studies are initiated to provide more adequate data for the region. Research needs here include: 1) estimating technical coefficients and final demand values associated with the economic sectors of the western Montana region (preferably, these estimates should be for as recent a time period as is possible); 2) estimating environmental coefficients necessary to fully operationalize the environmental matrix associated with the linkage model (estimates should be based on the most recent data available; and these data should be related specifically to the region whenever possible); and 3) estimating the parameters necessary for the operation of an environmental simulation submodel similar to that proposed in an earlier section of this report. Clearly, some of this research cannot be undertaken until a more detailed definition of data requirements associated with certain portions of the model is available. However, it is felt that this report does contain adequate guidelines for identifying many of the essential data requirements associated with the model.

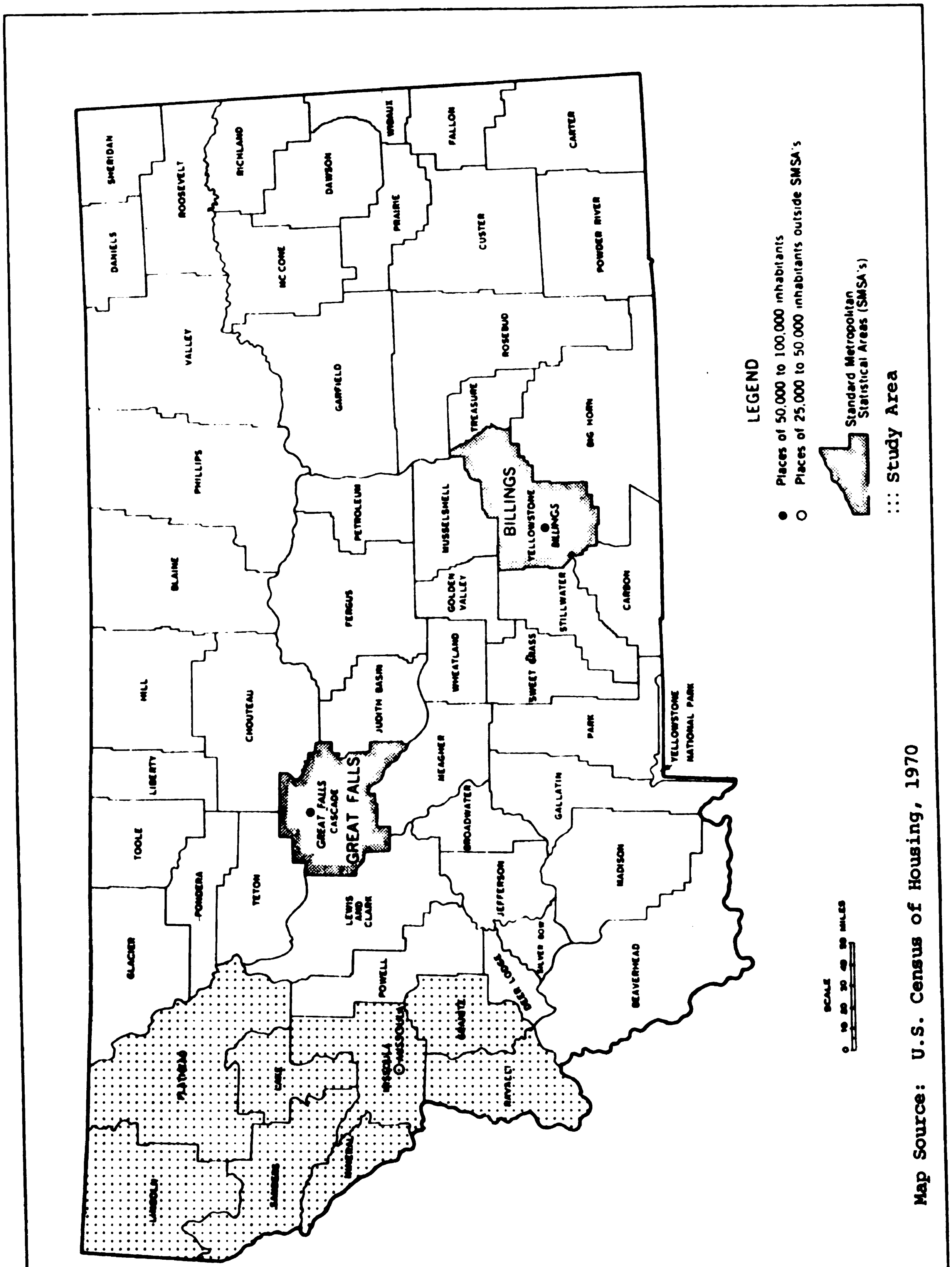
Finally, it would be most gratifying if the results of this research were found to be useful to resource managers and research personnel concerned with a variety of problems in the western Montana region. It is hoped that the feasible linkage model discussed in the fifth chapter can be operationalized in the region in the near future. At the very least, this entire study will have been somewhat successful if the discussion in this report promotes additional thought and investigation on the part of decision-makers into the very critical problem areas identified here.

# APPENDICES

# APPENDIX A

## MAP OF THE STUDY REGION

# APPENDIX A


LEGEND
Places of 50,000 to 100,000 inhabitants
Places of 25,000 to 50,000 inhabitants outside SMSA's
Standard Metropolitan Statistical Areas (SMSA's)
Study Area
SCALE
0 10 20 30 40 50 MILES
Map Source: U.S. Census of Housing, 1970
GREAT FALLS
CASCADE
BILLINGS
YELLOWSTONE
MISSOULA
SHERIDAN
DANIELS
ROOSEVELT
RICHLAND
DAWSON
WIBAUX
FALLON
CARTER
PRAIRIE
McCONE
CUSTER
POWDER RIVER
VALLEY
GARFIELD
ROSEBUD
TREASURE
BIG HORN
PHILLIPS
PETROLEUM
MUSSELSHELL
BLAINE
FERGUS
GOLDEN VALLEY
STILLWATER
CARBON
HILL
CHOUTEAU
JUDITH BASIN
WHEATLAND
SWEET GRASS
YELLOWSTONE NATIONAL PARK
PARK
LIBERTY
MEAGHER
GALLATIN
TOOLE
BROADWATER
PONDERA
TETON
LEWIS AND CLARK
JEFFERSON
MADISON
GLACIER
SILVER BOW
BEAVERHEAD
POWELL
DEER LODGE
GRANITE
FLATHEAD
LAKE
RAVALLI
MINERAL
SANDERS
LINCOLN

# APPENDIX B

# DESCRIPTION OF THE STUDY REGION

# APPENDIX B

The description contained in this appendix is quite brief and is intended only as a general discussion of some major features of the economic and environmental systems of western Montana. The description is organized into three sections. These sections are: 1) the economic system of western Montana, 2) the physical setting, and 3) western Montana's forest resource. The discussion of the region's economic system includes the following topical headings: 1) economic growth in western Montana, and 2) the structure of the western Montana economy. The region's physical setting is described under the following subheadings: 1) climate, 2) topography, 3) hydrographic features, 4) soils, and 5) flora and fauna. The description of western Montana's forest resource incorporates these topics: 1) the forest land area and ownership pattern, 2) the timber resource, 3) the recreation resource, 4) the range resource, 5) the wildlife resource, 6) the mineral resource, and 7) the timber economy.

## The Economic System of Western Montana

Two outstanding features appear to distinguish the western Montana economy from the State economy in general. The first of these involves the rate of growth in several important economic indicators, while the second feature has to do with the structure of the regional economy.

Economic Growth in Western Montana

Johnson has noted that on a ". . . geographic basis, western Montana has posted the best record in the State in terms of economic growth."[1] From 1950 to 1970 the combined population of the eight western counties has increased by 38 percent, while for the same time period the State population increased by only 17 percent or less than half of the growth rate for the region.[2] The population growth differential has been even more pronounced over the last decade (i.e., 1960 to 1970), with the regional population increasing by 22.5 percent and the State recording a 2.9 percent increase.[3] Table B.1 provides a summary of population statistics for each of the eight western Montana counties in addition to both regional and State figures.

To some extent, population growth in the region reflects an increase in job opportunities. Johnson reports that total civilian employment for the State was 228,500 in 1950 and 236,900 in 1960, while for the western Montana region total civilian employment in 1950 was 42,760 and in 1960 it had increased to 43,270.[4] Civilian employment figures reported by the Bureau of the Census for 1970 show total State employment at 260,649 and total regional employ-

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[1]Johnson, loc. cit., p. 18 [2]Johnson, loc. cit.

[3]U.S. Department of Commerce, Bureau of the Census, County and City Data Book, 1972 (Washington: U.S. Government Printing Office, 1973), Table 2, Counties, pp. 282-305, and Appendix B, Table B-1, p. 829.

[4]Johnson, loc. cit., p. 19.

TABLE B.1

LAND AREA AND POPULATION: COUNTIES, REGION, AND STATE, 1970[a]

| Areal Unit | Land Area Sq. Mi. | Population | Per Square Mile | Population Change 1960-1970 (%) | Net Migration 1960-1970 (%) |
|---|---|---|---|---|---|
| Flathead | 5,137 | 39,460 | 8 | 19.7 | 10.0 |
| Granite | 1,733 | 2,737 | 2 | -9.2 | -15.2 |
| Lake | 1,494 | 14,445 | 10 | 10.2 | 1.7 |
| Lincoln | 3,714 | 18,063 | 5 | 44.1 | 26.1 |
| Mineral | 1,222 | 2,958 | 2 | -2.6 | -13.8 |
| Missoula | 2,612 | 58,263 | 22 | 30.5 | 14.9 |
| Ravalli | 2,382 | 14,409 | 6 | 16.8 | 13.2 |
| Sanders | 2,778 | 7,093 | 3 | 3.1 | -3.3 |
| Region | 21,072 | 157,428 | 7.5 | 22.5 | 10.9 |
| State | 145,587 | 694,409 | 5 | 2.9 | -8.6 |

[a]Values for individual counties and state totals taken from: U.S. Department of Commerce, Bureau of the Census, <u>County and City Data Book, 1972</u> (Washington: U.S. Government Printing Office, 1973), Table 2, Counties, pp. 282-305, and Appendix B, Table B-1, p. 829. Values for the western Montana region calculated from individual county figures.

ment at 58,191.[5] Thus for the entire period, 1950 to 1970, civilian employment in the State increased by 14.1 percent and in the region by 36.1 percent. As in the case of population growth, the employment growth differential between the State and region was even larger during the period 1960 to 1970 than for the entire 20-year period. During this period civilian employment in the State increased by 10 percent while the regional increase amounted to 30.7 percent. Table B.2 summarizes the 1970 employment picture for the eight counties, the region and the State.

Statistics also show that western Montana has experienced income growth at a faster rate than for the State as a whole. Johnson reports that between 1950 and 1969, real income from participation in the labor force (in dollars of 1958 purchasing power) increased 75 percent in western Montana, while total income, which includes property income and transfer payments, was 93 percent higher in 1969 than in 1950.[6] Figure B.1 illustrates how these rates compare with the State experience.

Per capita personal income for western Montanans has also increased more rapidly than has the statewide average. According to Johnson, per capita incomes increased 42 percent in the region and 30 percent in the State from 1950 to 1968.[7] However, despite these relative gains the per cap-

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[5] U.S. Department of Commerce, Bureau of the Census, op. cit., Table 2, pp. 282-305.

[6] Johnson, loc. cit., p. 20. [7] Johnson, loc. cit., p.11.

TABLE B.2

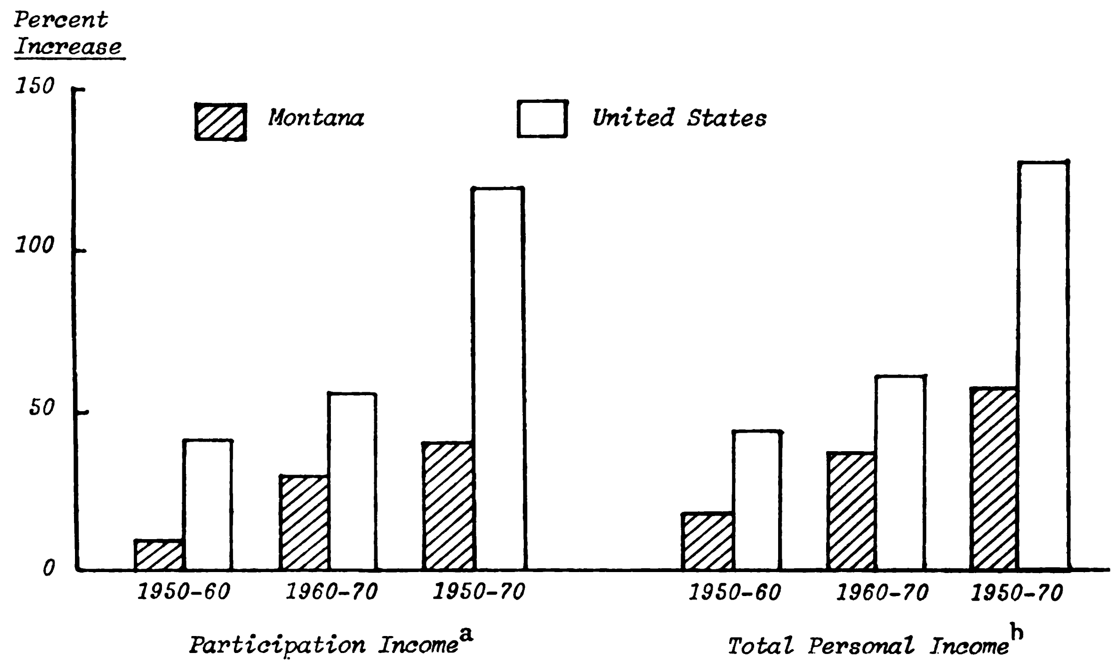
EMPLOYMENT: COUNTIES, REGION, AND STATE, 1970[a]

| Areal Unit | Civilian Labor Force 16 and over | Unemployed | Manufacturing | Wholesale & Retail Trade | Services | Educational Services | Construction |
|---|---|---|---|---|---|---|---|
| | | (%) | (%) | (%) | (%) | (%) | (%) |
| Flathead | 13,613 | 9.8 | 23.0 | 23.4 | 7.4 | 7.2 | 7.6 |
| Granite | 999 | 5.1 | 19.4 | 8.5 | 6.6 | 7.2 | 14.9 |
| Lake | 4,821 | 6.5 | 12.1 | 20.1 | 7.6 | 9.5 | 4.8 |
| Lincoln | 6,697 | 10.3 | 27.8 | 15.6 | 5.4 | 6.9 | 20.5 |
| Mineral | 1,216 | 13.9 | 24.7 | 15.0 | 5.5 | 17.4 | 7.7 |
| Missoula | 23,104 | 7.6 | 12.1 | 24.0 | 8.2 | 16.2 | 6.0 |
| Ravalli | 5,261 | 7.9 | 13.0 | 19.0 | 7.0 | 8.5 | 5.1 |
| Sanders | 2,480 | 11.9 | 21.6 | 20.5 | 7.0 | 10.3 | 4.9 |
| Region | 58,191 | 8.6 | 17.3 | 21.5 | 7.4 | 11.4 | 8.0 |
| State | 260,649 | 6.2 | 9.7 | 22.3 | 7.3 | 10.2 | 6.4 |

[a]Values for individual counties and state totals taken from: U.S. Department of Commerce, Bureau of the Census, County and City Data Book, 1972 (Washington: U.S. Government Printing Office, 1973), Table 2, Counties, pp. 282-305. Values for the western Montana region calculated from individual county figures.

TABLE B.2 (cont'd.)

| Areal Unit | Government | White Collar Workers | | Craftsmen and Foremen |
|---|---|---|---|---|
| | | Professional, Managerial | Sales and Clerical | |
| | (%) | (%) | (%) | (%) |
| Flathead | 15.8 | 23.5 | 19.7 | 17.0 |
| Granite | 21.1 | 16.5 | 11.4 | 14.0 |
| Lake | 18.9 | 22.2 | 15.8 | 10.5 |
| Lincoln | 15.3 | 20.8 | 13.4 | 20.1 |
| Mineral | 31.7 | 22.1 | 13.5 | 11.7 |
| Missoula | 24.4 | 29.0 | 23.4 | 13.2 |
| Ravalli | 23.0 | 26.4 | 12.4 | 12.0 |
| Sanders | 25.4 | 21.6 | 14.7 | 13.1 |
| Region | 20.9 | 25.3 | 19.0 | 14.5 |
| State | 20.8 | 24.5 | 20.8 | 12.7 |




[a]Total earnings of labor force participants; includes wages and salaries, fringe benefits, and the income of proprietors of unincorporated businesses.
[b]Includes participation income, property income (rent, dividends, and interest), and transfer payments (payments for which no current services are rendered in return, such as retirement pensions, veterans' payments, and welfare).

Figure B.1.--Income Growth in Montana and Eight Western Counties, 1950-1969, Measured in 1958 Dollars

Source: Maxine C. Johnson, "Wood Products in Montana: A Special Report on the Industry's Impact on Montana's Income and Employment," Montana Business Quarterly, Vol. 10, No. 2 (1972), p. 17.

ita income of western Montana residents has been consistently below the average for the State. Regional per capita income (measure in 1958 dollars) in 1950 was $1,640 or only 84 percent of the statewide average.[8] In 1959, the regional figure had risen to $1,852 which was 93 percent of the statewide average,[9] and by 1969 it had climbed to $2,314 which amounted to 91 percent of this average.[10] The Montana Economic Study points to very low agricultural incomes as a partial explanation for why "Montana's most dynamic region" has had such a low per capita income figure:[11] while Johnson has noted the high percentage of unemployment in the region (8.6 percent in 1970 as compared to 6.2 percent for the State as a whole[12]) and suggests that this may also be a contributing factor.[13] It is also possible that a high rate of seasonal unemployment, normally associated with forest and recreation industries, was another factor in the region's low per capita income figure. A summary of income statistics for the counties, region, and State is provided in Table B.3.

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[8] Bureau of Business and Economic Research, op. cit., Part I, Vol. 3, Chapter 5, p. 11.

[9] Bureau of Business and Economic Research, loc. cit.

[10] Johnson, loc. cit., p. 21.

[11] Bureau of Business and Economic Research, op. cit., Part I, Vol. 3, Chapter 5, p. 12.

[12] U.S. Dept. of Commerce, Bureau of the Census, loc. cit.

[13] Johnson, loc. cit., p. 20.

TABLE B.3

INCOME: COUNTIES, REGION, AND STATE, 1969[a]

| Areal Unit | Families 1970 | Families with Income in 1969 (%) Less than $3,000 | $3,000 to $4,999 | $5,000 to $6,999 | $7,000 to $9,999 | $10,000 to $14,999 | $15,000 or $24,999 | $25,000 or more | Median Family Income ($) | Per Capita Money Income ($) |
|---|---|---|---|---|---|---|---|---|---|---|
| Flathead | 10,020 | 10.9 | 9.7 | 14.7 | 28.3 | 24.8 | 9.2 | 2.4 | 8,567 | 2,558 |
| Granite | 745 | 9.9 | 17.0 | 22.0 | 25.4 | 19.9 | 3.9 | 1.9 | 7,123 | 2,500 |
| Lake | 3,668 | 17.1 | 16.3 | 18.7 | 21.0 | 18.8 | 6.8 | 1.3 | 6,786 | 2,165 |
| Lincoln | 4,596 | 6.0 | 7.0 | 11.8 | 28.0 | 33.2 | 11.2 | 2.9 | 9,711 | 2,814 |
| Mineral | 789 | 9.4 | 9.0 | 13.7 | 32.9 | 24.6 | 9.3 | 1.1 | 8,491 | 2,489 |
| Missoula | 14,288 | 9.6 | 9.5 | 13.6 | 24.8 | 26.0 | 13.2 | 3.3 | 9,052 | 2,940 |
| Ravalli | 3,795 | 16.3 | 18.0 | 14.7 | 20.7 | 21.7 | 6.9 | 1.7 | 7,135 | 2,314 |
| Sanders | 1,832 | 13.1 | 11.5 | 16.6 | 28.3 | 19.9 | 8.0 | 2.6 | 7,839 | 2,449 |
| Region | 39,733 | 11.0 | 10.9 | 14.5 | 25.6 | 25.0 | 10.3 | 2.6 | (I)[b] | 2,663 |
| State | 171,812 | 10.5 | 11.5 | 15.1 | 24.5 | 24.8 | 10.7 | 2.9 | 8,509 | 2,696 |

[a]Values for individual counties and state totals taken from: U.S. Department of Commerce, Bureau of the Census, County and City Data Book, 1972 (Washington: U.S. Government Printing Office, 1973), Table 2, Counties, pp. 282-305. Values for the western Montana region calculated from individual county figures.

[b]I - Insufficient information. Census does not provide sufficient information for calculating this value.

The Montana Economic Study has predicted that the growth in population, employment and income in western Montana will continue through the 1970's at higher rates than for the State as a whole; but at a slower rate than the region has experienced during the 1960's.[14] The Study has projected the 1980 population in the region to be 171,100 which would amount to a 12.6 percent increase over the 1968 regional population figure.[15] For the State, the projected population for 1980 would amount to only a 4 percent growth rate from 1968.[16] The Study's employment projection for the region calls for 65,450 jobs by 1980, an increase of 15.8 percent over the 1968 total.[17] The projected employment growth rate for the State over the same period is 9.4 percent.[18] In making the employment projections for the western Montana region, the Study assumed increases in manufacturing, mining, and federal government jobs; and expected these increases to offset an anticipated decline in agricultural and railroad employment, yielding a net increase of 4 percent in

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[14]Bureau of Business and Economic Research, op. cit., Part I, Vol. 3, Chapter 5, p. 14.

[15]Bureau of Business and Economic Research, op. cit., Part I, Vol. 3, Chapter 5, p. 15.

[16]Bureau of Business and Economic Research, op. cit., Part I, Vol. 1, Chapter 1, p. 21.

[17]Bureau of Business and Economic Research, op. cit., Part I, Vol. 3, Chapter 5, p. 14.

[18]Bureau of Business and Economic Research, op. cit., Vol. 1, Chapter 1, p. 21.

total primary employment.[19] The Study projects a 22.6 percent increase in derivative employment (i.e., nonrail transportation, communication, and utilities; contract construction; wholesale and retail trade, services, finance, insurance and real estate; and state and local government) which when combined with the growth in primary employment yields the 15.8 percent increase in total civilian employment.[20] The Study projects total personal income for the region in 1980 of $541 million and per capita personal income of $3,164 (both in 1958 dollars).[21] For total personal income, this amounts to an average annual rate of increase of 4.2 percent from 1966 to 1980, and for per capita income the average annual rate over the same period would be 2.9 percent.[22] For the State, the Study projects total personal income to increase at an average annual rate of 2.6 percent and per capita income at the rate of 2.4 percent from 1966 to 1980.[23] Clearly, then, regional income is predicted to grow at a faster rate than is income for the State as a whole. It is interesting to note, however, that despite the fact

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[19] Bureau of Business and Economic Research, op. cit., Part I, Vol. 3, Chapter 5, p. 14.

[20] Bureau of Business and Economic Research, op. cit., Part I, Vol. 3, Chapter 5, p. 17.

[21] Bureau of Business and Economic Research, loc. cit.

[22] Bureau of Business and Economic Research, op. cit., Part I, Vol. 3, Chapter 5, p. 18.

[23] Bureau of Business and Economic Research, loc. cit.

that the region's per capita income is projected to rise faster than the statewide average through 1980, it would still be 5 percent below the predicted statewide average in that year.[24]

## The Structure of the Western Montana Economy

Western Montana has been described as:

> . . . the most diverse of the six regions. Among other things, it embraces large irrigated valleys, lumber operations on the west slope of the Rockies, and aluminum reduction facilities in Columbia Falls. It contains much of the state's most attractive recreational land and water, and does a heavy tourist business.[25]

However, despite this diversity, the regional economy is not without a dominant emphasis or focus. In western Montana, unlike the other economic regions in the State, the emphasis is on manufacturing, particularly the wood products industry. Indeed, though the region accounts for only 14.5 percent of the land area and 22.7 percent of the population of the State,[26] western Montana provides 39.8 percent of the State's employment in manufacturing for the civilian labor force.[27]

Between 1950 and 1968, according to the Montana Economic Study, the western Montana region underwent a transformation that saw manufacturing replace agriculture as the

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[24] Bureau of Business and Economic Research, op. cit., Part I, Vol. 3, Chapter 5, p. 17.

[25] Bureau of Business and Economic Research, op. cit., Part I, Vol. 3, Chapter 5, p. 3.

[26] Computed from data in Table B.1, supra, p. 268.

[27] Computed from data in Table B.2, supra, pp. 270-271.

dominant industry.[28] During this transition, the decade from 1950 to 1960 saw employment in agriculture decrease by nearly 40 percent,[29] while employment in the railroad industry declined approximately 37 percent and federal government employment dropped 4 percent over the same period.[30] During this period, manufacturing employment in western Montana increased from 6,200 in 1950 to 7,900 in 1960 (i.e., a 27 percent increase),[31] with the increase in the lumber, wood products and paper industries amounting to approximately 35 percent.[32] In addition, the decade of the 1950's saw employment in western Montana's mining industry increase by 23 percent.[33] The combined influence of these trends resulted in an 11 percent decrease in total primary employment in the region from 1950 to 1960. The decrease in primary employment was just offset by employment increases in the derivative industries totaling 11 percent.[34] This resulted in a 1 percent net increase in total civilian employment in western Montana from 1950 to 1960.[35] By 1960, employment in the lumber, wood products and paper industries accounted for 82.4 percent of all manufacturing jobs in the

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[28]Bureau of Business and Economic Research, op. cit., Part I, Vol. 3, Chapter 5, p. 9.

[29]Bureau of Business and Economic Research, loc. cit.

[30]Johnson, loc. cit., p. 19.

[31]Bureau of Business and Economic Research, op. cit., Part I, Vol. 3, Chapter 5, p. 11.

[32]Johnson, loc. cit. [33]Johnson, loc. cit.

[34]Johnson, loc. cit. [35]Johnson, loc. cit.

region.[36] Clearly, the growth in these industries salvaged what could have been a disasterous ten years for western Montana.

During the 1960's, the declines in agricultural and railroad employment continued, but at a slower rate. Between 1960 and 1968, agricultural employment declined by approximately 15 percent while employment in the railroad industry dropped 22 percent over the same period.[37] During this period, employment in manufacturing went from 7,900 in 1960 to 11,600 in 1968.[38] This represents a 46.8 percent increase. During this same period, employment in the lumber, wood products and paper industries increased approximately 28 percent to 8,300.[39] The 1960's also saw a large increase in Federal government employment (an increase of 56 percent from 1960 to 1968), and in manufacturing employment other than lumber, wood products and paper (136 percent increase).[40] These trends combined to produce a 23 percent increase in total primary employment which when combined with a 36 percent increase in derivative employment resulted in a net increase in total civilian employment of 31 percent for western Montana from 1960 to 1968.[41]

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[36] Computed from data in, Johnson, loc. cit.

[37] Johnson, loc. cit.

[38] Bureau of Business and Economic Research, loc. cit.

[39] Johnson, loc. cit. [40] Johnson, loc. cit.

[41] Johnson, loc. cit.

Thus by 1968, the transition from a primarily agricultural economy to one emphasizing manufacturing was essentially complete. Over the entire period, 1950 to 1968, employment in manufacturing had increased by 88 percent, with the increase in the lumber, wood products, and paper industries totaling 73 percent and the growth in all other manufacturing industries amounting to 141 percent.[42] During this period, employment in agriculture declined 47 percent and employment in the railroad industry declined 51 percent.[43] In addition, employment in federal government agencies in the region increased a total of 49 percent.[44] The net increase in total civilian employment for the region from 1950 to 1960 amounted to a healthy 32 percent.[45] The impressive record of economic growth in western Montana has been attributed to this transformation to a manufacturing economy, and, in particular, to the rise of forest industries in that part of the State.[46] With the exception of the dominance of manufacturing and relative unimportance of agriculture, the structure of the western Montana economy is quite similar to that of the State as a whole. Tables B.4-B.9 provide a summary of certain aspects of the structure of the regional economy based on Bureau of the Census statistics.

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[42]Johnson, _loc. cit._ [43]Johnson, _loc. cit._

[44]Johnson, _loc. cit._ [45]Johnson, _loc. cit._

[46]Johnson, _loc. cit._, p. 11.

TABLE B.4

LOCAL GOVERNMENT FINANCES: COUNTIES, REGION, AND STATE, 1967[a]

| Areal Unit | Revenue | | | | Direct General Expenditure | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | Inter-Govern- | Taxes | | Total | Edu-ca-tion | High-ways | Public Wel-fare | Health and Hospit-als |
| | | | Total | Pro-perty per Capita | | | | | |
| | (mil. dol.) | (%) | (%) | ($) | (mil. dol.) | (%) | (%) | (%) | (%) |
| Flathead | 7.7 | 29.8 | 58.5 | 119 | 9.5 | 70.0 | 6.5 | 2.5 | .6 |
| Granite | .8 | 11.4 | 71.2 | 184 | .7 | 48.8 | 12.6 | 1.3 | 10.0 |
| Lake | 3.5 | 27.4 | 60.2 | 139 | 3.5 | 63.2 | 9.9 | 6.5 | .5 |
| Lincoln | 3.6 | 37.6 | 53.6 | 131 | 3.5 | 69.0 | 9.4 | 2.2 | .1 |
| Mineral | 1.0 | 28.0 | 59.5 | 168 | .9 | 61.6 | 9.8 | 4.1 | 9.0 |
| Missoula | 12.0 | 20.8 | 66.0 | 135 | 13.3 | 62.7 | 8.8 | 3.5 | .7 |
| Ravalli | 2.8 | 29.4 | 61.6 | 115 | 2.7 | 61.5 | 8.7 | 2.3 | .8 |
| Sanders | 2.3 | 10.8 | 78.7 | 258 | 1.9 | 57.5 | 13.8 | 2.8 | 7.3 |
| Region | 33.7 | 25.2 | 62.8 | 156 | 36.0 | 64.6 | 8.7 | 3.2 | 1.3 |
| State | 185.9 | 20.2 | 64.5 | 163 | 180.9 | 56.4 | 9.9 | 2.4 | 3.3 |

[a]Values for individual counties and state totals taken from: U.S. Department of Commerce, Bureau of the Census, County and City Data Book, 1972 (Washington: U.S. Government Printing Office, 1973), Table 2, Counties, pp. 282-305. Values for the western Montana region calculated from individual county figures.

