for

LGL Alaska Ltd.
Anchorage and Fairbanks, Alaska

SUSITNA HYDROELECTRIC PROJECT
DRAFT REPORT
TERRESTRIAL ENVIRONMENTAL MITIGATION PLANNING SIMULATION MODEL

by

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e material in this report is preliminary in nature
.d should not be cited in technical publications.

The model described herein was developed at a series of workshops at which representatives of LGL Alaska, the Alaska Department of Fish and Game, ESSA Ltd. and others contributed many ideas and suggestions. The material presented in this report is preliminary in nature and should not be cited in any technical publications without the written approval of both LGL Alaska and the Alaska Department of Fish and Game.

ACKNOWLEDGEMENTS

We would like to thank the over fifty different participants at the workshops who devoted much time and considerable energy to the process of building the model. In particular, we thank Warren Ballard and SuzAnne Miller of the Alaska Department of Fish and Game for allowing us to use their modelling work on moose as a basis for the moose submodel described in this report. They also contributed the technical Appendix I on moose population modelling in the Upper Susitna Basin.

Once again, Jean Zdenek showed patience and wizardry in typing and correcting this and earlier drafts of this report.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd.)

TABLE OF CONTENTS (cont'd.)

<u>TABLE OF CONTENTS</u> (cont'd.)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (cont'd.)

LIST OF FIGURES (cont'd.)

1.0 INTRODUCTION

The technical feasibility, economic viability, and environmental impacts of a hydroelectric development project in the Susitna River Basin are being studied on behalf of the Alaska Power Authority. As part of these studies, LGL Alaska Research Associates Inc. has been contracted to coodinate the terrestrial environmental studies being performed by the Alaska Department of Fish and Game and, as subcontractors to LGL, several University of Alaska research groups. LGL is responsible for further quantifying the potential impacts of the project on terrestrial wildlife and vegetation, and for developing a plan to mitigate adverse impacts on the terrestrial environment. The impact assessment and mitigation approach is included as part of a license application to the Federal Energy Regulatory Commission (FERC), submitted in February, 1983.

The quantification of impacts, mitigation planning, and design of future research is being organized using a computer simulation modelling approach. Through a series of workshops attended by researchers, resource managers, and policy-makers, a computer model has been developed and is being refined for use in the quantification of impacts on terrestrial wildlife and vegetation, and for evaluating different mitigation measures such as habitat enhancement and the designation of replacement lands to be managed as wildlife habitat. This report describes the current status of the model.

A preliminary model was developed at the first workshop held August 23 - 27, 1982 in Anchorage. Considerable refinements for the model were proposed in a series of technical meetings held from November, 1982 to February, 1983. Many of these refinements were incorporated into the computer simulation model and this refined version was presented at the mitigation planning workshop held February 28 - March 2, 1983 in Anchorage. This report describes the current status of the model, needed refinements, and makes suggestions about studies for the terrestrial program.

1.1 Objectives

The ultimate purpose of the workshops and simulation modelling is to develop a framework that can be used as a basis for assessing impacts of and evaluating mitigation options for the effect of the Susitna Hydroelectric Project on the terrestrial environment in the Susitna Basin.

The specific objectives for achieving this purpose are to:

a) develop an understanding of the biophysical processes of the Susitna Basin with respect to wildlife and vegetation;

b) develop this understanding by integrating information on big game, furbearers, small mammals, birds, and plant ecology into a computer simulation model;

c) refine the model during a series of technical meetings;

d) update the model as new information becomes available from field studies; and

e) use the model as a framework and guide to assess terrestrial impacts of the Susitna Hydroelectric Project and to evaluate ways of mitigating impacts.

The workshops play a major role in attainment of these objectives. They provide a systematic approach to organizing information and people. As such, they are a major tool for consensus building and interdisciplinary coordination.

1.2 Relationship to Mitigation Planning

Many aspects of mitigation planning will be accomplished outside of the simulation modelling workshop process. Many mitigation measures, such as controlling dust along roads, leaving clumps of trees along the reservoir margin for eagle nesting, minimizing aircraft disturbance, locating recreation facilities away from critical wildlife areas, and deciding upon environmentally sound access road design criteria can easily be developed without a quantitative model. Most of these measures to be incorporated into engineering design and construction planning have been developed or will be developed prior to the submittal of the FERC application.

However, certain mitigation measures, such as habitat enhancement or compensation lands for habitat lost, may require several years of analysis and discussion. The primary purpose of the simulation modelling workshop process is to incorporate these more complex issues into the mitigation planning. Recognizing that these issues will not be resolved prior to the license application, the workshop process allows for an adaptive approach to planning. It provides a framework for increased communication, and a mechanism for designing and utilizing the results of future research and monitoring studies.

1.3 Simulation Modelling Workshops

There has been an enormous increase in public concern over environmental impacts of development projects in the past two decades. One consequence of this concern has been the use of detailed environmental impact assessments as an integral part of major resource development activities. These impact assessments are always multidisciplinary, but, in most cases, little effort is made to develop a coordinated, interdisciplinary approach. Consequently, vital information required to make predictions of impacts encompassing more than one discipline is often overlooked or not collected.

Over the past ten years a group of environmental scientists and systems analysts at the University of British Columbia and the International Institute for Applied Systems Analysis (IIASA) in Austria have developed a methodology to deal explicitly with interdisciplinary ecological problems (Holling, 1978). The core of the methodology is a five day workshop involving a team of four or five experienced simulation modellers and a group of fifteen to twenty specialists. The focus of the workshop is the construction of a quantitative simulation model of the system under study. The development of the simulation model forces specialists to view their area of interest in the context of the whole system. This promotes an interdisciplinary understanding of the system, and allows ecological and environmental knowledge to be integrated with economic and social concerns at the beginning, rather than at the end, of an impact assessment.

Simulation models require unambiguous information. In the workshop setting specialists are forced to be explicit about their assumptions. This objectivity exposes critical conceptual uncertainties about the behavior of the system, and identifies research needs.

1.3.1 Workshop Activities

The first step in the workshop is to clearly define and bound the problem. Bounding makes the modelling problem more explicit, thereby making it easier to decompose the system into manageable components or subsystems. In bounding, development actions (alternate controls available to management as well as development strategies) and indicators (those measures used by management in evaluating system performance in response to various combinations of actions) are generated. The model embodies the biophysical rules required to transform the actions into indicator time streams. Bounding also involves defining the spatial extent and resolution required to adequately represent the system, and specification of the temporal extent or time horizon and an appropriate time step.

The final bounding exercise of the workshop is called "looking outward". It focuses attention on the subsystems defined by the actions and indicators and those variables required by each subsystem from the other subsystems. In looking outward, the standard question of analysis is recast. Instead of asking "what can you provide to the other subsystems from subsystem X?", the question "what do you need to know about all other subsystems in order to predict how subsystem X will behave?" is asked. This question demands a more dynamic view and forces one to describe a particular subsystem in the context of the entire system. The looking outward exercise generates, for each subsystem, a list of "inputs" it needs from the other subsystems and a list of "outputs" it must provide to the other subsystems.

The second step of the workshop is submodel construction. The workshop and each subgroup develops submodels for one of the subsystems. One workshop facilitator works within each subgroup and acts as the submodel programmer. The submodel must be able to generate the output variables required by other submodels and the appropriate indicator variables identified earlier.

The final step of the workshop is to put each of the submodels into the computer and link them into the system model. The system model is run under a variety of development scenarios to explore the consequences of various actions and hypotheses about system structure. The principal objective of this exercise in an initial workshop is to point out model deficiencies and identify areas requiring better understanding and information.

1.3.2 Beyond the Workshop

The first workshop can be followed by a period of independent work on identified research needs by collaborating individuals which will lead to a second workshop and possibly subsequent ones in a phased sequence. Early in the sequence, workshops concentrate on technical issues, but later, they focus more and more on communication to policy advisors and the affected constituencies. The emphasis on communication enables an effective and logical move to implementation, either in a pilot project or a full-scale program.

Throughout the workshop sequence, the simulation model is an expression and synthesis of new information and the changing mental models of scientists, managers and policy makers. The involvement and interaction of these groups means that learning becomes as much a product as does problem solving.

2.0 BOUNDING

All systems are hierarchial in nature; each is comprised of smaller parts, and is, in turn, embedded in, or part of a larger system. The most critical decisions that are made in planning research and analysis are the choices of components to be explicitly addressed. The same is true for modelling.

Within simulation modelling workshops, these choices are made during an exercise called bounding. Bounding forces the participants in the workshop to define lists of actions and indicators and place them in an appropriate spatial and temporal framework. Once accomplished, the "looking outward" exercise defines the key interrelationships between components of the system under scrutiny.

2.1 Actions

Actions, in the context of modelling, are normally thought of as human intervention into the environment. With regard to the proposed developments on the Susitna, four major categories of actions (Table 2.1) were identified for inclusion into the model. The first relates to the construction and operation of reservoirs; the second relates to recreational development, use, and control; the third relates to development other than hydroelectric; and the fourth corresponds to mitigation options.

2.2 Indicators

Indicators are those quantities which are used to evaluate the performance or health of a system in response to the defined actions. The set of indicators (Table 2.2) identified by participants in the workshops are primarily related to wildlife populations and wildlife habitat measures, although instream flows and indicators of recreational use are included.

Table 2.1: Actions identified at workshop.

I. Reservoirs

a. Construction

- roads
- borrow pits
- transmission lines
- camp sites
- village sites
- river bed mining
- reservoir clearing
- air strip construction
- aircraft use
- staging areas

b. Operation

- operating rule curves

II. Recreation/Access

- reservoir recreational development (access and facilities)
- recreational use (back packing, hunting, fishing)
- increased traffic on existing roads/railroads

III. General

- changes in land use patterns (mining, oil and gas development)
- increased population in surrounding communities

IV. Mitigation

- habitat enhancement
- controlled burn
- replacement lands
- vegetation crushing
- flow regulation for fish and wildlife
- fire protection
- control of access
- hunting/fishing regulation
- scheduling of construction activities
- siting of roads
- reclamation/revegetation

Table 2.2: Indicators identified at workshop.

Hydrology

- instream flows

Vegetation

- acres of selected vegetation types

Wildlife

- populations of:

moose	raptors
black bear	beaver
brown bear	marten
wolves	birds

- carrying capacity for the above populations
- numbers of animals harvested by hunters
- habitat quality

Recreation

- number of user days
- non-consumptive uses of wildlife

The predicted changes in indicators are used to help determine the impacts of the actions over time, and in turn, evaluate the quantity, quality, and timing of mitigative actions.

2.3 Spatial Considerations

Defining the spatial extent and reoslution of any research or analysis is a critical step. It determines the level of detail and places geographical limits on what is to be considered. Simulation models require an unambiguous definition of the spatial extent and resolution.

The spatial extent of the model was guided by estimated home ranges of brown bear and moose. An area corresponding to all of a home range was included. With this criterion, the Upper Susitna Basin, extended to include the Prairie Creek-Stephan Lakes region, was chosen as the area for assessing impacts upstream of the Devil Canyon Dam site. Within this upstream area, the Watana and Devil Canyon impoundments are considered separately and the remaining land is designated as a third spatial unit (Figure 2.1). Downstream (Devil Canyon Dam site to Cook Inlet), an area corresponding to moose home range was defined using estimates from Modafferi (1982). Moose home range probably occurs in a band 60 km wide; 30 km on each side of the Susitna. The model simulates this band as far downstream as Talkeetna. The Susitna floodplain is considered separately within the downstream area. Areas downstream of Talkeetna were not included because the present and future hydrologic regime there, and its influence on vegetation dynamics, was considered too complex to construct an adequate predictive model.

Therefore, there are five spatial areas in the model:

a) the Watana impoundment;

b) the Devil Canyon impoundment;

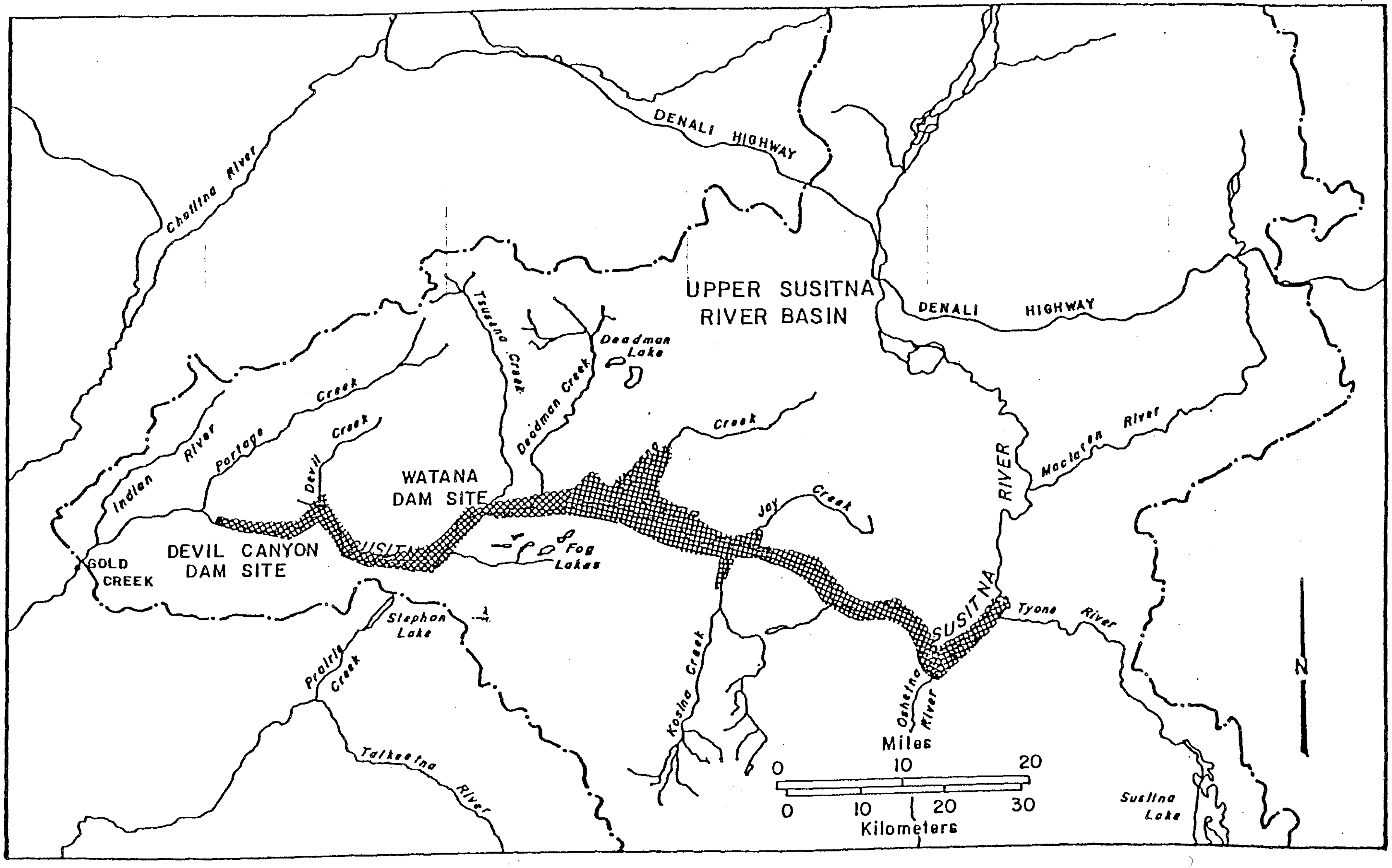


Figure 2.1a: Upper Susitna Basin showing the Devil Canyon and Watana impoundments (shaded area).

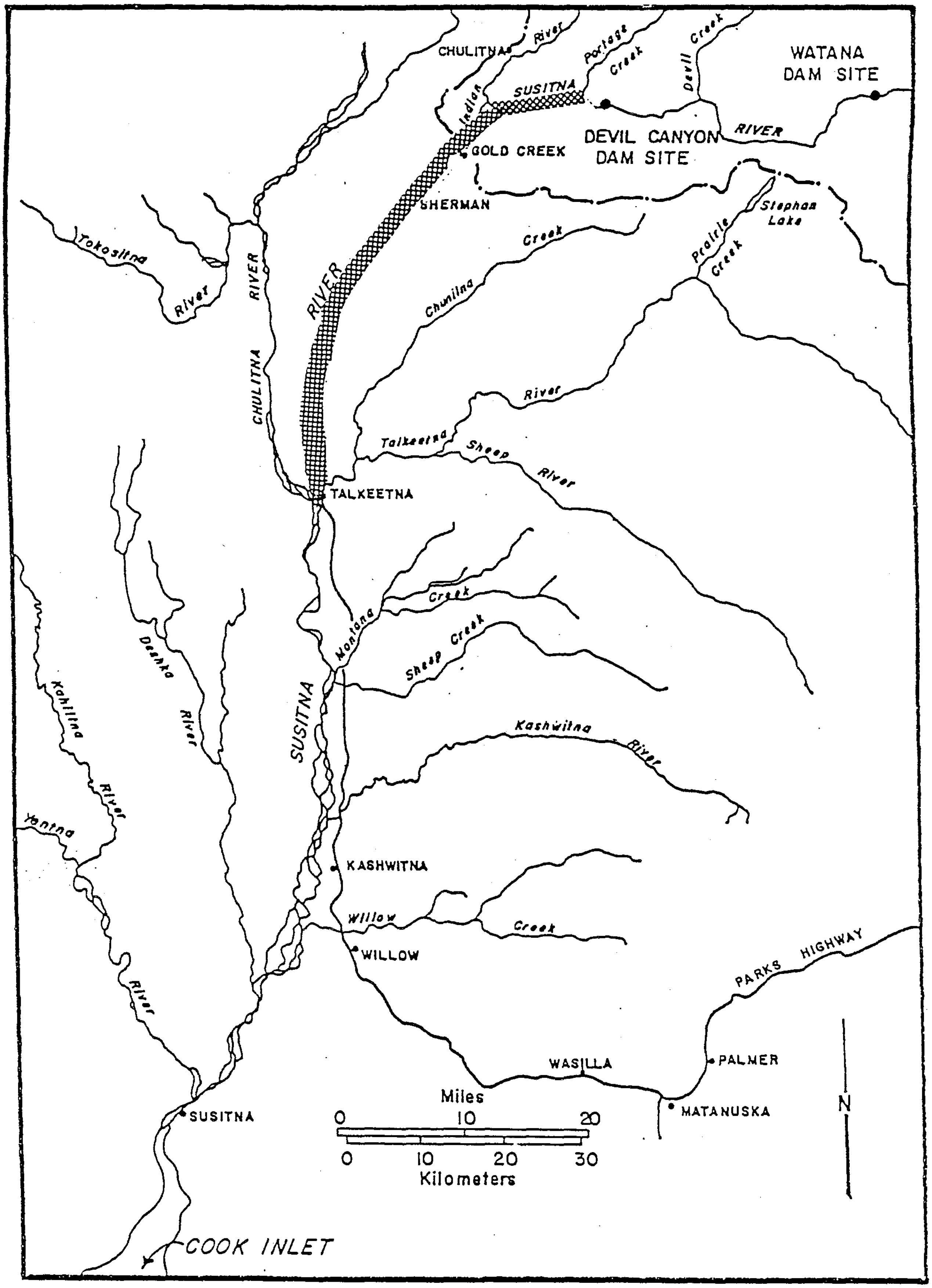


Figure 2.1b: Lower Susitna Basin showing Devil Canyon to Talkeetna riparian zone (shaded area) designated for the model.

c) the remainder of the Susitna Basin upstream of Gold Creek;

d) the floodplain from Devil Canyon Dam to Talkeetna; and

e) the remaining land in a 60 km strip from Devil Canyon Dam to Talkeetna.

Within each of the spatial areas, fourteen vegetation types (Table 2.3) were defined.

2.4 Temporal Considerations

The choice of the temporal resolution or time step for the model is always problematic because of widely different time scales of important processes. Many biological processes depend on water levels at critical times throughout the year requiring monthly, and sometimes daily, water level estimates. However, wildlife and waterfowl populations do not change substantially from one day to the next making daily population estimates unnecessary. These considerations, combined with the necessity of representing much slower successional processes, led to a mixed temporal structure. Average and peak flows are available monthly from hydrology. All other submodels have a one year time step but may implicitly include seasonal dynamics when needed. A time horizon of 50 - 80 years was chosen (to capture the successional effects).

2.5 Submodel Definition

The breakdown of the system into component subsystems is reflected in the breakdown of the simulation model into the submodels:

Table 2.3: Fourteen vegetation types associated with the spatial areas.

Conifer forest
- woodland
- open

Deciduous and Mixed Forest
Tundra
Tall shrub - alder
Medium shrub
Low shrub
- birch
- willow
- mixed

Unvegetated
- water
- rock/snow/ice

Disturbed
- temporary
- permanent

Pioneer

a) physical processes/development/recreation;

b) vegetation;

c) furbearers/birds;

d) moose; and

e) bears.

The major components of each submodel (Table 2.4) were decided upon through discussion by workshop participants.

2.6 Looking Outward

The purpose of "looking outward" is to define the pieces of information that a particular subsystem requires from all other subsystems to predict its dynamic behavior. This is a qualitatively different question than the traditional one which generates lists of factors which affect a particular component of a system. The product of "looking outward" is an interaction matrix, with columns specifying what information a subsystem requires from each of the other subsystems (Table 2.5). The diagonals are blank because they represent the internal dynamics of each subsystem.

Each piece of information listed in the matrix represents a specific hypothesis about system behavior. For example, the furbearers/birds submodel requires information on the length of sloughs and side channels that maintain at least .5 m of ice-free water throughout the winter from the physical processes/development submodel. The underlying hypothesis is that this represents potential overwintering habitat for beavers.

Table 2.4: Submodel components decided on by workshop participants.

1. Physical Processes/Development/Recreation:

    - flows
    - stages
    - ice processes
    - reservoir elevations
    - aquatic furbearer habitat
    - hydroelectric development scenarios
    - other development scenarios
    - recreational use
    - recreational development

2. Vegetation:

    - areal extent of vegetation types
    - browse production
    - berry production
    - ecological succession

3. Furbearers/Birds:

    - beavers
    - marten
    - golden eagles
    - passerine birds

4. Moose:

    - moose
    - moose habitat

5. Bears:

    - bears
    - bear habitat

Table 2.5: Looking Outward Matrix. Major information transfers between submodels.

	PHYSICAL PROCESSES/ DEVELOPMENT/ RECREATION	VEGETATION	FURBEARERS/BIRDS	MOOSE	BEARS
PHYSICAL PROCESSES/ DEVELOPMENT/ RECREATION		-location & areas (ha) of development activities -minimum water surface area (ha) in floodplain during growing season -area (ha) of ice scouring in downstream floodplain	-length (km) of slough, side channel, & mainstem habitat with > .5 m ice-free water -reservoir elevations (ft) -human disturbance	-snow depth (ft)	-recreational use (days)
VEGETATION			-areas of vegetation types (ha) -proportion of slough, side channel, & mainstem habitats that have balsam poplar or birch	-areas of vegetation types (ha) -standing crop (kg/ha) & areas of: Paper Birch Lowbush Cranberry Balsam Poplar Willow Shrub Aspen	-production of berries (kg/ha) -area (ha) of berries suitable for bear food -areas of vegetation types (ha)
FURBEARERS/ BIRDS		-number of beaver colonies			
MOOSE		-consumption (kg/ha) of browse species by season and type			
BEARS		-consumption (kg/ha) of forage species by season and type			-bear population (numbers)

3.0 SUBMODEL DESCRIPTIONS

The five submodels, described in this section, hydrology/ development/recreation, vegetation, furbearers/birds, moose, and bear, are an interdisciplinary representation of the terrestrial biophysical processes of the Susitna Basin. In some cases, the relationships described are based on good scientific evidence; in other cases, they are simply crude hypotheses or educated guesses. These models require critique and refinement before a reasonable representation of important terrestrial processes is achieved.

3.1 Physical Processes/Development/Recreation

The Susitna hydroelectric development will impact the terrestrial environment directly through disturbance and vegetation loss on lands needed for project facilities, and indirectly through alteration of the hydrologic and ice regimes of the Susitna River. Another possible and perhaps major impact on the terrestrial environment will occur through increased recreational opportunities that may result from increased access and the development of recreational facilities at or near the reservoir. Also, while development associated directly with the hydroelectric project may have a substantial impact and is the primary focus of this project, it is important to place this development in the context of development activities that are indirectly related to the project, such as mining, oil and gas exploration and production, and new recreational facilities.

3.1.1 Physical Processes

Almost all the physical processes considered in the model are related to the flow regime or climate or the interaction of both factors. Currently, the model simulates the flow regime at three stations (Gold Creek, Sunshine, and Susitna) for four different cases:

a) preproject flows;

b) Case A, which corresponds to optimum power generation;

c) Case C, which corresponds to case used in the FERC license application; and

d) Case D, which corresponds to the best development for meeting instream flow targets.

The post project cases A, C, and D can be used assuming Watana operating alone or with both Devil Canyon and Watana in place. Thus, the model uses one of seven possible flow regimes downstream of Devil Canyon. The flows are based on historical preproject flow data and estimates provided by Acres American Ltd. (Dave Crawford, pers. comm.) for post project flows under different operating conditions. Thirty-two years of data for each case are used and repeated. Figure 3.1 is a comparison among the four cases using the data used for simulation year 12. Average monthly flow is usually a poor indicator of the stress on an ecosystem and, in many cases, extreme flows (minima and maxima) are more important. The model makes daily and 3 day minimum and maximum flow estimates using data supplied by R & M Consultants (pers. comm.).

3.1.1.1 <u>Reservoir Elevations</u>

The operation of the dams causes the reservoirs to vary throughout the year as seen for the simulation year 12 in Figure 3.2. The model provides the reservoir elevations for Watana Reservoir based on monthly estimates provided by Acres American.

3.1.1.2 <u>Stage</u>

The calculation of stage is based on stage-discharge rating curves like the ones shown for Gold Creek (Figure 3.3).

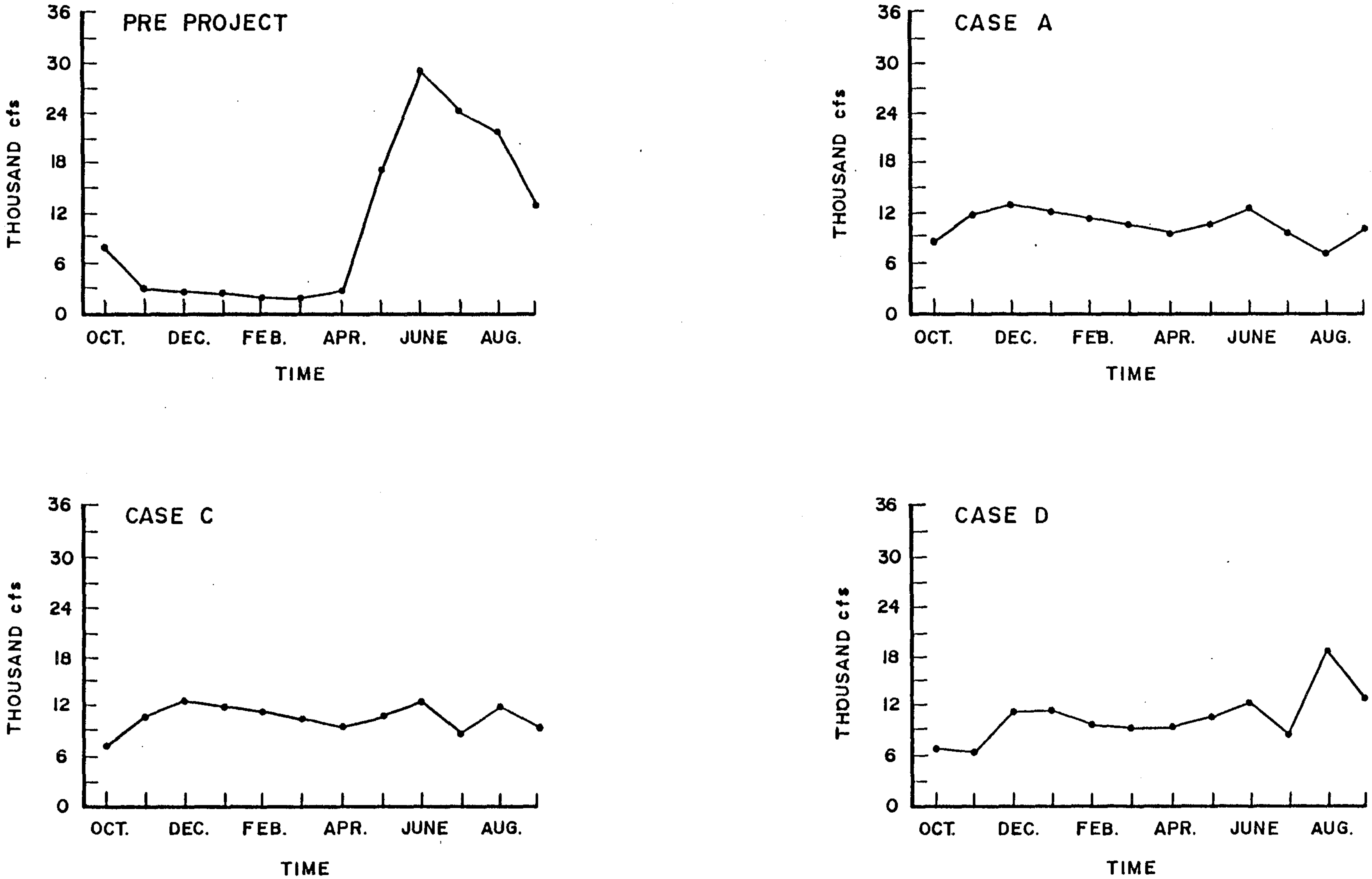


Figure 3.1: Gold Creek flows for preproject, case A, case C, and case D, assuming both dams operating.

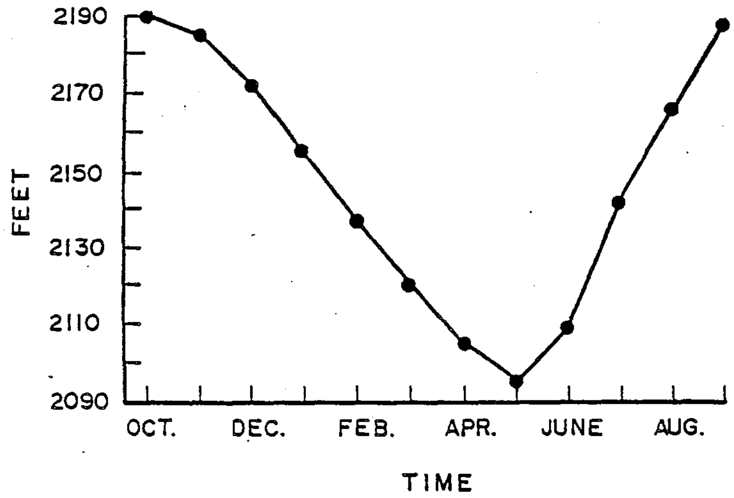


Figure 3.2: Watana Reservoir elevations throughout the year.

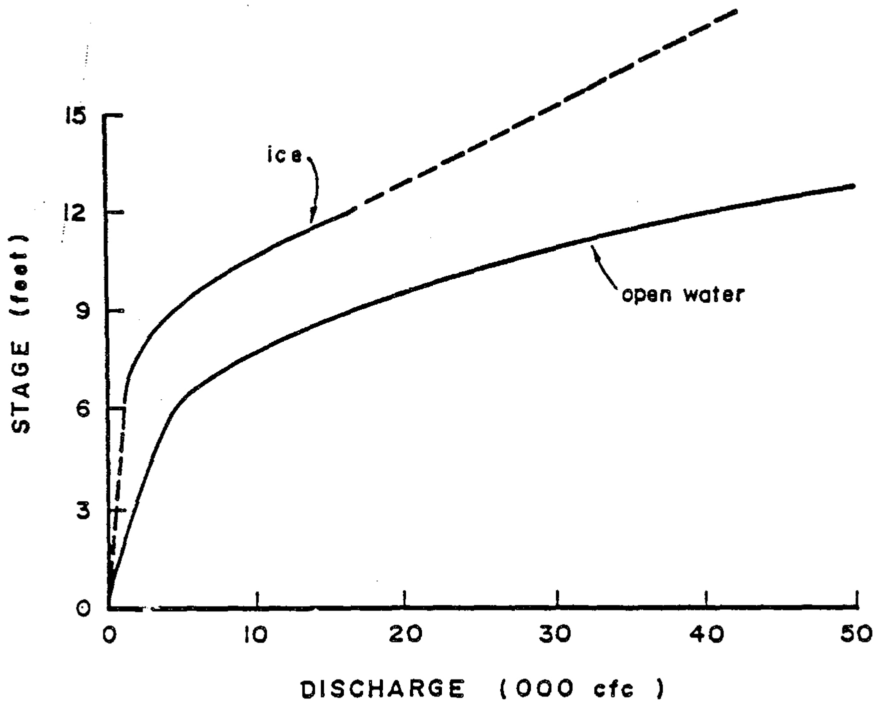


Figure 3.3: Stage-discharge rating curves for Gold Creek Station. Open water case based on USGS data gathered since October 1, 1967. Ice case estimated from data in the FERC license application (Exhibit E, Chapter 2). The dotted line indicates uncertainty for the given discharge ranges.

Both the open water and ice covered curves shown are used by the model. The open water case is based on USGS data gathered since October, 1967; the ice cover case is estimated from the FERC license application (Exhibit E, Chapter, Figure E.2.185).