TABLE B.4 (cont'd.)

| Areal Unit | | General Debt Outstanding | Local Government Employment (Oct. 1967) | | Federal Government Employment (Dec. 1970) |
|---|---|---|---|---|---|
| | Per Capita (excluding capital outlay) | Total | Total Full-Time Equivalent | Payroll | |
| | ($) | (mil. dol.) | | (mil. dol.) | |
| Flathead | 200 | 7.1 | 915 | .5 | 493 |
| Granite | 219 | .2 | 111 | (z)[b] | 26 |
| Lake | 227 | .8 | 421 | .2 | 205 |
| Lincoln | 218 | 2.0 | 457 | .2 | 346 |
| Mineral | 265 | .5 | 129 | .1 | 57 |
| Missoula | 193 | 10.3 | 1,080 | .6 | 1,117 |
| Ravalli | 166 | 2.2 | 249 | .1 | 407 |
| Sanders | 264 | .4 | 249 | .1 | 129 |
| Region | 219 | 23.5 | 3,611 | 1.8 | 2,780 |
| State | 215 | 139.7 | 18,368 | 9.0 | 10,292 |

[b]Intergovernmental revenue covers receipts from other governments for fiscal aid or as reimbursement for performance of general services for the paying government. It excludes any amounts received from other governments for sale of property, commodities, and utility services.

TABLE B.5

MANUFACTURERS: COUNTIES, REGION, AND STATE, 1967[a]

| Areal Unit | Establishments | | | All Employees Payroll | Production Workers Wages | Value Added by Manufacture | |
|---|---|---|---|---|---|---|---|
| | Total | With 20-99 Employees | With 100 or more Employees | | | Total | Change 1963 to 1967 |
| | | (%) | (%) | (mil. dol.) | (mil. dol.) | (mil. dol.) | (%) |
| Flathead | 115 | 18.3 | 5.2 | 16.9 | 13.9 | 41.8 | 60.8 |
| Granite | 15 | 13.3 | 0.0 | .3 | .3 | .6 | 0.0 |
| Lake | 29 | 13.8 | 10.3 | 3.8 | 3.4 | 6.3 | 1.6 |
| Lincoln | 70 | 7.1 | 1.4 | 11.2 | 9.6 | 16.4 | 24.1 |
| Mineral | 7 | 0.0 | 14.3 | (D)[b] | (D)[b] | (D)[b] | (D)[b] |
| Missoula | 95 | 23.2 | 6.3 | 22.9 | 17.9 | 52.7 | 38.7 |
| Ravalli | 27 | 29.6 | 0.0 | 2.2 | 2.0 | 3.3 | 3.1 |
| Sanders | 31 | 9.7 | 6.5 | 3.1 | 2.8 | 4.9 | 6.5 |
| Region | 389 | 16.7 | 4.9 | 60.4 | 49.9 | 126.1 | 37.3 |
| State | 923 | 16.3 | 4.4 | 129.5 | 96.4 | 311.6 | 31.9 |

[a]Values for individual counties and state totals taken from: U.S. Department of Commerce, Bureau of the Census, County and City Data Book, 1972 (Washington: U.S. Government Printing Office, 1973), Table 2, Counties, pp. 282-305. Values for the western Montana region calculated from individual county figures. The regional change in value added by manufacture, 1963 to 1967 calculated using 1963 county value added figures from: U.S. Department of Commerce, Bureau of the Census, County and City Data Book, 1967 (Washington: U.S. Government Printing Office, 1967), Table 2, Counties, p. 226.

[b]D - Withheld to avoid disclosure.

TABLE B.6

RETAIL TRADE: COUNTIES, REGION, AND STATE, 1967[a]

| Areal Unit | Establishments | | Proprietors | Sales | | | Sales for all Establishments, by Kind of Business | |
|---|---|---|---|---|---|---|---|---|
| | Total | With Payroll[b] | | All Establishments | | Establishments with Payroll | Food Stores | Automotive Dealers |
| | | | | Total | Change 1963-1967 | | | |
| | | (%) | | ($1000) | (%) | (%) | Percent of Total Sales for all Establishments | |
| Flathead | 410 | 76.1 | 402 | 64,293 | 29.5 | 96.4 | 26.4 | 20.4 |
| Granite | 45 | 75.6 | 53 | 2,916 | -24.1 | 85.3 | 31.2 | (D)[c] |
| Lake | 170 | 79.4 | 163 | 19,830 | 51.4 | 95.1 | 20.3 | 23.8 |
| Lincoln | 165 | 73.3 | 165 | 20,840 | 70.2 | 93.8 | 28.5 | 19.0 |
| Mineral | 39 | 79.5 | 40 | 2,646 | -17.5 | 91.5 | 20.0 | (D)[c] |
| Missoula | 490 | 75.1 | 449 | 107,495 | 36.2 | 96.3 | 21.2 | 23.9 |
| Ravalli | 153 | 76.5 | 152 | 16,362 | 28.0 | 96.7 | 29.6 | 24.1 |
| Sanders | 79 | 74.7 | 78 | 5,295 | 6.8 | 92.2 | 14.4 | 17.4 |
| Region | 1,551 | 75.9 | 1,502 | 239,677 | 34.1 | 95.8 | 23.7 | 22.4 |
| State | 7,454 | 77.5 | 6,877 | 1,136,643 | 17.7 | 96.0 | 21.8 | 20.3 |

[a]Values for individual counties and state totals taken from: U.S. Department of Commerce, Bureau of the Census, County and City Data Book, 1972 (Washington: U.S. Government Printing Office, 1973), Table 2, Counties, pp. 282-305. Values for the western Montana region calculated from individual county figures. The regional change in sales for all establishments, 1963 to 1967 calculated using sales figures for counties, 1963, taken from: U.S. Department of Commerce, Bureau of the Census, County and City Data Book, 1967 (Washington: U.S. Government Printing Office, 1967), Table 2, Counties, p. 228.

TABLE B.6 (cont'd.)

| Areal Unit | Sales for All Establishments, by Kind of Business | | | | | | |
|---|---|---|---|---|---|---|---|
| | General Merchandise Stores | Eating and Drinking Places | Gasoline Service Stations | Furniture, Home Furnishings and Equipment Stores | Building Materials Hardware, Farm Equipment Dealers | Apparel and Accessory Stores | Drugstores and Proprietary Stores |
| | Percent of Total Sales for all Establishments | | | | | | |
| Flathead | 10.4 | 7.1 | 7.9 | 5.0 | 6.5 | 3.2 | 2.4 |
| Granite | 0.0 | 22.9 | 4.5 | (D)[c] | 6.2 | (D)[c] | 5.3 |
| Lake | 3.4 | 6.6 | 13.5 | (D)[c] | 11.9 | 2.7 | 3.9 |
| Lincoln | 3.2 | 10.8 | 9.3 | (D)[c] | 4.5 | 5.2 | 3.1 |
| Mineral | (D)[c] | 18.2 | 25.9 | 0.0 | 0.0 | 0.0 | (D)[c] |
| Missoula | 12.4 | 7.5 | 9.5 | 4.2 | 6.4 | 3.3 | 4.1 |
| Ravalli | 4.8 | 7.2 | 12.3 | 2.1 | 7.4 | 3.3 | (D)[c] |
| Sanders | 21.1 | 14.3 | 12.5 | 0.0 | (D)[c] | 0.0 | 4.4 |
| Region | 9.8 | 8.0 | 9.8 | 4.1 | 6.7 | 3.3 | 3.5 |
| State | 9.2 | 8.4 | 8.9 | 3.8 | 11.3 | 4.2 | 3.9 |

[b]Excludes establishments with no paid employees or, depending on the kind of business, with no more than 1-3 paid employees.

[c]Withheld to avoid disclosure.

TABLE B.7

**SELECTED SERVICES: COUNTIES, REGION, AND STATE, 1967**[a]

| Areal Unit | Establishments | | Receipts | | | Receipts, All Establishments | | |
|---|---|---|---|---|---|---|---|---|
| | Total | With Payroll | All Establishments | | Establishment with Payroll | Hotels, Motels, Camps | Automotive Repair and Services | Amusement, Recreation (including motion pictures) |
| | | | Total | Change 1963-1967 | | | | |
| | | (%) | ($1000) | (%) | (%) | (%) | (%) | (%) |
| Flathead | 286 | 45.5 | 7,103 | 19.4 | 85.9 | (NA)[b] | (NA)[b] | (NA)[b] |
| Granite | 24 | 33.3 | 185 | -46.2 | 47.6 | (NA)[b] | (NA)[b] | (NA)[b] |
| Lake | 81 | 38.3 | 1,147 | 11.7 | 74.5 | (NA)[b] | (NA)[b] | (NA)[b] |
| Lincoln | 98 | 46.9 | 2,051 | 85.8 | 75.7 | (NA)[b] | (NA)[b] | (NA)[b] |
| Mineral | 34 | 47.1 | 314 | 3.3 | 80.9 | (NA)[b] | (NA)[b] | (NA)[b] |
| Missoula | 348 | 50.6 | 11,714 | 21.6 | 90.9 | 29.6 | 23.1 | (D)[d] |
| Ravalli | 84 | 32.1 | 1,110 | 22.7 | 63.7 | (NA)[b] | (NA)[b] | (NA)[b] |
| Sanders | 58 | 27.6 | 845 | 74.6 | 75.3 | (NA)[b] | (NA)[b] | (NA)[b] |
| Region | 1,013 | 44.4 | 24,469 | 23.9 | 85.2 | (I)[c] | (I)[c] | (I)[c] |
| State | 4,204 | 49.2 | 111,320 | 10.9 | 86.5 | 29.1 | 14.6 | 11.1 |

[a]Values for individual counties and state totals taken from: U.S. Department of Commerce, Bureau of the Census, County and City Data Book, 1972 (Washington: U.S. Government Printing Office, 1973), Table 2, Counties, pp. 282-305. Values for the western Montana region calculated from individual county figures. The regional value for the 1963 to 1967 change in receipts for all establishments calculated using 1963 county receipt figures from: U.S. Department of Commerce, Bureau of the Census, County and City Data Book, 1967 (Washington: U.S. Government Printing Office, 1967), Table 2, Counties, p. 229.

[b]NA - Not available.

[c]I - Insufficient information. Census does not provide sufficient information for calculating this value.

[d]D - Withheld to avoid disclosure.

TABLE B.8

WHOLESALE TRADE AND MINERAL INDUSTRIES: COUNTIES, REGION, AND STATE, 1967[a]

| Areal | Wholesale Trade, 1967 | | | | Mineral Industries, 1967 | | | |
|---|---|---|---|---|---|---|---|---|
| | Establishments | Sales | | Payroll, Entire Year | Establishments | All Employees | | Value of Shipments and Receipts |
| | | Total | Merchant Whole salers | | | Number | Payroll | |
| | | ($1000) | (%) | ($1000) | | (1000) | (mil. dol.) | (mil. dol.) |
| Flathead | 62 | 29,312 | 67.7 | 2,020 | 3 | (NA)[c] | (NA)[c] | (NA)[c] |
| Granite | 5 | 498 | 0.0 | 37 | 8 | (D)[b] | (D)[b] | (D)[b] |
| Lake | 14 | 3,979 | 16.9 | 214 | 0 | 0.0 | 0.0 | 0.0 |
| Lincoln | 18 | 3,962 | 48.2 | 198 | 3 | (D)[b] | (D)[b] | (D)[b] |
| Mineral | 3 | (D)[b] | (D)[b] | (D)[b] | 0 | 0.0 | 0.0 | 0.0 |
| Missoula | 85 | 82,273 | 68.7 | 5,679 | 5 | (NA)[c] | (NA)[c] | (NA)[c] |
| Ravalli | 18 | 3,103 | 16.9 | 194 | 1 | (NA)[c] | (NA)[c] | (NA)[c] |
| Sanders | 10 | 3,172 | (D)[b] | 156 | 3 | (NA)[c] | (NA)[c] | (NA)[c] |
| Region | 215 | 126,299 | 64.6 | 8,498 | 23 | (I)[d] | (I)[d] | (I)[d] |
| State | 1,509 | 1,081,494 | 47.1 | 53,755 | 311 | 5.5 | 39.0 | 199.0 |

[a]Values for individual counties and state totals taken from: U.S. Department of Commerce, Bureau of the Census, County and City Data Book, 1972 (Washington: U.S. Government Printing Office, 1973), Table 2, Counties, pp. 282-305. Values for the western Montana region calculated from individual county figures.

[b]D - Withheld to avoid disclosure. [c]NA - Not available.

[d]I - Insufficient information. Census does not provide sufficient information for calculating this value.

TABLE B.9

AGRICULTURE: COUNTIES, REGION, AND STATE, 1969[a]

| Areal Unit | Farm Population, 1970 | | | Farms, 1969 | | Land in Farms, 1969 | | | Value of Land and Buildings | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Change 1960-1970 | Mediam Family Income in 1969 | Total | Change 1964-1969 | Total Acreage | Change 1964-1969 | Pro-portion of all land | Aver-age Value per Farm | Aver-age Value per Acre |
| | | (%) | ($) | | (%) | (1000 acres) | (%) | (%) | ($1000) | ($) |
| Flathead | 3,229 | -11.9 | 8,089 | 825 | -24.2 | 394 | -16.3 | 12.0 | 84 | 176 |
| Granite | 476 | -33.1 | 6,133 | 140 | -3.4 | 394 | 12.6 | 35.6 | 214 | 76 |
| Lake | 3,284 | -25.6 | 5,820 | 1,012 | -18.4 | 570 | 12.4 | 59.6 | 67 | 119 |
| Lincoln | 554 | -33.5 | 10,419 | 190 | -33.8 | 101 | -23.6 | 4.2 | 65 | 122 |
| Mineral | 171 | -10.9 | (B)[b] | 46 | -38.7 | 27 | -22.4 | 3.4 | 61 | 106 |
| Missoula | 787 | -49.3 | 9,722 | 327 | -24.1 | 339 | -12.8 | 20.3 | 124 | 120 |
| Ravalli | 2,667 | -30.0 | 6,840 | 860 | -16.6 | 298 | -19.2 | 19.5 | 72 | 207 |
| Sanders | 1,378 | -10.6 | 6,842 | 376 | -16.3 | 500 | 8.4 | 28.1 | 90 | 68 |
| Region | 12,546 | -25.0 | (I)[c] | 24,951 | -20.4 | 2,623 | -3.4 | 19.4 | 84 | 121 |
| State | 82,129 | -22.2 | 7,367 | 3,776 | -7.7 | 62,918 | -4.4 | 67.5 | 150 | 60 |

[a]Values for individual counties and state totals taken from: U.S. Department of Commerce, Bureau of the Census, County and City Data Book, 1972 (Washington: U.S. Government Printing Office, 1973), Table 2, Counties, pp. 282-305. Values for the western Montana region calculated from individual county figures. The value for percent change in farm population, 1960 to 1970, calculated using 1960 county farm population figures from: U.S. Department of Commerce, Bureau of the Census, 1960 Census of Population, Vol. 1,

TABLE B.9 (cont'd.)

| Areal Unit | Size of Farms | | | Farms with Sales of $2,500 and Over | | | | Farms with Sales Under $2,500 | |
|---|---|---|---|---|---|---|---|---|---|
| | Average | Farms Under 10 Acres | Farms 1,000 Acres and Over | Total | Operated by Corporations | With Sales $10,000-$39,000 | With Sales $40,000 and Over | Total | Part-time Farms |
| | (acres) | | | | (%) | (%) | (%) | | (%) |
| Flathead | 477 | 44 | 60 | 465 | 1.3 | 33.8 | 8.0 | 359 | 70.2 |
| Granite | 2,816 | 8 | 80 | 121 | 9.1 | 54.5 | 20.7 | 19 | 42.1 |
| Lake | 563 | 85 | 82 | 688 | .4 | 43.0 | 7.4 | 322 | 59.0 |
| Lincoln | 529 | 1 | 20 | 91 | 2.2 | 34.1 | 3.3 | 99 | 70.7 |
| Mineral | 579 | 1 | 7 | 23 | 4.3 | 39.1 | 0.0 | 23 | 87.0 |
| Missoula | 1,038 | 32 | 60 | 171 | 4.1 | 38.6 | 9.4 | 154 | 64.3 |
| Ravalli | 346 | 49 | 59 | 538 | 1.3 | 38.7 | 8.6 | 321 | 62.3 |
| Sanders | 1,331 | 4 | 86 | 255 | 3.1 | 39.2 | 3.9 | 120 | 68.3 |
| Region | 694 | 224 | 454 | 2,352 | 1.9 | 39.7 | 8.0 | 1,417 | 65.0 |
| State | 2,522 | 1,283 | 12,296 | 20,603 | 3.6 | 53.7 | 15.0 | 4,255 | 62.6 |

Part 28, Table 93, pp. 167-171. The regional change values for farms and land in farms calculated using 1964 county values from: U.S. Department of Commerce, Bureau of the Census, County and City Data Book, 1967 (Washington: U.S. Government Printing Office, 1967), Table 2, Counties, p. 230.

[b]B - Data not shown where number of families is less than 100.

[c]I - Insufficient information. Census does not provide sufficient information for calculating this value.

TABLE B.9 (cont'd.)

| Areal Unit | Value of Farm Products Sold by Farms with Sales of $2,500 and Over | | | | | | Farm Operators | |
|---|---|---|---|---|---|---|---|---|
| | Total | Average per Farm | Crops | Dairy Products | Livestock and Livestock Products | Poultry and Poultry Products | Residing on Farm Operated | Working 100 or More Days Off Farm |
| | ($1000) | ($) | (%) | (%) | (%) | (%) | (%) | (%) |
| Flathead | 8,359 | 17,976 | 24.2 | 10.3 | 61.6 | 1.0 | 82.9 | 50.4 |
| Granite | 3,330 | 27,522 | 6.5 | .2 | 91.9 | (Z) | 83.6 | 20.0 |
| Lake | 10,932 | 15,889 | 22.8 | 14.3 | 61.3 | 1.4 | 82.4 | 39.0 |
| Lincoln | 1,027 | 11,289 | 8.6 | .7 | 73.1 | 2.4 | 84.7 | 56.8 |
| Mineral | 195 | 8,466 | (D) | .4 | 63.2 | .5 | 76.1 | 60.9 |
| Missoula | 3,030 | 17,716 | 18.1 | 6.4 | 72.5 | .4 | 77.4 | 48.3 |
| Ravalli | 9,438 | 17,543 | 10.7 | 12.8 | 69.8 | 6.4 | 84.0 | 45.5 |
| Sanders | 3,341 | 13,101 | 12.9 | 1.0 | 81.5 | .2 | 85.9 | 51.9 |
| Region | 39,652 | 16,858 | 17.3 | 9.8 | 68.8 | 2.2 | 82.9 | 45.5 |
| State | 568,703 | 27,602 | 33.0 | 2.3 | 63.6 | .8 | 77.5 | 26.5 |

[d] D - Withheld to avoid disclosure.

[e] Z - Less than 0.05%.

## The Physical Setting

In contrast to the relatively large amount of readily available information about the regional economy of western Montana, great difficulty was experienced in locating and acquiring current information related to the physical environment of the region. It should be noted that much of the research described in this report supports the notion that environmental data related specifically to the western Montana region are almost entirely unavailable from secondary sources. It is felt that the brevity of this section reflects this very critical problem. However it is felt that the discussion presented below is sufficient to impart to the reader a general understanding of the major features of western Montana's physical setting.

The Continental Divide separates Montana into two physically distinct regions. The larger of the two regions lies east of the Divide. In this eastern portion, the weather is influenced by cool or cold dry air from northern Canada. West of the Divide, the weather is primarily influenced by moist Pacific maritime air masses. The result is an average January temperature below 20 degrees Fahrenheit in most of the eastern part of the State and around 20 degrees in nearly all of the western region.[47] In July, the effect is somewhat reversed. In the west, the cool Pacific air and generally higher elevations combine to moderate summer tem-

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[47] Bureau of Business and Economic Research, op. cit., Part I, Vol. 3, Chapter 8, p. 7.

peratures, while in the eastern region the influence of the dry continental air mass and lower elevations produces higher temperatures. In general then, the average temperatures for cities east of the Divide are significantly higher in summer and lower in winter than those for western cities.

The climate of Montana is generally dry with approximately half of the State receiving less than 15 inches of precipiation per year.[48] In general, the western region receives more moisture than the eastern part. This results because the western region is on the windward side of the mountains. Prevailing winds are from the west out of the warm, moist Pacific air mass. As air is forced to rise over the mountains, it cools and condensation occurs, causing a loss of moisture on the western slopes. By the time this air flows over the mountains into the eastern portion of the State, it has been essentially "squeezed" dry and the descent down the eastern slopes warms the air. The eastern region receives a larger part of its annual precipitation from summer thundershower activity, while precipitation in the west is more evenly distributed with winter snowfall accounting for a larger portion of the moisture received. Though snowfall can be quite heavy at exceptionally high elevations, the majority of the State falls in the 30 to

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[48] Bureau of Business and Economic Research, op. cit., Part I, Vol. 3, Chapter 8, p. 9.

60 inches of snow range.[49]

In general then, the climate in the western portion of the State (it should be noted that the study region lies wholly west of the Divide) is more moderate and significantly wetter than that of the eastern region. While these differences may appear small, they do have a significant impact on many other features that make up the physical setting of the study region.

## Climate[50]

The major climatic influences affecting western Montana have been noted above. However, it is felt that a more specific description of the results of these major influences in the region is useful. The National Weather Service maintains two first-order weather stations in the study region. One is located at Kalispell in central Flathead County. The other station is in Missoula which is located in central Missoula County. The location of the Kalispell station approximates the center of the northern half of the study region while the Missoula station is situated in the northern portion of the southern half of the region. Due to the general climatic similarity of the western portion of

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[49] Bureau of Business and Economic Research, loc. cit.

[50] Much of the discussion in this section was adapted from: U.S. Department of Commerce, Local Climatological Data: Annual Summary with Comparative Data, 1968, Kalispell, Montana (Washington: U.S. Government Printing Office, 1968); and Local Climatological Data: Annual Summary with Comparative Data, 1968, Missoula, Montana (Washington: U.S. Government Printing Office, 1968).

the State, it is felt that data from these two stations afford an adequate basis for describing the regional climate.

The Kalispell station in the Flathead Valley is approximately 40 miles west of the Continental Divide. The high mountains to the east of Kalispell form a barrier preventing many of the very severe winter cold waves that migrate down from Alberta, Canada, from spilling over into the area. These mountains rise steeply to elevations of 4,500 feet above the valley floor.[51] These elevations when combined with the snow remaining on the peaks until late spring are sufficient to assure frequent rains by cooling of moist maritime air moving from the west.

The influence of this moderate Pacific air mass limits temperature extremes in the area. Found within the valley are Flathead Lake, four smaller lakes, three rivers, and many streams.[52] Until late in winter when most of the smaller lakes become frozen over, this large water surface also helps to moderate temperature extremes. It has been noted that this effect is most noticeable in the southern end of the valley due to the stronger influence of huge Flathead Lake.[53] Because of its size, this lake seldom freezes.

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[51]U.S. Department of Commerce, Local Climatological Data: Kalispell, Montana, p. 1.

[52]U.S. Department of Commerce, Local Climatological Data: Kalispell, Montana, loc. cit.

[53]U.S. Department of Commerce, Local Climatological Data: Kalispell, Montana, loc. cit.

Table B.10 contains general climatic information (i.e., normals, means, and extremes associated with temperature, precipitation, wind, etc.) based on data collected for the Kalispell station. Table B.11 presents historical temperature and degree day data for the Kalispell station, while historical precipitation data for Kalispell are found in Table B.12. It is important to note that the station is located at the Flathead County Airport, approximately 8.5 miles northeast of Kalispell.[54] Weather in Kalispell is different in some respects from the weather at the airport. In general, there is more cloudiness at the airport since it is closer to the mountains lying east and north. This is another result, for the most part, of the moist air moving in from the west and southwest, lifting up the mountain slopes and cooling to form condensation. For the same reasons, there is, on average, more precipitation on the east side of the valley than on the west side. During the winter, average snowfall is 67 inches at the airport and 49.4 inches at Kalispell.[55]

Beginning in March and continuing through September, the prevailing wind from 11:00 a.m. until 7:00 p.m. is from the southeast.[56] This wind blows off Flathead Lake and is

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[54] U.S. Department of Commerce, Local Climatological Data: Kalispell, Montana, loc. cit.

[55] U.S. Department of Commerce, Local Climatological Data: Kalispell, Montana, loc. cit.

[56] U.S. Department of Commerce, Local Climatological Data: Kalispell, Montana, loc. cit.

# TABLE B.10

## CLIMATIC NORMALS, MEANS, AND EXTREMES: KALISPELL

Temperature and Normal degree days

| Month | Normal: Daily maximum | Normal: Daily minimum | Normal: Monthly | Extremes: Record highest | Year | Extremes: Record lowest | Year | Normal degree days |
|---|---|---|---|---|---|---|---|---|
| (a) | (b) | (b) | (b) | 9 | | 9 | | (b) |
| J | 27.6 | 12.0 | 19.8 | 50 | 1968 | -26 | 1963+ | 1401 |
| F | 34.0 | 14.9 | 24.5 | 56 | 1962 | -22 | 1960 | 1134 |
| M | 42.2 | 21.3 | 31.8 | 71 | 1966 | -29 | 1960 | 1029 |
| A | 56.5 | 30.9 | 43.7 | 81 | 1968 | 14 | 1968 | 639 |
| M | 66.4 | 37.9 | 52.2 | 89 | 1966 | 22 | 1963 | 397 |
| J | 72.5 | 44.7 | 58.6 | 93 | 1962+ | 30 | 1962 | 207 |
| J | 83.7 | 47.6 | 65.7 | 104 | 1960 | 32 | 1962 | 50 |
| A | 81.2 | 45.0 | 63.1 | 105 | 1961 | 31 | 1962 | 99 |
| S | 70.2 | 39.2 | 54.7 | 99 | 1967 | 23 | 1960 | 321 |
| O | 56.0 | 31.7 | 43.9 | 79 | 1960 | 18 | 1966+ | 654 |
| N | 39.3 | 22.7 | 31.0 | 64 | 1959 | -28 | 1959 | 1020 |
| D | 31.2 | 18.7 | 25.0 | 54 | 1965 | -35 | 1968 | 1240 |
| YR | 55.1 | 30.6 | 42.8 | 105 | AUG. 1961 | -35 | DEC. 1968 | 8191 |

Precipitation

| Month | Normal total | Maximum monthly | Year | Minimum monthly | Year | Maximum in 24 hrs. | Year | Snow, Sleet: Mean total | Snow, Sleet: Maximum monthly | Year | Snow, Sleet: Maximum in 24 hrs. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (a) | (b) | 19 | | 19 | | 19 | | 19 | 19 | | 19 | |
| J | 1.37 | 2.74 | 1954 | 0.75 | 1961 | 0.75 | 1950 | 18.4 | 32.8 | 1954 | 10.9 | 1950 |
| F | 1.00 | 1.93 | 1958 | 0.42 | 1967 | 0.65 | 1961 | 11.1 | 20.6 | 1958 | 7.2 | 1951 |
| M | 0.96 | 1.87 | 1950 | 0.31 | 1965 | 0.72 | 1950 | 6.1 | 13.3 | 1964 | 7.6 | 1953 |
| A | 1.04 | 2.04 | 1951 | 0.26 | 1968 | 1.74 | 1951 | 2.4 | 8.1 | 1961 | 10.0 | 1951 |
| M | 1.67 | 3.34 | 1960 | 0.43 | 1950 | 1.47 | 1964 | 1.3 | 8.9 | 1964 | 7.5 | 1964 |
| J | 2.21 | 4.72 | 1966 | 0.62 | 1960 | 2.35 | 1966 | T | 0.3 | 1962 | 0.3 | 1962 |
| J | 1.04 | 2.74 | 1950 | 0.02 | 1953 | 1.19 | 1954 | 0.0 | 0.0 | | 0.0 | |
| A | 1.09 | 3.47 | 1965 | T | 1955 | 1.38 | 1968 | 0.0 | 0.0 | | 0.0 | |
| S | 1.04 | 3.84 | 1959 | 0.12 | 1952 | 1.25 | 1959 | 0.2 | 3.1 | 1968 | 3.0 | 1968 |
| O | 1.24 | 2.96 | 1951 | 0.04 | 1953 | 0.78 | 1957 | 1.1 | 9.9 | 1951 | 6.2 | 1951 |
| N | 1.43 | 4.44 | 1959 | 0.55 | 1956 | 0.95 | 1959 | 8.9 | 39.0 | 1959 | 10.1 | 1959 |
| D | 1.33 | 4.23 | 1964 | 0.32 | 1954 | 1.35 | 1964 | 17.0 | 49.7 | 1951 | 15.4 | 1951 |
| YR | 15.42 | 4.72 | JUN. 1966 | T | AUG. 1955 | 2.35 | JUN. 1966 | 66.5 | 49.7 | DEC. 1951 | 15.4 | DEC. 1951 |

Relative humidity, Wind & and Mean number of days

| Month | Relative humidity: 5 AM | 11 AM | 5 PM | 11 PM (Standard time used: MOUNTAIN) | Wind: Mean hourly speed | Fastest mile: Speed | Fastest mile: Direction | Fastest mile: Year | Mean sky cover sunrise to sunset | Sunrise to sunset: Clear | Partly cloudy | Cloudy | Precipitation .01 inch or more | Snow, Sleet 1.0 inch or more | % Thunderstorms | % Heavy fog | Temperatures Max.: 90 and above | Max.: 32 and below | Min.: 32 and below | Min.: 0 and below |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (a) | 4 | 9 | 4 | 3 | 6 | 2 | 2 | | 19 | 19 | 19 | 19 | 19 | 19 | 18 | 8 | 9 | 9 | 9 | 9 |
| J | 85 | 83 | 80 | 85 | 7.1 | 37 | 02 | 1968+ | 8.7 | 2 | 4 | 25 | 16 | 6 | 0 | 5 | 0 | 17 | 30 | 6 |
| F | 85 | 81 | 73 | 83 | 6.9 | 40 | 01 | 1965 | 8.3 | 2 | 5 | 21 | 12 | 4 | * | 5 | 0 | 8 | 26 | 3 |
| M | 79 | 66 | 54 | 76 | 8.0 | 40 | 02 | 1965 | 7.8 | 3 | 7 | 21 | 11 | 2 | * | 2 | 0 | 5 | 28 | 2 |
| A | 77 | 53 | 45 | 69 | 8.7 | 35 | 19 | 1968+ | 7.4 | 4 | 6 | 20 | 9 | 1 | 1 | 0 | 0 | 0 | 21 | 0 |
| M | 78 | 51 | 42 | 67 | 7.9 | 40 | 23 | 1965 | 6.7 | 6 | 9 | 16 | 11 | * | 3 | 1 | 0 | 0 | 8 | 0 |
| J | 84 | 52 | 48 | 75 | 7.4 | 36 | 01 | 1965 | 6.3 | 7 | 10 | 13 | 12 | 0 | 6 | 1 | 1 | 0 | 1 | 0 |
| J | 83 | 42 | 33 | 70 | 6.9 | 32 | 03 | 1964 | 3.6 | 17 | 9 | 5 | 6 | 0 | 5 | 1 | 8 | 0 | * | 0 |
| A | 81 | 47 | 37 | 70 | 6.7 | 37 | 32 | 1968 | 4.7 | 13 | 9 | 9 | 8 | 0 | 5 | 1 | 6 | 0 | * | 0 |
| S | 85 | 56 | 46 | 76 | 7.0 | 35 | 36 | 1965 | 5.4 | 10 | 9 | 11 | 8 | * | 2 | 2 | * | 0 | 6 | 0 |
| O | 87 | 71 | 58 | 84 | 6.0 | 29 | 21 | 1966 | 7.0 | 6 | 7 | 18 | 10 | * | * | 6 | 0 | 0 | 20 | 0 |
| N | 87 | 82 | 74 | 86 | 6.6 | 29 | 02 | 1966+ | 8.4 | 2 | 6 | 22 | 12 | 3 | * | 4 | 0 | 5 | 25 | * |
| D | 85 | 85 | 81 | 85 | 6.9 | 39 | 02 | 1966+ | 8.9 | 2 | 3 | 26 | 15 | 5 | 0 | 5 | 0 | 16 | 29 | 4 |
| YR | 83 | 64 | 56 | 77 | 7.2 | 40 | 23 | MAY 1965+ | 6.9 | 74 | 84 | 207 | 132 | 22 | 25 | 35 | 16 | 51 | 194 | 15 |

(a) Length of record, years.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months or years.
T Trace, an amount too small to measure.
Below-zero temperatures are preceded by a minus sign.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Degree day totals are the sums of the negative departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3; partly cloudy days 4-7; and cloudy days 8-10 tenths.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North, i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

% The station operated less than 24 hours daily prior to July 1964, therefore fog and thunderstorm data may be incomplete.