3.1.1.3 Water Surface Area in the Downstream Floodplain (Devil Canyon to Susitna-Chulitna Confluence)

Total area of water surface between Devil Canyon and the Susitna-Chulitna confluence was estimated at various flow levels using the U.S. Corps of Engineers HEC-2 runs (dated February 2, 1982) (R & M Consultants, pers. comm.). Figures were computed by using the average width of adjacent cross sections and multiplying by the length between them. The steep slope around a flow of 20,000 cfs shown in Figure 3.4 exists due to the addition of sloughs to the flow regime of that level.

Knowledge of the water surface area and an estimate of the total area in the floodplain allows the vegetation submodel to estimate the total surface area exposed in the floodplain.

3.1.1.4 Ice Dynamics

The ice dynamics in the downstream area are considered to be the critical determinants of the suitability of fish and furbearer habitat and vegetation succession. The introduction of the project is expected to change the timing of freeze-up, ice staging, ice scouring, the timing of break-up, and create year round open water in part of the downstream area (Devil Canyon to Talkeetna).

3.1.1.4.1 Formation of Ice Cover

Under preproject conditions, the model assumes that the entire downstream reach (Devil Canyon to Talkeetna) is completely covered with ice by mid-December. Under post project conditions,

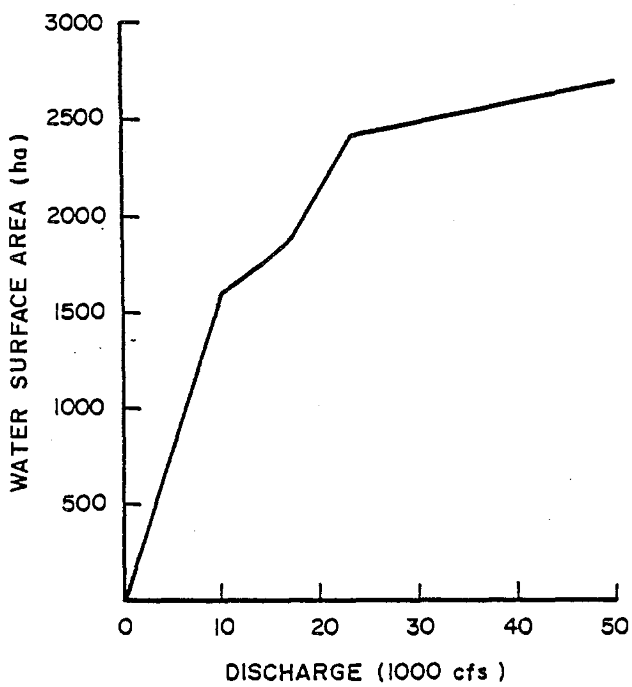


Figure 3.4: Water surface area in the downstream floodplain (Devil Canyon to Susitna-Chulitna confluence) as a function of discharge measured at Gold Creek Station.

an ice front is formed by mid-January delineating the ice covered and open water stretches of the reach. If Watana alone is operating, this front is formed somewhere between Portage Creek and Sherman; if both projects are operating, the front is formed somewhere between Talkeetna and Sherman. The exact position of the front is dependent on climatic conditions simulated using a uniform random number.

3.1.1.4.2 Ice Staging

The formation of ice cover causes significant ice staging, that is, a significant increase in stage over what would be present under open water condition. This condition, illustrated by Figure 3.3, has implications for maintenance of groundwater upwelling in sloughs and for vegetation damage caused by the ice as the river stages. As the river stages, it lifts the ice already in place and tears or scours the vegetation along the edges of the channel. To make a rough estimate of the area affected, the model calculates the difference between the water surface area assuming open water (Figure 3.4) and the area covered at maximum ice cover (Figure 3.5). This area is considered to be area subjected to potential vegetation damage due to ice during freeze-up.

3.1.1.4.3 Break-up

Prior to the project, the model assumes that break-up occurs in early May and more often than not is triggered by high inflows from tributary streams. After the projects are operating, break-up will occur in mid-April and more often than not the ice cover will melt in place before the high inflows from tributary streams occur. As a result, there will be significantly less ice scouring after the project. To simulate the break-up processes and the occurrence of ice scouring, the model stochastically generates the timing (Figure 3.6) of melting and high inflow from tributary streams. If the ice melts in place before the high inflows occur, no ice scouring occurs; if high

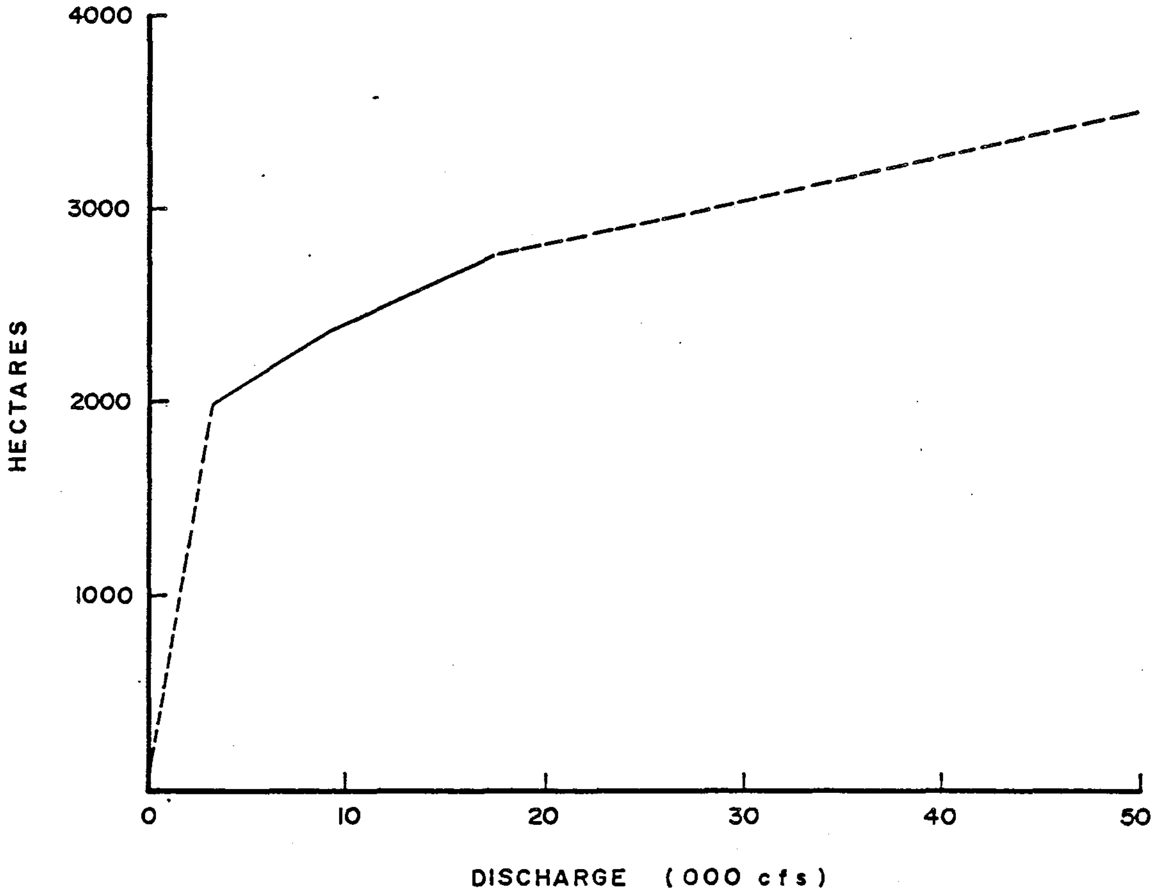


Figure 3.5: Hypothetical relationship of area of maximum ice cover as a function of discharge. The dotted lines indicate uncertainty for the given discharge ranges.

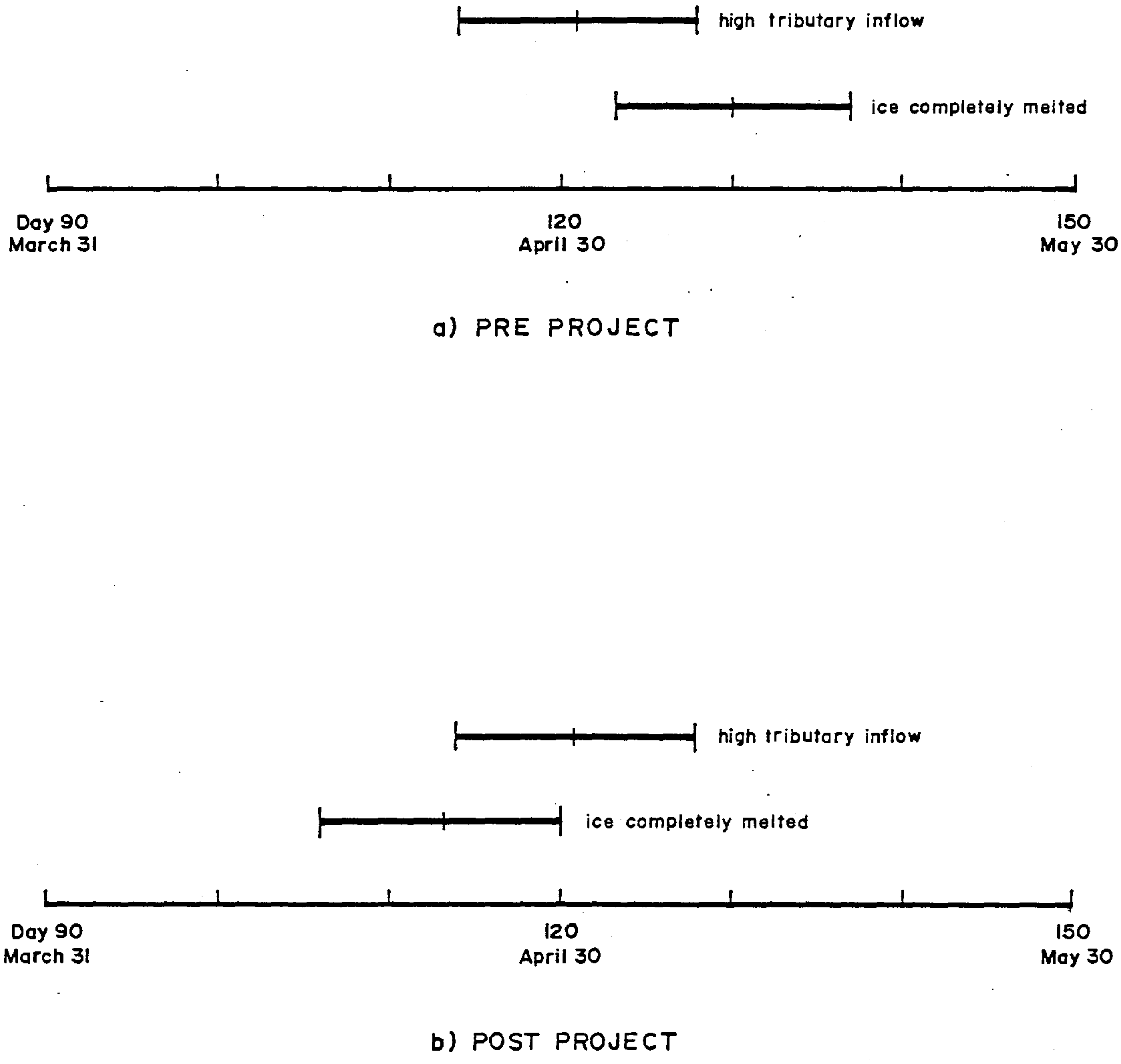


Figure 3.6: Simulated timing of events affecting break-up.

inflows occur before the ice has completely melted, then the area subject to ice scouring is calculated using the water surface area-discharge relationship for the open water case (Figure 3.4).

3.1.1.5 Flood Events

The model calculates the area flooded based on the water surface area curve (Figure 3.4) at various times throughout the year. In particular, the maximum flooded area is calculated and usually occurs in June, July, or August. The minimum flood area during the growing season is calculated and provided to the vegetation submodel.

3.1.1.6 Downstream Effects

The processes represented in the physical submodel are important because of their effects downstream of Devil Canyon. In the reach extending as far as Talkeetna, the model is currently concerned with how changes in the hydrologic regime will effect beaver overwintering habitat and vegetation succession.

3.1.1.6.1 Beaver Overwintering Habitat

Side channels and sloughs that retain greater than .5 m in depth of unfrozen water throughout the winter provide potential overwintering habitat for beaver. In the major area of concern, downstream of Devil Canyon Dam to Talkeetna, the amount of this habitat is directly related to water level (stage) and ice thickness. The stage depends on flow (Section 3.1.1.2), and the ice thickness depends on flow and the severity of the winter. In the model, the effect of the severity of winter was simulated as a random process that increased or decreased the amount of habitat for beaver.

Before discussing the relationships used to estimate the amount of potential overwintering habitat for beaver, a careful definition of mainstem, side channel, and side slough habitat is necessary. The following definitions are adopted from Trihey (November, 1982).

Mainstem habitat consists of those portions of the Susitna River which normally convey streamflow throughout the year. Both single and multiple channel reaches are included in this habitat category. In general, this habitat category is characterized by high-velocity streamflows and well armored streambeds. Substrates generally consist of boulder and cobble size materials with interstitial spaces filled with a grout-like mixture of small gravels and glacial sand. Suspended sediment concentrations and turbidity are high from late May through early October due to the influence of glacial melt water. Streamflows recede, and the water appreciably clears in the early to mid fall before an ice cover forms on the river in late November or December. Groundwater and tributary inflow appear to be inconsequential contributors to the overall characteristics of this habitat category. Seasonal temperatures of the mainstem river respond primarily to air temperature and solar radiation. Mainstem surface water appears to establish mainstem intragravel water temperatures.

Side channel habitat consists of those portions of the Susitna River which normally convey streamflow during the open water season but which become appreciably dewatered during periods of low flow. The controlling streambed elevations at the upstream entrance to the side channels are less than the water surface elevations of the mean monthly flows for June, July and August. Side channel habitats are characterized by shallower depths, lower velocities and smaller streambed materials than mainstem habitats. In general, the streamflow, sediment, and thermal regimes of the side channel habitats reflect attenuated mainstem conditions. Tributary and groundwater inflow may prevent some side channel habitats from becoming completely dewatered when mains em flows recede. However, the presence of these limited inflows could conceivably not be considered a critical component of side channel habitat. A winter ice cover, similar to that which forms on the mainstem, generally exists in the side channels.

Side slough habitats are found in spring-fed perched overflow channels which only convey glacial meltwater from the mainstem during median summer and high flow periods. At intermediate and low flow periods, the side sloughs convey clear water from small tributaries and/or upwelling groundwater. The controlling streambed/streambank elevations at the upstream end of the side sloughs are slightly less than the water surface elevations of the mean monthly flows for June, July, and August. Side sloughs generally exist along the edge of the floodplain, separated from the mainstem by well-vegetated bars. An exposed alluvial berm often separates the head of the slough from mainstem or side channel flows where as the water surface elevation of the river generally causes a backwater to extend well up into the slough from its lower end. It is important to note that, even though a substantial backwater exists, hydraulically the sloughs function very much like small stream systems. Several hundred feet of the slough channel often conveys water independent of mainstem backwater effects.

Except when the discharge in the maintstem river is sufficient to have overtopped the upper end of the slough, surface water temperatures in the side sloughs appear to be independent of those in the mainstem river. Surface water temperatures in the side sloughs during summer months are principally a function of air temperature, solar radiation, and the temperature of the local runoff. During winter months, surface water temperatures are strongly influenced by upwelling groundwater. The large deposits of alluvium through which the upwelling water flows appear to act as a buffer or thermal reservoir, attenuating summer temperatures and providing very stable winter temperatures.

The model assumes that all side slough habitat that retains at least .5 m of ice free water throughout the winter can support beavers. The side channels are only considered suitable if the velocity is low enough (less than 4.4 ft/sec) in addition to maintaining sufficient depth of ice free water.

Apparently, the amount of ice free water in sloughs and side channels is related to the amount of warm groundwater inflow. The groundwater inflow is related directly to the hydraulic head between the mainstem and the sloughs and side channels. The hydraulic head is physically dependent on the mainstem stage. Under present conditions, the model assumes that the increased stage associated with a winter ice cover makes it possible for the same hydraulic head to exist between the mainstem and adjacent side slough habitats during the winter as exists during late summer.

In the model, the amount of suitable overwintering habitat is functionally related to stage. In the case where the reach is ice covered, the ice staging curve is used; in the case where there is open water, the open water curve is used (Figure 3.4). The relationship between the amount of habitat and the stage (Figure 3.7) saturates at high stages under the assumption that increased groundwater inflow does not make a given area any more desirable, although it may make areas that were formerly unsuitable, desirable habitat.

Under current conditions, the entire reach becomes ice covered during the winter; with the project, an ice front will form far downstream from Devil Canyon. The exact location depends on the scale of the project and the severity of the winter. In any case, only a portion of the reach will be ice covered. Because of this, the model calculates the available habitat for the ice covered portion of the reach and for the open water portion. In addition, the model makes separate calculations for sloughs, side channels, and mainstem habitat. The slough and side channel habitat numbers are aggregated before being provided to the beaver submodel.

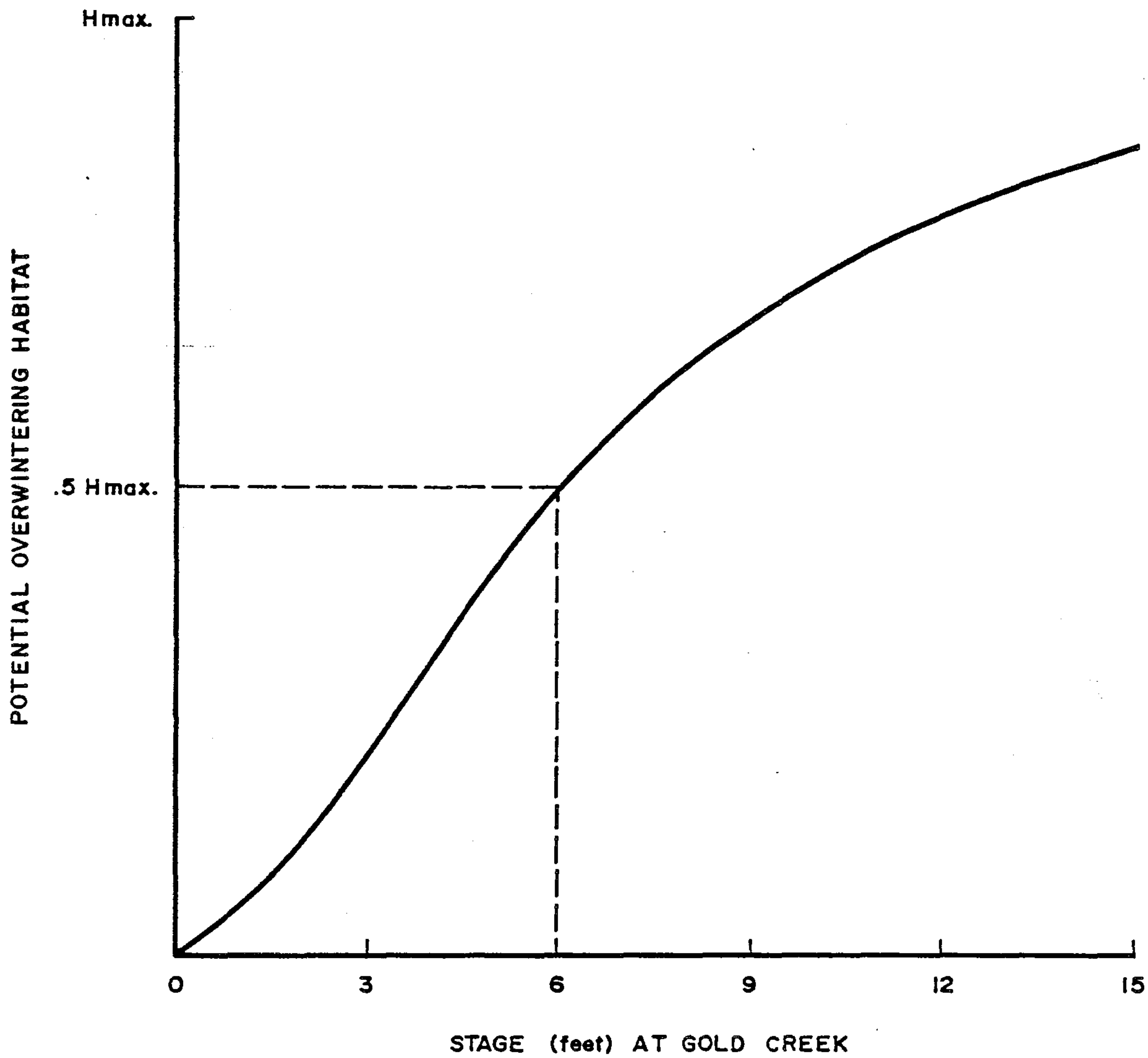


Figure 3.7: Potential overwintering habitat as a function of stage. Hmax represents the maximum for a given habitat.

3.1.1.6.2 Vegetation Succession

The regular flooding and ice scouring in the downstream reach provides a regular stress to the vegetation types that occur at lower elevations relative to the water surface elevation. Previous sections (3.1.1.4.2, 3.1.1.4.3, 3.1.1.5) have discussed how the extent of ice scouring and flooding is determined in the model. The description of the vegetation model will discuss how these processes affect succession.

3.1.1.7 Snow

Snowfall is simply generated stochastically because there was insufficient conceptual understanding of snow dynamics. This is a major model deficiency because snow levels can seriously affect utilization of moose winter range.

3.1.2 Hydroelectric Development Activities

The timing, location, and areas affected by project activities considered by the model are listed in Table 3.1. The areal values in Table 3.1 are from the FERC license application, Exhibit E, Chapter 3; Tables E.3.80, E.3.83, E.3.84, and E.3.85. At the appropriate time and location, the model alters the vegetation classification for the area associated with the site for the activity to the "disturbed" category (c.f. Table 2.3). The site may be permanently disturbed or may be reclaimed or revegetated at a later date.

3.1.3 Other Land Use Activities

There are a number of current and potential uses for the land with the geographic area being considered by the model. These include agriculture, forestry, recreation, settlement, coal development, mining development, oil and gas development, and transportation. There appears to be little potential for agriculture, coal development, and oil and gas development

Table 3.1: Hydroelectric development project actions.

ACTION	AREA AFFECTED	TIME	LOCATION
1. TRANSMISSION CORRIDORS (clearing)			
• Watana to Devil Canyon	380 hectares	1989-1990	Watana to Devil Canyon
• Devil Canyon to Intertie	132 hectares	1989-1990	Devil Canyon to Chulitna Pass/Indian River
2. CAMPS			
• Watana	63 hectares	1985-1994	Between Tsusena & Deadman Creeks
	Reclamation starts (No permanent structures)	1994	
• Devil Canyon	36 hectares	1994-2002	South of Susitna River on plateau opposite Portage Creek
	Reclamation starts (No permanent structures)	2002	
3. VILLAGES			
• Watana (permanent)	70 hectares	1986-	Between Watana Camp site and Tsusena Creek, surrounding small lake
• Devil Canyon (no permanent buildings)	39 hectares	1996-2002	South of Susitna River on plateau opposite Portage Creek
4. RESERVOIR CLEARING			
• Watana	3405 hectares	1989	Watana impoundment
	3642 hectares	1990	Watana impoundment
	3642 hectares	1991	Watana impoundment
	4047 hectares	1992	Watana impoundment
• Devil Canyon	1000 hectares	1999	Devil Canyon impoundment
	1196 hectares	2000	Devil Canyon impoundment
	1000 hectares	2001	Devil Canyon impoundment

ACTION	AREA AFFECTED	TIME	LOCATION
5. STAGING AREAS			
• Access Plan #13 (north)	61 hectares	1985-2002	Hurricane
• Access Plan #16 (south)	61 hectares	1985-2002	Hurricane
	61 hectares	1985-2002	Gold Creek
• Access Plan #17 (Denali)	61 hectares	1985-2002	Cantwell
• Access Road (FERC)	61 hectares	1994-2002	Gold Creek
6. CONTRACTOR WORK AREAS			
• Watana	77 hectares	1985-1994	Between Watana Camp and Dam Site
	146 hectares	1986-1994	
	77 hectares	1987-1994	
• Devil Canyon (including batching plant)	61 hectares	1994-2002	Between Devil Canyon Camp and dam site
	61 hectares	1995-2002	
	61 hectares	1996-2002	
	12 hectares	1997-2002	
7. CONTAINMENT STRUCTURES			
• Watana	14 hectares	1986-	Watana Dam site including floodplain
	36 hectares	1987-	
	26 hectares	1988-	
	3 hectares	1989-	
	10 hectares	1990-	
	4 hectares	1991-	
• Devil Canyon	1 hectare	1996-	Devil Canyon Dam site including floodplain
	5 hectares	1997-	
	13 hectares	1998-	
8. AIRSTRIPS			
• Watana	17 hectares	1985-	Adjacent to Watana Camp

ACTION	AREA AFFECTED	TIME	LOCATION
9. ACCESS ROAD (clearing)	192 hectares	Construction: 1985 Intensive use: 1985-2002	Denali Hwy to Watana Denali Hwy to Watana
	189 hectares	Construction: 1991-1993 Intensive use: 1994-2002	Watana to Devil Canyon Watana to Devil Canyon
	29 hectares	Construction: 1991-1993 Intensive use: 1994-2002	Devil Canyon to Gold Creek Devil Canyon to Gold Creek
10. BORROW AREAS WATANA			
• A	333 hectares	1985-1993	
• D	287 hectares	1985-1993	
• E	180 hectares	1985-1993	
• F	280 hectares	1985-1993	
• H	489 hectares	1985-1993	
• I	34 hectares	1985-1993	
• Devil Canyon K	148 hectares	1995-1999	

although lease sales have been proposed. Forestry and settlement may increase in the downstream portion of the Susitna. Perhaps the greatest potential is for increased mineral development and recreational opportunities.

Currently, the model only considers additional lands needed for settlement, mining development, and recreational development. Present use of the area is low, although substantial growth is expected if the Susitna project goes ahead. Estimates of current use (Table 3.2) are unsubstantiated, and must be revised when better estimates appear.

3.1.4 Disturbance to Wildlife

Associated with project activities and other land use activities is disturbance to wildlife as a result of the presence of humans. The model keeps track of three major classes of disturbance:

a) disturbance from recreational use;

b) disturbance due to the influx of construction workers; and

c) disturbance from vehicle and aircraft movements.

The disturbance from construction workers and vehicle traffic is provided in Table 3.3. Recreational disturbance is based on the use information from the FERC license application, Exhibit E, Chapter 7.

3.1.4.1 Recreational Use

In the model, recreational use is divided into eight categories consisting of (FERC license application, Exhibit E, Chapter 7): big game hunting, waterfowl hunting, freshwater fishing, developed camping, canoeing/kayaking, hiking, picnicking,

Table 3.2: Estimates of current land use and recreational use in geographic area considered in the model.

	Upper Susitna Basin	Downstream (Devil Canyon-Talkeetna)
Mining (hectares)	10,000	14,000
Settlement (hectares)	2,021	6,064

	Project Area
Recreational Use (use days)	
Big Game Hunting	800
Waterfowl Hunting	100
Freshwater Fishing	1500
Developed Camping	4000
Canoeing/Kayaking	200
Hiking	--
Picnicking	--
Cross-country Skiing	100

Table 3.3: Disturbance associated with construction workers and vehicle traffic.

DISTURBANCE	LOCATION	TIME	MAGNITUDE
Construction workers	Watana Camp & Construction Area	1983	180 workers on site at one time
		84	192
		85	690
		86	780
		87	1,140
		88	1,500
		89	1,680
		90	2,070
		91	1,920
		92	1,500
		93	780
		94	360
		95	48
	Devil Canyon Camp & Construction Area	1994	60 workers on site at one time
		95	240
		96	480
		97	750
		98	990
		99	1,020
		2000	900
		01	540
		02	48
Vehicle traffic	To Watana	1985-1995	53 trucks per week each direction
	To Devil Canyon	1994-2002	92 trucks per week each direction
	Gold Creek to Devil Canyon	1994-2002	4 trains per week each direction (if Denali Route is chosen)
Big Game Harvests	Game Management Unit #13	Present	Caribou - 750/year Moose - 750/year Brown Bear - 100/year Black Bear - 60/year
Diversion Structures - Blasting -	Watana Dam site	1985-1987	Unknown
	Devil Canyon Dam site	1995-1996	Unknown

and cross country skiing. Estimates of current recreational use (Table 3.2) are based on FERC license application, Exhibit E, Chapter 7 (1983). The reliability of these estimates is questionable. In particular, the estimate of big game hunting appears to be grossly understated.

The model assumes that recreation demand will approximately double by the year 2000 without the Susitna hydroelectric project. If the project goes ahead and the proposed recreation plan is adopted, recreation demand will be approximately sevenfold by the year 2000. These projections are based on the FERC license application, Exhibit E, Chapter 7, and are summarized in Table 3.4.

The model allows for a choice of access routes (Table 3.1). The choice of the access route will affect the amount and level of vegetation impacted and may impact critical wildlife areas. Another aspect is whether public access to the project area via the new access road is desirable. The model allows for open or restricted access.

3.2 Vegetation

The vegetation submodel is a set of rules for simulating vegetation and land use processes in response to direct Susitna development activities and indirect changes of the hydrologic regime in the downstream floodplain. The model is based on a land classification system in which areas in each land class are updated annually in response to human activities and processes of natural vegetation change. The Looking Outward Matrix (Table 2.5) identifies the processes simulated by the vegetation submodel in terms of information required by other submodels. The information consists of area of various land classes for each spatial unit, berry production in each land class, the standing stock of potential browse for moose in each land class, and a measure of the proportion of both main channel and sloughs or side channels with associated vegetation preferred by beaver.

Table 3.4: Estimated recreation demand (adapted from FERC license application, Exhibit E, Chapter 7).

	BIG GAME HUNTING	WATERFOWL HUNTING	FRESHWATER FISHING	DEVELOPED CAMPING	CANOEING/ KAYAKING	HIKING	PICNICKING	X-COUNTRY SKIING	TOTAL
Assumed 1980 Use of the Project Recreation Area, User Days	800	100	1,500	4,000	200	--	--	100	6,700
Estimated 2000 Use of the Project Recreation Area Without Susitna Hydroelectric Project, User Days	1,300	170	2,500	8,000	370	--	--	220	12,540
Estimated 2000 Use of the Project Recreation Area With Susitna Hydroelectric Project Proposed Recreation Plan, User Days	2,200 - 2,400	170	4,800 - 5,200	12,000 - 14,000	100	12,000 - 14,000	12,000 - 14,000	350	43,520

The only actions for which the vegetation submodel is directly responsible are controlled burning and vegetation crushing.

3.2.1 Structure

The sequence of calculations for the vegetation submodel is outlined in Figure 3.8. Given the 50 - 80 year time horizon for model runs, long-term successional dynamics in upland areas were not simulated in the absence of development activities. An attempt was made to simulate shorter-term riparian vegetation dynamics despite a limited understanding of riparian succession and the effects of ice processes.

3.2.2 Classification System

The classification system was developed from work described in the Plant Ecology Phase I Final Report (McKendrick et al., 1982). The classification system in the model distinguishes 14 classes of land, primarily defined on the basis of vegetation type, in each spatial unit (see Section 2.3). Initial conditions (Table 3.5) were estimated for all spatial units, except the one representing moose range in the area downstream from Devil Canyon. The impoundment areas estimated are slightly larger than the areas that would be cleared if the development proceeds. In addition to the spatial units described above, total areas in the upper Susitna Basin were calculated as the sum of the two impoundment areas and the rest of the upper Susitna unit.

The land classification was expanded slightly from McKendrick et al. for this project. A medium shrub class was defined in order to calculate bird indicator variables. Two disturbed classes were defined to represent land disturbed by construction of permanent facilities or by temporary activities which would be followed by artificial or natural revegetation. A pioneer class was added to represent the initial stages of herbaceous vegetation in riparian areas and following temporary human disturbance.