Data for September - December 1950 considered in extracting temperature extremes above.
Means and extremes in the above table are from the existing location. Annual extremes have been exceeded at other locations as follows:
Lowest temperature -38 in January 1950; maximum monthly precipitation 5.17 in November 1897.

Source: U.S. Department of Commerce, Local Climatological Data: Annual Summary with Comparative Data, 1968, Kalispell, Montana (Washington: U.S. Government Printing Office, 1968), p. 2.

TABLE B.11

# AVERAGE TEMPERATURE AND TOTAL DEGREE DAY DATA: KALISPELL

## Average Temperature

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1931 | [illegible] | 27.9 | 35.7 | 44.5 | 54.6 | 61.0 | 67.2 | 67.0 | 54.8 | 44.2 | 27.2 | 25.6 | 44.8 |
| 1932 | 19.7 | 25.7 | 28.6 | 44.2 | 52.6 | 61.2 | 65.8 | 65.2 | 54.8 | 42.2 | 37.4 | 20.8 | 43.2 |
| 1933 | 26.4 | 19.9 | 35.5 | 42.4 | 48.9 | 61.9 | 66.6 | 64.6 | 52.2 | 45.6 | 37.2 | 31.3 | 44.3 |
| 1934 | 33.4 | 32.8 | 39.8 | 51.4 | 57.2 | 59.2 | 67.0 | 66.0 | 51.2 | 46.2 | 39.0 | 27.6 | 47.6 |
| 1935 | 21.6 | 27.8 | 31.9 | 38.2 | 50.9 | 57.5 | 65.2 | 62.2 | 57.5 | 43.0 | 28.0 | 28.8 | 42.7 |
| 1936 | 25.0 | 6.2 | 32.6 | 44.7 | 58.9 | 61.4 | 70.8 | 66.5 | 54.3 | 45.2 | 25.1 | 26.6 | 43.1 |
| 1937 | [illegible] | 21.8 | 33.8 | 42.4 | 53.2 | 58.9 | 68.0 | 62.0 | 58.1 | 47.4 | 35.4 | 27.2 | 42.4 |
| 1938 | 25.2 | 23.4 | 34.4 | 45.4 | 51.5 | 61.4 | 68.0 | 64.4 | 62.4 | 46.0 | 30.4 | 27.5 | 45.0 |
| 1939 | 30.2 | 21.2 | 35.0 | 46.6 | 54.7 | 54.8 | 67.3 | 66.0 | 56.2 | 46.4 | 35.4 | 31.4 | 45.4 |
| 1940 | 20.4 | 30.2 | 40.2 | 45.0 | 56.0 | 63.0 | 68.2 | 66.7 | 60.8 | 48.4 | 25.3 | 29.1 | 46.1 |
| 1941 | 24.4 | 28.8 | 39.8 | 47.5 | 53.4 | 60.8 | 69.3 | 64.4 | 50.5 | 43.2 | 36.2 | 28.5 | 45.7 |
| 1942 | 17.4 | 22.7 | 35.2 | 45.8 | 50.4 | 54.8 | 65.6 | 64.6 | 56.0 | 45.5 | 29.6 | 28.2 | 43.0 |
| 1943 | 12.9 | 26.4 | 25.3 | 47.8 | 48.8 | 54.0 | 64.8 | 63.6 | 56.6 | 46.2 | 33.5 | 25.7 | 42.1 |
| 1944 | 25.8 | 27.4 | 30.8 | 45.3 | 53.7 | 59.0 | 65.7 | 62.2 | 56.5 | 49.2 | 33.4 | 23.6 | 44.4 |
| 1945 | 29.2 | 30.0 | 33.9 | 39.6 | 52.1 | 56.8 | 67.6 | 66.4 | 52.0 | 46.8 | 32.6 | 26.1 | 44.4 |
| 1946 | 27.1 | 29.9 | 38.4 | 45.4 | 52.0 | 58.0 | 67.0 | 64.2 | 53.8 | 39.4 | 27.5 | 24.0 | 43.9 |
| 1947 | [illegible] | 27.0 | 34.6 | 45.6 | 55.0 | 55.6 | 67.8 | 62.4 | 54.4 | 47.1 | 31.2 | 27.0 | 44.1 |
| 1948 | 25.2 | 24.2 | 28.6 | 42.0 | 52.6 | 61.6 | 61.8 | 62.3 | 54.8 | 43.1 | 33.0 | 19.4 | 42.4 |
| 1949 | 6.6 | 19.8 | 31.0 | 47.0 | 55.6 | 57.4 | 63.8 | 65.2 | 55.0 | 40.0 | 38.2 | 24.2 | 42.0 |
| 1950 | 4.0 | 25.7 | 30.4 | 41.0 | 49.1 | 57.5 | 64.5 | 63.7 | 54.9 | 44.6 | 30.8 | 29.2 | 41.3 |
| 1951 | 18.9 | 27.8 | 27.6 | 42.2 | 50.9 | 54.5 | 65.1 | 61.4 | 52.0 | 41.0 | 31.5 | 16.0 | 40.8 |
| 1952 | 18.8 | 27.9 | 31.1 | 46.5 | 53.5 | 57.9 | 62.4 | 63.4 | 56.7 | 46.2 | 30.8 | 27.5 | 43.5 |
| 1953 | 34.5 | 32.2 | 37.0 | 41.0 | 50.0 | 56.1 | 64.6 | 63.8 | 56.5 | 45.7 | 36.6 | 30.6 | 45.7 |
| 1954 | 21.1 | 30.4 | 29.6 | 39.6 | 52.5 | 54.7 | 63.6 | 60.6 | 52.9 | 40.8 | 37.9 | 28.2 | 42.7 |
| 1955 | 24.3 | 20.9 | 23.4 | 39.6 | 46.7 | 59.3 | 63.6 | 63.4 | 53.2 | 43.9 | 22.7 | 20.8 | 40.2 |
| 1956 | 22.2 | 20.0 | 30.8 | 43.5 | 54.4 | 57.3 | 66.0 | 62.1 | 54.8 | 43.7 | 29.6 | 27.9 | 42.7 |
| 1957 | 9.6 | 21.6 | 32.6 | 43.2 | 56.4 | 59.0 | 64.5 | 63.0 | 55.4 | 40.7 | 31.2 | 31.1 | 42.4 |
| 1958 | 28.0 | 29.2 | 33.6 | 43.2 | 60.3 | 61.5 | 65.2 | 68.3 | 54.5 | 43.6 | 30.9 | 27.0 | 45.5 |
| 1959 | 22.7 | 22.6 | 34.3 | 43.5 | 47.5 | 59.2 | 64.8 | 59.9 | 52.9 | 42.4 | 22.1 | 24.2 | 41.3 |
| 1960 | 14.3 | 19.3 | 27.3 | 43.0 | 50.2 | 58.0 | 69.8 | 61.0 | 54.7 | 43.4 | 31.3 | 21.5 | 41.2 |
| 1961 | 23.9 | 35.5 | 36.7 | 40.5 | 52.4 | 64.2 | 68.9 | 69.1 | 49.1 | 40.0 | 26.6 | 20.8 | 44.0 |
| 1962 | 17.0 | 25.7 | 29.8 | 45.8 | 50.7 | 57.7 | 62.8 | 62.0 | 53.9 | 43.0 | 36.1 | 31.2 | 42.9 |
| 1963 | 10.4 | 31.6 | 37.2 | 43.2 | 50.2 | 58.7 | 63.0 | 65.2 | 58.9 | 45.8 | 34.0 | 22.0 | 43.3 |
| 1964 | 24.6 | 23.9 | 27.9 | 40.7 | 49.7 | 56.8 | 64.0 | 58.4 | 50.1 | 42.3 | 31.0 | 18.0 | 40.6 |
| 1965 | 25.9 | 24.2 | 24.5 | 43.5 | 48.1 | 56.0 | 64.5 | 63.3 | 45.1 | 45.3 | 34.3 | 26.1 | 41.7 |
| 1966 | 24.3 | 23.9 | 32.5 | 41.7 | 53.0 | 54.8 | 64.4 | 61.6 | 59.3 | 41.2 | 30.7 | 27.3 | 42.9 |
| 1967 | 28.8 | 30.3 | 30.7 | 39.2 | 50.3 | 58.7 | 65.8 | 67.7 | 59.5 | 44.5 | 32.3 | 23.8 | 44.3 |
| 1968 | 20.4 | 31.9 | 39.1 | 40.2 | 49.8 | 58.0 | 65.5 | 61.8 | 53.0 | 41.0 | 31.4 | 17.8 | 42.5 |
| RECORD MEAN | 21.4 | 25.2 | 33.1 | 43.7 | 52.0 | 58.4 | 65.4 | 63.3 | 54.0 | 43.9 | 32.2 | 24.9 | 43.2 |
| MAX | 28.5 | 33.5 | 42.4 | 54.9 | 64.0 | 70.7 | 80.6 | 78.4 | 67.1 | 54.8 | 39.2 | 31.0 | 53.8 |
| MIN | 14.2 | 16.9 | 23.7 | 32.5 | 40.0 | 46.1 | 50.2 | 48.1 | 40.8 | 33.0 | 25.2 | 18.7 | 32.5 |

## Total Degree Days

| Season | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1930-31 | 41 | 32 | 248 | 734 | 1060 | 1256 | 1154 | 1038 | 908 | 616 | 324 | 148 | 7559 |
| 1931-32 | 46 | 44 | 335 | 642 | 1134 | 1222 | 1404 | 1140 | 1128 | 626 | 382 | 158 | 8261 |
| 1932-33 | 56 | 90 | 308 | 704 | 828 | 1370 | 1196 | 1292 | 915 | 678 | 499 | 125 | 8061 |
| 1933-34 | 34 | 100 | 383 | 602 | 834 | 1044 | 978 | 903 | 780 | 407 | 273 | 189 | 6527 |
| 1934-35 | 16 | 34 | 422 | 582 | 781 | 1158 | 1344 | 1042 | 1026 | 804 | 438 | 230 | 7897 |
| 1935-36 | 81 | 112 | 228 | 683 | 1110 | 1124 | 1239 | 1703 | 1006 | 608 | 240 | 164 | 8298 |
| 1936-37 | 13 | 44 | 322 | 613 | 1196 | 1188 | 1982 | 1208 | 968 | 680 | 363 | 210 | 8787 |
| 1937-38 | 21 | 124 | 226 | 547 | 889 | 1171 | 1234 | 1164 | 950 | 586 | 421 | 132 | 7465 |
| 1938-39 | 32 | 75 | 126 | 566 | 1037 | 1162 | 1082 | 1224 | 932 | 554 | 321 | 320 | 7451 |
| 1939-40 | 58 | 50 | 267 | 576 | 890 | 1040 | 1383 | 1009 | 770 | 602 | 282 | 124 | 7051 |
| 1940-41 | 27 | 31 | 152 | 514 | 1191 | 1112 | 1258 | 1013 | 781 | 526 | 363 | 160 | 7128 |
| 1941-42 | 5 | 92 | 432 | 676 | 866 | 1131 | 1473 | 1183 | 924 | 574 | 451 | 304 | 8111 |
| 1942-43 | 59 | 95 | 265 | 594 | 1061 | 1138 | 1617 | 1081 | 1234 | 518 | 501 | 331 | 8498 |
| 1943-44 | 85 | 70 | 254 | 584 | 947 | 1215 | 1217 | 1091 | 1060 | 586 | 355 | 195 | 7659 |
| 1944-45 | 54 | 104 | 266 | 487 | 945 | 1285 | 1109 | 781 | 963 | 764 | 401 | 257 | 7616 |
| 1945-46 | 33 | 43 | 338 | 569 | 972 | 1205 | 1175 | 982 | 824 | 584 | 401 | 211 | 7397 |
| 1946-47 | 30 | 64 | 340 | 731 | 1127 | 1276 | 1353 | 1062 | 940 | 586 | 314 | 283 | 8186 |
| 1947-48 | 27 | 113 | 318 | 553 | 1014 | 1185 | 1236 | 1185 | 1130 | 689 | 384 | 128 | 7962 |
| 1948-49 | 112 | 104 | 306 | 682 | 958 | 1416 | 1813 | 1262 | 1056 | 541 | 294 | 229 | 8773 |
| 1949-50 | 95 | 68 | 330 | 775 | 804 | 1264 | 1894 | 1095 | 1066 | 715 | 487 | 228 | 8791 |
| 1950-51 | 68 | 56 | 315 | 623 | 1016 | 1103 | 1423 | 1035 | 1155 | 676 | 433 | 308 | 8211 |
| 1951-52 | 77 | 139 | 383 | 734 | 996 | 1513 | 1426 | 1070 | 1043 | 546 | 346 | 216 | 8489 |
| 1952-53 | 110 | 101 | 246 | 575 | 1019 | 1155 | 937 | 911 | 865 | 713 | 460 | 267 | 7359 |
| 1953-54 | 67 | 91 | 248 | 593 | 844 | 1057 | 1355 | 964 | 1089 | 755 | 379 | 304 | 7746 |
| 1954-55 | 93 | 140 | 356 | 744 | 805 | 1132 | 1258 | 1228 | 1286 | 754 | 559 | 194 | 8549 |
| 1955-56 | 130 | 69 | 363 | 644 | 1264 | 1364 | 1320 | 1299 | 1053 | 638 | 327 | 233 | 8703 |
| 1956-57 | 61 | 106 | 332 | 651 | 1056 | 1144 | 1716 | 1209 | 998 | 648 | 259 | 183 | 8333 |
| 1957-58 | 60 | 101 | 286 | 744 | 1007 | 1042 | 1139 | 996 | 964 | 646 | 171 | 119 | 7275 |
| 1958-59 | 59 | 31 | 330 | 656 | 1016 | 1171 | 1305 | 1180 | 945 | 636 | 537 | 185 | 8051 |
| 1959-60 | 94 | 169 | 365 | 693 | 1283 | 1260 | 1568 | 1321 | 1164 | 654 | 452 | 212 | 9235 |
| 1960-61 | 15 | 149 | 307 | 664 | 1006 | 1342 | 1269 | 821 | 870 | 730 | 393 | 70 | 7636 |
| 1961-62 | 11 | 15 | 467 | 768 | 1146 | 1365 | 1488 | 1094 | 1089 | 570 | 439 | 222 | 8674 |
| 1962-63 | 119 | 120 | 326 | 674 | 858 | 1042 | 1690 | 928 | 855 | 649 | 449 | 200 | 7910 |
| 1963-64 | 106 | 73 | 186 | 591 | 926 | 1327 | 1246 | 1187 | 1143 | 726 | 470 | 239 | 8220 |
| 1964-65 | 69 | 199 | 439 | 700 | 1011 | 1454 | 1204 | 1138 | 1249 | 638 | 515 | 270 | 8886 |
| 1965-66 | 62 | 115 | 591 | 602 | 914 | 1201 | 1252 | 1144 | 1002 | 693 | 373 | 301 | 8250 |
| 1966-67 | 68 | 128 | 162 | 733 | 1023 | 1161 | 1118 | 964 | 1059 | 766 | 449 | 190 | 7821 |
| 1967-68 | 32 | [illegible] | 176 | 627 | 972 | 1272 | 1379 | 953 | 795 | 735 | 468 | 211 | 7642 |
| 1968-69 | 80 | 133 | 354 | 737 | 999 | 1458 | | | | | | | |

Record mean values above (not adjusted for instrument location changes listed in the Station Location table) are means for the period beginning in 1897.

A horizontal line drawn on the above tables indicates a break in the data sequence due to a change in instrument exposure or a station move (see Station Location table).

Source: U.S. Department of Commerce, Local Climatological Data: Annual Summary with Comparative Data, 1968, Kalispell, Montana (Washington: GPO, 1968), p. 3.

# TABLE B.12

## PRECIPITATION DATA: KALISPELL

### Total Precipitation

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1931 | 0.55 | 0.27 | 0.93 | 0.25 | 0.52 | 1.46 | 0.70 | 0.01 | 2.89 | 0.44 | 2.57 | 1.72 | 12.31 |
| 1932 | 1.18 | 0.65 | 1.75 | 1.06 | 1.96 | 0.50 | 0.68 | 1.85 | 0.15 | 1.35 | 1.34 | 0.96 | 13.43 |
| 1933 | 1.10 | 1.25 | 0.21 | 1.43 | 2.51 | 1.37 | 0.21 | 1.77 | 1.04 | 2.70 | 1.31 | 3.22 | 18.12 |
| 1934 | 0.88 | 0.06 | 2.72 | 0.68 | 1.22 | 2.96 | 0.27 | 0.07 | 0.71 | 2.26 | 0.97 | 0.94 | 13.74 |
| 1935 | 1.97 | 0.25 | 1.18 | 1.81 | 1.04 | 1.03 | 1.11 | 0.37 | 0.14 | 0.53 | 1.02 | 1.02 | 11.47 |
| 1936 | 1.93 | 2.10 | 1.50 | 1.33 | 0.40 | 1.73 | 0.45 | 0.47 | 1.04 | 1.00 | 0.42 | 1.68 | 14.05 |
| 1937 | 2.12 | 1.03 | 0.44 | 1.22 | 1.00 | 2.25 | 0.83 | 0.66 | 0.91 | 0.87 | 1.24 | 1.23 | 13.80 |
| 1938 | 0.71 | 1.07 | 0.94 | 0.37 | 1.72 | 1.17 | 1.06 | 0.56 | 1.14 | 0.80 | 1.27 | 1.13 | 11.94 |
| 1939 | 1.27 | 0.93 | 0.84 | 0.56 | 1.09 | 3.80 | 0.38 | 0.21 | 0.96 | 0.22 | 0.59 | 0.94 | 11.79 |
| 1940 | 0.58 | 2.13 | 1.10 | 1.49 | 1.08 | 0.83 | 2.26 | 0.02 | 1.69 | 1.05 | 2.02 | 0.81 | 15.06 |
| 1941 | 1.26 | 0.50 | 0.54 | 0.55 | 1.75 | 1.51 | 1.07 | 0.80 | 2.30 | 0.82 | 1.68 | 1.05 | 13.53 |
| 1942 | 0.79 | 1.48 | 0.49 | 1.43 | 3.92 | 4.13 | 2.72 | 0.90 | 0.31 | 0.74 | 2.39 | 1.51 | 20.81 |
| 1943 | 3.40 | 0.76 | 0.90 | 1.13 | 1.16 | 3.33 | 0.45 | 0.42 | 0.23 | 1.28 | 0.83 | 0.28 | 14.17 |
| 1944 | 0.27 | 0.51 | 0.84 | 0.97 | 1.48 | 1.46 | 0.60 | 1.34 | 0.75 | 0.15 | 1.47 | 0.63 | 10.42 |
| 1945 | 1.19 | 0.67 | 1.37 | 1.21 | 1.20 | 2.82 | 0.31 | 0.82 | 1.57 | 1.77 | 0.91 | 2.12 | 15.95 |
| 1946 | 1.07 | 0.73 | 0.55 | 0.51 | 1.40 | 1.81 | 0.97 | 0.77 | 1.30 | 3.18 | 1.99 | 1.82 | 16.10 |
| 1947 | 1.00 | 0.90 | 0.90 | 0.65 | 1.79 | 4.56 | 0.47 | 3.28 | 0.99 | 2.16 | 1.22 | 0.81 | 18.73 |
| 1948 | 0.86 | 1.27 | 1.24 | 1.92 | 4.36 | 2.76 | 3.15 | 2.33 | 0.10 | 0.40 | 1.50 | 1.02 | [illegible] |
| 1949 | 1.07 | 1.28 | 1.30 | 0.58 | 1.54 | 1.13 | 1.52 | 0.58 | 0.95 | 1.33 | 1.54 | 1.06 | 13.88 |
| 1950 | 2.08 | 1.18 | 1.87 | 0.79 | 0.43 | 3.56 | 2.74 | 1.24 | 0.54 | 2.58 | 0.96 | 2.11 | [illegible] |
| 1951 | 1.24 | 1.52 | 0.44 | 2.04 | 2.31 | 1.81 | 1.09 | 2.63 | 1.88 | 2.96 | 0.85 | 3.11 | 21.87 |
| 1952 | [illegible] | 0.52 | 0.68 | 0.31 | 1.68 | 3.26 | 0.72 | 1.02 | [illegible] | 0.15 | 0.63 | 0.96 | 11.15 |
| 1953 | 2.21 | 0.85 | 1.01 | 1.28 | 1.37 | 2.93 | [illegible] | 1.98 | 0.44 | 0.04 | 0.99 | 1.50 | 14.61 |
| 1954 | 2.74 | 0.75 | 0.69 | 0.45 | 1.05 | 1.98 | 2.09 | 3.04 | 0.81 | 0.50 | 0.87 | [illegible] | 15.29 |
| 1955 | [illegible] | 1.00 | 0.47 | 0.89 | 1.23 | 3.06 | 1.32 | T | 1.55 | 1.61 | 2.39 | 2.36 | 16.91 |
| 1956 | 1.54 | 1.27 | 0.89 | 1.35 | 1.44 | 2.92 | 2.32 | 1.93 | 0.92 | 0.88 | 0.55 | 1.08 | 17.07 |
| 1957 | 1.12 | 1.28 | 0.49 | 1.39 | 1.25 | 1.87 | 0.85 | 0.45 | 0.20 | 2.00 | 0.56 | 0.98 | 12.44 |
| 1958 | 1.46 | 1.93 | 0.72 | 1.42 | 1.80 | 2.20 | 0.86 | 0.22 | 1.94 | 0.60 | 2.65 | 2.30 | 18.00 |
| 1959 | 2.03 | 1.08 | 0.61 | 1.22 | 3.08 | 1.58 | 0.04 | 0.68 | 3.84 | 1.97 | 4.44 | 0.40 | 20.97 |
| 1960 | 1.30 | 0.83 | 1.11 | 0.82 | 3.34 | 0.62 | 0.03 | 2.31 | 0.33 | 1.00 | 1.59 | 0.96 | 14.24 |
| 1961 | 0.75 | 1.32 | 1.42 | 2.01 | 2.35 | 0.71 | 1.20 | 0.67 | 2.08 | 0.92 | 1.07 | 2.20 | 16.40 |
| 1962 | 0.97 | 0.92 | 1.09 | 1.05 | 2.04 | 0.82 | 0.16 | 0.95 | 0.42 | 1.25 | 1.00 | 0.81 | 11.48 |
| 1963 | 1.61 | 1.00 | 1.25 | 0.88 | 0.81 | 3.94 | 0.95 | 0.81 | 1.26 | 0.67 | 0.71 | 1.33 | 15.22 |
| 1964 | 1.24 | 0.50 | 1.26 | 0.60 | 2.56 | 3.56 | 1.69 | 1.77 | 1.87 | 0.95 | 2.13 | 4.23 | 22.36 |
| 1965 | 1.84 | 0.69 | 0.31 | 1.44 | 0.74 | 2.73 | 0.85 | 3.47 | 1.17 | 0.11 | 0.72 | 0.57 | 14.64 |
| 1966 | 1.61 | 1.02 | 0.79 | 0.65 | 1.63 | 4.72 | 0.37 | 1.05 | 0.29 | 0.88 | 2.52 | 1.58 | 17.11 |
| 1967 | 1.75 | 0.42 | 1.09 | 0.59 | 0.95 | 2.38 | 0.07 | 0.01 | 0.33 | 1.60 | 0.58 | 1.45 | 11.22 |
| 1968 | 1.01 | 1.00 | 0.43 | 0.26 | 2.59 | 2.16 | 0.46 | 3.10 | 3.33 | 1.50 | 1.55 | 2.56 | 19.95 |
| RECORD MEAN | 1.32 | 0.96 | 0.95 | 0.92 | 1.63 | 2.15 | 1.03 | 1.10 | 1.24 | 1.08 | 1.43 | 1.36 | 15.17 |

### Total Snowfall

| Season | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1930-31 | 0.0 | 0.0 | 0.0 | 2.5 | 30.4 | 5.2 | 4.6 | 1.9 | 4.7 | 1.6 | 0.0 | 0.0 | 50.9 |
| 1931-32 | 0.0 | 0.0 | 0.0 | T | 31.3 | 16.4 | 15.5 | 4.4 | 16.8 | 0.1 | T | 0.0 | 84.5 |
| 1932-33 | 0.0 | 0.0 | 0.0 | 1.9 | 2.5 | 12.5 | 12.9 | 14.9 | 1.6 | 11.0 | 7.4 | 0.0 | 64.7 |
| 1933-34 | 0.0 | 0.0 | T | 9.5 | 0.6 | 14.5 | 1.1 | 0.4 | 17.4 | 2.6 | 0.0 | 0.0 | 46.1 |
| 1934-35 | 0.0 | 0.0 | T | T | 3.6 | 9.0 | 19.5 | 0.4 | 7.6 | 5.5 | T | 0.0 | 45.6 |
| 1935-36 | 0.0 | 0.0 | 0.0 | 3.0 | 6.8 | 5.9 | 20.3 | 30.7 | 17.9 | 0.0 | 0.0 | 0.0 | 84.6 |
| 1936-37 | 0.0 | 0.0 | 0.0 | 5.3 | 7.2 | 13.7 | 34.2 | 14.5 | 2.4 | T | 0.0 | 0.0 | 77.3 |
| 1937-38 | 0.0 | 0.0 | 0.0 | 0.0 | 5.4 | 11.6 | 8.6 | 17.2 | 10.0 | T | T | 0.0 | 52.8 |
| 1938-39 | 0.0 | 0.0 | 0.0 | 0.0 | 8.1 | 16.8 | 18.8 | 17.0 | 12.6 | 1.0 | 0.0 | 0.0 | 74.3 |
| 1939-40 | 0.0 | 0.0 | 0.0 | 2.9 | T | 5.2 | 9.0 | 16.6 | 2.3 | 3.5 | 0.0 | 0.0 | 39.5 |
| 1940-41 | 0.0 | 0.0 | 0.0 | 0.0 | 15.4 | 4.5 | 17.9 | 4.6 | 0.0 | 0.3 | 0.0 | 0.0 | 42.7 |
| 1941-42 | 0.0 | 0.0 | T | T | 4.3 | 6.2 | 8.1 | 25.0 | 5.4 | 1.0 | T | 0.0 | 50.0 |
| 1942-43 | 0.0 | 0.0 | 0.0 | T | 22.1 | 18.5 | 35.9 | 10.1 | 6.2 | T | T | 0.0 | 92.8 |
| 1943-44 | 0.0 | 0.0 | 0.0 | T | 0.2 | 1.7 | 2.8 | 5.0 | 4.9 | T | T | 0.0 | 14.6 |
| 1944-45 | 0.0 | 0.0 | 0.0 | 0.0 | 10.2 | 5.3 | 4.3 | 3.0 | 8.9 | 2.9 | 0.0 | T | 34.6 |
| 1945-46 | 0.0 | 0.0 | 1.3 | 1.7 | 8.8 | 18.6 | 16.0 | 9.3 | 1.7 | T | T | 0.0 | 57.4 |
| 1946-47 | 0.0 | 0.0 | 0.0 | 11.2 | 25.9 | 22.1 | 11.8 | 11.6 | 9.4 | 0.8 | 0.0 | 0.0 | 92.8 |
| 1947-48 | 0.0 | 0.0 | T | 0.0 | 13.2 | 11.4 | 4.0 | 6.7 | 19.3 | 10.5 | T | 0.0 | 65.1 |
| 1948-49 | 0.0 | 0.0 | 0.0 | T | 6.3 | 14.9 | 21.4 | 14.6 | 18.0 | T | T | 0.0 | 75.2 |
| 1949-50 | 0.0 | 0.0 | T | T | 3.5 | 17.6 | 30.4 | 10.8 | 7.8 | 1.2 | T | T | 71.3 |
| 1950-51 | 0.0 | 0.0 | T | 0.0 | 7.0 | 13.7 | 16.2 | 13.7 | 6.2 | 6.2 | 5.0 | 0.0 | 68.0 |
| 1951-52 | 0.0 | 0.0 | 0.0 | 9.9 | 8.3 | 49.7 | 17.1 | [illegible] | 9.2 | 0.3 | 0.0 | 0.0 | 101.2 |
| 1952-53 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 12.8 | 11.4 | 11.4 | 7.9 | 0.4 | T | 0.0 | 44.7 |
| 1953-54 | 0.0 | 0.0 | 0.0 | 0.0 | T | 9.1 | 32.8 | 4.8 | 3.2 | 5.4 | 0.0 | 0.0 | 55.3 |
| 1954-55 | 0.0 | 0.0 | 0.0 | T | 2.2 | 1.3 | 17.1 | 16.3 | 8.4 | 1.8 | T | 0.0 | 47.1 |
| 1955-56 | 0.0 | 0.0 | 0.0 | 1.0 | 23.4 | 19.0 | 18.1 | 16.1 | 4.8 | 1.0 | 2.2 | T | 85.6 |
| 1956-57 | 0.0 | 0.0 | 0.0 | 1.8 | 3.9 | 5.8 | 24.3 | 16.8 | 6.5 | 0.4 | 0.0 | 0.0 | 59.5 |
| 1957-58 | 0.0 | 0.0 | T | 2.3 | 4.5 | 9.2 | 8.4 | 20.6 | 3.7 | 0.3 | 0.0 | 0.0 | 49.0 |
| 1958-59 | 0.0 | 0.0 | 0.0 | 1.6 | 8.0 | 22.3 | 18.9 | 17.1 | 3.4 | 0.6 | T | 0.0 | 71.9 |
| 1959-60 | 0.0 | 0.0 | 0.0 | 0.4 | 39.0 | 3.9 | 20.6 | 13.9 | 8.8 | 3.6 | T | 0.0 | 90.2 |
| 1960-61 | 0.0 | 0.0 | 0.0 | 0.5 | 10.1 | 17.5 | 5.5 | 3.5 | 7.2 | 8.1 | 4.1 | 0.0 | 56.5 |
| 1961-62 | 0.0 | 0.0 | T | 1.8 | 19.1 | 30.0 | 15.1 | 7.7 | 6.5 | 3.1 | 0.0 | 0.3 | 83.6 |
| 1962-63 | 0.0 | 0.0 | T | 0.0 | 1.5 | 2.4 | 27.2 | 6.5 | 2.3 | 3.0 | 0.2 | 0.0 | 43.1 |
| 1963-64 | 0.0 | 0.0 | 0.0 | T | 2.5 | 18.3 | 20.6 | 6.7 | 13.3 | 1.1 | 8.9 | 0.0 | 71.4 |
| 1964-65 | 0.0 | 0.0 | 0.0 | 1.6 | 10.5 | 32.0 | 20.7 | 10.7 | 4.9 | 4.0 | 0.2 | 0.0 | 84.6 |
| 1965-66 | 0.0 | 0.0 | 0.4 | 0.0 | 3.9 | 8.0 | 22.6 | 17.6 | 1.9 | 0.9 | 0.6 | 0.0 | 55.9 |
| 1966-67 | 0.0 | 0.0 | 0.0 | T | 11.9 | 15.7 | 8.9 | 5.8 | 10.0 | 2.1 | 2.8 | 0.0 | 57.2 |
| 1967-68 | 0.0 | 0.0 | 0.0 | T | 2.3 | 21.3 | 14.1 | 3.0 | 0.7 | 1.9 | 1.4 | 0.0 | 44.7 |
| 1968-69 | 0.0 | 0.0 | 3.1 | T | 11.1 | 30.3 | | | | | | | |

Record mean values above (not adjusted for instrument location changes listed in the Station Location table) are means for the period beginning in 1897.

A horizontal line drawn on the above tables indicates a break in the data sequence due to a change in instrument exposure or a station move (see Station Location table).

Source: U.S. Department of Commerce, Local Climatological Data: Annual Summary with Comparative Data, 1968, Kalispell, Montana (Washington: GPO, 1968), p. 3.

the result of differential heating of land and water surfaces. During the daytime, land surfaces heat more rapidly (and achieve higher temperatures) than the water surface of the Lake. Therefore, the layer of air over the land is heated causing it to rise thereby creating a local low pressure area. Cooler air over the lake thus moves on-shore to replace the warmer air which has risen. The wind thus created is very noticeable at both Kalispell and the airport, often reaching 20 miles per hour and occasionally becoming quite gusty.[57] Because this wind is the result of local influences, there are times when other effects, e.g., cloudiness, frontal passages, etc., may cause the wind to be from another direction. The yearly prevailing wind direction at Kalispell is from the west while at the airport it is from the south. In addition, average wind speeds are considerably stronger at the airport than in Kalispell.[58]

During winter, cold air moving down the east side of the Continental Divide does occasionally break through the mountain barrier. The airport is in direct line of the mountain pass through which this cold air enters the Flathead Valley. When this happens, wind at the airport is from the northeast with speeds normally reaching 50 to 60 miles per

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[57]U.S. Department of Commerce, Local Climatological Data: Kalispell, Montana, loc. cit.

[58]U.S. Department of Commerce, Local Climatological Data: Kalispell, Montana, loc. cit.

hour.[59] The strongest gust of wind reported during one of these cold waves was 84 miles per hour.[60] As this cold air proceeds down the valley it spreads out, resulting in a decrease in wind velocity, and mixes with the warmer air already in the valley. Unless these strong, cold winds persist for three or four days, wind in the lower portion of the valley will be from the northwest, due to the influence of Flathead Lake and the mountains to the west.[61] This wind is always much stronger in the northeast end of the valley (where the airport is located) than at any other place in the valley. In the northwest corner, where Whitefish is located, and in the southeast portion of the valley, there is rarely any wind from these movements.

The Missoula station is situated in the heart of the Montana Rockies in the extreme north portion of the Bitterroot Valley, and about 5 miles east of the confluence of the Bitterroot and Clark Fork Rivers.[62] The Clark Fork Valley originates at Missoula and extends approximately 20 miles in a west-northwesterly direction, while the Bitterroot Valley extends about 70 miles due southward from

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[59] U.S. Department of Commerce, Local Climatological Data: Kalispell, Montana, loc. cit.

[60] U.S. Department of Commerce, Local Climatological Data: Kalispell, Montana, loc. cit.

[61] U.S. Department of Commerce, Local Climatological Data: Kalispell, Montana, loc. cit.

[62] U.S. Department of Commerce, Local Climatological Data: Missoula, Montana, p. 1.

Missoula.[63] From Missoula, the Continental Divide lies 60 to 80 miles east and the Bitterroot Range of mountains is only about 20 miles to the southwest.[64] These two mountain ranges have a marked effect on the climate of the Missoula area.

Prevailing winds in the Missoula area are from the west and southwest during spring and summer months, and from the west and northwest during the winter. This air must, therefore, pass over the Bitterroot Mountains and, in so doing, it loses much of its moisture on the western slopes of this range. Because of this, climate in the Missoula area is quite dry with between 12 and 15 inches of precipitation annually on the average.[65] This amount of precipitation puts the Missoula area climate in the semiarid category, though the nearby mountains provide an adequate supply of irrigation water. The heaviest precipitation is received during May and June, with average rainfall of approximately 2 inches in each of these months.[66]

In general, spring months in the Missoula area are cool and damp, with shower activity occurring almost daily in the wet months of May and June. The last freeze of the

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[63] U.S. Department of Commerce, Local Climatological Data: Missoula, Montana, loc. cit.

[64] U.S. Department of Commerce, Local Climatological Data: Missoula, Montana, loc. cit.

[65] U.S. Department of Commerce, Local Climatological Data: Missoula, Montana, loc. cit.

[66] U.S. Department of Commerce, Local Climatological Data: Missoula, Montana, loc. cit.

spring normally occurs about mid May and there are approximately 137 growing days each year between the last spring freeze and the first fall freeze.[67] The summer months are generally dry with rather moderate temperatures and cool nights. Rarely does the temperature reach 100 degrees, and minimum temperatures during July and August average near 50 degrees.[68] One very attractive aspect of the Missoula climate is the complete absence of the oppressively hot nighttime temperatures found elsewhere in the State.

As for the rest of the western portion of the State, the Continental Divide shields the Missoula area from most of the extremely cold air moving down from the interior regions of Canada. Occasionally, however, cold air does break through the mountain barrier and, as was the case in the Flathead Valley, moves forcefully into the Bitterroot and Clark Fork Valleys. The absence of the moderating influence of a large water body, such as Flathead Lake in the north of the region, indicates that these cold air breakthroughs result in rather severe blizzard conditions in the Missoula area. The cold air enters the Missoula area through the relatively narrow mouth of the Clark Fork River canyon called "Hell Gate." These blizzards are referred to locally

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[67] U.S. Department of Commerce, Local Climatological Data: Missoula, Montana, loc. cit.

[68] U.S. Department of Commerce, Local Climatological Data: Missoula, Montana, loc. cit.

as "Hell Gate Blizzards".[69] Once the valleys of western Montana are filled with cold, arctic air, prolonged cold spells may occur. January is generally the coldest month in the Missoula area with periods of subzero weather occurring occasionally in December and February as well. Infrequently, there are brief periods of subzero weather in November and March. Due mainly to the surrounding mountains and their effect on airflow and air temperature, sunshine during the winter months is limited to about 30 percent of the possible amount.[70] Tables B.13, B.14, and B.15 contain climatic data for the Missoula station.

Topography

Montana includes significant portions of three major physiographic provinces of the United States--the Northern Rocky Mountains and Middle Rocky Mountains in the western portion of the State, and the Great Plains in the central and eastern portions. Montana includes more than half of the U.S. portion of the Northern Rockies but not their highest elevations. [71] Indeed, the mean elevation of the State is approximately 3,400 feet above sea level making it

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[69] U.S. Department of Commerce, Local Climatological Data: Missoula, Montana, loc. cit.

[70] U.S. Department of Commerce, Local Climatological Data: Missoula, Montana, loc. cit.

[71] Phyllis R. Gries, "Montana: Geographic Features," Collier's Encyclopedia, Vol. XVI (1974), p. 486.

# TABLE B.13

## CLIMATIC NORMALS, MEANS, AND EXTREMES: MISSOULA

| Month | Temperature ∮ Normal: Daily maximum | Normal: Daily minimum | Normal: Monthly | Extremes: Record highest | Year | Record lowest | Year | Normal degree days |
|---|---|---|---|---|---|---|---|---|
| (a) | (b) | (b) | (b) | 9 | | 9 | | (b) |
| J | 28.0 | 10.3 | 19.2 | 48 | 1965+ | -27 | 1963 | 1420 |
| F | 34.0 | 15.9 | 25.0 | 60 | 1967 | -10 | 1964+ | 1120 |
| M | 43.8 | 23.6 | 33.7 | 70 | 1966+ | - 9 | 1965 | 970 |
| A | 57.1 | 31.4 | 44.3 | 83 | 1968 | 16 | 1966 | 621 |
| M | 66.6 | 38.5 | 52.6 | 91 | 1966 | 22 | 1965+ | 391 |
| J | 72.8 | 44.2 | 58.5 | 96 | 1961 | 31 | 1960 | 219 |
| J | 85.0 | 49.0 | 67.0 | 105 | 1960 | 34 | 1962 | 34 |
| A | 82.7 | 46.9 | 64.8 | 105 | 1961 | 32 | 1960 | 74 |
| S | 71.5 | 39.2 | 55.4 | 99 | 1967 | 23 | 1964 | 303 |
| O | 57.5 | 30.4 | 44.0 | 85 | 1963 | 17 | 1960 | 651 |
| N | 39.9 | 21.0 | 30.5 | 65 | 1965 | - 8 | 1967 | 1035 |
| D | 31.6 | 15.4 | 23.5 | 57 | 1965 | -30 | 1964 | 1287 |
| YR | 55.9 | 30.5 | 43.2 | 105 | AUG. 1961+ | -30 | DEC. 1964 | 8125 |

| Month | Precipitation: Normal total | Maximum monthly | Year | Minimum monthly | Year | Maximum in 24 hrs. | Year | Snow, Sleet: Mean total | Maximum monthly | Year | Maximum in 24 hrs. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (a) | (b) | 24 | | 24 | | 24 | | 24 | 24 | | 24 | |
| J | 0.92 | 2.38 | 1963 | 0.31 | 1945 | 0.88 | 1948 | 12.6 | 42.5 | 1963 | 11.2 | 1954 |
| F | 0.87 | 1.37 | 1953 | 0.27 | 1967 | 0.76 | 1953 | 8.0 | 18.6 | 1966 | 9.7 | 1959 |
| M | 0.73 | 1.39 | 1961 | 0.20 | 1953 | 0.40 | 1956 | 6.0 | 13.4 | 1955 | 4.5 | 1960 |
| A | 0.97 | 2.46 | 1956 | 0.08 | 1952 | 1.65 | 1951 | 2.6 | 6.9 | 1950 | 6.9 | 1950 |
| M | 1.87 | 4.10 | 1948 | 0.25 | 1963 | 1.82 | 1957 | 1.0 | 7.5 | 1964 | 6.5 | 1961 |
| J | 1.91 | 4.19 | 1958 | 0.35 | 1961 | 1.61 | 1964 | T | T | 1954 | T | 1954 |
| J | 0.85 | 3.05 | 1946 | 0.11 | 1953 | 1.47 | 1946 | 0.0 | 0.0 | | 0.0 | |
| A | 0.72 | 2.38 | 1968 | T | 1967 | 1.43 | 1947 | 0.0 | 0.0 | | 0.0 | |
| S | 1.02 | 3.11 | 1959 | 0.13 | 1948 | 1.34 | 1954 | T | 0.2 | 1965 | 0.2 | 1965 |
| O | 0.99 | 2.33 | 1946 | 0.09 | 1953 | 1.49 | 1946 | 0.6 | 4.6 | 1961 | 2.0 | 1951 |
| N | 0.90 | 2.41 | 1947 | 0.23 | 1954 | 0.60 | 1960 | 6.1 | 17.7 | 1947 | 6.2 | 1961 |
| D | 1.08 | 3.15 | 1964 | 0.27 | 1959 | 0.94 | 1964 | 11.3 | 31.6 | 1964 | 9.6 | 1955 |
| YR | 12.83 | 4.19 | JUN. 1958 | T | AUG. 1967 | 1.82 | MAY 1957 | 48.2 | 42.5 | JAN. 1963 | 11.2 | JAN. 1954 |

| Month | Relative humidity: 5 AM | 11 AM | 5 PM | 11 PM | Wind: Mean hourly speed | Fastest mile: Speed | Direction & | Year | Mean sky cover sunrise to sunset | Mean number of days: Sunrise to sunset: Clear | Partly cloudy | Cloudy | Precipitation .01 inch or more | Snow, Sleet 1.0 inch or more | Thunderstorms | Heavy fog | Temperatures Max.: 90 and above | Max.: 32 and below | Min.: 32 and below | Min.: 0 and below |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Standard time used: MOUNTAIN | | | | | | | | | | | | | | | | | | | |
| (a) | 8 | 8 | 8 | 8 | 24 | 24 | 24 | | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 8 | 8 | 8 | 8 |
| J | 84 | 81 | 77 | 82 | 5.1 | 52 | S | 1953 | 8.4 | 3 | 4 | 24 | 14 | 4 | • | 5 | 0 | 17 | 30 | 6 |
| F | 84 | 79 | 69 | 80 | 5.7 | 47 | NW | 1963 | 8.2 | 2 | 5 | 21 | 11 | 2 | 0 | 4 | 0 | 7 | 26 | 1 |
| M | 81 | 67 | 53 | 74 | 6.6 | 47 | NW | 1951 | 7.9 | 3 | 6 | 22 | 11 | 2 | • | 1 | 0 | 4 | 28 | 1 |
| A | 79 | 56 | 42 | 67 | 7.3 | 51 | NW | 1950 | 7.5 | 4 | 6 | 20 | 10 | 1 | • | • | 0 | 0 | 21 | 0 |
| M | 79 | 51 | 43 | 66 | 7.3 | 57 | SW | 1954 | 7.0 | 5 | 9 | 17 | 12 | • | 3 | • | • | 0 | 8 | 0 |
| J | 84 | 55 | 43 | 69 | 6.8 | 51 | S | 1956 | 6.6 | 6 | 8 | 16 | 12 | 0 | 5 | • | 2 | 0 | • | 0 |
| J | 76 | 43 | 29 | 54 | 6.7 | 72 | SE | 1957 | 3.5 | 17 | 10 | 4 | 6 | 0 | 7 | • | 9 | 0 | 0 | 0 |
| A | 71 | 44 | 30 | 55 | 6.6 | 58 | SW | 1956 | 4.5 | 14 | 9 | 8 | 7 | 0 | 6 | • | 10 | 0 | 0 | 0 |
| S | 83 | 59 | 42 | 71 | 5.9 | 41 | W | 1952+ | 5.5 | 10 | 9 | 11 | 8 | 0 | 2 | 1 | 1 | 0 | 4 | 0 |
| O | 88 | 72 | 54 | 81 | 4.9 | 51 | SW | 1950 | 6.9 | 6 | 7 | 18 | 8 | • | • | 4 | 0 | 0 | 19 | 0 |
| N | 87 | 80 | 73 | 85 | 4.8 | 42 | NW | 1961 | 8.3 | 2 | 5 | 23 | 11 | 2 | • | 5 | 0 | 5 | 26 | • |
| D | 86 | 82 | 79 | 84 | 4.6 | 56 | W | 1957 | 8.6 | 2 | 4 | 25 | 13 | 4 | 0 | 6 | 0 | 17 | 30 | 3 |
| YR | 82 | 64 | 53 | 72 | 6.0 | 72 | SE | JUL. 1957 | 6.9 | 74 | 82 | 209 | 124 | 16 | 25 | 28 | 22 | 50 | 192 | 11 |

∮ For period March 1960 through the current year.
Means and extremes in the above table are from the existing and comparable locations. Annual extremes have been exceeded at other locations as follows:
Lowest temperature -33 in January 1957; maximum monthly precipitation 7.09 in December 1917; minimum monthly precipitation 0.00 in August 1917 and earlier dates; maximum monthly snowfall 43.5 in February 1936; maximum snowfall in 24 hours 22.8 in February 1936.

(a) Length of record, years.
(b) Climatological standard normals (1931-1960).
• Less than one half.
\+ Also on earlier dates, months or years.
T Trace, an amount too small to measure.
Below-zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.

\# To 8 compass points only.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Degree day totals are the sums of the negative departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3; partly cloudy days 4-7; and cloudy days 8-10 tenths.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

Source: U.S. Department of Commerce, Local Climatological Data: Annual Summary with Comparative Data, 1968, Missoula, Montana (Washington: GPO, 1968), p. 2.

# TABLE B.14

## AVERAGE TEMPERATURE AND TOTAL DEGREE DAY DATA: MISSOULA

### Average Temperature

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1931 | 27.6 | 29.8 | 37.6 | 46.0 | 56.3 | 62.7 | 69.0 | 68.7 | 55.8 | 44.2 | 28.6 | 22.0 | 45.7 |
| 1932 | 21.6 | 24.4 | 31.6 | 45.5 | 53.2 | 61.8 | 66.8 | 66.3 | 56.4 | 44.3 | 37.8 | 18.0 | 44.0 |
| 1933 | 25.6 | 19.4 | 36.4 | 43.2 | 49.2 | 64.2 | 69.7 | 66.2 | 53.9 | 48.0 | 38.0 | 33.4 | 45.6 |
| 1934 | 34.0 | 34.5 | 42.1 | 52.4 | 58.6 | 60.8 | 67.8 | 67.8 | 52.5 | 47.4 | 39.8 | 28.6 | 48.9 |
| 1935 | 23.3 | 30.6 | 34.1 | 40.1 | 51.0 | 59.0 | 67.8 | 64.9 | 60.4 | 44.6 | 32.0 | 28.4 | 44.7 |
| 1936 | 26.8 | 12.2 | 35.4 | 48.6 | 60.8 | 64.2 | 74.4 | 70.4 | 57.0 | 49.2 | 30.6 | 31.4 | 46.8 |
| 1937 | 4.6 | 26.5 | 37.4 | 44.4 | 56.4 | 61.0 | 72.6 | 66.5 | 62.6 | 51.8 | 38.4 | 30.5 | 46.1 |
| 1938 | 25.5 | 27.0 | 37.0 | 47.5 | 53.6 | 63.8 | 71.0 | 67.5 | 66.2 | 48.7 | 32.0 | 31.4 | 47.6 |
| 1939 | 33.8 | 24.6 | 39.9 | 49.0 | 57.7 | 57.8 | 71.0 | 70.2 | 59.6 | 48.2 | 36.6 | 33.4 | 48.5 |
| 1940 | 21.0 | 33.1 | 42.6 | 47.6 | 58.3 | 65.7 | 71.8 | 71.0 | 63.1 | 50.6 | 30.0 | 30.4 | 48.8 |
| 1941 | 27.6 | 34.9 | 43.3 | 48.8 | 55.8 | 62.8 | 72.2 | 67.6 | 52.4 | 45.0 | 36.6 | 29.4 | 48.0 |
| 1942 | 17.0 | 24.6 | 37.6 | 49.2 | 51.6 | 57.2 | 70.2 | 69.0 | 60.2 | 49.0 | 34.0 | 29.6 | 45.8 |
| 1943 | 17.6 | 29.0 | 30.0 | 49.2 | 50.0 | 56.2 | 67.6 | 66.6 | 61.0 | 49.6 | 35.8 | 22.0 | 44.6 |
| 1944 | 24.7 | 29.9 | 32.4 | 47.2 | 55.2 | 60.0 | 68.0 | 65.4 | 59.3 | 51.0 | 35.2 | 19.6 | 45.7 |
| 1945 | 27.4 | 31.6 | 34.8 | 40.6 | 53.2 | 56.5 | 69.0 | 68.1 | 54.8 | 48.8 | 33.9 | 24.1 | 45.2 |
| 1946 | 26.2 | 31.0 | 40.7 | 46.3 | 53.2 | 59.1 | 68.9 | 66.6 | 54.8 | 40.8 | 30.8 | 26.8 | 45.4 |
| 1947 | 21.6 | 31.1 | 38.6 | 45.6 | 56.6 | 56.3 | 69.8 | 65.0 | 55.8 | 47.8 | 30.2 | 25.5 | 45.3 |
| 1948 | 22.2 | 26.8 | 31.6 | 43.1 | 53.0 | 62.0 | 63.5 | 64.2 | 54.9 | 43.6 | 32.2 | 13.7 | 42.6 |
| 1949 | 4.5 | 21.4 | 31.7 | 47.0 | 56.2 | 59.4 | 65.6 | 67.6 | 57.6 | 40.8 | 38.0 | 24.6 | 42.9 |
| 1950 | 10.7 | 26.1 | 33.8 | 41.9 | 48.7 | 57.4 | 65.4 | 65.1 | 55.9 | 46.5 | 29.7 | 28.7 | 42.5 |
| 1951 | 18.9 | 29.9 | 29.8 | 43.7 | 51.6 | 55.9 | 67.1 | 64.2 | 54.5 | 43.4 | 30.7 | 19.4 | 42.4 |
| 1952 | 17.3 | 26.5 | 32.0 | 48.1 | 53.4 | 58.3 | 64.7 | 66.0 | 59.4 | 48.3 | 30.0 | 26.0 | 44.2 |
| 1953 | 35.8 | 31.8 | 37.7 | 42.0 | 48.2 | 56.3 | 67.8 | 65.5 | 59.1 | 47.2 | 37.3 | 32.1 | 46.7 |
| 1954 | 23.4 | 31.7 | 32.2 | 42.7 | 53.4 | 55.7 | 67.2 | 62.1 | 54.8 | 43.0 | 38.5 | 25.4 | 44.2 |
| 1955 | 22.3 | 22.4 | 25.4 | 39.8 | 47.7 | 59.4 | 65.1 | 66.6 | 55.2 | 45.9 | 24.3 | 20.6 | 41.3 |
| 1956 | 22.8 | 20.4 | 31.9 | 46.0 | 55.7 | 59.1 | 67.8 | 63.1 | 57.4 | 44.6 | 30.7 | 30.0 | 44.1 |
| 1957 | 10.5 | 26.2 | 35.6 | 44.8 | 56.8 | 60.3 | 67.3 | 65.1 | 59.2 | 42.2 | 32.7 | 32.0 | 44.4 |
| 1958 | 28.8 | 33.3 | 36.2 | 43.7 | 60.5 | 61.4 | 65.8 | 68.9 | 55.6 | 45.2 | 32.6 | 29.3 | 46.8 |
| 1959 | 26.1 | 23.4 | 36.5 | 44.3 | 48.5 | 61.6 | 67.2 | 62.4 | 54.0 | 44.8 | 26.4 | 26.6 | 43.5 |
| 1960 | 16.7 | 25.7 | 32.9 | 43.6 | 49.7 | 60.1 | 72.2 | 62.4 | 56.4 | 43.6 | 32.9 | 18.3 | 42.9 |
| 1961 | 21.6 | 34.2 | 37.0 | 42.2 | 51.1 | 64.7 | 69.3 | 70.3 | 49.9 | 41.1 | 27.1 | 21.5 | 44.2 |
| 1962 | 15.2 | 24.9 | 30.9 | 45.4 | 50.1 | 57.3 | 64.1 | 62.9 | 54.8 | 43.0 | 33.9 | 30.3 | 42.7 |
| 1963 | 8.7 | 31.2 | 38.7 | 44.0 | 53.6 | 59.1 | 64.1 | 66.6 | 59.4 | 47.5 | 34.8 | 18.0 | 43.8 |
| 1964 | 21.9 | 22.6 | 28.5 | 42.1 | 48.9 | 57.0 | 66.2 | 60.8 | 51.1 | 42.1 | 30.4 | 19.4 | 40.9 |
| 1965 | 24.6 | 24.6 | 25.6 | 44.7 | 48.9 | 57.2 | 65.0 | 64.1 | 47.8 | 47.0 | 36.4 | 27.2 | 42.7 |
| 1966 | 26.3 | 26.5 | 35.3 | 43.7 | 55.1 | 58.1 | 69.1 | 66.8 | 62.9 | 44.0 | 34.0 | 29.5 | 45.9 |
| 1967 | 31.0 | 34.5 | 34.0 | 40.9 | 51.4 | 60.3 | 70.0 | 71.2 | 62.2 | 44.6 | 31.9 | 22.9 | 46.2 |
| 1968 | 20.2 | 32.4 | 41.7 | 42.1 | 52.6 | 59.8 | 69.8 | 64.2 | 54.7 | 42.0 | 33.7 | 21.8 | 44.6 |
| RECORD MEAN | 21.8 | 27.4 | 35.4 | 44.8 | 52.8 | 59.8 | 67.8 | 65.9 | 56.4 | 45.3 | 33.1 | 25.2 | 44.6 |
| MAX | 29.9 | 36.4 | 45.8 | 57.4 | 66.4 | 74.0 | 85.1 | 83.0 | 71.3 | 57.8 | 41.4 | 32.3 | 56.7 |
| MIN | 13.7 | 18.4 | 24.9 | 32.4 | 39.2 | 45.5 | 50.5 | 48.8 | 41.4 | 32.8 | 24.7 | 18.0 | 32.5 |

### Total Degree Days

| Season | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1930-31 | 8 | 9 | 232 | 700 | 1053 | 1324 | 1163 | 989 | 853 | 564 | 272 | 104 | 7271 |
| 1931-32 | 30 | 27 | 299 | 645 | 1094 | 1330 | 1348 | 1177 | 1035 | 584 | 368 | 146 | 8083 |
| 1932-33 | 42 | 63 | 258 | 645 | 812 | 1466 | 1223 | 1276 | 889 | 649 | 491 | 85 | 7899 |
| 1933-34 | 4 | 76 | 330 | 526 | 810 | 982 | 958 | 853 | 709 | 379 | 237 | 148 | 6012 |
| 1934-35 | 22 | 5 | 385 | 546 | 777 | 1129 | 1295 | 960 | 960 | 749 | 431 | 184 | 7443 |
| 1935-36 | 40 | 68 | 152 | 633 | 1009 | 1132 | 1176 | 1526 | 937 | 494 | 204 | 116 | 7487 |
| 1936-37 | 1 | 24 | 250 | 483 | 1030 | 1040 | 1875 | 1079 | 853 | 620 | 271 | 175 | 7701 |
| 1937-38 | 10 | 55 | 147 | 398 | 801 | 1068 | 1222 | 1061 | 865 | 525 | 361 | 79 | 6592 |
| 1938-39 | 17 | 49 | 67 | 508 | 1010 | 1041 | 971 | 1131 | 779 | 484 | 244 | 246 | 6547 |
| 1939-40 | 30 | 9 | 173 | 518 | 848 | 980 | 1447 | 971 | 735 | 539 | 263 | 88 | 6601 |
| 1940-41 | 10 | 2 | 125 | 474 | 1090 | 1102 | 1213 | 880 | 704 | 529 | 310 | 128 | 6567 |
| 1941-42 | 1 | 53 | 396 | 663 | 910 | 1163 | 1598 | 1210 | 929 | 519 | 450 | 263 | 8155 |
| 1942-43 | 35 | 62 | 208 | 553 | 983 | 1217 | 1580 | 1121 | 1176 | 530 | 479 | 281 | 8225 |
| 1943-44 | 58 | 46 | 175 | 520 | 940 | 1403 | 1328 | 1056 | 1056 | 559 | 326 | 168 | 7635 |
| 1944-45 | 40 | 58 | 231 | 521 | 960 | 1404 | 1165 | 934 | 936 | 730 | 366 | 269 | 7614 |
| 1945-46 | 17 | 22 | 329 | 505 | 935 | 1269 | 1205 | 954 | 755 | 558 | 367 | 186 | 7102 |
| 1946-47 | 23 | 38 | 317 | 753 | 1030 | 1187 | 1346 | 948 | 818 | 584 | 262 | 261 | 7567 |
| 1947-48 | 13 | 70 | 282 | 533 | 1050 | 1228 | 1327 | 1110 | 1035 | 655 | 377 | 111 | 7791 |
| 1948-49 | 72 | 67 | 307 | 667 | 985 | 1592 | 1878 | 1220 | 1031 | 539 | 277 | 189 | 8824 |
| 1949-50 | 59 | 41 | 225 | 755 | 811 | 1250 | 1679 | 1086 | 962 | 684 | 500 | 231 | 8283 |
| 1950-51 | 59 | 34 | 304 | 569 | 1052 | 1119 | 1424 | 978 | 1086 | 633 | 408 | 270 | 7936 |
| 1951-52 | 67 | 83 | 306 | 663 | 1022 | 1408 | 1474 | 1112 | 1015 | 500 | 348 | 206 | 8204 |
| 1952-53 | 82 | 59 | 171 | 514 | 1041 | 1203 | 897 | 924 | 840 | 680 | 511 | 257 | 7179 |
| 1953-54 | 27 | 62 | 175 | 546 | 825 | 1016 | 1285 | 927 | 1007 | 665 | 354 | 276 | 7165 |
| 1954-55 | 37 | 122 | 300 | 677 | 790 | 1220 | 1316 | 1186 | 1221 | 750 | 528 | 199 | 8346 |
| 1955-56 | 117 | 19 | 324 | 587 | 1217 | 1370 | 1302 | 1286 | 1019 | 566 | 296 | 186 | 8289 |
| 1956-57 | 54 | 90 | 226 | 626 | 1024 | 1078 | 1686 | 1078 | 906 | 599 | 256 | 161 | 7784 |
| 1957-58 | 26 | 58 | 178 | 699 | 964 | 1017 | 1116 | 879 | 889 | 634 | 173 | 132 | 6765 |
| 1958-59 | 47 | 30 | 295 | 608 | 964 | 1098 | 1201 | 1159 | 872 | 613 | 505 | 134 | 7526 |
| 1959-60 | 67 | 101 | 337 | 617 | 1151 | 1185 | 1494 | 1135 | 988 | 636 | 466 | 148 | 8325 |
| 1960-61 | 8 | 136 | 256 | 655 | 957 | 1642 | 1340 | 856 | 862 | 679 | 425 | 67 | 7683 |
| 1961-62 | 6 | 10 | 448 | 734 | 1128 | 1343 | 1541 | 1117 | 1048 | 580 | 455 | 234 | 8644 |
| 1962-63 | 83 | 104 | 298 | 674 | 925 | 1065 | 1745 | 941 | 808 | 623 | 350 | 204 | 7820 |
| 1963-64 | 76 | 51 | 183 | 535 | 899 | 1449 | 1327 | 1222 | 1124 | 680 | 492 | 240 | 8278 |
| 1964-65 | 30 | 153 | 409 | 698 | 1031 | 1406 | 1246 | 1124 | 1218 | 602 | 491 | 230 | 8638 |
| 1965-66 | 44 | 88 | 509 | 555 | 849 | 1165 | 1194 | 1075 | 914 | 631 | 304 | 216 | 7544 |
| 1966-67 | 23 | 46 | 94 | 645 | 921 | 1097 | 1045 | 848 | 952 | 712 | 416 | 145 | 6944 |
| 1967-68 | 2 | 4 | 116 | 630 | 987 | 1299 | 1383 | 941 | 718 | 678 | 379 | 168 | 7305 |
| 1968-69 | 10 | 97 | 305 | 705 | 935 | 1333 | | | | | | | |

Record mean values above (not adjusted for instrument location changes listed in the Station Location table) are means for the period beginning in 1892 for temperature and 1886 for precipitation.