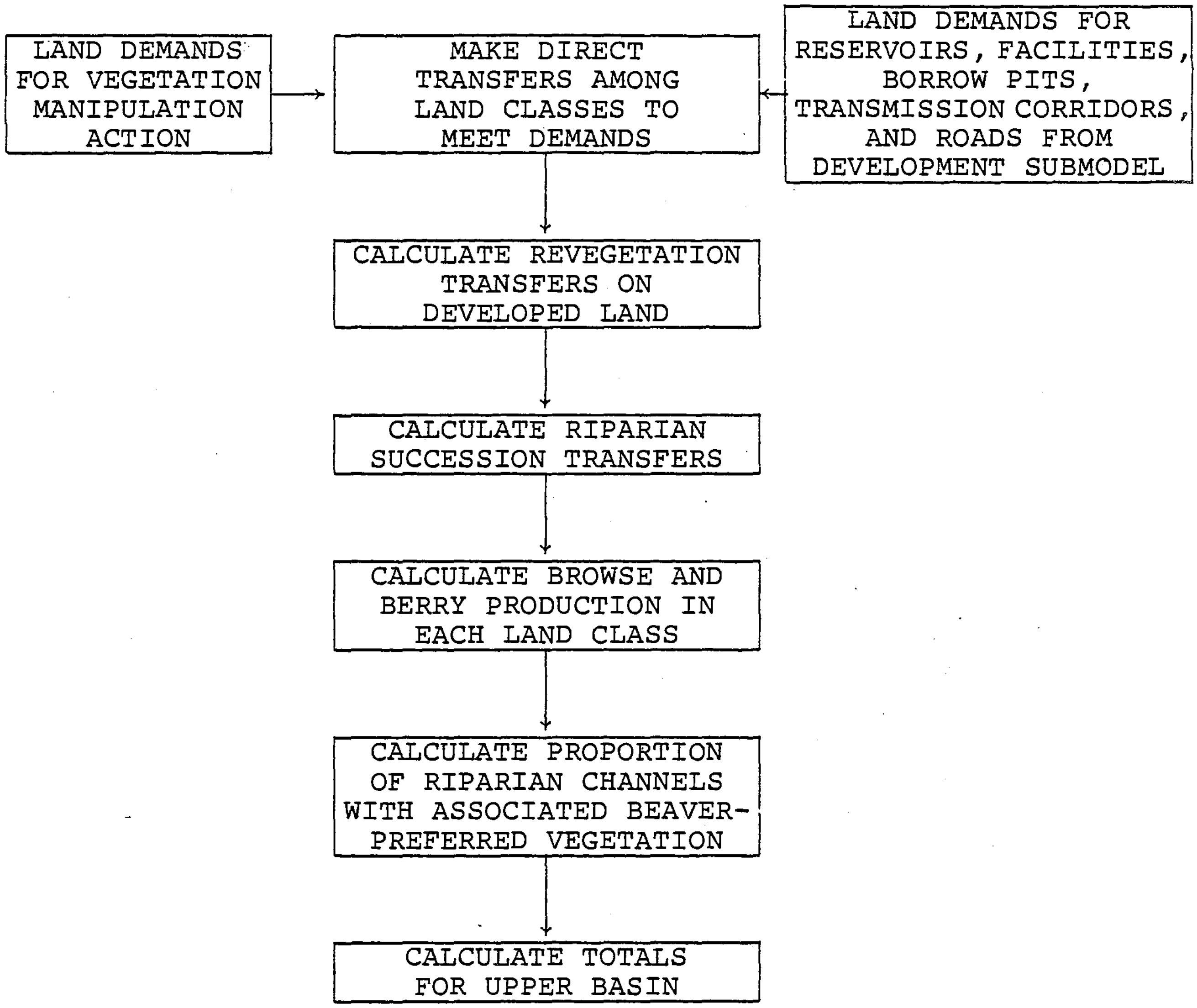


Figure 3.8: Calculation sequence for the vegetation submodel.

Table 3.5: Initial conditions for vegetation types. All values are in hectares.

LAND CLASS	WATANA IMPOUNDMENT AREA	DEVIL CANYON IMPOUNDMENT AREA	REST OF UPPER SUSITNA BASIN	RIPARIAN ZONE TALKEETNA TO DEVIL CANYON
Coniferous Forest-woodland and closed	4275	153	183963	0
Coniferous Forest-open	3633	633	114607	0
Deciduous and Mixed Forest	2911	1516	36218	3500
Tundra	84	11	394590	0
Tall Shrub	537	3	128495	300
Medium Shrub	44	5	3306	0
Low Birch Shrub	400	44	29750	0
Low Willow Shrub	66	14	10565	0
Low Mixed Shrub	673	4	470784	400
Unvegetated-water	2060	813	36967	600
Unvegetated-rock, snow, ice	60	15	203478	0
Disturbed-temporary	0	0	0	0
Disturbed-permanent	1	1	1	0
Pioneer	1	1	1	200

3.2.3 Development Activities

The vegetation submodel responds to demands for land associated with reservoir development, road construction, transmission corridor construction, borrow pits, and construction of permanent facilities. These demands, calculated each year by the development submodel, result in transfers of land among various land classes within the respective spatial units. Generally, the development land demands in a given spatial unit are met from the various land classes in the spatial unit according to their relative proportions in that unit. However, land demands for roads are specified as proportions of various classes associated with specific routes.

Clearing for reservoirs is simulated by subtracting the appropriate proportions of the reservoir land demand from the respective land classes and adding the total to the inundated land class.

The development demand for facilities is met by transferring land to the permanently disturbed class.

Access road construction is simulated by taking land from various land classes according to development submodel demand and route-specific land class proportions. Land for roads is added to the low mixed shrub class under the assumption that the biggest areal change is in the associated right-of-way.

The demand for transmission corridors is met by initially transferring land to the low mixed shrub class. This land is then subject to succession to the medium shrub class at an annual proportional rate of 20%.

Borrow pits are developed by transferring land to the temporarily disturbed class. User specified fractions of the borrow pit land are then subject to either inundation or revegetation. Inundated borrow pits are transferred to the water class, while revegetation of borrow pits consists of an initial transfer to the pioneer land class followed by a transition to low mixed shrub at a proportional rate of 10% per year.

Finally, the action of vegetation manipulation (controlled burning and crushing) transfers land from the deciduous and mixed forest class to the low mixed shrub class. This land is then subject to succession to the medium mixed shrub class (at a rate of 20% of the low mixed shrub class per year), followed by transfer to the deciduous and mixed forest class (at a rate of 7% of the medium shrub class per year). The area of land transferred by vegetation manipulation is provided as an action to the model as a whole, rather than as a value calculated by the development submodel. This action is intended to roughly simulate controlled burning and vegetation crushing which were discussed as possible mitigation measures designed to increase wildlife habitat value. The land is transferred only from the deciduous and mixed forest land class. It was felt that this would be the preferred land for vegetation manipulation because of relative increase in habitat value resulting from converting this land class to earlier successional stages.

3.2.4 Riparian Succession

Dynamics of vegetation in the riparian zone from Devil Canyon to Talkeetna are represented as the net effect of two opposing processes; natural succession and disturbance due to erosion and ice processes. The successional sequence is represented in Figure 3.9. Annual transfers among land classes (Figure 3.9) were estimated from observed ages of individual trees and shrubs within the various vegetation types.

The effects of ice processes on riparian vegetation are poorly understood. However, an attempt was made to include these effects in the model, primarily as a mechanism to help identify what information and studies might be required to

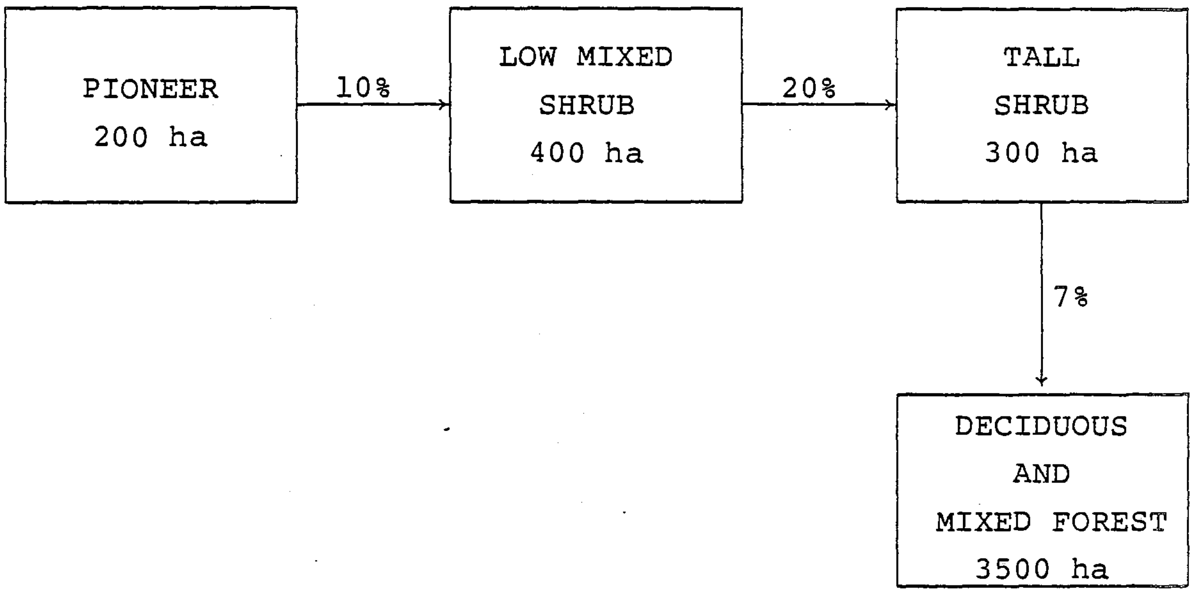


Figure 3.9: Successional sequence in the Talkeetna to Devil Canyon riparian zone. Numbers within each compartment are the estimated initial conditions. Numbers on the solid arrows represent the annual percentage transfers of land.

understand these effects sufficiently for mitigation planning. It was assumed that the vegetation communities are arrayed along an elevational gradient with pioneer vegetation occupying the lowest portion of the gradient and deciduous and mixed forest the highest. Based on this assumption and the surface area covered by ice (estimated by the physical processes submodel), the amount of each vegetation type scoured by ice is calculated. The total amount of vegetation scoured is the area covered by ice minus the area of the river channel. Because it is lowest on the elevational gradient, pioneer vegetation is assumed to be scoured first. If the area scoured is greater than the amount of pioneer vegetation, then some low shrub is also scoured. If the area scoured is greater than the amount of pioneer and low shrub, then some tall shrub is also scoured, and so on. The effect of scouring (i.e. the amount of vegetation converted to pioneer) depends on the vegetation type. Early successional stages are assumed to be less resistant to scouring than later successional stages at the same flow. However, later successional stages are assumed to be scoured only during high flow events when the energy of scouring is very great. The vegetation subgroup did not have sufficient information to determine the net effect of resistance to scouring/energy of scouring. However, they felt for the pre-project situation, it was reasonable to assume the riparian successional stages were in approximate equilibrium (i.e. no net long-term changes in the amount of land in each vegetation type). The model parameters controlling ice process effects were therefore adjusted until an approximate equilibrium was obtained.

The amount of scouring and the water level during the growing season determines how much new pioneer vegetation becomes established each year. If water levels are the same as last year, then the new pioneer vegetation is that created by scouring. If water levels are lower, new pioneer vegetation is that created by scouring plus those additional areas in the river channel exposed because of lower water. If water levels are higher than last year, new pioneer is only the portion created by scouring which remains above the higher water.

If water levels are much higher, then there may be no new pioneer vegetation established (even if scouring occurred) and some areas of existing pioneer vegetation may be flooded long enough to eliminate the vegetation.

3.2.5 <u>Wildlife Habitat</u>

The wildlife submodels required a measure of browse, a measure of berry production, and an index of the suitability of vegetation along channels in the riparian zone (for beaver) as measures of habitat.

An estimate of potential browse (kg dry weight/ha) is obtained for each land class by multiplying the relative cover of the primary browse species in each of the land classes by the quantity (kg/ha) of browse (measured to the average point of browse) associated with each species (Table 3.5). Random variation (standard deviation of 10%) is applied to these estimates to yield annual values. Annual berry production (kg dry weight/ha) is calculated in a similar fashion by applying the same random annual variation to an average production estimate (Table 3.6) based on production of berry species and their relative cover in the various land classes.

The suitability of channel vegetation in the riparian zone for beaver was difficult to calculate given the available information and the spatial scale of the model. The furbearer/bird submodel requires the proportion of both main channel and sloughs/side channels, with certain substrate conditions, which have willow or balsam poplar in close proximity to the channel. While it was not possible to make distinctions between main and sloughs/side channels or substrate conditions, an examination of aerial photographs indicated approximately 25% of the channels in the riparian spatial unit (Talkeetna to Devil Canyon) currently have willow or balsam poplar vegetation in close proximity to the banks. Cover values for willow and balsam poplar in each of the land classes in the riparian zone,

Table 3.6: Estimates of average values for potentially available browse (to average point of browse) standing crop and annual berry production in each land class. Average values are modified in the model by a random variation.

LAND CLASS	POTENTIALLY AVAILABLE BROWSE (kg dry weight/ha)	BERRY PRODUCTION (kg dry weight/ha
Coniferous Forest - woodland and closed	198	66
Coniferous Forest - open	283	66
Deciduous and Mixed Forest	144	25
Tundra	111	99
Tall Shrub	200	0
Medium Shrub	588	50
Low Birch Shrub	588	70
Low Willow Shrub	300	30
Low Mixed Shrub	275	45
Unvegetated - water	0	0
Unvegetated - rock, snow, ice	0	0
Disturbed - temporary	0	0
Disturbed - permanent	0	0
Pioneer	0	0

as estimated from data in McKendrick et al. (1982), are combined to yield a total cover value for the vegetation preferred by beaver for each land class. These cover values are then averaged across the various land classes, weighting each value by the relative area in that land class:

$$TBC = \left[\sum_{t=1}^{14} BC_t * HA_t \right] / THA \qquad (6)$$

where,

TBC = total cover value (percent) of beaver preferred species;

BC_t = cover value (percent) of species preferred by beaver in each land class;

HA_t = area of each land class (hectares);

THA = total non-water area in riparian zone (hectares); and

t = land class type (1 through 14).

TBC increases if vegetation changes increase the proportions of riparian area in land classes with high cover values for willow and balsam poplar and decreases if vegetation changes result in proportionally more areas with low cover values for willow and balsam poplar. Encouragingly, the value of TBC calculated from the initial areas in each land class is within 0.5% of the independently estimated 25% of channel currently having willow or balsam poplar in close proximity. Since a value of 0 for TBC would also imply that 0 percent of the channels had willow or balsam poplar in close proximity, TBC was assumed to be a reasonable, direct indicator of the percent of channels in the riparian zone which had associated vegetation characteristics suitable for beaver.

3.3 Furbearers and Birds

The Susitna hydroelectric development will impact furbearers and birds primarily through habitat changes, although increased access may cause increased trapping intensity on furbearers. Habitat changes will result from habitat losses due to impoundments and to alteration of the downstream hydrologic and ice regimes.

At the first workshop, the participants decided to concentrate on the population dynamics of one furbearer, the beaver, and to utilize a habitat approach for birds. In the intervening period between workshops, a simple population model for marten was added and the beaver and bird aspects were refined.

3.3.1 Beaver

The major sources of impact on beaver were hypothesized to be:

1) a change in the amount of appropriate habitat for food and denning sites; and

2) an increase in beaver trapping intensity due to improved access to the region.

A simple beaver population model was built to simulate the effects of these two sources of impact. A simple but rigorous approach, neglecting some detailed biology (i.e. ingestion rates, growth rates, fat content, fecundity, etc.), is appropriate given the current state of knowledge. A more detailed representation of beaver may be needed when more data and understanding are available.

The model chosen is commonly used in biology - the logistic growth model with an additional mortality term:

$$\frac{dB}{dt} = rB(1 - \frac{B}{K}) - M$$

where,

B = number of beaver colonies;

r = intrinsic growth rate (yr^{-1});

K = carrying capacity (number of beaver colonies); and

M = mortality term.

The group chose the number of beaver colonies (also called dens or lodges) as the measure of population because the number of beaver in a colony is extremely variable. The population time trajectory is easily predicted (Figure 3.10) if the carrying capacity, intrinsic growth rate, and mortality are constant over time. However, the trajectory is more complex if the parameters change with time. The remainder of this section describes how the subgroup chose to represent the variation of these parameters as a function of the information available from the other subsystems.

3.3.1.1 Beaver Carrying Capacity

In the context of this model, carrying capacity is the maximum number of beaver colonies that can be supported within the floodplain from Devil Canyon to Talkeetna. To determine this number, it is necessary to first define good beaver habitat and second, to estimate the maximum number of colonies that can successfully use that habitat.

Beaver habitat was defined as kilometers of shoreline satisfying the following conditions:

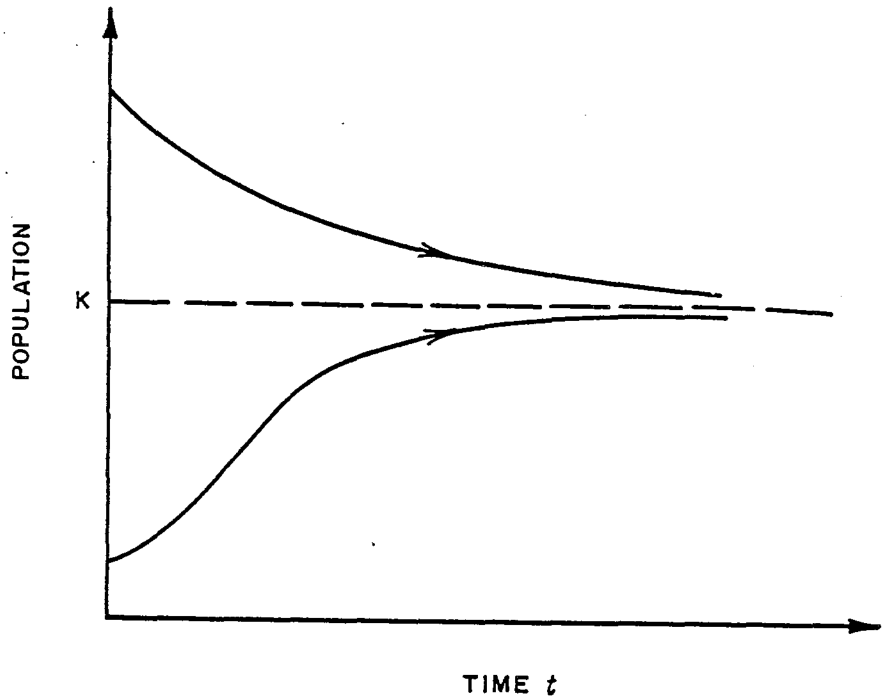


Figure 3.10: Time dynamics of a population based on the logistic growth model. A population that starts above its carrying capacity (K) will decline to its carrying capacity. A population that starts below its carrying capacity will increase towards its carrying capacity.

a) willow and balsam poplar are the dominant vegetation adjacent to a shoreline with a bank composed primarily of silt (from the vegetation submodel);

b) the water adjacent to the bank is sufficiently deep so there is at least .5 m of unfrozen water below the maximum ice cover (from the physical processes/ development/recreation submodel); and

c) water velocity adjacent to the bank does not exceed 4.4 feet/second between mid August and freeze-up.