A horizontal line drawn on the above tables indicates a break in the data sequence due to a change in instrument exposure or a station move (see Station Location table). Data are from Cooperative locations and the Montana Building through November 1944. Later data are from Airport locations.

Source: U.S. Department of Commerce, Local Climatological Data: Annual Summary with Comparative Data, 1968, Missoula, Montana (Washington: GPO, 1968), p. 3.

# TABLE B.15

## PRECIPITATION DATA: MISSOULA

### Total Precipitation

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1931 | 0.48 | 0.65 | 1.03 | 0.18 | 0.22 | 1.15 | 0.78 | 0.11 | 2.17 | 0.15 | 0.74 | 0.50 | 8.16 |
| 1932 | 0.54 | 0.80 | 1.00 | 0.82 | 3.58 | 0.74 | 0.54 | 1.41 | 0.15 | 0.71 | 0.51 | 0.47 | 11.27 |
| 1933 | 1.02 | 1.00 | 0.20 | 0.81 | 2.64 | 1.52 | 0.19 | 1.12 | 1.17 | 2.87 | 0.70 | 2.35 | 15.59 |
| 1934 | 0.92 | 0.08 | 2.02 | 0.69 | 0.55 | 2.67 | 0.31 | 0.25 | 0.78 | 1.80 | 0.78 | 0.69 | 11.54 |
| 1935 | 0.60 | 0.20 | 0.83 | 0.78 | 2.02 | 1.04 | 0.77 | 0.44 | 0.33 | 0.81 | 0.57 | 0.28 | 8.67 |
| 1936 | 1.23 | 2.63 | 0.54 | 0.51 | 1.54 | 2.05 | 0.50 | 0.39 | 1.22 | 0.47 | 0.13 | 0.68 | 11.89 |
| 1937 | 0.75 | 1.03 | 0.52 | 0.93 | 0.97 | 1.08 | 0.47 | 0.33 | 0.57 | 0.68 | 0.54 | 2.47 | 10.34 |
| 1938 | 0.59 | 1.35 | 0.76 | 0.74 | 2.69 | 3.13 | 0.66 | 0.63 | 0.66 | 0.91 | 0.50 | 0.40 | 13.02 |
| 1939 | 0.59 | 1.25 | 1.03 | 0.83 | 2.31 | 2.14 | 0.49 | 0.10 | 0.88 | 0.86 | 0.14 | 1.94 | 12.56 |
| 1940 | 1.01 | 1.43 | 1.22 | 1.64 | 0.88 | 1.14 | 1.08 | 0.14 | 1.68 | 0.83 | 1.04 | 0.23 | 12.32 |
| 1941 | 0.55 | 0.63 | 0.27 | 1.04 | 2.72 | 3.10 | 1.38 | 0.93 | 1.62 | 1.07 | 1.59 | 0.93 | 15.79 |
| 1942 | 0.55 | 0.71 | 0.33 | 0.66 | 3.77 | 2.05 | 0.55 | 0.64 | 1.51 | 1.21 | 1.41 | 1.50 | 14.89 |
| 1943 | 1.79 | 0.82 | 0.73 | 3.15 | 1.93 | 2.70 | 0.78 | 0.46 | 0.05 | 1.73 | 0.54 | 1.03 | 15.71 |
| 1944 | 0.04 | 0.72 | 1.24 | 1.11 | 1.69 | 3.47 | 0.45 | 1.43 | 1.20 | 0.38 | 0.44 | 1.05 | 13.22 |
| 1945 | 0.31 | 0.34 | 0.40 | 2.00 | 1.42 | 0.73 | 0.20 | 0.16 | 1.31 | 0.48 | 0.92 | 1.51 | 9.78 |
| 1946 | 0.41 | 0.34 | 0.76 | 0.33 | 0.36 | 1.38 | 3.05 | 0.44 | 0.78 | 2.33 | 0.82 | 1.43 | 12.43 |
| 1947 | 0.42 | 1.05 | 0.47 | 0.38 | 1.50 | 1.92 | 0.78 | 2.18 | 1.70 | 1.09 | 2.41 | 0.78 | 14.68 |
| 1948 | 1.32 | 0.97 | 0.41 | 0.65 | 4.10 | 3.36 | 1.50 | 0.24 | 0.13 | 0.23 | 0.92 | 1.04 | 14.67 |
| 1949 | 0.34 | 0.97 | 0.51 | 0.12 | 1.71 | 1.06 | 0.57 | 0.22 | 1.33 | 0.74 | 0.72 | 0.65 | 8.94 |
| 1950 | 1.75 | 0.50 | 0.58 | 0.71 | 0.61 | 2.35 | 1.19 | 1.62 | 0.61 | 1.41 | 1.74 | 1.11 | 14.18 |
| 1951 | 1.08 | 0.51 | 0.92 | 2.25 | 1.29 | 1.15 | 0.92 | 0.83 | 1.28 | 1.31 | 1.67 | 1.81 | 15.02 |
| 1952 | 0.79 | 0.62 | 0.48 | 0.08 | 1.96 | 1.76 | 0.24 | 0.63 | 0.69 | 0.13 | 0.61 | 0.63 | 8.62 |
| 1953 | 2.19 | 1.37 | 0.20 | 0.89 | 2.78 | 1.12 | 0.11 | 0.45 | 0.72 | 0.09 | 0.62 | 0.82 | 11.36 |
| 1954 | 2.21 | 1.05 | 0.48 | 0.68 | 1.60 | 2.42 | 0.79 | 1.14 | 2.22 | 0.40 | 0.23 | 0.38 | 13.60 |
| 1955 | 0.61 | 0.87 | 1.16 | 1.04 | 2.28 | 1.85 | 2.49 | 0.02 | 0.62 | 0.48 | 1.66 | 2.74 | 15.82 |
| 1956 | 0.80 | 0.95 | 1.17 | 2.46 | 0.66 | 2.87 | 1.96 | 1.00 | 0.49 | 1.35 | 0.46 | 0.99 | 15.16 |
| 1957 | 1.12 | 0.51 | 0.94 | 0.53 | 3.22 | 0.86 | 0.69 | 0.92 | 0.21 | 1.35 | 0.45 | 1.41 | 12.21 |
| 1958 | 0.52 | 1.14 | 0.41 | 1.42 | 1.27 | 4.19 | 1.67 | 0.67 | 1.15 | 1.35 | 1.78 | 1.41 | 16.98 |
| 1959 | 2.08 | 1.14 | 0.62 | 0.88 | 2.43 | 1.69 | 0.13 | 0.93 | 3.11 | 1.71 | 1.30 | 0.27 | 16.29 |
| 1960 | 1.04 | 0.53 | 0.72 | 0.72 | 1.41 | 0.53 | 0.13 | 1.69 | 0.37 | 0.67 | 1.09 | 0.97 | 9.87 |
| 1961 | 0.53 | 1.01 | 1.39 | 1.52 | 2.58 | 0.35 | 0.40 | 0.89 | 1.53 | 1.34 | 1.38 | 1.18 | 14.10 |
| 1962 | 1.21 | 1.32 | 0.66 | 0.72 | 1.88 | 1.49 | 0.40 | 0.59 | 0.90 | 1.35 | 0.61 | 0.86 | 11.99 |
| 1963 | 2.38 | 0.80 | 1.26 | 0.68 | 0.25 | 3.29 | 1.11 | 1.29 | 1.54 | 0.62 | 0.61 | 1.06 | 14.89 |
| 1964 | 0.70 | 0.51 | 0.67 | 1.49 | 1.22 | 3.13 | 0.94 | 1.84 | 0.51 | 0.50 | 0.56 | 3.15 | 15.22 |
| 1965 | 1.46 | 0.62 | 0.67 | 1.68 | 0.63 | 1.55 | 1.59 | 2.24 | 2.11 | 0.17 | 1.05 | 0.43 | 14.20 |
| 1966 | 1.44 | 0.96 | 0.86 | 0.66 | 0.50 | 1.81 | 0.71 | 1.01 | 0.96 | 0.81 | 0.59 | 0.79 | 11.10 |
| 1967 | 1.22 | 0.27 | 1.09 | 0.93 | 1.33 | 2.67 | 0.40 | T | 0.49 | 1.64 | 0.65 | 1.71 | 12.40 |
| 1968 | 0.87 | 0.73 | 0.60 | 0.94 | 1.05 | 1.89 | 0.21 | 2.38 | 1.92 | 0.54 | 0.55 | 1.17 | 12.85 |
| RECORD MEAN | 1.01 | 0.85 | 0.87 | 1.03 | 1.78 | 2.01 | 0.93 | 0.87 | 1.22 | 1.06 | 1.06 | 1.12 | 13.81 |

### Total Snowfall

| Season | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1930-31 | 0.0 | 0.0 | 0.0 | 1.7 | 3.0 | 3.4 | 5.3 | 6.2 | 0.3 | 0.0 | 0.0 | 0.0 | 19.9 |
| 1931-32 | 0.0 | 0.0 | 0.0 | 0.0 | 4.5 | 6.3 | 2.1 | 7.8 | 7.9 | 0.0 | 0.0 | 0.0 | 28.6 |
| 1932-33 | 0.0 | 0.0 | 0.0 | 1.5 | 0.0 | 6.3 | 7.4 | 15.6 | 2.5 | 1.3 | 2.0 | 0.0 | 36.6 |
| 1933-34 | 0.0 | 0.0 | 0.0 | T | 1.3 | 10.3 | 0.5 | 1.5 | 5.0 | 2.0 | 0.0 | 0.0 | 20.6 |
| 1934-35 | 0.0 | 0.0 | 1.5 | 0.0 | 3.2 | 8.5 | 9.6 | T | 2.0 | 1.5 | 0.0 | 0.0 | 26.3 |
| 1935-36 | 0.0 | 0.0 | 0.0 | 3.3 | 1.0 | T | 10.0 | 43.5 | 2.8 | 1.1 | T | 0.0 | 61.7 |
| 1936-37 | 0.0 | 0.0 | 0.0 | 0.2 | 1.5 | 8.8 | 12.6 | 18.0 | 7.2 | 0.4 | 0.0 | T | 48.7 |
| 1937-38 | 0.0 | 0.0 | T | 0.0 | 0.9 | 7.2 | 7.8 | 14.3 | 3.5 | T | T | 0.0 | 33.7 |
| 1938-39 | 0.0 | 0.0 | 0.0 | T | 3.5 | 2.6 | 5.5 | 15.8 | 5.1 | T | 0.0 | 0.0 | 32.5 |
| 1939-40 | 0.0 | 0.0 | 0.0 | 3.0 | T | 5.1 | 11.2 | 5.8 | 1.1 | T | 0.0 | 0.0 | 26.2 |
| 1940-41 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 | 1.4 | 3.7 | 3.3 | T | 1.4 | T | 0.0 | 14.8 |
| 1941-42 | 0.0 | 0.0 | 0.0 | T | 0.7 | 5.9 | 10.6 | 10.6 | 3.2 | T | 0.8 | 0.0 | 31.8 |
| 1942-43 | 0.0 | 0.0 | 0.0 | 0.4 | 12.1 | 12.7 | 21.2 | 11.3 | 5.3 | T | 0.9 | 0.0 | 63.9 |
| 1943-44 | 0.0 | 0.0 | 0.0 | T | T | 5.8 | 0.8 | 9.2 | 10.4 | T | T | 0.0 | 26.2 |
| 1944-45 | 0.0 | 0.0 | T | 0.0 | 0.8 | 19.2 | 2.2 | 4.6 | 3.6 | 2.5 | 0.0 | 0.0 | 32.9 |
| 1945-46 | 0.0 | 0.0 | T | T | 5.0 | 13.2 | 3.0 | 3.3 | 2.7 | T | 0.0 | 0.0 | 27.2 |
| 1946-47 | 0.0 | 0.0 | 0.0 | 0.2 | 9.2 | 11.9 | 5.8 | 2.0 | 3.8 | T | 0.0 | 0.0 | 32.9 |
| 1947-48 | 0.0 | 0.0 | T | 0.0 | 17.7 | 10.0 | 4.2 | 4.0 | 4.7 | 2.6 | 1.0 | 0.0 | 44.2 |
| 1948-49 | 0.0 | 0.0 | T | 0.3 | 5.4 | 15.2 | 6.0 | 12.5 | 8.1 | T | 0.0 | 0.0 | 47.5 |
| 1949-50 | 0.0 | 0.0 | T | 0.7 | 2.0 | 8.5 | 19.5 | 3.4 | 3.0 | 6.9 | 0.1 | 0.0 | 44.1 |
| 1950-51 | 0.0 | 0.0 | T | 0.1 | 12.9 | 12.3 | 11.6 | 4.8 | 8.5 | 6.1 | T | 0.0 | 56.3 |
| 1951-52 | 0.0 | 0.0 | 0.0 | 2.0 | 12.1 | 25.0 | 13.0 | 6.3 | 6.6 | T | 0.0 | 0.0 | 65.0 |
| 1952-53 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 5.8 | 6.5 | 14.7 | 0.5 | 2.2 | 3.4 | 0.0 | 33.7 |
| 1953-54 | 0.0 | 0.0 | 0.0 | 0.0 | T | 4.2 | 24.2 | 2.1 | 1.4 | 2.8 | 0.0 | T | 34.7 |
| 1954-55 | 0.0 | 0.0 | T | T | T | 2.0 | 9.6 | 11.4 | 13.4 | 2.0 | 0.5 | 0.0 | 38.9 |
| 1955-56 | 0.0 | 0.0 | T | 0.6 | 16.0 | 20.1 | 11.4 | 15.6 | 7.1 | 3.5 | T | 0.0 | 74.3 |
| 1956-57 | 0.0 | 0.0 | 0.0 | 2.5 | 1.6 | 1.8 | 19.9 | 6.5 | 9.6 | T | 0.0 | 0.0 | 41.9 |
| 1957-58 | 0.0 | 0.0 | T | 1.2 | 4.5 | 4.0 | 5.3 | 14.5 | 2.2 | 2.9 | T | 0.0 | 34.6 |
| 1958-59 | 0.0 | 0.0 | 0.0 | T | 4.3 | 9.0 | 13.8 | 18.5 | 4.9 | 0.5 | 1.3 | 0.0 | 52.3 |
| 1959-60 | 0.0 | 0.0 | T | 0.2 | 13.8 | 2.7 | 17.9 | 7.4 | 7.2 | 2.3 | T | 0.0 | 51.5 |
| 1960-61 | 0.0 | 0.0 | 0.0 | 0.2 | 5.1 | 11.7 | 7.9 | 3.3 | 5.2 | 4.7 | 6.5 | 0.0 | 44.6 |
| 1961-62 | 0.0 | 0.0 | T | 4.6 | 15.1 | 11.3 | 9.0 | 10.4 | 6.9 | T | 0.0 | 0.0 | 57.3 |
| 1962-63 | 0.0 | 0.0 | T | T | 0.8 | 1.1 | 42.5 | 3.5 | 6.7 | 1.5 | 0.1 | 0.0 | 56.2 |
| 1963-64 | 0.0 | 0.0 | 0.0 | T | 3.0 | 20.6 | 12.2 | 8.9 | 11.1 | 0.5 | 7.5 | 0.0 | 63.8 |
| 1964-65 | 0.0 | 0.0 | 0.0 | 1.7 | 3.7 | 31.6 | 21.5 | 11.2 | 8.4 | 4.0 | T | 0.0 | 82.1 |
| 1965-66 | 0.0 | 0.0 | 0.2 | 0.0 | 3.2 | 6.4 | 14.3 | 18.6 | 9.0 | 5.7 | T | 0.0 | 57.4 |
| 1966-67 | 0.0 | 0.0 | 0.0 | 0.2 | 3.4 | 11.2 | 7.4 | 2.2 | 8.9 | 5.7 | 2.6 | 0.0 | 41.6 |
| 1967-68 | 0.0 | 0.0 | 0.0 | 0.3 | 5.1 | 12.6 | 14.5 | 2.8 | 1.5 | 5.8 | T | 0.0 | 42.6 |
| 1968-69 | 0.0 | 0.0 | T | T | 1.5 | 19.5 | | | | | | | |

Record mean values above (not adjusted for instrument location changes listed in the Station Location table) are means for the period beginning in 1892 for temperature and 1886 for precipitation.

A horizontal line drawn on the above tables indicates a break in the data sequence due to a change in instrument exposure or a station move (see Station Location table). Data are from Cooperative locations and the Montana Building through November 1944. Later data are from Airport locations.

Source: U.S. Department of Commerce, Local Climatological Data: Annual Summary with Comparative Data, 1968, Missoula, Montana (Washington: GPO, 1968), p. 3.

the lowest for the Rocky Mountain states.[72] However considerable areas, notably in the western portion, have elevations in excess of 5,000 feet.[73] There are, within the State, four peaks in excess of 12,000 feet, 13 in excess of 11,000 feet, and 48 which exceed 10,000 feet.[74] While the study region encompasses many of these majestic mountains (though it should be noted that the highest peaks are found east of the Continental Divide), it also includes the lowest point in the State--1,800 feet above sea level in Lincoln County where the Kootenai River leaves the State.[75]

The Rocky Mountains occupy approximately one-third (49,000 square miles) of the total area of Montana.[76] These mountains consist of generally parallel ranges on a northwest-southeast axis, with the Continental Divide, however, following a meandering course north and south.[77] Within this rugged, generally forested region are found more than 25 mountain ranges between which are located many basins and valleys, the larger of which are 10 to 20 miles wide and 25 to 100 miles long.[78] The study region includes the follow-

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[72] Montana State University, The Montana Almanac (Missoula, Montana: Montana State University, 1958), 1959-60 Edition, p. 6.

[73] Ibid. [74] Ibid., pp. 6-7. [75] Ibid., p. 7.

[76] Ibid., p. 3.

[77] Federal Writers' Project of the Work Projects Administration, Montana: a State Guidebook, ed. J. A. Stahlberg (New York: The Viking Press for the Department of Agriculture, Labor, and Industry, State of Montana, 1939), p. 9.

[78] Montana State University, op. cit., pp. 3-4.

ing principal ranges: Bitterroot Range, Mission Range, Garnet Range, Cabinet Mountains, Purcell Mountains, Flathead Mountains, Lewis Range, and Sapphire Mountains.

The topography of western Montana is the result of a long geologic history. Indeed, it has been noted that ". . . all geologic periods have left traces in Montana."[79] Initially, during the Archaean period, the entire region was the bottom of an arm of the Pacific Ocean. It shared the lush vegetation characteristic of later Paleozoic times and was the swampy home of numerous Mesozoic reptiles.[80] During the mountain building processes that occurred near the end of Cretaceous time, the predecessors of the modern Rocky Mountains were formed and the region began to look something like it does today. The region was then peneplained, and, during the Eocene Period, there was much volcanic action.[81] During this time, the volcanic action forced hot lava to the surface forming conical hills ranging to several thousand feet in height.[82] In the Miocene and again in the Pliocene, much of the western portion of the State was uplifted, with subsequent river erosion separating the ranges and local glaciation carving mountain tops and broadening valleys.[83]

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[79] Federal Writers' Project, op. cit., p. 12.

[80] Federal Writers' Project, loc. cit.

[81] Federal Writers' Project, loc. cit.

[82] Federal Writers' Project, loc. cit.

[83] "Rocky Mountains," Collier's Encyclopedia, Vol. XX (1974), p. 136.

During the Pleistocene Epoch, four great ice sheets moved down from the northern part of the continent, with each one erasing most of the visable effects left by its predecessor.[84] The last of these ice sheets, the Wisconsin sheet, came only as far as the Missouri River and stayed exclusively east of the Rockies. Thus the abundance of glacial features characterizing much of the western Montana landscape are a result of the action of piedmont glaciers, independent of the Wisconsin sheet.[85]

All of the western mountains were glaciated during the Pliestocene Epoch (approximately one million years ago).[86] The huge moraines deposited by these mountain glaciers acted as great dams causing the formation of hundreds of lakes. Two of the largest of these lakes are Missoula Lake (now dry), formed by the blocking of the Clark Fork of the Columbia, and Flathead Lake, presently one of the largest fresh-water bodies in the United States.[87] With the passing of the glaciers, the topography of the western Montana region was left substantially as it is today.

## Hydrographic Features

According to the Montana Almanac, the State ". . .

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[84] Federal Writers' Project, *loc. cit.*

[85] Federal Writers' Project, *loc. cit.*

[86] Gries, *loc. cit.*, p. 486.

[87] Federal Writers' Project, *loc. cit.*

has the distinction of having within its borders portions of three major drainage systems."[88] The territory west of the Continental Divide (including the study region) is drained via the Columbia River into the Pacific Ocean. The principal stream in the Montana portion of the Columbia River Basin is the Clark Fork of the Columbia River. The headwaters of the Clark Fork are in the mountains south and east of the city of Butte. Major tributaries of the Clark Fork include the Bitterroot River, which drains the Bitterroot Valley and joins the Clark Fork in the Missoula Valley; the Big Blackfoot River, which drains an extensive area north of the Garnet Range and enters the Clark Fork approximately eight miles east of Missoula; and the Flathead River whose numerous tributaries gather water from the Mission, Swan, Flathead, Whitefish, Galton, and McDonald Ranges, and which, after flowing through Flathead Lake, enters the Clark Fork near Paradise, nearly 70 miles northwest of Missoula.[89] The Kootenai River, which joins the Columbia in Canada, makes only a brief dip into the northwestern corner of the State.

The U.S. Geological Survey has estimated that an average of approximately 4.7 billion cubic feet (35 billion gallons or 108 thousand acre feet) of water are drained

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[88] Montana State University, op. cit., p. 33.

[89] Montana State University, op, cit., p. 34.

from the State daily.[90] Of this total volume, approximately 63 percent leaves via the Columbia Basin (Clark Fork River--38 percent, Kootenai River--25 percent), and about 37 percent via the Missouri system.[91]

The majority of Montana's natural lakes are found in the western portion of the State. Lakes found within the study region include Flathead Lake. Straddling the boundary between Flathead and Lake Counties, Flathead Lake has a surface area of approximately 188 square miles, making it the largest lake in the State and the second largest natural freshwater lake west of the Mississippi River.[92] Other lakes located in the western Montana region include Whitefish, McDonald, Swan, and Mary Ronan. In addition to these natural lakes, the study region includes several large resevoirs. Among these resevoirs, the Cabinet Gorge (on the Clark Fork) and Hungary Horse (on the South Fork of the Flathead River) are the largest.

Soils

The spatial distribution of soil types is controlled, essentially, by climate and topography. Other factors influencing the soil-forming process include: parent material (i.e., bedrock), natural vegetation, organisms, and of course, time. It has already been noted that the

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[90]Montana State University, op. cit., p. 33.

[91]Montana State University, loc. cit.

[92]Montana State University, loc. cit.

climate and topography of the western Montana region are significantly different from that which characterizes the eastern portion of the State. Thus, it is not surprising that western Montana soils are also quite different from those found throughout eastern Montana.

In the rugged territory west of the Continental Divide, the soil cover consists mainly of only partially decomposed rock which may be residual at the site of decomposition, may be slowly moving down slope under the influence of erosion and gravity, or may have accumulated in the valley bottoms.[93] Elevation is a key factor with different major soil groups being found at each level. The higher elevations are associated with Podzol type soils, followed by Brown Podzolic and Gray Wooded soils, developed under forest cover, to the Chernozem, Chestnut, and Brown soils, developed under grasses in the valleys.[94] Many mountain soils are immature and thin because erosion has carried the richer decomposed materials into the valleys. These poorly developed soils, whether residual or transported, retain some of the characteristics associated with the parent material from which they developed.

It should be noted that the soil pattern of the mountain areas is complex. Differences in elevation, degree of slope, climatic conditions, and bedrock can produce a wide range of soil types, often existing in close proximity

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[93] Montana State University, _op. cit_., p. 82.

[94] Montana State University, _loc. cit_.

to one another. These micro-differences in soil type make generalized discussions of soils of limited value for many applications. This is especially true in mountainous regions.

Flora and Fauna

The physical environment of western Montana boasts many species of plants and provides excellent habitat for a large variety of animal life. The variety is so great as to preclude a comprehensive listing of all the genera, species, and sub-species found in the region. According to the Montana Almanac, more than 2,000 species of wild flowers and nonflowering plants are found in Montana.[95] These can be divided into three broad categories: subalpine, montane, and plains. The subalpine group is found at the higher elevations in the mountains, especially the Northern Rockies, during the short mid-summer season.[96] Included in this category are: glacier lilies, alpine poppies, columbines, white dryads, globeflowers, Indian paint-brushes, violets, asters, and arnicas; and at the highest elevations, Rocky Mountain laurel, white and purple heathers, and Labrador tea.[97]

The montane group (found at lower mountain elevations, valleys, and foothills), includes most of the coniferous

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[95] Montana State University, op. cit., p. 42.

[96] Montana State University, loc. cit.

[97] Montana State University, loc. cit.

trees. These include the following commercial species: Douglas-fir, alpine fir, grand fir, mountain hemlock, western hemlock, Rocky Mountain juniper, alpine larch, western larch, lumber pine, lodgepole pine, ponderosa pine, western white pine, whitebark pine, western redceder, Engelmann spruce, and western white spruce; in addition to Pacific yew, a noncommercial species.[98] Also included in the montane category are small amounts of commercial hardwood varieties (ash, aspen, birch, boxelder, cottonwood, elm, and willow) and noncommercial hardwoods (alder, chokecherry, hawthorn, maple, mountain-ash, and mountain-mahogany).[99] Flowers in this group include: dogtooth violets, windflowers, Mariposa lilies, beargrass, and, the State flower, the bitterroot.[100] The montane group also includes numerous shrubs.

Range lands found in the mountain valleys and the dry, open slopes and ridges in the forests of the region include the following native forage plants: bluebunch wheatgrass, needle and thread grass, and native blue grass, common on the drier and lower slopes; Idaho fescue and rough fescue, important on the better soils and at higher elevations; and many other grasses and herbs found with these dominant

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[98] Montana State University, op. cit., p. 74.

[99] Montana State University, loc. cit.

[100] Montana State University, op. cit., p. 42.

types.[101] The plains category includes species which are found mainly in the prairie regions of eastern Montana.

There are more than 90 species of mammals in Montana.[102] Among those commonly found in the western Montana region are many varieties of shrews and bats, black bear, marten, short-tailed weasel, long-tailed weasel, mink, striped skunk, badger, coyote, bobcat, golden-mantled marmot, Columbian ground squirrel, manteled ground squirrel, yellow pine chipmunk, rufous-tailed chipmunk, red squirrel, northern flying squirrel, northern pocket gopher, beaver, deer mouse, bushy-tailed woodrat, red-backed mouse, meadow vole, longtail vole, mountain vole, Richardson vole, muskrat, Rocky Mountain jumping mouse, house mouse, porcupine, pika, snowshoe rabbit, white-tailed jack rabbit, mountain cottontails, elk, white-tailed deer, mule deer, moose, and mountain goat.[103] In addition, the region also provides habitat for many less common or rare species including: pigmy shrew, grizzly bear, fisher, wolverine, otter, red fox, timber wolf, cougar, Canada lynx, hoary marmot, woodland caribou (which now only enter the State from British Columbia), and bighorn sheep.[104]

Also found within the State are 31 species of amphib-

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[101] Montana State University, op. cit., p. 82.

[102] Montana State University, op. cit., p. 42.

[103] Montana State University, op. cit., pp. 49-50.

[104] Montana State University, loc. cit.

ians and reptiles, approximately 60 species of fish, and over 300 species of birds.[105] Some of the amphibians and reptiles found in the study region include: long-toed salamander, rough-skinned newt, tailed frog, western toad, Pacific tree frog, northern wood frog, leopard frog, spotted frog, western painted turtle, western skink, northern alligator lizard, Great Basin rubber snake, western yellow-bellied racer, gopher snake, wandering garter snake, common garter snake, and western rattlesnake.[106]

Species of fish found in the rivers, lakes, and streams of the study region include the following native species: white sturgeon, Dolly Varden or bull trout, coastal cutthroat (Salmon Family), mountain whitefish, pigmy whitefish (rare), largescale sucker, longnose sucker, longnose dace (Minnow Family), peamouth chub (Minnow Family), redside shiner (Minnow Family), northern squawfish (Minnow Family), Burbot or ling (Cod Family), torrent sculpin, slimy sculpin, and Rocky Mountain mottled sculpin.[107] In addition, introduced species found in the region include: kokanee or sockeye salmon, coho or silver salmon, brook trout, lake trout, brown trout, yellowstone cutthroat trout, golden trout, rainbow trout, lake whitefish, grayling, carp, northern black bullhead, yellow

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[105] Montana State University, *op. cit.*, p. 42.

[106] Montana State University, *op. cit.*, p. 62.

[107] Montana State University, *op. cit.*, p. 60.

perch, yellow walleye or pikeperch, largemouth bass, and pumpkinseed (Sunfish Family).[108]

The spatial distribution of the more than 300 species of birds in Montana is very complex. Thus it is difficult to determine which of these species are found within the study region. A rather comprehensive list of the various species of birds found in Montana, grouped together as characteristic inhabitants of major vegetation types or communities, is presented in the Almanac.[109] The major vegetation types employed in this classification are:[110]

1. Alpine tundra
2. Coniferous forest
    a. Subalpine forest
    b. Montane forest
3. Woodland
    a. Upland woodland
    b. Streamside woodland (riparian)
4. Shrubland
    a. Streamside shrubland (riparian)
    b. Upland shrubland
5. Grassland
6. Wetlands
    a. Marsh

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[108] Montana State University, loc. cit.

[109] Montana State University, op. cit., pp. 52-60.

[110] Montana State University, op. cit., p. 52.

b. Lake and river margins.

The list of species provided in the Almanac is considered too lengthy for duplication in this report.

It should be noted that both State and Federal agencies are pursuing active wildlife management programs in an effort to maintain and hopefully improve the State's wildlife population. The Montana State Fish and Game Department maintains game ranges, wildlife development areas, preserves, game bird farms, and fish hatcheries and spawning stations.[111] In addition, numerous Federal facilities are also operated in the State for the purpose of protecting and enhancing Montana's valuable wildlife resource.

<u>Western Montana's Forest Resource</u>

A discussion of western Montana's forest resource necessarily includes elements from both the economic and ecologic systems of the region. As such, the discussion does not fit neatly into the individual discussions of these systems presented above. Thus the topic is discussed here in a separate section. Another justification for discussing the region's forest resource apart from the general descriptions of the economic system and physical environment is the great importance of this resource in western Montana.

It should be noted at the outset, that the term

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[111] Montana State University, <u>op. cit</u>., p. 43.

"forest resource" is a general one used to refer to what is actually a composite of several distinct resources. Indeed, a recent study identifies six separate resources associated with the forest land base: 1) the timber resource, 2) the recreation resource, 3) the range resource, 4) the wildlife resource, 5) the water resource, and 6) the mineral resource.[112] It is important to recognize the existence of these separate resources and, also, to recognize that no one resource is inherently more important than the others. Rather, each resource can assume primary importance depending upon the associated circumstances. It should also be pointed out that information necessary to develop a meaningful description of the region's forest resource was seldom available in dissaggregated form. Most often, relevant information could be obtained only for the State as a whole. Thus the discussion in this section is largely of the forest resources of the State and not specifically of the western Montana region. However, since the eight county region contains approximately 50.4 percent of the State's commercial forest land and 51.5 percent of the total forest land in the State (i.e., commercial and non-commercial), it is felt that a general description based on statewide data is also very descriptive of the

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[112] Benson, et al., op. cit., Chapter II, pp. 6-19.

western Montana region.[113]

The Forest Land Area and Ownership Pattern

Montana's total land area is approximately 93 million acres. Three-fourths of this land has been described as ". . . the wide open 'Big Sky' spaces that have given rise to Montana's colorful history and image of cowboys, open range, brawling mining camps, and frontier hardships."[114] The remaining one-fourth or approximately 23 million acres is classified as forest land. Figure B.2 provides a graphic representation of the overall land use pattern for the State.

Geographically, it has been estimated that about 80 percent of the total land area for that portion of the State lying west of the Continental Divide is in forest cover while only 12 percent of the eastern portion of the State is forested.[115] Indeed, as already noted, the eight county western Montana region, which lies west of the Divide, contains better than half of both the commercial and total forest land in the State. This concentration is even more striking when it is remembered that the region accounts for only 14.5 percent of the State's total land

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[113] Percentage figures computed from data found in: Forest Sub-Committee, Montana Rural Area Development Committee, Opportunities for Developing Montana's Forest Resources (Bozeman, Montana: Montana State University Cooperative Extension Service, 1971), pp. 16-17.

[114] Benson, *et al.*, *op. cit.*, p. iii.

[115] Benson, *et al.*, *op. cit.*, Chapter I, p. 1.

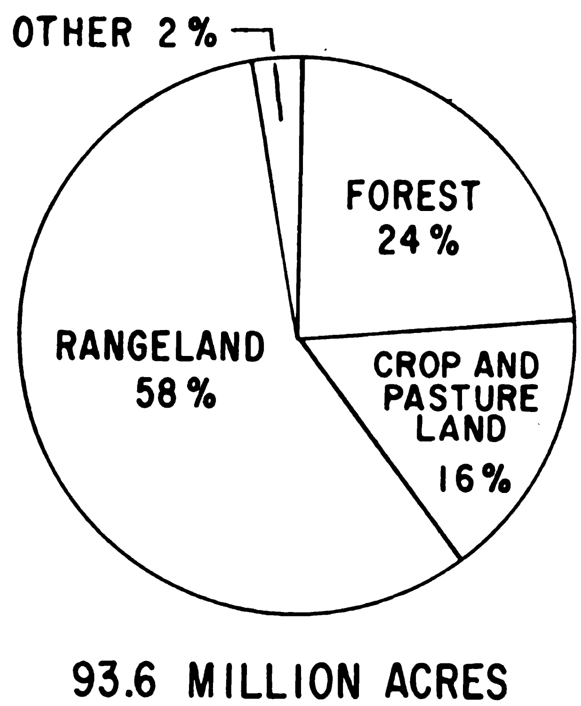


Figure B.2.--Montana's Land Use Pattern

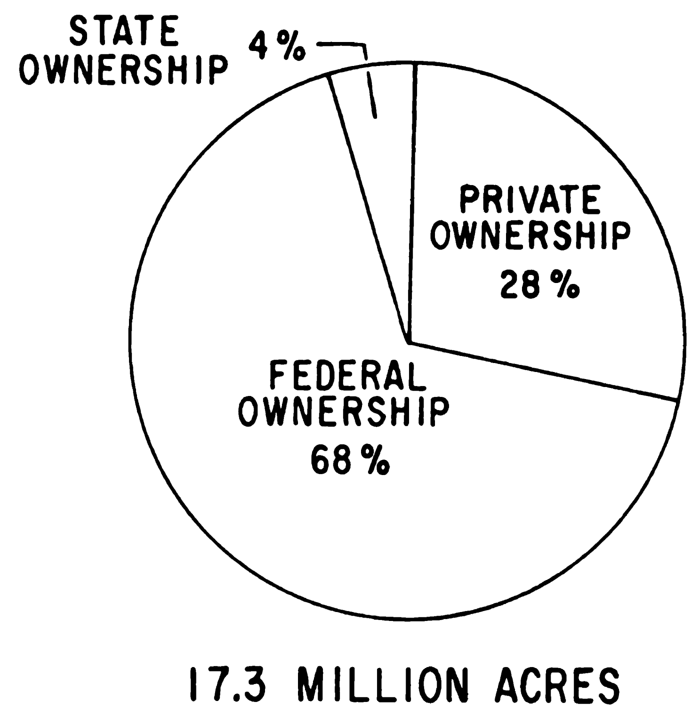


Figure B.3.--Montana's Commercial Forest Ownership Pattern

Source: Forest Sub-Committee, Montana Rural Area Development Committee, _Opportunities for Developing Montana's Forest Resources_ (Bozeman, Montana: Cooperative Extension Service, Montana State University, 1971), p. 15.

area. Of the 23 million acres of Montana forest land, approximately 17.3 million acres of 75 percent is classified as commercial.[116] Table B.16 provides information on the region's forest land by county and for the region as a whole.

While knowledge of the physical resource base is necessary, it is perhaps of equal importance to understand the ownership pattern associated with this base. This is particularly true because of the influence ownership has on the utilization and productivity of these lands.

The Federal Government is the largest owner of forest land in Montana. Of the estimated 22 to 24 million acres of Montana forest land,[117] approximately 75 percent or 17,057,800 acres are Federally owned.[118] Approximately 16,526,700 acres of the State's forest land is in National Forests.[119] This amounts to nearly 97 percent of Montana's Federally owned forest land and makes the Forest Service by far the largest single owner of such land in the State. Private holdings (i.e., forest industry, farmers, and other private holdings)total 4,565,400 acres which is about 20

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[116] Forest Sub-Committee, _op. cit_., p. 15.

[117] Estimates vary from one source to another. The variance is due largely to differences in the criteria used for classification.

[118] Benson, _et al_., _op. cit_., Chapter II, p. 2

[119] Benson, _et al_., _loc. cit_.

TABLE B.16

FOREST LAND IN WESTERN MONTANA

| Areal Unit | Forest Land-All Ownerships | | | | Non-Federal Forest Land | |
|---|---|---|---|---|---|---|
| | Commercial (acres) | Non-Commercial (acres) | Total (acres) | % Total Land Area | Acres | % Total Forest Land |
| Flathead | 1,610,082 | 1,294,644 | 2,904,726 | 87.7 | 657,119 | 22.6 |
| Granite | 648,574 | 157,320 | 805,894 | 73.3 | 159,411 | 19.8 |
| Lake | 444,879 | 91,767 | 536,646 | 55.9 | 375,863 | 70.0 |
| Lincoln | 1,845,865 | 422,811 | 2,268,676 | 95.4 | 535,970 | 23.6 |
| Mineral | 539,444 | 220,706 | 760,150 | 97.1 | 115,445 | 15.2 |
| Missoula | 1,193,795 | 270,607 | 1,464,402 | 87.0 | 790,303 | 54.0 |
| Ravalli | 554,156 | 691,669 | 1,235,825 | 81.0 | 162,649 | 13.2 |
| Sanders | 1,108,694 | 346,787 | 1,455,481 | 80.9 | 510,255 | 35.1 |
| Region[a] | 7,945,489 | 3,496,311 | 11,431,800 | 84.8 | 3,307,015 | 28.9 |

[a]Regional values computed by author.

Source: Forest Sub-Committee, Montana Rural Area Development Committee, Opportunities for Developing Montana's Forest Resources (Bozeman, Montana; Cooperative Extension Service, Montana State University, 1971), pp. 16-17.

percent of the total forest land in the State.[120] In 1971, 14,000 individuals owned privately held forest land in Montana, with 5,000 of these owners being farmers and ranchers who together owned approximately 41 percent of the privately owned forest land in the State.[121]

A similar pattern exists for the ownership of Montana's commercial forests. When only these commercial lands are considered, the private holdings are somewhat larger (28 percent) and Federal ownership is smaller (68 percent).[122] Figure B.3 illustrates the ownership pattern for the State's commercial forest lands.

The Timber Resource

In 1970, the current inventory volume of timber on Montana's commercial timberland totaled over 33 billion cubic feet.[123] The overwhelming majority of the State's forest is softwoods, with Lodgepole pine and Douglas-fir accounting for 30.9 percent and 28.8 percent of Montana's commercial forest land respectively.[124] Hardwoods, primarily cottonwood and some aspen, account for slightly

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[120] Computed from values contained in: Benson, et al., loc. cit.

[121] Forest Sub-Committee, op. cit., p. 13

[122] Forest Sub-Committee, op. cit., p. 15.

[123] Benson, et al., op. cit., Chapter II, p. 6.

[124] Benson, et al., loc. cit.

over 1 percent of the State's commercial forest.[125] Table B.17 classifies the forest types in Montana by principal species for commercial forest lands. Another way to classify Montana's timber inventory is by timber type. This is significant for a number of reasons with perhaps the most important being that commercial value varies from one type to another. Table B.18 provides such a classification and indicates that over half of the current inventory volume is in sawlogs.

It has been noted that an essential consideration in evaluating forest land as a timber resource base is its productivity, i.e., its capacity to grow usable wood.[126] Montana's forests have been classified for productive capacity. The breakdown for all commercial forest land in the State is shown in Table B.19. These data indicate that while some of the forest is highly productive, the major portion is classified in the middle to lower end of the growth potential range. While this classification provides an approximation of the growth potential for the State's forest land, it does not tell the whole story. An important measure of growth and use is the rate at which changes in inventory have been taking place over time. Table B.20 indicates that from 1952 to 1970, rate of growth and mortality of all growing stock remained the same with net

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[125] Benson, et al., loc. cit.

[126] Benson, et al., op. cit., Chapter II, p. 5.

TABLE B.17

MONTANA'S FOREST TYPES: PRINCIPAL SPECIES AS A PERCENT OF COMMERCIAL FOREST LAND

| Forest Type | Percent of Commercial Forest Land |
|---|---|
| Ponderosa pine | 16.5 |
| Douglas-fir | 28.8 |
| Lodgepole pine | 30.9 |
| Western larch | 7.8 |
| Alpine fir and spruce | 11.8 |
| All other softwood types | 3.0 |
| Hardwood | 1.2 |

Source: R. E. Benson, *et al.*, *A Descriptive Analysis of Montana's Forest Resources: A Progress Report* (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974), Chapter II, p. 6.

TABLE B.18

MONTANA'S CURRENT INVENTORY VOLUME
CLASSIFIED BY TIMBER TYPE[a]

| Class of Timber | Volume (billion cu. ft.) | Percent of Total Volume |
|---|---|---|
| Sawtimber trees[b] | | |
| Sawlog portion | 17.8 | 54 |
| Upper stem portion | 1.8 | 5 |
| Pole timber trees[c] | 9.0 | 27 |
| Subtotal growing stock | 28.6 | 86 |
| Rough and rotten trees | 1.5 | 4 |
| Salvable dead | 3.0 | 9 |
| Total | 33.2 | 100 |

[a]Sum not equal to total due to rounding.

[b]Trees 9 inches d.b.h. or larger.

[c]Trees 5 to 8 inches d.b.h.

Source: R. E. Benson, *et al.*, *A Descriptive Analysis of Montana's Forest Resources: A Progress Report* (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974), Chapter II, p. 7.

TABLE B.19

GROWTH POTENTIAL OF MONTANA'S CURRENT INVENTORY VOLUME

| Growth Potential Per Acre Per Year (cu. ft.) | Percentage of all Commercial Forest Land |
|---|---|
| 165 or more | 1 |
| 120 to 165 | 9 |
| 85 to 120 | 25 |
| 50 to 85 | 30 |
| 20 to 50 | 34 |

TABLE B.20

RATE OF GROWTH, MORTALITY, AND NET GROWTH AS A PERCENT OF GROWING STOCK VOLUME ON ALL GROWING STOCK IN MONTANA

| Measure | Percent of Growing Stock Volume | | |
|---|---|---|---|
| | 1952 | 1962 | 1970 |
| Gross growth<br>Less mortality | 2.1<br>-.6 | 2.1<br>-.6 | 2.1<br>-.6 |
| Net growth | 1.5 | 1.5 | 1.5 |
| Removals | .5 | .7 | 1.1 |

Source: R. E. Benson, et al., A Descriptive Analysis of Montana's Forest Resources: A Progress Report (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974), Chapter II, p. 5 (Table I.19) and p. 7 (Table I.20).

growth at approximately 1.5 percent of growing stock volume in each period.[127] However, in these same years, removals have increased from .5 percent of growing stock volume in 1952 to 1.1 percent in 1970, an increase of 100 percent. Subtracting the removals figure for each year from the corresponding net growth figure yields the rate at which total growing stock volume is changing. These rates are, approximately: 1.0 percent (1952), .8 percent (1962), and .4 percent (1970). Thus while the total growing stock volume was still increasing in 1970, the rate of increase was less than half of the rate for 1952. While these data may be subject to large errors, they do indicate a rather persistent decline in the rate of increase in inventory over time. However, it should be emphasized that despite the steady increase in removals through harvest, growth still exceeds removals on Montana's forests.[128]

In general, the State's forest land can be characterized as having a relatively low productive capacity for usable timber. This is at least partly due to underutilization of some species. It has been noted that while Douglas-fir, larch, and ponderosa pine are presently being cut above the allowable annual harvest for these species, lodgepole pine and spruce are being harvested at a rate of 85 percent below their allowable annual harvest.[129]

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[127] Benson, _et al._, _op. cit._, Chapter II, p. 7.

[128] Benson, _et al._, _op. cit._, Chapter II, p. 8.

[129] Forest Sub-Committee, _op. cit._, p. 27.

Another important contributing factor is the relatively poor age distribution of Montana timber, which has been attributed, in part, to many severe fires that occurred in the early part of this century.[130] As a result, a high percentage of the trees are over 120 years or under 60 years in age.[131]

Despite their apparent low productivity, Montana's forests have, during the past decade, provided about 3.5 to 4 percent of the total U.S. consumption of softwood lumber.[132] The 1969 species mix of sawlogs received at Montana mills is shown in Table B.21.

TABLE B.21

1969 SPECIES MIX OF SAWLOGS RECEIVED AT MONTANA SAWMILLS

| Species | Million bd. ft. |
|---|---|
| Douglas-fir | 343 |
| Ponderosa pine | 268 |
| Western larch | 234 |
| Engelmann spruce | 207 |
| Lodgepole pine | 107 |
| Other | 132 |
| Total | 1,291 |

Source: Benson, *et al.*, *op. cit.*, Chapter II, p. 12.

Another important product from the State's forests is plywood. A relatively recent development (the first plywood mills in Montana were built in the 1950's), Montana's

[130] Forest Sub-Committee, *loc. cit.*

[131] Forest Sub-Committee, *loc. cit.*

[132] Benson, *et al.*, *op. cit.*, Chapter II, p. 12.

plywood mills currently supply about 3 percent of U.S. consumption of softwood plywood.[133] According to one source, the output ". . . of other products--poles, posts, etc.--is relatively minor in Montana and accounts for about 2 percent of the total U.S. consumption."[134] Thus, even though Montana does not claim any unique products or species, it still makes an important contribution to the National supply of forest products.

The Recreation Resource

Despite the current uncertainty about fuel and energy supplies, the demand for outdoor recreation is expected to continue to grow, though possibly less rapidly than in the recent past. Due to the State's extremely attractive physical setting (especially the mountainous western region), the demand is expected to increase at an even more rapid rate in Montana than for the Nation as a whole.[135] However, there are conceptual difficulties involved in defining forest land as a recreation resource. Part of this problem involves the difficulties experienced in deciding what portion of the outdoor recreation experience should be attributed to the forest resource, e.g., is fishing in a mountain stream forest recreation just because the stream runs through forested land? Another complicating factor

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[133] Benson, _et al._, _loc. cit._

[134] Benson, _et al._, _loc. cit._

[135] Forest Sub-Committee, _op. cit._, p. 22.

stems from the now well known problem of quantifying recreational use in a meaningful way. While these conceptual difficulties certainly complicate the problem of defining the forest recreation resource, it is still possible to obtain at least a rough idea of its extent.

Some take the view that the entire 23 million acres of forest land in the State can be included as recreation resource while others confine this category to the 3 million acres in Montana on which recreation is the dominant use.[136] Much of this forest land on which recreation is the dominant use is in Wilderness Areas and National Parks. Table B.22 indicates the approximate acreage in each category. A recent report indicates that an additional

TABLE B.22

DISTRIBUTION OF MONTANA'S FOREST RECREATION LAND

| Category | Million Acres (forest land) |
| --- | --- |
| Wilderness and Primitive Areas .......... | 1.9 |
| Glacier and Yellowstone (portion) National Parks ................ | .9 |
| Other campgrounds, recreation areas, etc. (estimated) .............. | .2 |
| Total .................... | 3.0 |

Source: Benson, _et al_., _op. cit_., Chapter II, p. 14.

1.4 million acres of National Forest land are currently being considered for addition to the National Wilderness

[136] Benson, _et al_., _op. cit_., Chapter II, pp. 13-14.

Preservation System.[137]

Another way to estimate the size of Montana's forest recreation resource is to look at the extent of the developed recreational facilities in the State's forests. At the present time nearly 800 public recreational facilities of various types and ownerships can be found on Montana's forested land.[138] In addition, according to Benson, *et al.*,:

> Over 1,700 private recreation residences are located on leased public forest lands, and the residences in private forest lands would undoubtedly number in the thousands if data were available. For example, there are nearly 5,000 rural, nonfarm second homes in the State, and over 2,300 of these are in the 17 westernmost forested counties. It would be reasonable to assume that many of these are used for forest-oriented recreation.[139]

Statistics indicate that, in recent years, the number of facilities on public lands has remained relatively constant while the number of privately owned campgrounds has increased.[140] Table B.23 shows the types of facilities that have been developed on Montana's forest land by ownership.

Two very popular forms of recreation which, until recently, have received little attention by professionals are pleasure driving and hiking. Currently, Montana's National Forests provide approximately 17,000 miles of roads

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[137] Benson, *et al.*, *loc. cit.*

[138] Benson, *et al.*, *loc. cit.*

[139] Benson, *et al.*, *loc. cit.*

[140] Benson, *et al.*, *loc. cit.*

TABLE B.23

DEVELOPED RECREATION SITES ON MONTANA FOREST LANDS[a]

| Type | Ownership | | | | | |
|---|---|---|---|---|---|---|
| | National Forest | BLM | National Park | State Forest, Hwy., & Park | Private and Other[b] | Total |
| Campgrounds[c] | 256 | 6 | 88 | 16 | 139 | 505 |
| Picnic grounds | 85 | (NI)[d] | (NI)[d] | (NI)[d] | (NI)[d] | 85 |
| Boat-swim-fish | 60 | (NI)[d] | (NI)[d] | (NI)[d] | (NI)[d] | 60 |
| Lodge-resort | 31 | 0 | 2 | 0 | 7 | 40 |
| Winter sport | 17 | 0 | 0 | 2 | 10 | 29 |
| Other | 34 | 1 | 0 | 20 | (NA)[e] | 55 |
| Total Public | 483 | 7 | 90 | 38 | 156 | 764 |
| Residences | 1,100 | 0 | 0 | 603 | (NA)[e] | 1,703 |

[a]All developed sites reported by National Forests, National Parks, and State forests are included. For other owners, only areas or developed sites in or near forested land are included. Data for public lands from annual office reports and personal communication. Estimate of private ownerships developed from "1972 Sunset Western Campsite Directory," Lane Magazine and Book Co., Menlo Park, California.

[b]Includes Indian lands, community, and service group facilities.

[c]Includes organization camps, trail campsites, and shelters on National Parks.

[d]Not identified as to this activity; included in "campgrounds" in this ownership group.

[e]Not available.

Source: R. E. Benson, *et al.*, *A Descriptive Analysis of Montana's Forest Resources: A Progress Report* (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974), Chapter II, p. 15.

and 14,000 miles of trails.[141] While some roads and trails were constructed specifically to support recreational activities, most were developed to facilitate timber harvesting or management and protection activities. Indeed, according to Benson, et al., most of the trails ". . . are 35 to 70 years old and were built for a very different use than they now receive."[142] This does not, however, detract from their present value as a recreation resource. In recent years, the road system has grown steadily while trail mileage has declined as roads and aircraft have reduced the need for trail access in management activities.[143]

Perhaps a more meaningful measure of the forest recreation resource in Montana is the use of existing facilities. Though complete data are unavailable, it is possible to provide some numbers which do indicate the extent of forest-based recreational activity in the State. According to Benson, et al.,:

> In 1969, outdoor recreation in Montana, excluding transportation, was estimated to be a $145.5 million industry. A major share of these dollars were, no doubt, spent by visitors traveling to forested parts of the State. Other dollars were spent for second homes, recreation sites, and activities that depend upon nearby forests to provide desirable settings.[144]

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[141] Benson, et al., op. cit., Chapter II, p. 15.

[142] Benson, et al., loc. cit.

[143] Benson, et al., loc. cit.

[144] Benson, et al., op. cit., Chapter IV, p. 1.

On three of the principal forest land ownerships in the State, almost 9 million visitor-days were counted in 1971.[145] On the State's National Forests, 6,863,000 visitor-days were recorded, representing approximately 4.5 percent of all visits to all National Forests in that year.[146] Table B.24 shows the number of visitor-days recorded on each of these three ownerships for 1971.

TABLE B.24

VISITOR-DAYS ON EACH OF THREE PRINCIPAL FOREST LAND OWNERSHIPS IN MONTANA, 1971

| Ownership | Visitor-days |
|---|---|
| National Forests | 6,863,000 |
| Bureau of Land Management | 474,000 |
| Glacier National Park | 1,339,000 |
| Yellowstone National Park[a] | 225,000 |
| Total | 8,901,000 |

[a]10 percent of total 2,252,000 visitor-days estimated for Montana's portion of park attendance.

Source: Benson, _et al._, _op. cit._, Chapter IV, p. 2

Montana has approximately 13 percent of the Nation's Wilderness and Primitive Area acreage.[147] These areas occupy between 11 and 12 percent of all National Forest lands in the State and receive about 5 percent of the recreation use.[148] The extent and use of Montana's Wilder-

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[145] Benson, _et al._, _op. cit._, Chapter IV, p. 2.

[146] Benson, _et al._, _op. cit._, Chapter IV, p. 3.

[147] Benson, _et al._, _op. cit._, Chapter IV, p. 3.

[148] Benson, _et al._, _op. cit._, Chapter IV, pp. 3-4.

ness and Primitive Areas is shown in Table B .25.

Table B.26 indicates the 1971 allocation of total time spent in recreation among the various recreational activities on Montana National Forests. These use figures indicate that more time is spent traveling than in any of the

TABLE B.26

TIME SPENT IN VARIOUS RECREATION ACTIVITIES ON MONTANA NATIONAL FORESTS, 1971

| Activities | Percent of Total Time Spent in Recreation |
|---|---|
| Mechanized travel .............. | 26 |
| Camping ........................ | 21 |
| Hunting and fishing ............ | 19 |
| Winter sports .................. | 5 |
| Recreation residences .......... | 5 |
| Picnicing ...................... | 4 |
| Hiking ......................... | 3 |
| Water sports ................... | 3 |
| Other .......................... | 14 |
| Total ................ | 100 |

Source: Benson, *et al.*, *op. cit.*, Chapter IV, p. 4.

other activities listed. The second most popular activity--camping--accounts for 21 percent of the total time spent in recreation. When travel time is added to time spent at developed sites, the total accounts for 60 percent of the visitor-days to forest land.[149]

Approximately 19 percent of total recreational time was spent in fishing and hunting activities. This is not surprising since Montana's forest lands offer a wide range of high quality opportunities in this category. Indeed,

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[149] Benson, *et al.*, *loc. cit.*

TABLE B.25

EXTENT AND USE OF MONTANA'S WILDERNESS AND PRIMITIVE AREAS, 1970

| Name | Acres | Visitor-days |
|---|---|---|
| **Wilderness Areas** | | |
| Anaconda-Pintlar | 158,000 | 19,000 |
| Bob Marshall | 950,000 | 115,000 |
| Cabinet Mountains | 94,000 | 9,000 |
| Gates of the Mountains | 29,000 | 2,000 |
| Scapegoat | 240,000 | (NA)[a] |
| Selway-Bitterroot | 252,000[b] | 56,000 |
| **Primitive Areas** | | |
| Absaroka | 64,000 | 15,000 |
| Beartooth | 230,000 | 45,000 |
| Mission Mountains | 73,000 | 5,000 |
| Spanish Peaks[c] | 50,000 | 17,000 |

[a]Created in 1972.

[b]Montana portion only; also about 1 million acres in Idaho.

[c]Proposed for expansion to 63,000 acres if classified as Wilderness.

Source: R. E. Benson, *et al.*, *A Descriptive Analysis of Montana's Forest Resources: A Progress Report* (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974), Chapter IV, p. 3.

Benson, et al., note that:

> Montana offers 47 species of birds and 21 species of fish that are legally classified as game animals. In addition, there are 12 species of big game, a greater variety than is found in any other state.
>
> Several big game--elk, bear, goat, and moose--are found almost exclusively in forested and high mountain habitats, as are a good share of both white-tail and mule deer, and bighorn sheep.[150]

In 1970, 669,000 visitor-days of hunting were recorded on National Forest land.[151] This represents a 45 percent increase over 1960 and a 183 percent increase over 1955.[152] It is apparent that this aspect of forest recreation will continue to grow in popularity in future years.