The willow and balsam poplar vegetation is required by beaver both as a source of food as well as lodge construction material. Only vegetation in the riparian zone on either side of the river is of interest because beaver rarely travel more than 100 m from their lodge location. The silty bank is hypothesized to be an indicator of suitable slope for den construction and lack of ice scouring.

The severe annual ice scour under the present flow and ice regimes prohibits development of suitable habitat along the main channel, and beaver habitat is only associated with the proper vegetation in sloughs and side channels. However, severe ice scour will likely be a rare event after impoundment. This will probably result in more willow and balsam poplar stands along the main channel which, given the predicted stabilitation of water levels between Devil Canyon and Talkeetna, could result in beaver establishing colonies on or near the main channel. Therefore, a proportion factor for willow and balsam poplar along the main channel, provided by the vegetation submodel, is used to convert shoreline length to appropriate habitat.

Ice-free water is a critical condition to the definition of habitat. Because a beaver den entrance is below the water line, ice-free water is the route by which the beaver leave their den in the winter to feed. The hypothesis is that the beaver will not survive the winter if there is less than .5 m of ice-free water.

The velocity criteria is likely only critical along the main channel where velocities often exceed 4.4 feet/second. This condition represents a maximum velocity, above which beaver would probably not build a den since they would not be able to swim upstream to forage the vegetation (Phil Gipson, pers. comm.).

To arrive at an actual carrying capacity for beaver colonies, it was assumed that the maximum colony density is 2 colonies/km of habitat. Therefore, the total carrying capacity for beaver in each spatial unit is:

$$K = ((S_s * V_s) + (2 * S_m * V_m)) * 2$$

where,

K = carrying capacity;

S_s = km of sloughs and side channels that do not freeze to within .5 m of the bottom (supplied by the hydrology submodel);

V_s = proportion of willow and balsam poplar with silty banks associated with S_s (supplied by the vegetation submodel);

S_m = km of suitable main channel that do not freeze to within .5 m of the bottom nor have velocities greater than 4.4 ft/sec (supplied by the hydrology submodel); and

V_m = proportion of willow and balsam poplar associated with S_m (supplied by the vegetation submodel).

3.3.1.2 Intrinsic Growth Rate (r)

The intrinsic growth rate is the maximum rate at which the population can increase. It assumes ideal conditions (i.e. plentiful resources, no competition for habitat, etc.). This growth rate is only realized in the logistic model when the population is very much smaller than the carrying capacity (i.e. when B is much less than K in the logistic equation, page 52). The intrinsic growth rate (r) can be estimated as the exponential growth rate in the equation:

$$N_t = N_o e^{rt}$$

where,

N_t = number of beaver colonies after t years;

N_o = number of initial beaver colonies; and

r = exponential growth rate.

Participants hypothesized one beaver colony would spawn a second colony in a minimum of two years if there was a surplus of appropriate habitat and no other beaver colonies competing for space. Therefore, a doubling of colony size in 2 years implies:

$$N_2 = N_o * e^{r*2} = 2N_o$$

and $$r = \frac{\ln 2}{2}$$

$$\cong .3$$

The intrinsic growth rate was assumed constant for this model.

3.3.1.3 Mortality

Water Levels

Beaver colonies are vulnerable to changes in water level within the year. Increases in water level on the order of a few meters can result in the flooding of a den (in summer) or the freezing of a food cache (in winter). Similarly, a drop in water level will expose the colony to increased predation or, even more likely, severe winter temperatures if the water level falls below the den entrance. This is likely not a problem in the sloughs and side channels but is definitely a major factor (along with ice scouring) currently preventing establishment of beaver colonies along the main channel. Since decreased fluctuations in water level are predicted after impoundment, the simulated beaver colonies which may have established themselves in available habitat along the main channel are subjected to a mortality factor from water level changes (Figure 3.11). Total mortality of main channel colonies is possible with sufficiently extreme water level fluctuations.

Ice Scouring

The mortality on the beaver is assumed directly proportional to the total land area scoured between Devil Canyon and Talkeetna (Figure 3.12). This mortality is applied to the appropriate population in the spring of each simulated year.

Predation

After some discussion, the subgroup felt that predation on beaver probably is insignificant. Beaver is a minor food item for both wolves and bear. Therefore, predation is not presently included in the model.

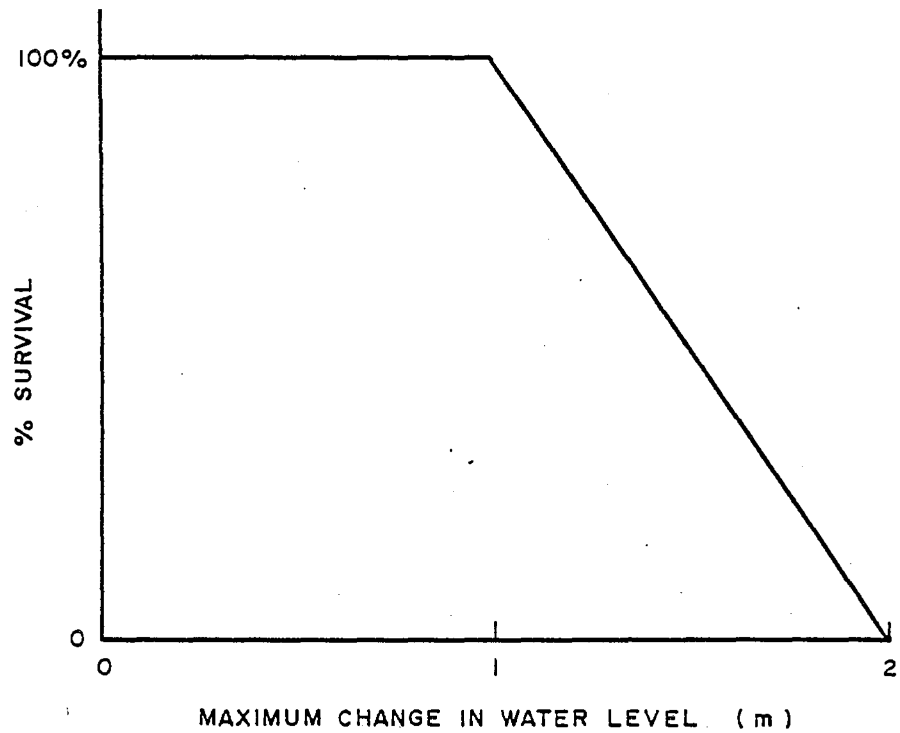


Figure 3.11: Percent survival of beaver colonies on main channel as a function of maximum change in water level from summer to winter.

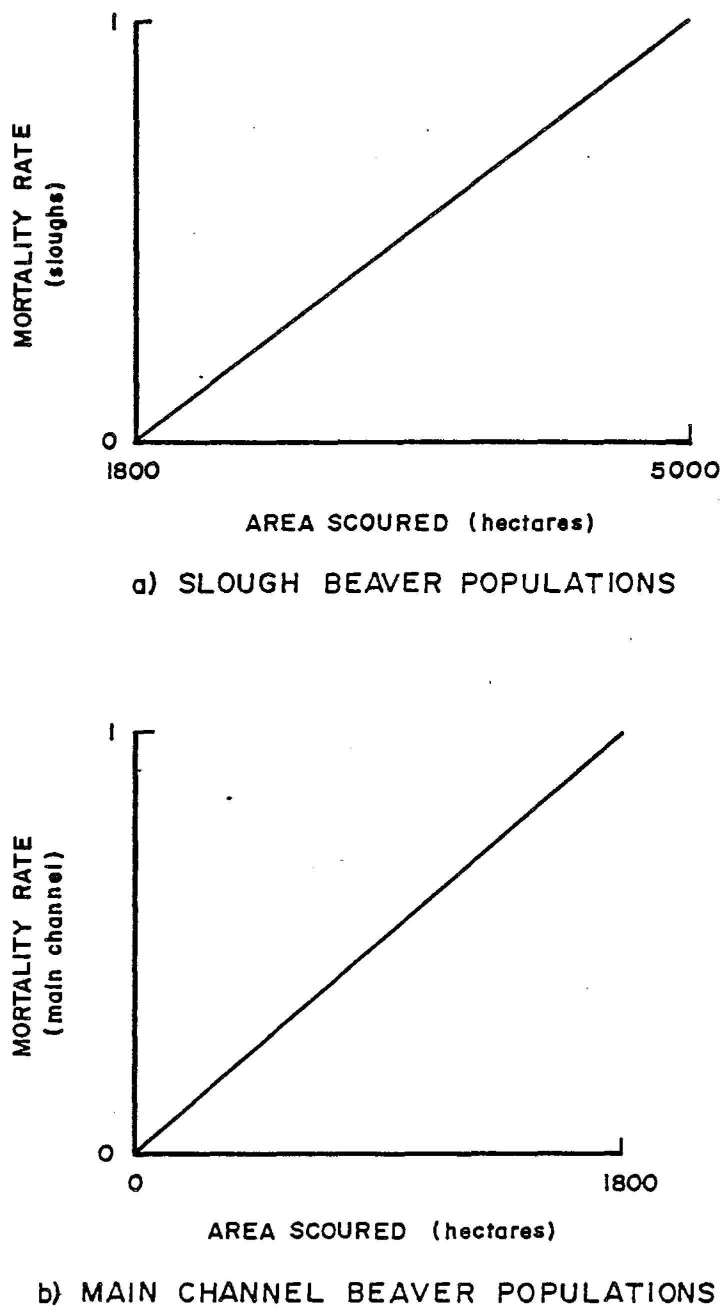


Figure 3.12: Mortality as a function of ice scouring area for slough (a) and main channel (b) beaver populations.

Trapping

Trapping is certainly one of the major potential sources of beaver mortality. Beaver are especially vulnerable to trapping during the winter when traps can be set over the beaver's access hole in the ice. The rapid decline of beaver populations in the lower 48 states when beaver trapping was a viable occupation is evidence of high vulnerability to trapping. Three factors were hypothesized to influence trapping effort:

1) beaver pelt prices;

2) knowledge about the location of beaver colonies; and

3) the number of other trappers in the area.

Price is certainly a key factor. Participants suggested that the beaver population in the Susitna Basin would probably be decimated within one year if beaver pelts were suddenly worth 5 to 10 times their current price (given the trappers knew where to go).

A maximum trapping mortality is calculated (Figure 3.13) using a price factor between 0 and 1. The price factor is model input and can be changed to explore the effect of a sudden price shift. This maximum mortality is modified by an access factor (Figure 3.14) expressed as a function of the number of people using the spatial area (i.e. construction workers plus public). For any given population, the access factor will change as a function of the user-specified price factor. The assumption is that access becomes less important as the relative price for beaver increases. Therefore, if the price factor reaches 1, then the beaver will experience the maximum trapping mortality (i.e. max_T). At present, max_T is equal to .9 and max_A is equal to 1. To limit access, an identified mitigation possibility, the user must specify a lower value for max_A.

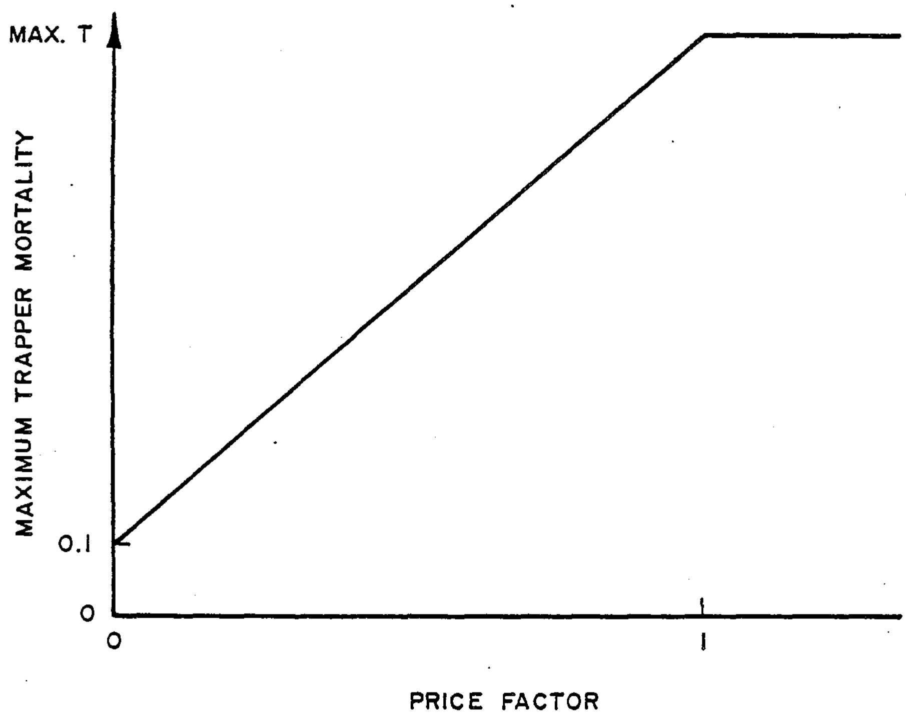


Figure 3.13: Maximum beaver trapping mortality as a function of a user specified price factor.

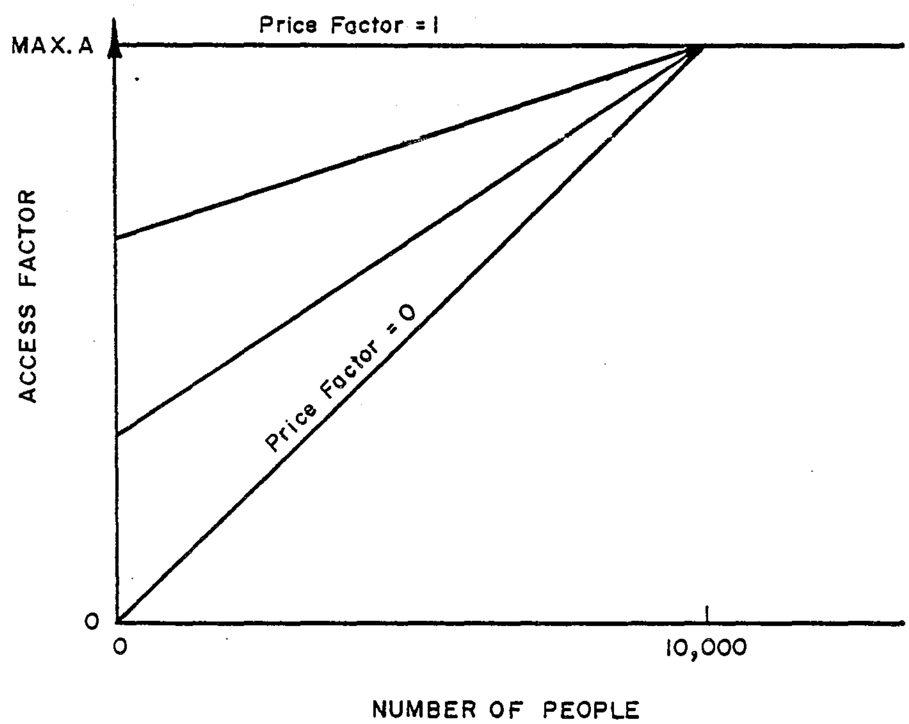


Figure 3.14: Trapper access factor as a function of the number of people using the area.

3.3.1.4 Beaver Migration

Since the water level changes are large before impoundment, the main channel population invariably suffers total mortality each year. Similarly, the population associated with sloughs can experience higher mortalities in years of extreme ice scouring. During periods of high mortality, it is expected that the non-utilized beaver habitat in the riparian zone will be colonized by migrants from other populations in the Susitna watershed.

This is incorporated into the model by increasing the number of colonies associated with both the main channel and sloughs by 25% of the difference between the carrying capacity and the spring population times the trapping survival factor. If the colony population exceeds the carrying capacity, the model assumes no migrants.

3.3.1.5 Beaver's Impact on Vegetation

The quality, quantity, and kind of streamside vegetation is critically important to beaver. The critical vegetation types are felt to be balsam poplar, willow, and cottonwood. Observations indicate that the balsam poplar and willow are generally concentrated in a band running more or less parallel to the channel and often within 40 m of the water's edge. The representation of appropriate vegetation along the water's edge (i.e. proportion - see Section 3.3.1.1) needs to be revised to include the information included in the river cross sections available from the hydrology field work. These cross sections identify specific vegetation zones relative to the water and permit a more acceptable approximation of the percent of good beaver habitat near the water's edge (see vegetation submodel description).