The Range Resource

It has been noted that Montana's forests produce a considerable amount of forage for domestic livestock.[153] Forests where ponderosa pine and Douglas-fir types exist are particularly attractive for grazing purposes. These timber species generally provide an understory of palatable grasses such as bluebunch wheatgrass, Idaho fescue, June grass, spike trisetum, and a variety of grazeable forbs, and shrubs.[154] There are approximately 65 million acres of grazing land in the State with about 11.5 million

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[150] Benson, et al., loc. cit.

[151] Benson, et al., op. cit., Chapter IV, p. 6.

[152] Benson, et al., loc. cit.

[153] Forest Sub-Committee, op. cit., p. 21.

[154] Forest Sub-Committee, loc. cit.

acres or 17.7 percent of this in grazeable woodland.[155] Table B .27 indicates the extent of Montana's forest-based range resource and total range resource.

TABLE B.27

MONTANA'S RANGE RESOURCE BY TYPE AND OWNERSHIP, 1973

| Type | Million Acres | | |
|---|---|---|---|
| | Private | Public | Total |
| Grazeable woodland | 4.4 | 7.1 | 11.5 |
| Rangeland | 41.6 | 11.2 | 52.8 |
| Total | 46.0 | 18.3 | 64.3 |

Source: Benson, _et al_., _op. cit_., Chapter II, p. 16.

Indications are that there is a potential for expanding the use of the forest-based range resource in the future. However, many people continue to believe that grazing and timber production are not compatible. This notion is probably the result of earlier times when poor management practices (or the complete absence of management practices) led to overgrazing which in turn was detrimental to the forest's capacity to produce usable timber. In addition, the possibility also exists that other forest land uses (notably recreation) may be adversely affected by grazing on these lands. Though a recent study has indicated that more than half of the forested

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[155] Benson, _et al_., _op. cit_., Chapter II, p. 16

lands in Montana could support grazing without unacceptable side effects,[156] the actual mix of activities on the State's forests is likely to be the subject of continuous debate. Table B.28 presents quality measures for selected characteristics of forested lands that would be expected under grazing, expressed as expert judgements.

The Wildlife Resource

The previously noted growth in popularity of wildlife related recreational pursuits suggests an increasing demand for larger wildlife populations. Fortunately, the forest lands of Montana provide excellent habitat and related resources for a large variety of wildlife. Montana wildlife includes many species of mammals, birds, fish, reptiles, and amphibians. Nearly all of these animals are dependent upon the forest for their existence.[157]

According to Benson, et al., a ". . . precise count of animal populations on all of Montana's forest lands is not available . . ."[158] however, partial estimates of some of the major game animals found on the State's National Forest and Bureau of Land Management (BLM) lands are available and provide a rough idea of what the forest land supports. Table B.29 gives estimates of the population for eight game animals in the State. It should be noted that the relation-

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[156] Benson, et al., op. cit., Chapter IV, p. 8.

[157] Benson, et al., op. cit., Chapter II, p. 16.

[158] Benson, et al., op. cit., Chapter II, p. 17.

TABLE B.28

QUALITY OF SELECTED CHARACTERISTICS OF FORESTED LANDS UNDER A MODERATE LEVEL OF GRAZING[a]

| Forest Types | Total Forested acres in Montana | Proportion of type that might be grazed | Characteristics | | | | |
|---|---|---|---|---|---|---|---|
| | Million Acres | Percent | Soil Stability | Beauty | Hunting | Other Recreation | Ease of Changing Management Direction |
| Douglas-fir | 5.6 | 35 | E | F | F | F | F |
| Ponderosa pine | 3.9 | 94 | E | F | F | F | E |
| Western white pine | 1.4 | 35 | B | B | B | B | B |
| Fir-spruce | 2.3 | 30 | E | F | B | F | F |
| Larch | 2.2 | 30 | E | F | B | F | E |
| Lodgepole pine | 6.3 | 59 | E | F | F | F | E |

[a]Scale: E = Excellent, F = Fair, B = Bad.

Source: R. E. Benson, *et al.*, *A Descriptive Analysis of Montana's Forest Resources: A Progress Report* (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974), Chapter IV, p. 8.

TABLE B.29

POPULATIONS OF SOME PRINCIPAL GAME ANIMALS ON MONTANA NATIONAL FOREST AND BLM LANDS

| Species | Thousand Animals | |
|---|---|---|
| | National Forest | Bureau of Land Management |
| Elk | 54.1 | 35.7 |
| Moose | 5.1 | .2 |
| Whitetail deer | 51.3 | 31.4 |
| Mule deer | 172.5 | 93.3 |
| Grizzly bear | .5 | 0.0 |
| Black bear | 12.9 | .7 |
| Mountain goat | 4.8 | .3 |
| Bighorn sheep | 2.2 | .4 |

Source: R. E. Benson, _et al_., _A Descriptive Analysis of Montana's Forest Resources: A Progress Report_ (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974), Chapter II, p. 17.

ship between the wildlife resource and the forest land base is always difficult to precisely define. The estimates provided in Table B.29 are for animals that ". . . are either highly dependent on forests for food and cover, or they are found primarily in areas managed as forest lands."[159]

### The Water Resource

The general consensus of many experts appears to be that water, if not now, at least in the near future, will be the most valuable resource associated with Montana's forest lands.[160] According to Benson, et al.:

> Water has been called the most important product of the forest lands of the West, and in Montana the forested mountains are the principal source of major streams. The Missouri and Yellowstone Rivers, which provide both hydroelectric power and irrigation water for much of the drier eastern part of the State, are fed by small streams originating in forested mountains. In the Columbia River drainage west of the Divide, the water produced is used for irrigation and power generation.[161]

Given the significance of the water resource, it follows that forest management policies directed towards improvement of the quality and quantity of usable water should be a prime consideration for land managers. Such management policies on forested watersheds can have significant impacts not only on water production but also on soil stabil-

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[159] Benson, et al., loc. cit.

[160] Forest Sub-Committee, op. cit., p. 19

[161] Benson, et al., op. cit., Chapter II, p. 18

ity, sedimentation, regulation of stream flow, pollution, wildlife habitat, and land values on property adjacent to water. Montana produces about 37 million acre-feet of water per year.[162] Of this total, it has been estimated that 60 to 70 percent of the water runoff comes from all forested lands.[163] It has also been estimated that while National Forests comprise only 18 percent of Montana's land area, they provide approximately 50 percent of the total water production.[164]

## The Mineral Resource

Perhaps the most often neglected aspect of forested land is the mineral resource found within the forest. The mineral resource is even more significant when one considers the impact of mining on timber production and the use of other forest resources. Much of Montana's mineral resource is found in the eastern portion of the State, including the vast, recently discovered deposits of coal. This land is, for the most part, not forested. However, significant mineral deposits do exist on forested land and consequently enhance the value of this land while, at the same time, complicating the task of forest managers.

There are approximately 20,000 mineral claims on the

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[162] Benson, *et al.*, *loc. cit.*

[163] Benson, *et al.*, *loc. cit.*

[164] Benson, *et al.*, *loc. cit.*

National Forests in Montana.[165] Table B.30 shows the approximate distribution of these claims by forest. It has been noted that the mineral claims average about 20 acres each for a total of approximately 4000,000 acres of National

TABLE B.30

DISTRIBUTION OF MINING CLAIMS ON MONTANA'S NATIONAL FORESTS

| National Forest | Number of Claims |
|---|---|
| Kaniksu .................. | 4,000 |
| Beaverhead .............. | 3,300 |
| Lolo ..................... | 3,200 |
| Kootenai ................ | 2,700 |
| Gallatin ................ | 1,900 |
| Deerlodge ............... | 1,600 |
| Helena .................. | 1,500 |
| Custer .................. | 800 |
| Lewis and Clark ......... | 400 |
| Bitterroot .............. | 300 |
| Flathead ................ | 50 |

Source: Benson, et al., op. cit., Chapter IV, p. 8.

Forest land directly involved.[166] In general, it can be concluded that the mineral resource associated with the forests of western Montana is important, but not nearly as significant as that found in the eastern portion of the State.

## The Timber Economy

As noted previously, much of the economic activity in western Montana is either directly or indirectly related to

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[165] Benson, et al., op. cit., Chapter IV, p. 8.

[166] Benson, et al., op. cit., Chapter IV, p. 9.

the forest land base. Indeed, previous sections of this report have indicated that timber-related industries are continuing to grow in importance in the regional economic system. The sheer significance of this aspect of the general regional economy justifies a brief description of some of the more outstanding features of the timber economy.

In attempting to describe the structure of the wood processing industry, it is perhaps useful to classify the State's wood processing plants by the products they produce. Table B.31 provides such a listing.

Lumber production in the State has followed the National trend towards larger sawmills. It has been noted that between 1956 and 1966, the number of mills producing less than 10 million board feet per year declined from 307 to 111, while for the same period, the number of mills producing more than 10 million board feet annually increased from 26 to 37.[167] During this period, the average annual production for these larger mills increased from 25 to 35 million board feet each.[168] The result of this concentration of production is that in 1966 lumber output from the 37 mills producing 10 million board feet or more accounted for about 90 percent of total lumber production for the State.[169] Indications are that this trend has continued

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[167] Benson, et al., op. cit., Chapter III, p. 2.

[168] Benson, et al., loc. cit.

[169] Benson, et al., loc. cit.

TABLE B.31

WOOD PROCESSING PLANTS IN MONTANA: LISTED BY PRODUCTS

| Kind of Output | Number of Plants | | 1972 Production | Comments |
|---|---|---|---|---|
| | 1966 | 1972 | | |
| Lumber | 148 | 100-125 est. | 1,350 MMBF est. | Average size increasing. |
| Plywood and veneer | 6 | 5 | 460 MM sq. ft. | 1 mill under construction. |
| Particleboard | 0 | 1 | 100 MM sq. ft. | 1 fiberboard/ particleboard mill under construction. |
| Paper and pulp | 1 | 1 | 1,150 tons/day | 60% increase in output planned. |
| Post, poles, piling, houselogs | 30 est. | 30 est. | Unknown | Currently no pressure-treating facilities in State. |
| Christmas trees | Unknown | Unknown | 2 MM trees est. | Declined since late 1950's. |

Source: R. E. Benson, _et al._, _A Descriptive Analysis of Montana's Forest Resources: A Progress Report_ (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974), Chapter III, p. 1.

to the present time.

An important aspect of the lumber industry is the ownership pattern for mills. In Montana, nearly all of the larger mills are owned by multi-state corporations headquartered outside of the State.[170] Figure B.4 indicates the shares of Montana's 1972 lumber output for all corporations owning mills that in the aggregate produced more than 50 million board feet within the State. It is interesting to note that these eight firms produce more than two-thirds of Montana's total lumber output.

The spatial distribution of sawmills in the State is also important to note. In general, the mills are concentrated in the western portion of the State. According to Benson, et al., in 1972 three communities produced more than 100 million board feet of lumber, four others produced in excess of 50 million board feet, while 18 more produced between 10 and 50 million board feet.[171] Figure B.5 illustrates the location of these production centers. It should be noted that there are indications that expansion of existing mills plus construction of new lumber producing facilities will make the communities of Bonner and Lewiston major lumber production centers.[172]

The situation is similar for plywood and veneer

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[170]Benson, et al., loc. cit.

[171]Benson, et al., loc. cit.

[172]Benson, et al., loc. cit.

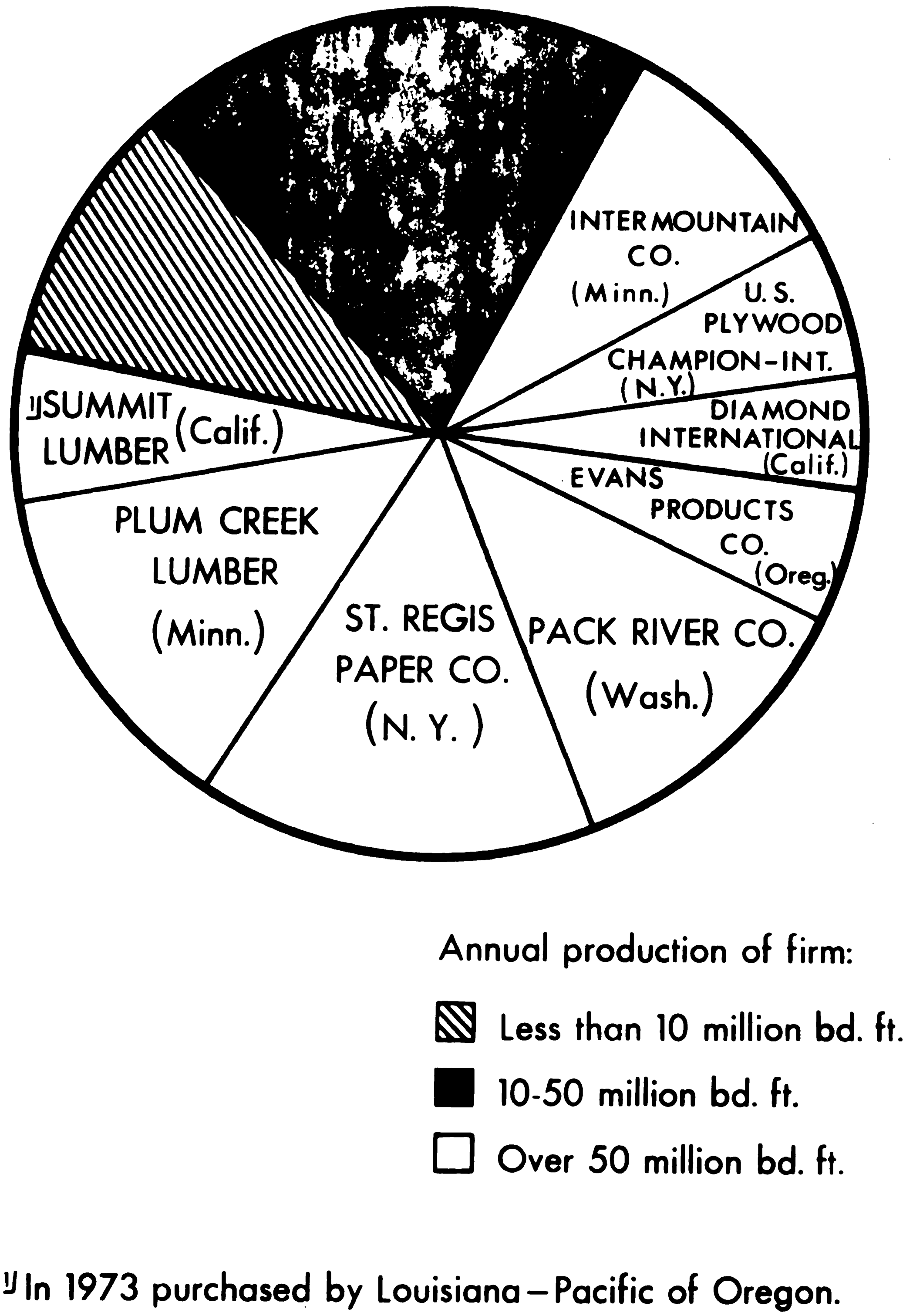


Figure B.4.--Montana's 1972 Lumber Production by Major Firms and Locations of Corporate Headquarters

Source: R. E. Benson, et al., A Descriptive Analysis of Montana's Forest Resources: A Progress Report (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974), Chapter III, p. 3.

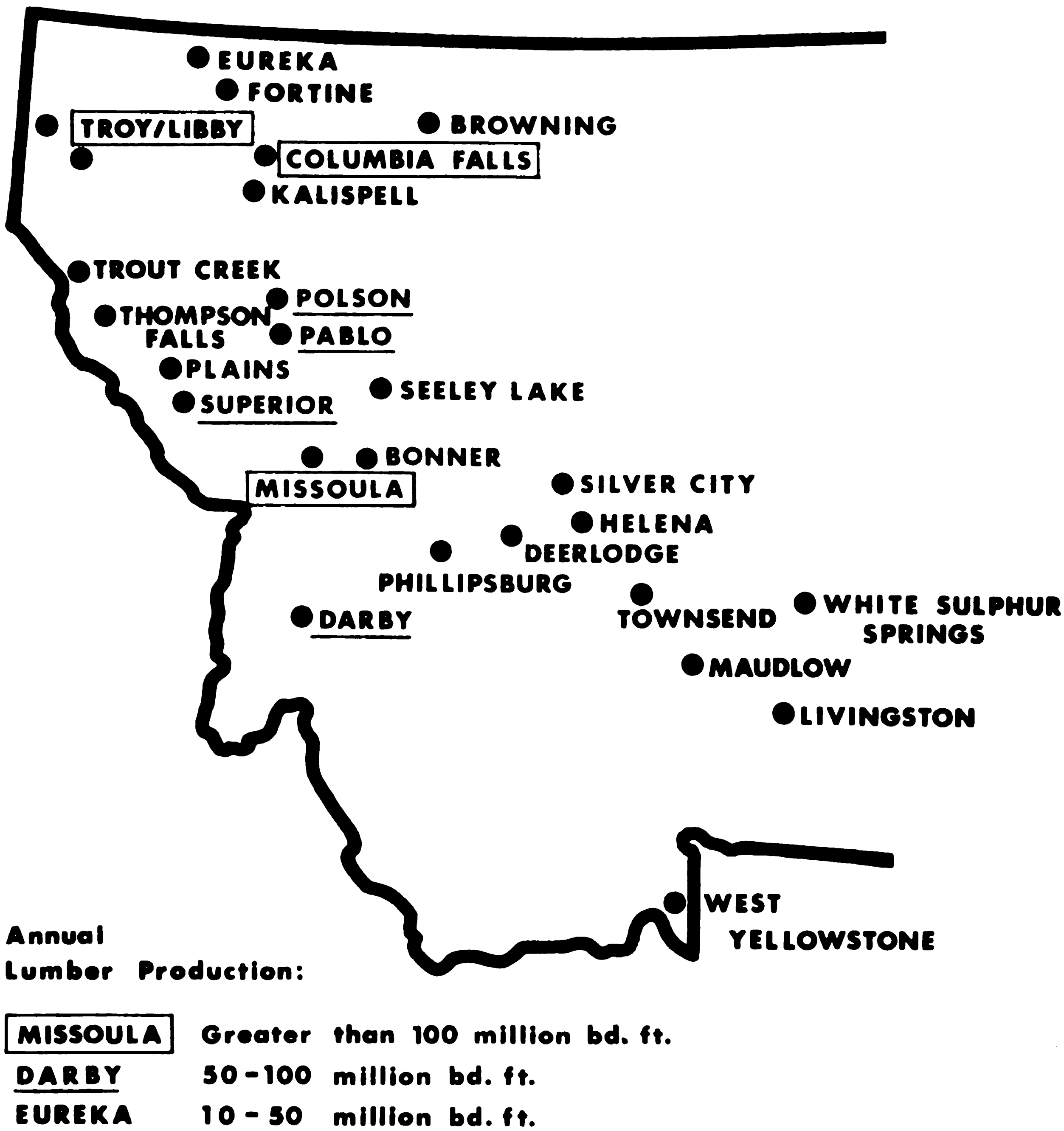


Figure B.5.--Principal Lumber Production Centers in Montana, 1972

Source: R. E. Benson, et al., A Descriptive Analysis of Montana's Forest Resources: A Progress Report (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974), Chapter III, p. 4.

production. Currently, five mills produce all of the plywood and veneer in the State.[173] The majority of this production is controlled by firms that are based outside of Montana (see Figure B.6). Spatially, production is even more concentrated than was the case for lumber production. The locations of plywood and veneer production along with other nonlumber wood products are illustrated in Figure B.7. It should be noted that the plywood facility under construction at Bonner in 1972 has since been completed and is being touted as the largest mill under one roof in the world.[174]

Other timber-related products produced in Montana include particleboard and paper. In 1972, all of the particleboard production took place at one facility--Evans Products Company--located in Missoula. In that year, the plant produced approximately 96 million square feet (3/4 inch basis) of particleboard.[175] Also in 1972, a new plant was under construction at Columbia Falls by Plum Creek Lumber Company. At that time, the annual production from this plant, when completed, was expected to be around 70 million square feet.[176] At the present time, the

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[173] Benson, et al., op. cit., Chapter III, p. 5.

[174] Interviews with various plant personnel, U.S. Plywood Corporation, Bonner, Montana, June 13, 1974.

[175] Benson, et al., loc. cit.

[176] Benson, et al., loc. cit.

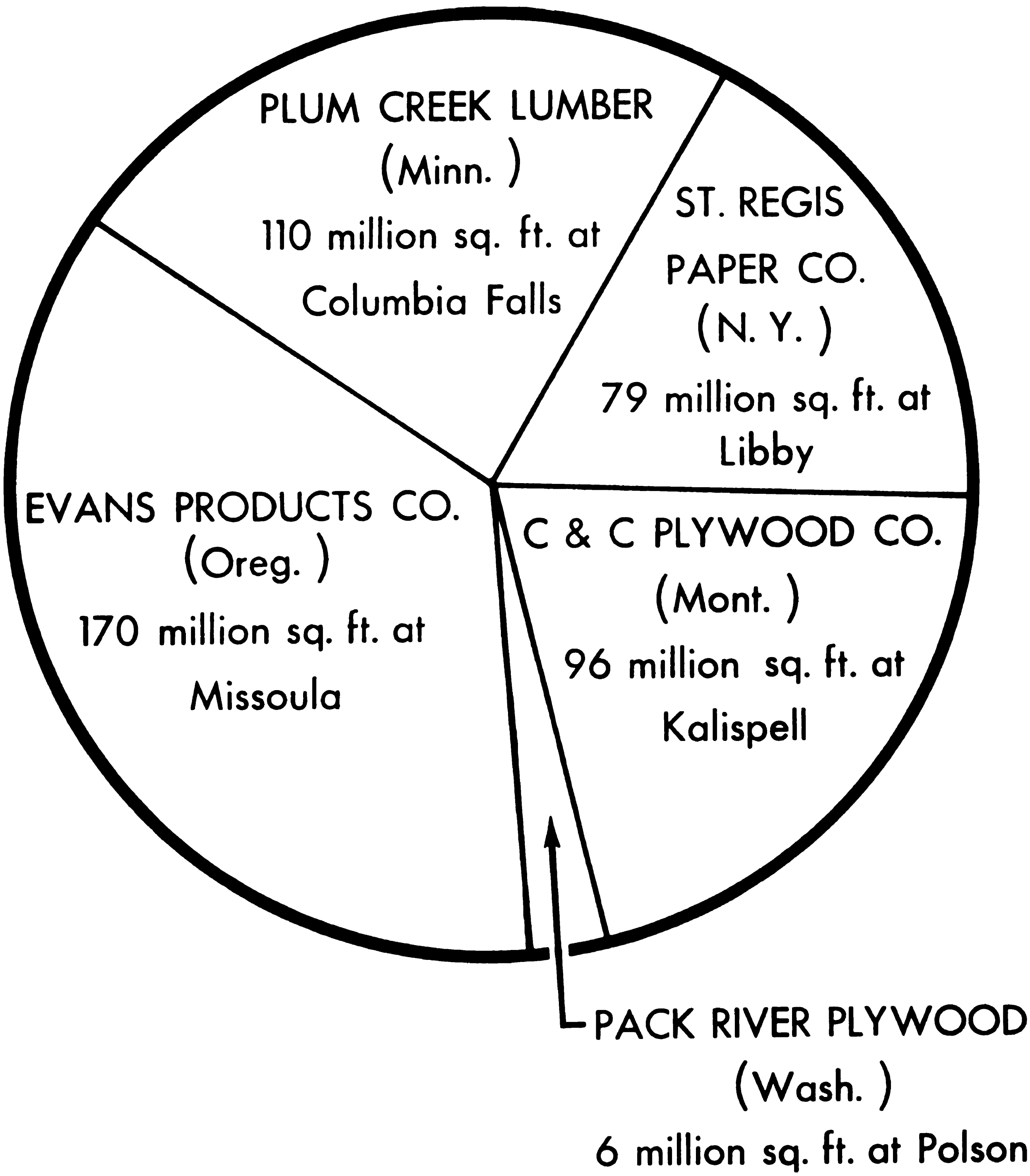


Figure B.6.--Montana's 1972 Plywood Production (sq. ft. 3/8-inch basis) by Firms and Locations of Corporate Headquarters

Source: R. E. Benson, et al., A Descriptive Analysis of Montana's Forest Resources: A Progress Report (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974), Chapter III, p. 6.

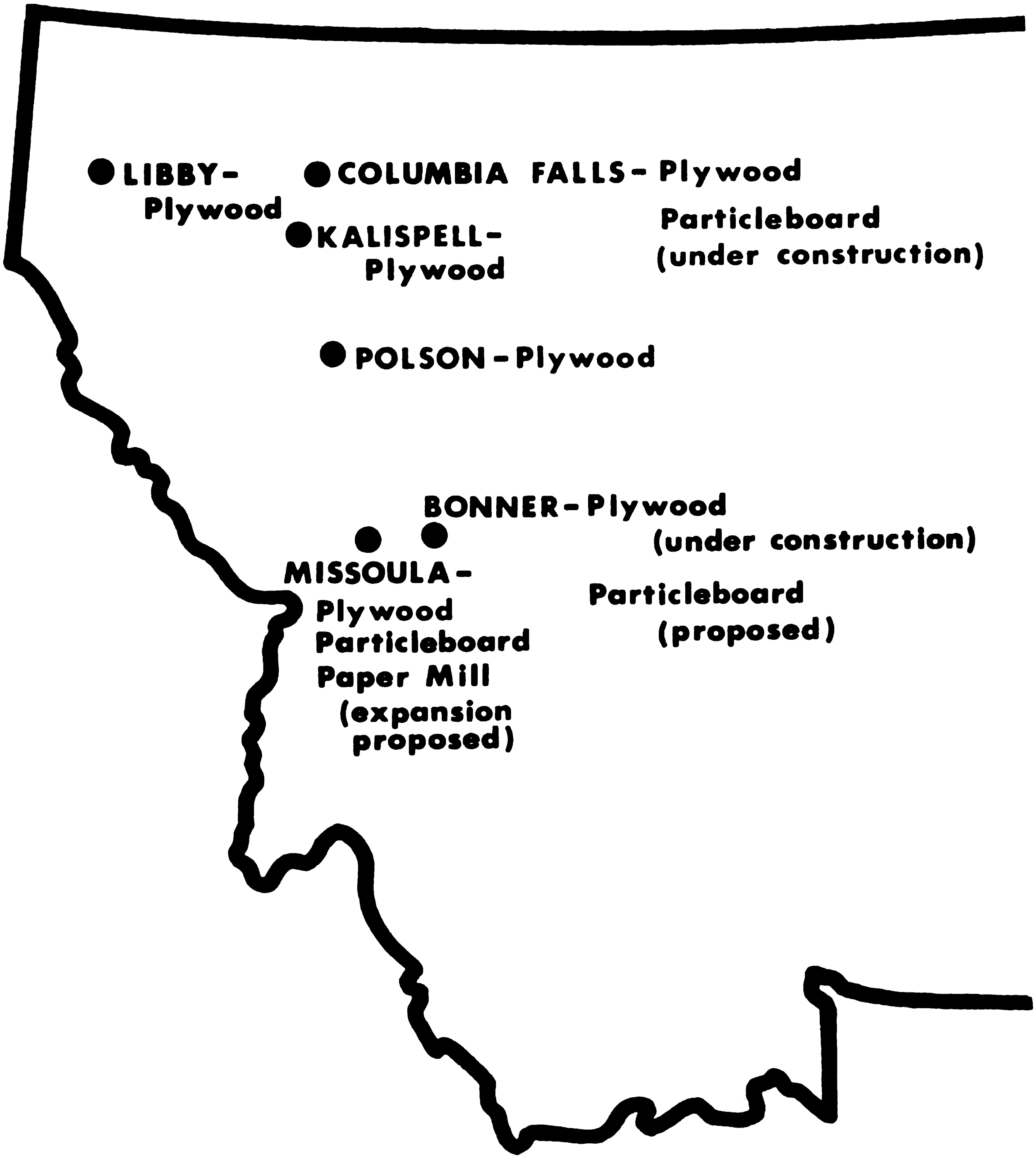


Figure B.7.--Production Centers for Plywood, Particleboard, and Paper in Montana, 1972, and Prospective Additions

Source: R. E. Benson, et al., A Descriptive Analysis of Montana's Forest Resources: A Progress Report (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974), Chapter III, p. 7.

Hoerner-Waldorf mill in Missoula is the only papermill in the State. Production at this plant averages about 1,000 tons per day of linerboard and 150 tons per day of bleached pulp.[177] Planned expansion at this plant could increase output to a combined total of 1,850 tons per day of Kraft pulp, paper, and linerboard.[178] With this additional productive capacity, total annual wood use is expected to be approximately 3 million cubic feet of roundwood and 121 million cubic feet of plant residues (e.g., chips).[179]

It appears as though management in the wood products industries has taken an optimistic view of the future in Montana. Benson, et al., report that planned expansion of production for all major wood products amounts to: lumber, 100 million board feet annually; plywood and veneer, 300 million square feet annually; particleboard, 100 million square feet annually; and paper 600 tons per day.[180] If these plans are actually implemented, they will clearly have a significant positive impact on the regional economy.

The wood products industry in the State also produces other roundwood products and Christmas trees, though little information is available concerning these products. It has been noted that in terms of total volume of wood used

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[177] Benson, et al., op. cit., Chapter III, p. 8

[178] Benson, et al., loc. cit.

[179] Benson, et al., loc. cit.

[180] Benson, et al., loc. cit.

and total employment and income generated in the production of these goods, they represent a small part of the State's economy.[181] However, production of these goods is more important in the regional economy of western Montana and, of course, can be extremely significant locally. The approximate output of these roundwood products, estimated for 1972, is shown in Table B.32. Benson, et al., report that Christmas tree shipments declined from a maximum of about 4 million in 1956, to about 2 million in 1964, where it has stablized.[182]

TABLE B.32

ESTIMATED OUTPUT OF MISCELLANEOUS ROUNDWOOD PRODUCTS IN MONTANA, 1972

| Product | Volume (MMBF) |
|---|---|
| Posts and poles ... | 5 |
| Poles ............. | 3 |
| Fuel .............. | 1 |
| Other ............. | 2 |

Source: Benson, et al., op. cit., Chapter III, p. 8.