It was also hypothesized that high densities of beaver could have a substantial impact on the vegetative successional progression in the riparian zone. Evidently, an average sized beaver colony will forage approximately .4 ha of tall to low shrub in a year which then usually reverts to low shrub.

3.3.2 Marten

3.3.2.1 Population Structure

Three age classes are represented: 0 - 1 year, 1 - 2 years, and older than 2 years. At the end of each simulated year, the population remaining in each class is advanced to the next category and the new litters are added to the first age class.

The population processes represented are reproduction, trapping, and natural mortality.

Reproduction is a function of the proportion of the females which conceive, the litter size (Table 3.7), and the male to female ratio (assumed constant at 50:50). Reproduction is calculated as follows:

$$\begin{matrix}\text{Total of} \\ \text{all litters}\end{matrix} = \sum_{i=1}^{n} \begin{matrix}\text{Pregnancy} \\ \text{rate}_i\end{matrix} * \begin{matrix}\text{Litter} \\ \text{size}_i\end{matrix} * \begin{matrix}\text{M/F} \\ \text{ratio}\end{matrix} * \begin{matrix}\text{\# marten in} \\ \text{age group } i\end{matrix}$$

where,

i = age group i; and

n = number of age groups.

Trapping mortality is assumed to be fixed at 20% of the total marten population per year. The proportion removed from each age class to make up that 20% is fixed (Table 3.7).

Observation has shown that marten are very territorial. It was estimated from available data that a maximum marten density in their preferred habitat (i.e. forest) would be of the order of .009 per hectare. Therefore, a density dependent mortality function was incorporated into the model to ensure the densities did not exceed this number (Figure 3.15).

Table 3.7: Various parameters for marten population model.

AGE CLASS	PREGNANCY RATE	LITTER SIZE	PROPORTION TRAPPED
0 - 1	0	0	.67
1 - 2	.69	3.3	.23
2 +	.79	3.8	.1

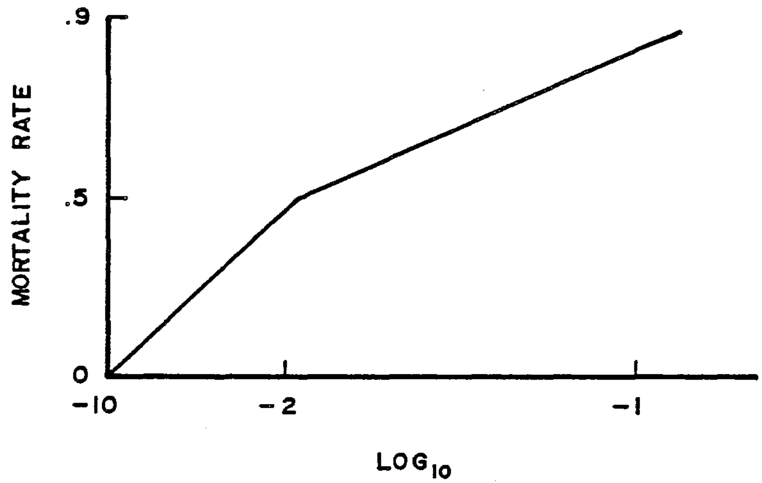


Figure 3.15: Density dependent mortality rate for marten population.

Although structured arbitrarily, it succeeds in maintaining the marten population levels at acceptable densities for an otherwise unstable population model.

Although an extremely simple population model, it does permit evaluation of how the potential marten population might be impacted by impoundment. The model also facilitates accumulation of the total number of marten trapped over the simulated time horizon, therefore indicating the total amount of marten production lost as a consequence of the project.

3.3.3 Birds

At the first workshop, the subgroup participants identified the golden eagle, yellow-rumped warbler, tree sparrow, fox sparrow, and the trumpeter swan as key bird species for discussion. However, after considerable discussion, participants concluded that the limited state of knowledge about these birds precluded a dynamic population model description of how they might be impacted by the project. Also, many critical survival processes for these species are controlled by events and conditions external to the model because they are migratory. Therefore, impacts were simulated as changes in habitat.

3.3.3.1 Passerine Birds

At the first workshop, the approach used for this group was the Habitat Evaluation Procedure (HEP). The number of species and bird density were identified as important to establishing the value of any particular habitat. Average magnitudes for these two criteria were specified for each vegetation type (Table 3.8) using data from field studies in 1980 and 1981 in the upper basin.

A per hectare suitability index is calculated for each vegetation type by taking the sum of 1/3 of the species number value from Figure 3.16 and 2/3 of the bird density value from Figure 3.17.

Table 3.8: Passerine bird density and number of species associated with different vegetation types.

VEGETATION TYPE	DENSITY #/10 ha	SPECIES #/10 ha
Coniferous Forest		
Open	15.7	8
Woodland	34.3	17
Deciduous and Mixed Forest	43.9	22
Tundra	3.9	7
Tall Shrub	12.5	10
Medium Shrub	39.	6
Low Shrub		
Birch	10.6	6
Willow	(10.6)	
Mixed	(10.6)	

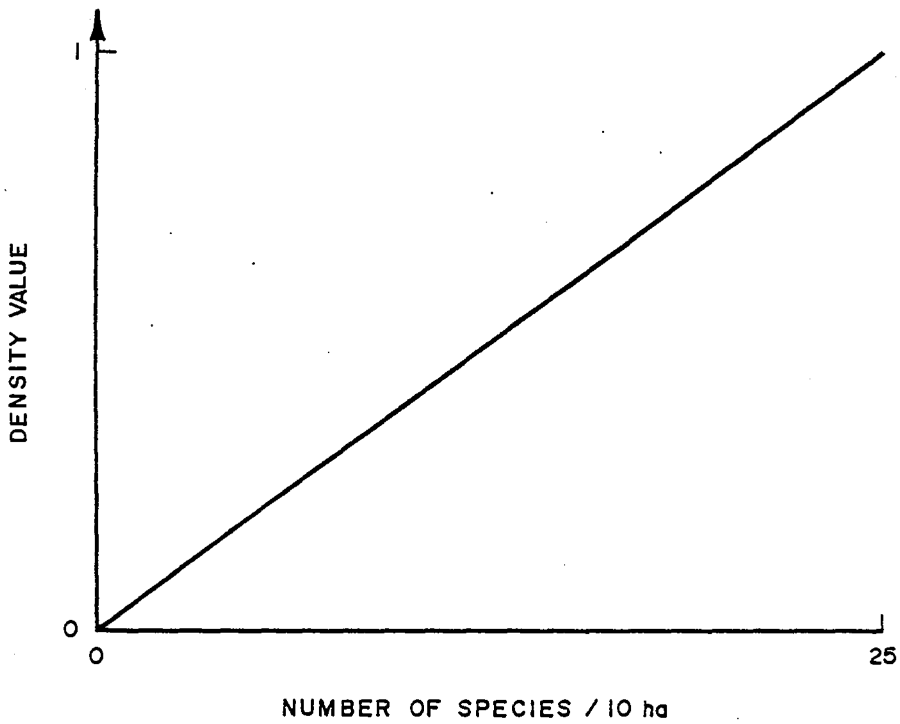


Figure 3.16: The relative value of species in any given vegetation type.

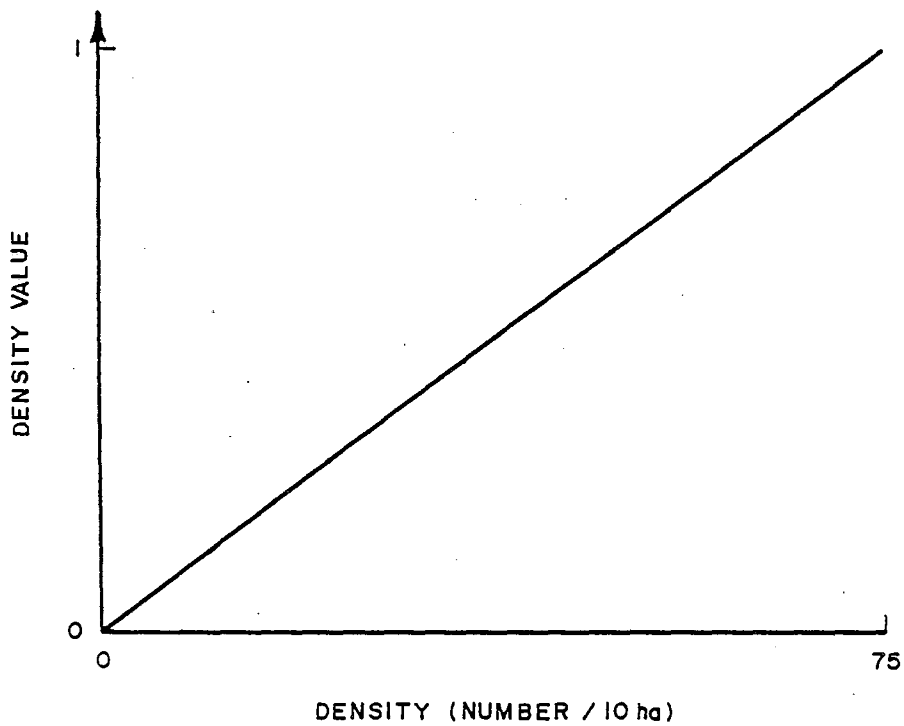


Figure 3.17: Relative value of bird density in any given vegetation type.

The relative weights for each criterion selected by the subgroup indicate that bird density is somewhat more important than number of species.

A total number of habitat units is then calculated within each spatial unit:

$$\text{Habitat units} = \sum_i TU_i * \text{Area}_i$$

where,

TU_i = suitability index for a given hectare of habitat i (from Figures 3.16, 3.17); and

Area_i = area of habitat i in spatial unit.

This representation assumes the birds, on average, will use land of any given vegetation type in exactly the same way each year. Although this is probably not a reasonable assumption, there is not enough information to take the model much further at this time.

At the second workshop, it was requested that the passerine birds be incorporated from the perspective of the number of avian territories per unit area. Then, by multiplying these numbers by the area of each vegetation group (some of which will change after impoundment), the change in the total number of bird territories could be predicted. This was done for certain species (Table 3.9) and total territories for all passerine birds (Table 3.10).

Table 3.9: Number of bird territories/10 ha for 12 bird species for each of the vegetation types represented in the model (FERC license application, Exhibit E, Chapter 3, Table E.3.136).

	DECIDUOUS AND MIXED FOREST	CONIFEROUS FOREST-CLOSED	CONIFEROUS FOREST-OPEN	TALL SHRUB	LOW WILLOW SHRUB	MEDIUM SHRUB	LOW BIRCH SHRUB	TUNDRA
SPRUCE GROUSE	1							
HAIRY WOODPECKER	1							
BROWN CREEPER	1.5							
SWAINSONS THRUSH	6.5		3					
YELLOW-RUMPED WARBLER	8.5	1.7	1	.1				
BLACKPOLL WARBLER	2.7	1.9	1					
NORTHERN WATERTHRUSH	2.2							
WILSONS WARBLER	3	9.4		1.2	9.2	8.8		
SAVANNAH SPARROW					12.3	3	5.8	1
DARK EYED JUNCO	3.2	2	2.5	2.8				
TREE SPARROW	5			1.5	15	11.8	2.5	
FOX SPARROW	2.3	3.2		1.6				

Table 3.10: Avian territories/ha used in model (taken from FERC license application, Exhibit E, Chapter 3, Table E.3.139).

AVIAN CENSUS PLOT	MODEL VEGETATION CATEGORY	NUMBER OF TERRITORIES/HA
Balsam Poplar Forest	Deciduous & Mixed Forest	6.1
White Spruce-Paper Birch Mixed Forest II	Deciduous & Mixed Forest	3.5
White Spruce-Paper Birch Mixed Forest I	Deciduous & Mixed Forest	4.2
Paper Birch Forest	Deciduous & Mixed Forest	3.8
White Spruce Woodland	Coniferous Forest Closed	4.4
Black Spruce Woodland	Coniferous Forest Closed	2.5
Open White Spruce Forest	Coniferous Forest Open	1.6
Tall Shrub	Tall Shrub	1.3
Low-Medium Willow Shrub	Low Willow & Low Mixed Shrub	4.5
Medium Birch Shrub	Medium Shrub	3.3
Dwarf-Low Birch Shrub	Low Birch Shrub	1.1
Alpine Tundra	Tundra	.4

3.3.3.2 Trumpeter Swan

Trumpeter swans are very sensitive to human disturbance. Although there are only a few breeding pairs in the area, it is known that Stephan Lake is a favored staging area during the spring and fall migration. Participants felt that the construction and use of roads and the transmission line would cause the major impacts. It was concluded that because potential impacts are known and predictable, the concern involved proper siting of roads and transmission lines to ensure minimum interference with nesting/ staging areas. This was not included in the model.

3.3.3.3 Golden Eagle

The major impact of the Susitna project on the golden eagle will probably by the destruction of their traditional cliff nesting sites due to inundation.

Most of the good eagle nesting sites that may be affected have been found in the Watana impoundment area. Representation of this impact in the model is done by comparing the elevation of each active site to the maximum elevation of the reservoir. If the nest elevation is less than the maximum reservoir level, then the nest site is counted as flooded. No attempt was made to determine just which sites had an active nest in any given year. Instead, this indicator shows the potential reduction in existing eagle nest carrying capacity as a consequence of impoundment.

3.4 Moose

Development of the moose submodel was guided by two fundamental considerations:

1) the need to produce indicators for evaluating both the impacts of Susitna hydrelectric development on moose and the potential effectiveness of various mitigation measures; and

2) the desire to represent population processes in a manner consistent with the information and understanding generated by Alaska Department of Fish and Game (ADF & G) studies in the Susitna area.

Fortunately, this moose submodel for mitigation planning was developed in parallel with the ADF & G Upper Susitna Basin moose population modelling (Ballard and Miller, 1983). A detailed description of the ADF & G moose model is provided in a technical appendix (Appendix I). Most of the data and many of the relationships incorporated into the moose submodel are based on the work described in Appendix I.

The bounding exercise (Table 2.2) identified three general types of indicators that should be responsive to impacts of development and mitigation alternatives:

1) measures of numbers of animals (e.g. population size and harvest);

2) indices or measures of habitat carrying capacity; and

3) indices or measures of habitat quality.

The present formulation of the moose submodel deals with the first two of these indicator categories.

3.4.1 Structure

The basic structure of the moose submodel is a life table (based on the structure of the ADF & G moose model described in Appendix I) that represents the birth and death processes for three age classes (calves, yearlings, and adults) of moose of each sex, combined with a simple model of winter carrying capacity. The spatial area considered by the population model was defined based on home range data for moose utilizing the impoundment area (Ballard, et al., 1983). This area includes approximately 1200 mi^2 surrounding the river from the Devil Canyon dam site to the east end of the Watana impoundment. Carrying capacity is computed for this area as well as for the five spatial areas defined in Section 2.3. Project impacts and mitigation measures can thus be evaluated either as they affect the carrying capacity and moose population in the area immediately around the impoundments, or as they affect carrying capacity of the more broadly defined spatial areas.

The computational sequence for the model (adapted from Appendix I) is illustrated in Figure 3.18. The biological year begins with calving. Animals surviving from the previous year are advanced to the next age class and calf production is calculated based on the number of females or reproductive age in the herd. The remainder of the model consists of removal of animals due to a series of age and sex specific mortality agents.

3.4.2 Wolf Population

Because wolf populations are not considered elsewhere in the model, it was necessary to incorporate a very simple representation of their dynamics in order to simulate their impacts on moose. The number of wolves is calculated from a reproductive function based on density and a mortality function based on snow accumulation.

The wolf fecundity rate is computed from Figure 3.19 based on the wolf population in the previous winter. The declining portion of this curve is hypothetical in nature and was incorporated only to keep the simulated population within reasonable limits. The calculated fecundity rate is then multiplied times the number of wolves remaining at the end of the previous year to produce a new population.

All of the mortality agents acting on wolves are encapsulated in a single mortality function dependent on snow accumulation (generated by the physical processes submodel) (Figure 3.20). While this representation is overly simplistic, it does capture the idea that wolves are harvested at higher rates (due to better visibility and landing conditions for ski planes) in years of greater snow accumulation.