In 1969, approximately 246 million cubic feet of wood, most of it in the form of sawlogs and veneer logs, was harvested from Montana's forests.[183] Table B.33 shows the approximate distribution of products from the 1969 wood harvest. Figure B.8 illustrates the proportions of log

[181] Benson, et al., loc. cit.

[182] Benson, et al., loc. cit.

[183] Benson, et al., op. cit., Chapter III, p. 9.

TABLE B.33

TIMBERLAND PRODUCTS FROM MONTANA'S 1969 WOOD HARVEST

| Timberland Products | Percent of 1969 Output |
|---|---|
| Sawlogs .................. | 85.9 |
| Veneer logs ............. | 11.6 |
| Pulpwood ................ | .7 |
| Mine Timbers ............ | .6 |
| Poles ................... | .3 |
| Other ................... | .9 |
| Total ................... | 100.0 |

Source: Benson, _et al_., _op. cit_., Chapter III, p. 9.

volumes received by Montana mills by species in 1969. Approximately 25 percent of the veneer and sawlogs used in Montana's mills in 1969 were Douglas-fir; ponderosa pine and western larch were also heavily used species.[184] Lodgepole pine was used in most of the other minor forest products.[185]

It is interesting to note the origin of the timber used in producing the State's wood products. In 1969, Montana mills used about 1,354 million board feet in logs.[186] Table B.34 indicates the counties from which this wood originated and lists the approximate share for each county. It can be noted from the table that all of the five counties listed by name are in the study region and provided a combined total of 82 percent of the logs used by Montana mills in 1969. It should also be mentioned that Montana is relatively

[184] Benson, _et al_., _loc. cit_.

[185] Benson, _et al_., _loc. cit_.

[186] Benson, _et al_., _loc. cit_.

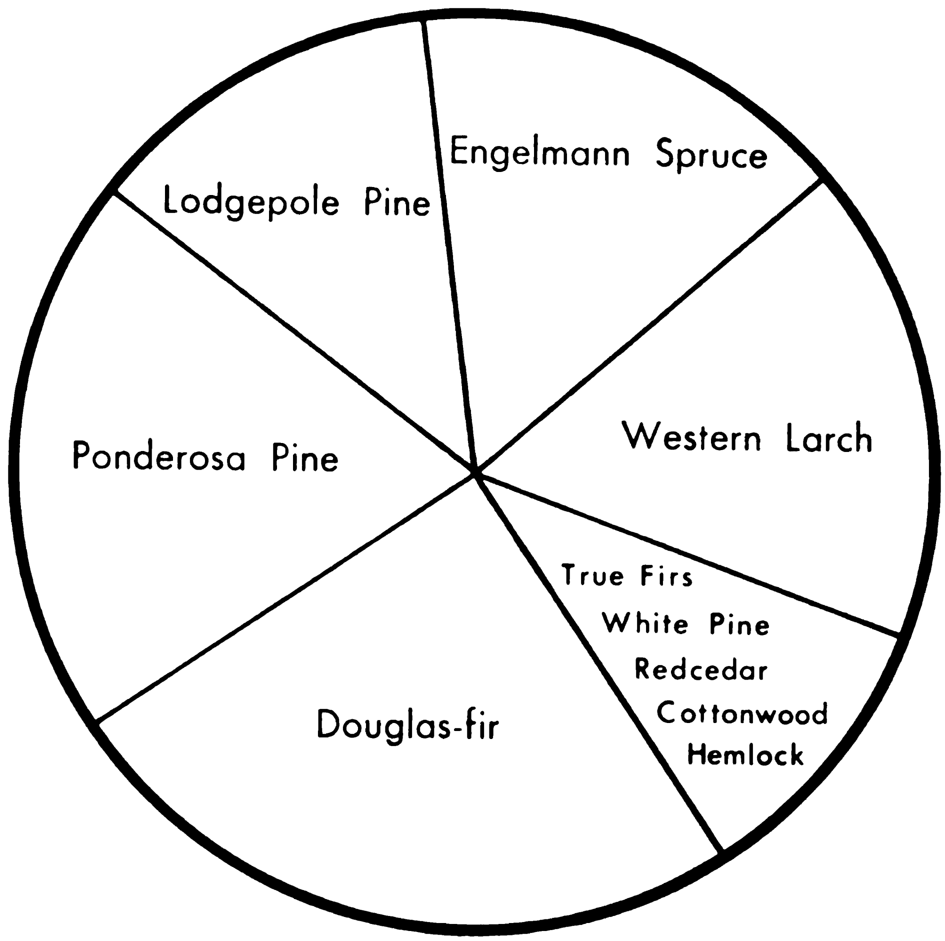


Figure B.8.--Proportions of Log Volumes Received by Montana Mills by Species, 1969

Source: R. E. Benson, et al., A Descriptive Analysis of Montana's Forest Resources: A Progress Report (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974), Chapter III, p. 10.

TABLE B. 34

COUNTIES OF ORIGIN FOR LOGS USED IN MONTANA MILLS IN 1969

| County | Share of Logs (percent) | Principal Species |
|---|---|---|
| Lincoln | 39 | Western larch, Douglas-fir, ponderosa pine |
| Flathead | 17 | Engelmann spruce, Douglas-fir |
| Missoula | 9 | Ponderosa pine, Douglas-fir |
| Lake | 6 | Western larch, Douglas-fir |
| Ravalli | 6 | Douglas-fir, ponderosa pine |
| Sanders | 5 | Ponderosa pine, Douglas-fir |
| Others | 18 | |

Source: Benson, *et al.*, *op. cit.*, Chapter III, p. 9.

independent in terms of its wood supply. In 1969, less than 1 percent of all logs used by Montana mills came from outside the State.[187]

Montana's log output, while concentrated in relatively few counties, comes from a variety of ownerships. Table B.35 shows the portion of total log output for 1966 and 1971 provided by each type of ownership. In general, the table indicates a decline in the proportion of the total supplied from public lands (National Forests and other public lands), and an increase in the share provided from private timberlands. Benson, *et al.*, report that these trends hold in absolute as well as relative terms.[188] In 1971, 660.5 million board feet of logs were received at

[187] Benson, *et al.*, *loc. cit.*

[188] Benson, *et al.*, *op. cit.*, Chapter III, p. 10.

TABLE B.35

MONTANA LOG OUTPUT BY OWNERSHIP, 1966 AND 1971

| Ownership | Percent 1966 | Percent 1971 |
|---|---|---|
| National Forest | 59 | 55 |
| Other public | 9 | 6 |
| Forest industry | 17 | |
| Other private | 15 | 39 |

Source: Benson, et al., op. cit., Chapter III, p. 10.

Montana mills from National Forests.[189] Three forests, the Kootenai (189.7 million board feet), Flathead (149.1 million board feet), and Lolo (124.7 million board feet), all in the western part of the State, supplied approximately 70 percent of this total.[190] It should also be noted that, in 1971, mills in the eight county study region received 587.8 million board feet or about 89 percent of the total logs supplied from Montana National Forests.[191] The counties and the total amount of logs (in million board feet) received from Montana National Forests in 1971 are: Flathead (167.8), Granite (10.6), Lake (23.5), Lincoln (176.6), Mineral (10.1), Missoula (99.2), Ravalli (49.8), and Sanders (50.2).[192]

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[189] Benson, et al., op. cit., Chapter III, p. 11.

[190] Benson, et al., loc. cit.

[191] Calculated from data supplied in Benson, et al., loc. cit.

[192] Benson, et al., loc. cit.

The impact of the wood products industry on regional income and employment has been noted in an earlier section of this chapter. However, Montana's forest lands also provide direct income to the State, counties, and Indian reservations. Table B.36 gives the total receipts from various timberland ownerships and the amount received by the State, counties, and Indian reservations in the aggregate, from each type of ownership. Clearly, the revenues received by State and county governments as well as by Indian reservations represent significant contributions to help cover the steadily increasing costs incurred by these governmental units.

TABLE B.36

TOTAL RECEIPTS FOR VARIOUS MONTANA FOREST LAND OWNERSHIPS AND THE SHARE PROVIDED AS DIRECT INCOME TO THE STATE, COUNTIES, AND INDIAN RESERVATIONS
1972

| Source of Receipts | Total 1972 Receipts (dollars) | Receipts by State, County, or Tribe (dollars) | Percent of Area of All Montana Timberlands (percent) |
|---|---|---|---|
| National Forests | 16,570,000 | 4,140,000 | 73 |
| Bureau of Indian Affairs | 4,200,000 | 3,900,000 | 3 |
| Bureau of Land Management | 240,000 | 10,000 | 2 |
| Montana State Forests | 890,000 | 890,000 | 2 |
| Private Timberlands (property taxes) | 640,000 | 640,000 | 20 |

Source: R. E. Benson, et al., A Descriptive Analysis of Montana's Forest Resources: A Progress Report (Ogden, Utah: U.S.D.A., Forest Service, Intermountain Forest and Range Experiment Station, 1974), Chapter III, p. 15.

# APPENDIX C

# AN ANNOTATED BIBLIOGRAPHY OF LITERATURE ON MODELING ECONOMIC-ECOLOGIC LINKAGES

# APPENDIX C

CONVERSE, A. O.

1971. "On the Extension of Input-Output Analysis to Account for Environmental Externalities." The American Economic Review. LXI, No. 1 (March, 1971). 197-198.

According to Converse, the modification of input-output analysis presented by Ayres and Kneese in their article in the American Economic Review (LIX, No. 3, June, 1969, 282-297), does not correctly account for the individual waste residues from the various production sectors. A modest change that overcomes this objection is presented in this paper. Further modifications that would allow one to account for the various types of waste residues from both production and consumption activities are presented. The need for such detail is caused by the specific activities of the various residues ($CO_2$ is significantly different from CO). It is noted that pollution treatment while changing the composition of the waste residues does increase the total amount of them. Hence any analysis that considers only the total amount will be unable to evaluate pollution control measures.

CUMBERLAND, John H.

1966. "A Regional Interindustry Model for the Analysis of Development Objectives." The Regional Science Association, Papers. XVII (1966). 65-94.

Recognizing that our inability to cope adequately with problems of urban design, regional development, mass transportation, and the quality of the human environment suggests the need for more comprehensive and appropriate concepts of regional analysis, Cumberland offers a model that will incorporate some of the key variables involved.

He employes a conventional, open, static, regional interindustry model, extended to emphasize the public sector and to include some critical environmental relationships for this purpose.

The environmental aspects are incorporated into the model with the addition of an environmental balance row and column to the standard transactions table. Professor Cumberland emphasizes that environmental data are much more difficult to obtain than are economic data. The paper also contains a discussion of the implications of this approach for urban and regional development.

CUMBERLAND, John H., et al.

1971. Design for a Maryland State Planning Model with Economic-Environmental Linkages. Baltimore: Maryland Department of State Planning.

This design study proposes the development of state planning models for the Maryland Department of State Planning which extend the conventional analysis of economic variables to include the increasingly important environmental variables of waste and pollution emissions which are associated with production and consumption processes. The development of such models is particularly appropriate and urgent for the State of Maryland, which faces an increasing number of environmental issues, including the critically important problem of protecting and managing the Chesapeake Bay, its tributaries, and resources.

The models are designed to provide information to state planners and officials which will permit them to evaluate the economic and environmental implications of alternative development strategies including continuation of existing trends, accelerated industrial expansion or pursuit of maximum economic welfare benefits at minimum levels of environmental damage.

The models will generate systems of regional economic accounts and environmental accounts in order to provide quantitative disaggregated estimates of the consequences of alternative state development policies and programs. The report includes a technical supplement which describes a demonstration of the environmental submodel and an environmental classification system.

The entire model is divided into two submodels. The first of these models the economic system using an input-output approach where gross outputs for each sector are computed by post-multiplying a set of exogenously determined final demands by the Leontief inverse matrix. These gross output estimates will then enter the environmental model as input where they will be multiplied by a set of environmental linkage coefficients to yield estimates of gross environmental residuals and other components of the environmental accounts. The environmental linkage coefficients are similar to the technical coefficients of the economic model in that they represent residuals (pollution) output as a function of the level of production in a given sector.

The report discusses briefly a long-run model which is similar to the short-run model already discussed except that the estimates of gross outputs will be made using a dynamic, long-run forecasting model rather than by the short-run interindustry (input-output) model.

CUMBERLAND, John H. and Robert J. KORBACH

1973. "A Regional Interindustry Environmental Model." Regional Science Association Papers. XXX, (1973). 61-75.

This paper provides a general description of the Maryland research on economic-ecologic linkages. Included are discussions of the development of a state economic-environmental planning model, a theoretical model of the processes involved, an environmental accounting system upon which the model is based, and a summary of currently available empirical results. The authors note that the purpose of their paper is to make progress toward providing local areas with an operational model and with appropriate sets of data which will permit these areas to compare the probable impacts of alternative programs of regional development and to compare the expected economic benefits with probable environmental and other costs of development.

The theoretical model proposed in this paper incorporates a static, interindustry input-output model, extended to reflect residuals production. The estimates of gross residuals generated by the input-output model are then entered into a series of seven waste-flow equations which model the flow of residuals through several categories.

D'ARGE, R. C. and K. C. KOGIKU

1971. "Economic Growth and the Natural Environment." Program in Environmental Economics: Working Paper Series, Working Paper No. 1. Riverside, California: University of California, Department of Economics, April, 1971.

D'Arge and Kogiku begin by developing a simple model of waste generation based on the conservation of matter-energy principle, with consumption behavior of the economy's inhabitants assumed to be predetermined. Essentially, they model material and waste flows as being linearly related to total income measured in material units (e.g., tons of steel). The authors recognize that the assumption of linearity in this case is highly restrictive. Most important, it specifies an implied technology relating output to raw material inputs.

In subsequent sections of the paper, the model is generalized to an "optimal control problem", where consumption and waste generation are allowed to be optimally regulated, and an attempt is made to integrate non-mutually exclusive processes of resource extraction and waste generation. With each refinement the simple initial model becomes increasingly complex.

ISARD, Walter, et al.

1968. "On the Linkage of Socio-Economic and Ecologic Systems." The Regional Science Association Papers. XXI (1968). 79-99.

The paper deals with the inclusion of the ecologic system into the general conceptual framework of a multiregion social system. The authors propose to accomplish this by extending the social accounting framework to include the ecologic system. Both the social and ecologic systems are viewed as very large sets of interdependant activities, involving as inputs and outputs many commodities. A few of these commodities are considered to be common to both systems, i.e., outputs of one system that become inputs to the other. To the extent that one system's imports and exports are the other system's exports and imports respectively, the ecologic and social systems can be effectively linked. Thus the input-output model can be used to evaluate these linkages. The paper illustrates two basic input-output relationships that would be found in a socio-economic-ecologic model. The first of these relationships is a food chain example. Here the ecologic system is providing an import (input) into the social system. The second example is that of water pollution outputs from the social system which are imports into the ecologic system. These two examples are offered as an illustration of how these newly defined relationships can be quantified. The paper also provides a hypothetical application of this framework to the Plymouth Bay region. The application is highly simplified but serves to indicate the complexities one would face in a realistic problem context. Though the policy issues are noted the full implications of this type of analysis for policy formulation are not discussed.

ISARD, Walter

1969. "Some Notes on the Linkage of the Ecologic and Economic Systems." The Regional Science Association Papers. XXII (1969). 85-96.

This paper contains a non-technical discussion of a "new conceptual framework" for linking the economic and ecologic systems, plus a brief discussion of how these linkages may

be quantified. The paper deals basically with an extension of the traditional input-output model to include ecologic or environmental sectors. A major portion of the paper is devoted to the topic of defining the coefficients in the expanded direct coefficients matrix.

ISARD, Walter, et al.

1972. Ecologic-Economic Analysis for Regional Development. xvii + 270 p. (outsize). New York: The Free Press.

The book is divided into five basic sections, the first of which contains a brief discussion of each of four economic models that have been used for regional analysis. They are: 1) comparative cost analysis, 2) input-output, 3) the gravity model, and 4) activity complex analysis. The next section contains a discussion of natural resources in a non-economic context. Included here are discussions on resource classification and several critical ecological principles. There is also an example given of how the ecological system can be represented in an input-output programming format. The third section attempts a synthesis of economic and ecologic analysis. This attempt is made in what the authors call an interrelations table. The table is large but very few of the cells are filled, and thus many of the interrelationships are unspecified. The table is somewhat simplified in that it considers only two regions--"Land" and "Marine." The fourth section of the book contains a very long (pp. 116-230) and often boring presentation of a case study involving the Plymouth-Kingston-Duxbury Bay area. The authors make use of each of the economic models previously discussed to evaluate the recreational potential of the region with some attempt at the end of the section to include consideration of ecologic costs. The final section contains the authors' recommendations and conclusions. Included here is a discussion of the potentials of the study for further development of a methodology for the synthesis of economic and ecologic analysis.

The title of the book is misleading with respect to its actual scope. The discussion is mainly oriented toward water-based recreation activities in relation to a specific set of ecological subsystems operating in a particular geographic area. As forewarned by the authors, both ecologists and economists are likely to be disappointed with those parts of the book dealing with their respective specialties. The book stands as a report of an outstanding research application in an emerging field, but is not as comprehensive as the title would indicate.

JOUN, Young P.

1971. "Information Requirements for Socio-Economic Models." The Annals of Regional Science. V, No. 1 (June, 1971). 25-32.

In this paper, Joun attempts to identify information requirements for various economic-ecologic models. While the paper provides no new conceptual insight regarding such models, it does contain a realistic appraisal of their potential for implementation.

Joun classifies recent attempts to quantify social costs into three categories: 1) those which attempt to measure "quality of life" and monitor changes in so-called "social indicators"; 2) those which attempt to introduce explicitly nonmarket variables into interindustry or ecological models and study environmental repercussions of economic growth or those which propose to build a social accounting system which includes a complete description of ecological chains and investigates interrelationships among them; and 3) those which attempt to construct a mathematical model which shows the consequence of a rapidly rising population on society and the natural environment.

Joun's paper contains a brief description of various socio-ecological models and their data requirements. Based on his research, Joun is able to reach several conclusions. First, he feels that there is an enormous gap between the need for data on the "quality of life" and actual supply of such data. Second, he concludes that conceptual model building, by identifying data requirements, delineates characteristics of statistical information systems that should be established for the purpose of closing this gap.

KNEESE, Allen V., Robert U. AYRES and Ralph C. D'ARGE

1970. Economics and the Environment: A Materials Balance Approach. 120 p. Baltimore and London: The Johns Hopkins Press, Inc. for Resources for the Future, Inc., Washington, D.C.

The authors express dissatisfaction with the traditional view of technological external diseconomies (more specifically the broad area of environmental pollution) as special or unique phenomena to be treated in an ad hoc fashion in the literature. Realization that one does not destroy matter but rather changes its form and utilizes the services that flow from it leads to the conclusion that the entire life-support system with its energy conversion, processing and consumption activities will inevitably result in residual materials which must either be recycled or discharged in one form or another to the environment. In essence then, the authors view the

life support-system in a materials balance context, i.e., the weight of materials drawn from the environment as inputs the life-support system must be nearly equal to the weight of the materials discharged from this system as output (residual materials) to the environment. The first chapter of the book develops this argument.

The second chapter contains an elaboration on the materials balance approach wherein the concept is applied to three major sectors of the national economy--the energy conversion, processing and consumption sectors. This chapter attempts to estimate the amount of residual materials produced by various groups of activities within each broad sector and provides many empirical results in this regard.

The third chapter uses a rather basic general equilibrium (input-output) model to demonstrate the pervasiveness of externalities associated with interrelationships between production, consumption and environmental sectors when environmental resources (common property) such as the assimilative capacity of a watercourse are scarce and thus have economic value but no price. In this model total residual flows from all sectors are related directly to final demands. The next section of this chapter addresses the question of whether decentralized decision-making coupled with environmental planning on the part of a governmental unit can, in the presence of pervasive externalities, re-establish or approach an optimum in social product. The fact that technological externalities are pervasive (more specifically the fact that the cost of environmental services is consistantly not included in production and consumption decisions) indicates that there is a divergence between private costs and social costs. That is, Paretian optimality conditions are determined in the absence of environmental considerations (only private costs are considered). The authors offer three methodological options in answering the question. If because of institutional, administrative, or information cost restrictions environmental services nevertheless bear a zero price, are there other behavioral rules that can be superimposed to reduce or counteract these social-private cost discrepancies? These options are: 1) to presume that complete correction for all deviations is plausible to such an extent that the "first best" Paretian conditions can be attained through appropriate dosages of environmental standards, taxes, subsidies, or other policy instruments, 2) (or that) pervasity of externalities is so encompassing, and/or detailed information on the general equilibrium system so costly, that deviations between private and social costs from these sources must be viewed as totally immutable, 3) (or that) the deviations between social and private costs are only partially correctable, so that a "second best" in the Davis-Whinston sense must be imposed following (or in conjunction with) the partial removal of deviations between social and private costs for environmental services. The basic model is extended through development of an objective function and functional constraints to conform to a linear programming format. This model is then used to evaluate these options. The authors conclude that a set of environmental standards does exist, at least conceptually, and could be implemented via administered pricing by a government agency and still retain individual decision-making regarding markets for final products and utilization of resources by industry, other than environmental services. However there are empirical problems involved, the most important of which is obtaining the necessary information to determine the standards. Thus the authors evaluate the other two options. They conclude that, in the case of the second option the totally immutable, non-optimal behavior by industries can be compensated for by means of government regulation of consumer purchases through taxes and/or subsidies. While this strategy preserves individual choice and decision-making, such decisions are considered to be emasculated. Also, the information requirements for designing the controls are even larger than in the case of the first option. The final option where both industries and consumers are regulated was also found to be successful in the attainment of optimal or "second best" welfare solutions, but the information requirement was even larger than for the first two options.

The final chapter is devoted to a discussion of the research conclusions and policy implications, and suggestions for further work.

LAURENT, Eugene A. and James C. HITE

1971. Economic-Ecologic Analysis in the Charleston Metropolitan Region: An Input Output Study. Clemson, South Carolina: Water Resources Research Institute in cooperation with the South Carolina Agricultural Experiment Station, Clemson University, Report No. 19, April 1971.

Regional planning can no longer be primarily concerned with the regional economy and its development, but it must also take cognizance of the effect of economic development on the natural environment. This expansion of regional planning, however, first necessitates development of new tools and methodologies for evaluation alternatives. The development of this type of methodology requires that the basic models be general in form. This need for a general model results from the fact that natural environmental pollution and its control is a materials balance problem. Air, water, and solid waste pollution are just separate components of this overall problem area.

A general model based on input-output analysis was developed to incorporate environmental as well as pecuniary values into management systems for natural resources. An environmental matrix showing the inflow from the environment and outflow to the environment associated with one dollar of gross sales by various economic activities was developed to fit within this system. The linking of the economic model to the environmental matrix completed the general model. The linkage operation involved post-multiplying the environmental matrix by the inverse matrix of the input-output model to form an economic-ecologic matrix.

The completed model was used to quantify economic-ecologic linkages in the Charleston, South Carolina, study area. Further, by taking the income multipliers generated by the input-output model and dividing into the economic-ecologic matrix, resource or environmental-income multipliers were generated. Those multipliers were used to indicate the direct and indirect impacts, both on the economic and ecologic system of various types of economic growth, as well as alternative management strategies.

LEONTIEF, Wassily

1970. "Environmental Repercussions and the Economic Structure, An Input-Output Approach." Review of Economics and Statistics. LII (August, 1970). 262-271.

Frequently unnoticed and too often disregarded, undesirable by-products (as well as certain valuable, but unpaid for natural inputs) are linked directly to the network of physical relationships that govern the day-to-day operations of our economic system. The purpose of this paper is to first explain how such externalities can be incorporated into the conventional input-output formulation of a national economy and, second, to demonstrate that--once this has been done--conventional input-output computations can yield concrete replies to some of the fundamental factual questions that should be asked and answered before a practical solution can be found to problems raised by the undesirable environmental effects of modern technology and uncontrolled economic growth.

The model developed in this paper accomplishes the linkage of the environmental and ecological systems via the addition of a pollution row and anti-pollution columns (one for each column-sector) to the input-output table of a national economy. The model is then solved by the standard procedure outlined in previously published materials by the author.

NOLL, Roger G. and John TRIJONIS

1971. "Mass Balance, General Equilibrium, and Environmental Externalities." The American Economic Review. LXI, No. 4 (September, 1971). 730-735.

The paper contains several proposals for generalizing the Ayres-Kneese model described in their article in the American Economic Review, (LIX, No. 3, June, 1969, 282-297), to make it more realistic and more applicable to pollution policy. Four specific extensions not found explicitly in the Ayres-Kneese model are suggested. They are: 1) separating "residuals" from "pollutants" and inclusion of the complex relations between these two catagories (much of which is lost through the mass balance approach that neglects differences in the seriousness of different types of pollutants and that ignores interaction among residuals and pollutants); 2) including pollution abatement as a final demand, sometimes in the form of a collective good and as a constraint on the production system; 3) freeing the fixed relationship between goods and consumer services by recognizing that in consumption, like production, opportunities exist for switching to different methods of producing goods characteristics; and 4) correcting the equation representing the effect of pollution on production to avoid the necessity of pollution as an input that is implicit in the Ayres-Kneese model.

ROBERTS, Kenneth J. and R. Bruce RETTIG

1974. "Linkages between the Economy and the Environment: An Analysis of Economic Growth in Clatsop County Oregon." Paper presented at the Economic Models for Management of Natural Resources Workshop, Big Sky, Montana, June 9-11, 1974.

This study involves the use of input-output analysis to provide insight regarding the natural resource impact of community growth prospects. The authors investigate this problem in the context of Clatsop County, Oregon.

Roberts and Rettig employ an extended input-output formulation, similar to the one used by Laurent and Hite in their Charleston study, to provide information relating the market and nonmarket aspects of pecuniary forces in the regional economy.

The model used in this research includes a 30-sector regional interindustry I-O model in addition to an ecologic matrix. The ecologic matrix contains coefficients relating the amount of natural resource inputs to and nonmarket residuals from the economic system to the volume of economic activity in the region. The ecologic matrix accounts for 14 substances that are either natural resource inputs or residuals and 30 economic sectors. Few of the cells in this matrix contain entries due to difficulties encountered in assembling data sufficient for estimating coefficients.

The authors conclude that their analysis did not provide the information they had anticipated. This was viewed as the result of incomplete data and stringent model assumptions.

RUSSELL, Clifford S. and Walter O. SPOFFORD, Jr.

1972. "A Quantitative Framework for Residuals Management Decisions." In Kneese and Bower (eds.), Environmental Quality Analysis: Theory and Method in the Social Sciences. Chapter 4. Baltimore: Johns Hopkins Press, Inc., 1972.

The paper begins with a general discussion of the environmental problem noting three basic reasons why this problem has been so difficult to solve, and indicating the relevance of this study to these problems.

The authors suggest a composite model consisting of three basic elements: 1) a linear programming industry model that relates inputs and outputs of the various production processes and consumption activities at specified locations within a region, including the unit amounts of types of residuals generated by the production of each product, the costs of transforming these residuals from one form to another (e.g., gaseous to liquid in the scrubbing of stack gases), the costs of transporting the residuals from one place to another, and the cost of any final discharge-related activity such as landfill operations; 2) environmental diffusion models which describe the fate of various residuals after their discharge into the environment; and 3) a set of receptor-damage functions relating the concentration of residuals in the environment to the resulting damages, whether these are sustained directly by humans or indirectly through the medium of such receptors as plants or animals in which man has a commercial, scientific, or aesthetic interest. The authors acknowledge that so far adequate damage functions have not been estimated for any phase of the residuals problem but explain that they are included in the conceptual model for completeness. The authors offer a currently feasible alternative for these functions.

The paper emphasizes that while none of these individual submodels is, in concept, original with the authors, nor is the idea of combining input-output type models with more or less sophisticated ecological models, their most important contribution is in having devised a workable system for optimizing in which these several basic models and at least the three major forms of residuals are included in a single conceptual framework.

A large portion of the paper is devoted to a detailed exposition of the methodology developed by the authors including the mathematical development of each sub-model.

The last section of the paper illustrates the application of the composite model to a hypothetical region.

TUMMALA, Ramamohan L. and Larry J. CONNOR

1973. "Mass-Energy Based Economic Models." A research report on Design and Management of Environmental Systems, submitted to Research Applied to National Needs, National Science Foundation under Grant GI-20.

In this semitutorial paper, economic models based on fundamental principles of conservation of mass and energy are developed. These models consider labor as a cost rather than a flow as in classical input-output analysis. This minor shift in concept, the authors claim, makes it possible to include technical economies of scale in production and transportation as an additive non-linearity to the cost equation. These economies of scale are shown to be of central concern in evaluating the tradeoffs between production "efficiency" and environmental and social costs incurred by excessive spatial concentration and regional specialization of production and consumption processes. Well known concepts in engineering are used to develop mass-energy-economic models of production systems that have all the basic characteristics of classical economic input-output models but offer additional benefits. The theories and concepts discussed in the paper are illustrated by example.

WILEN, James E.

1971. "Economic Systems and Ecological Systems: An Attempt at Synthesis." Program in Environmental Economics: Working Paper Series, Working Paper No. 10. Riverside, California: University of California, Department of Economics, April, 1971.

Wilen notes that much more research is needed in defining environmental objectives, determining the nature of man-environment interaction, and devising sets of environmental quality indicators which measure the extent of that interaction. In dealing with these questions in this paper, Wilen finds it useful to develop a model which is basically an extension of the materials balance approach. The basic model is extended so as to include an ecological system with corresponding linkages. The model employed is an input-output type model in which a vector of mass and energy inputs is transformed into what Wilen calls "Gross Ecosystem Product", i.e., a measure of production which represents an ecosystem's ability to support life. In such a model, the earth's biosphere is viewed as containing, at any moment, a fixed amount of mass and potential energy from which both economic product and ecosystem product are produced. Production in both the economic and ecologic systems is thus linked by the mass-energy vector which enters both systems as an input. Wilen traces further linkages pertaining to residual flows and energy transfers between systems.

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