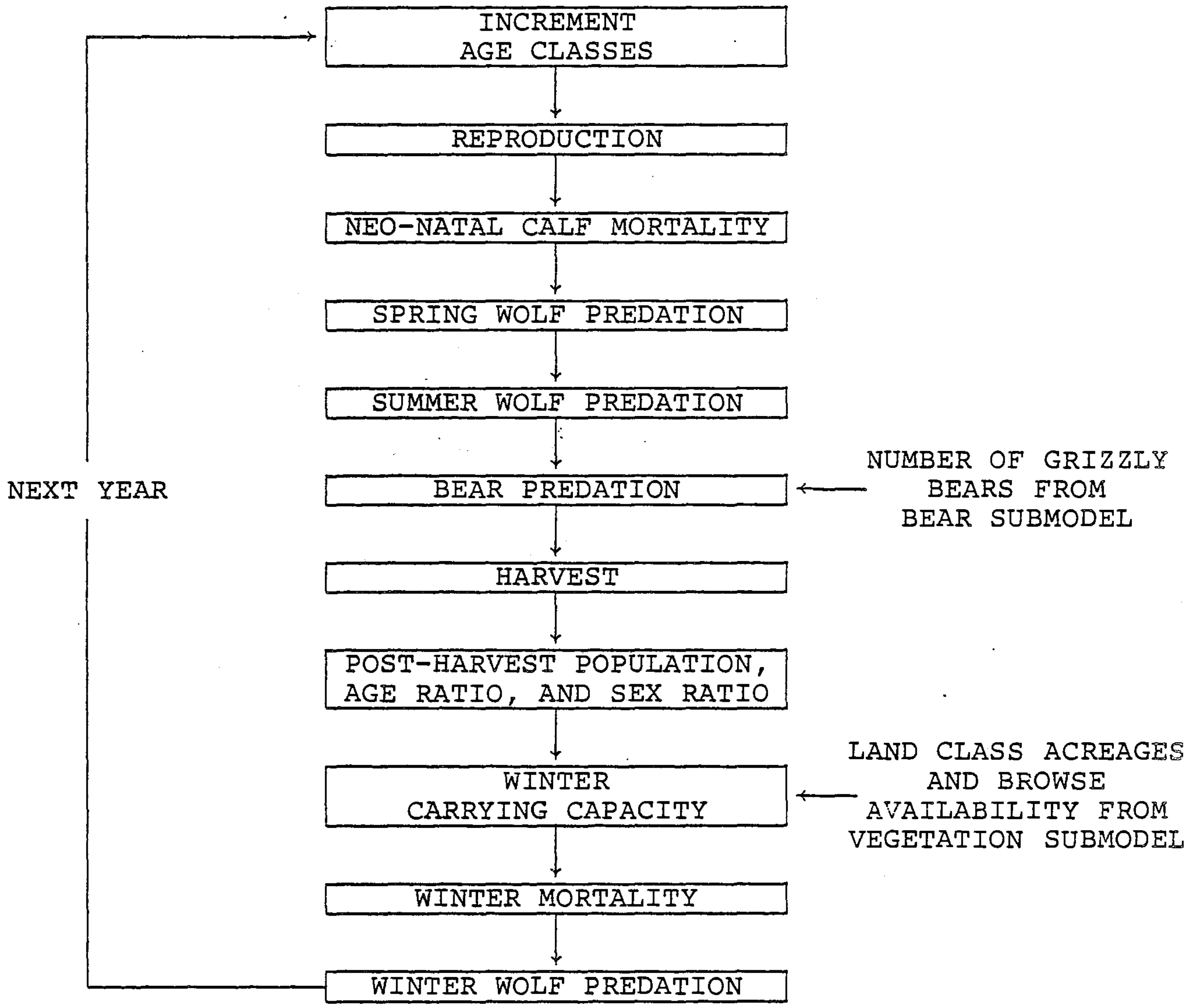


Figure 3.18: General structure of the moose submodel (adapted from Appendix I).

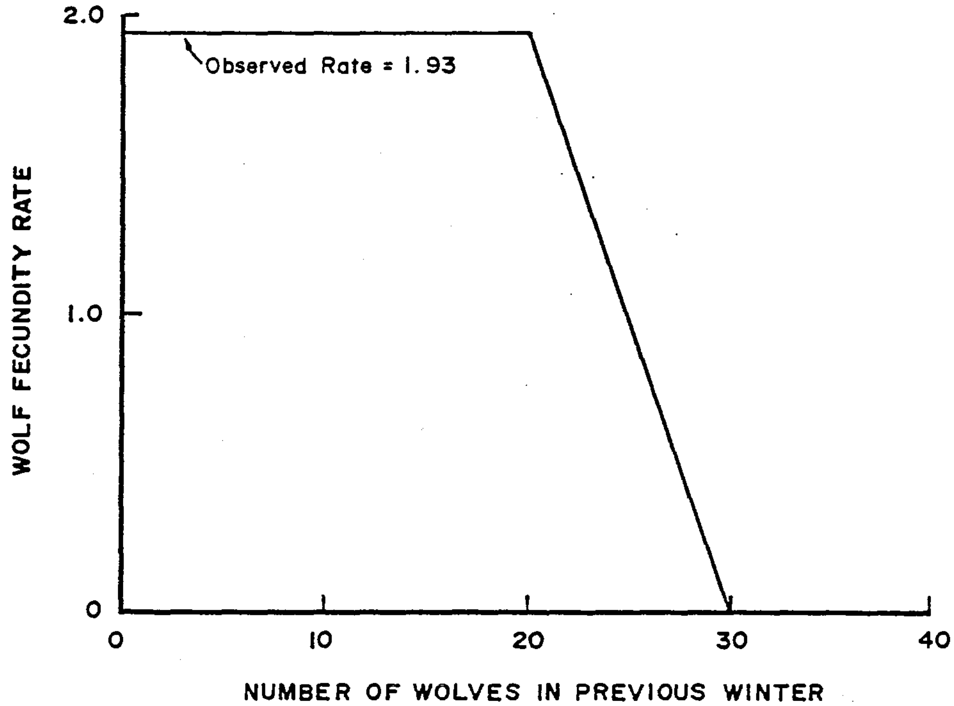


Figure 3.19: Wolf fecundity rate as a function of population size.

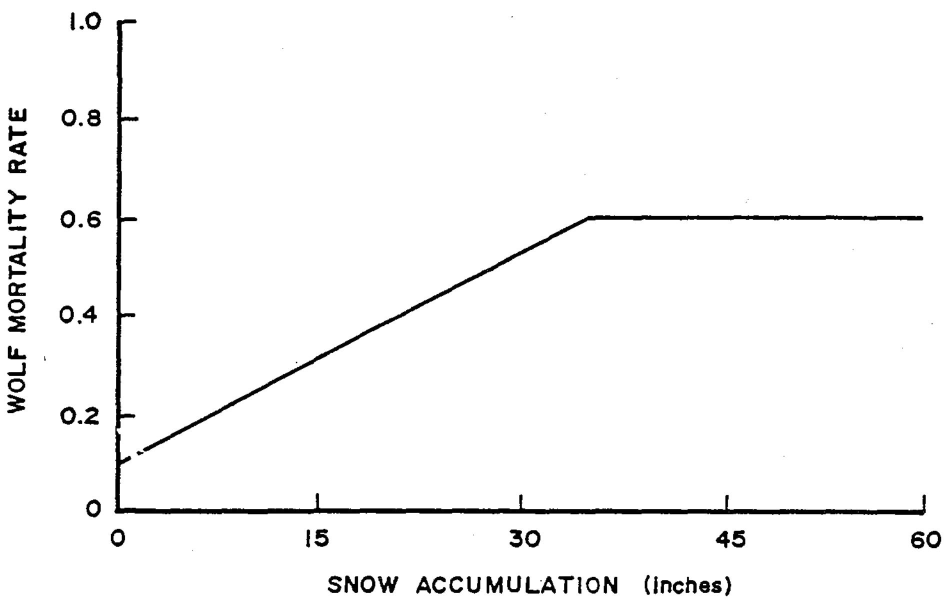


Figure 3.20: Wolf mortality rate as a function of snow accumulation.

3.4.3 Moose Reproduction

Reproduction is calculated separately for yearlings (those females 2 years old at the time calves are dropped) and adults (those 3 years or older at the time calves are dropped. A fecundity rate for each group was derived from Ballard, et al. (1983) and Blood (1973). Based on the fecundity rate data, a relationship based on the number of moose present in the previous winter was developed (Figure 3.21). The declining portions of these curves were incorporated only to prevent unlimited increase of the simulated population. Moose populations in the 10,000 - 15,000 range have never been observed in the field. As long as the simulated population remains within reasonable bounds, the effect of these curves is to produce constant fecundity rates. Fecundity rates are multiplied times the number of females in each cohort to arrive at the number of calves born. The sex ratio in the calf crop is assumed to be 50:50.

3.4.4 Mortality

Each mortality factor is represented by a series of mortality events described in detail in Appendix I. Specific mortality events considered are: neo-natal mortality, spring wolf predation, summer wolf predation, winter wolf predation, bear predation, and hunting. Organization of the model allows calculations of sex and age ratios and population size following each mortality event. This allows for comparison with composition counts done in the field, and provides a useful check on the simulation results.

3.4.4.1 Neo-Natal Mortality (based on Appendix I)

Calves are assumed to suffer a natural (non-predation) mortality of 6% in the period shortly after birth, reflecting accidents, abandonment, and a variety of other processes. Provisions are also made for mortality of other age classes at this time, but these are presently not invoked.

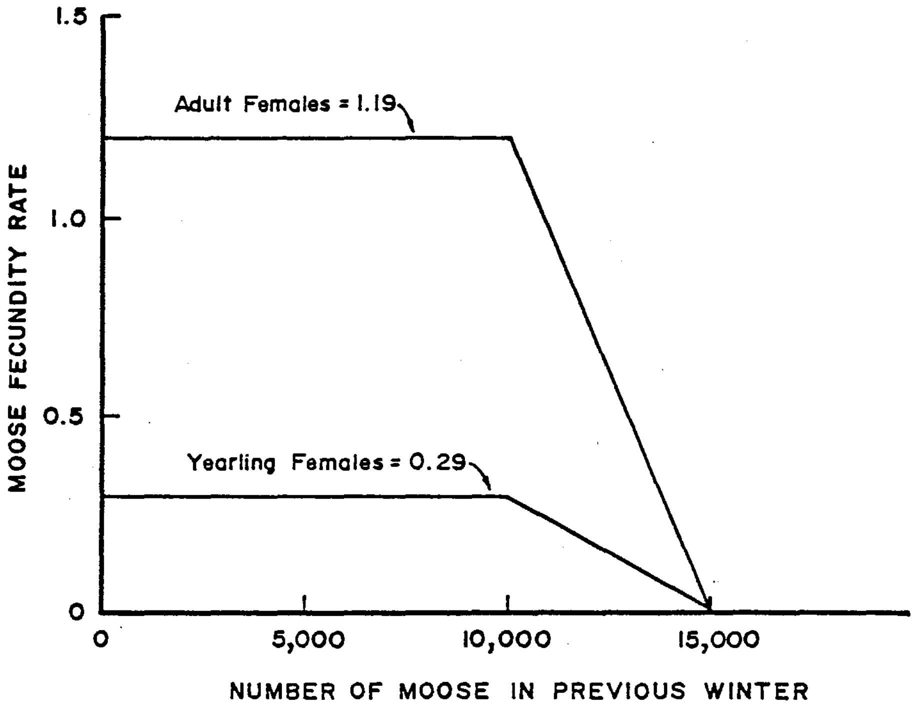


Figure 3.21: Moose fecundity rates as a function of population size.

3.4.4.2 Spring Wolf Predation (based on Appendix I)

Spring wolf predation on moose is calculated before the wolf population is incremented by reproduction. This is consistent with the fact that pups do not kill moose. Numbers of calves and older moose (yearlings plus adults) are computed in the following manner. The total weight of prey items required by the wolf population is calculated as:

$$K = N * C * D$$

where,

K = weight of prey items required by wolf population (kg);

N = number of wolves (excluding pups);

C = weight of prey items required each day by an individual wolf (7.1 kg/wolf/day); and

D = number of days in the predation period (80).

The number of calves or older animals killed is then:

$$M_c = (K * P_c)/W_c$$

$$M_o = (K * P_o)/W_o$$

where,

M_c = number of calves killed;

M_o = number of older animals killed;

K = weight of prey items required by wolf population (kg);

P_c = proportion of wolf diet composed of calves (0.35);

P_o = proportion of wolf diet composed of older animals (0.47);

W_c = average weight of calves (39 kg); and

W_o = older animals (kg).

The number of calves killed is distributed evenly between the two sexes. The number of older animals killed is distributed in proportion to their number, by sex, in the population.

3.4.4.3 Summer Wolf Predation (based on Appendix I)

Summer wolf predation is calculated in the same way with the following parameter changes:

1) pups are included in the wolf population;

2) the number of days in the predation period is changed to 108;

3) proportions of the wolf diet are changed to 0.12 (calves) and 0.755 (older animals); and

4) the average weight of a moose calf is changed to 94 kg.

3.4.4.4 Bear Predation (based on Appendix I)

The number of moose killed by grizzly bears is a function of both the number of bears and the number of moose present. The number of bears (excluding cubs and yearlings) is obtained from the bear submodel. Daily predation rates per bear on calves and older animals (adults and yearlings) are then computed from Figure 3.22. The number of moose killed is the product of the number of bears, the predation rate per day, and the number of days in the predation period (60). Calf losses are distributed evenly between the two sexes. Losses of older animals are distributed among the cohorts in proportion of their number in the population.

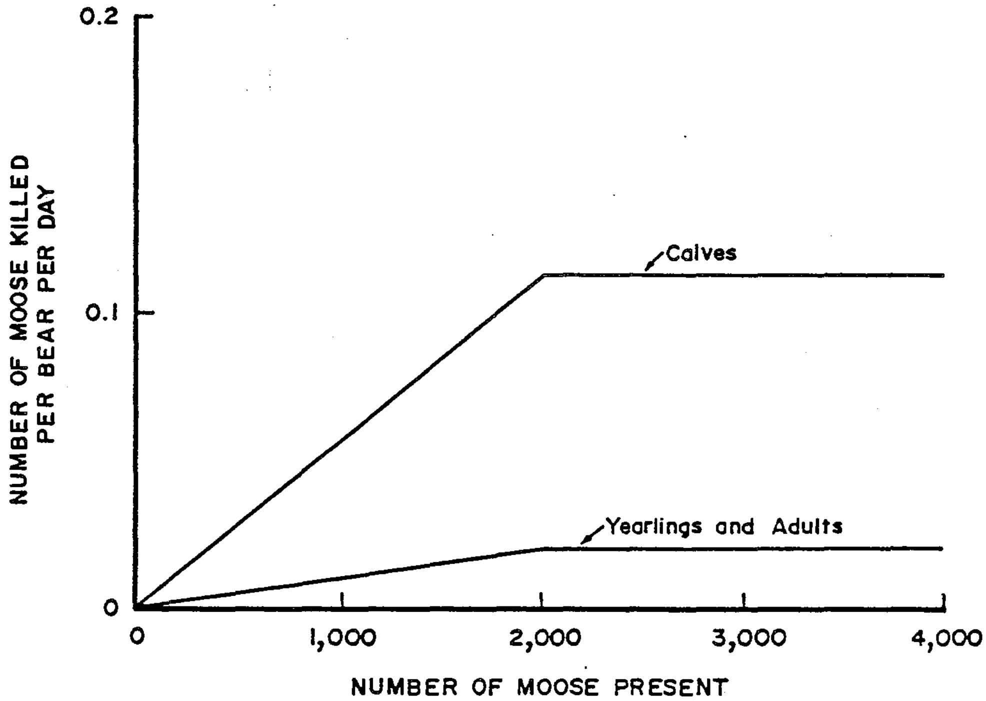


Figure 3.22: Bear predation rates as a function of moose population size.

Provisions are also made to adjust the shape of the curves in Figure 3.22 as a function of snow accumulation in the previous winter (reflecting increased vulnerability of moose following severe winters), but these are not presently used.

3.4.4.5 Harvest

Moose harvest is specified as either a specific rate to be applied to each cohort, or a specific number of animals to be removed from each cohort. The model presently assumes an annual harvest of 30% of the adult males. It was not considered important to relate moose harvest to human population in the project area, since harvest will likely be closely regulated to prevent detrimental impacts on the moose population.

3.4.4.6 Post-Harvest Population Statistics

The age ratio, sex ratio, and size of the herd are calculated following the harvest. The age ratio is obtained by dividing the number of surviving calves by the number of adult females. The sex ratio is obtained by dividing the number of adult bulls by the number of adult cows. These ratios are expressed as calves/100 cows and bulls/100 cows respectively. The simulated age ratio, sex ratio, and population size calculated after the harvest correspond roughly in time to composition counts actually done in the field, and provide a useful check on the reasonableness of simulations.

3.4.4.7 Winter Wolf Predation

Winter wolf predation is calculated in the manner described in Section 3.4.4.2 with the following parameter changes:

1) the wolf population is estimated by the average of the populations before and after the wolf mortality function (Section 3.4.2) is applied;

2) the number of days in the predation period is changed to 196;

3) proportions of the wolf diet are changed to 0.18 (calves) and 0.714 (adults); and

4) the average weight of a moose calf is changed to 148 kg.

3.4.5 Winter Carrying Capacity

The winter carrying capacity for each spatial subunit is calculated as the number of moose-days of browse available:

$$U = \sum_{j=1}^{14} A_j * B_j * (1 - L)/F$$

where,

U = moose-days of browse available;

A_j = area in land class j (ha);

B_j = available browse in land class j (kg dry weight/ha);

L = proportion of available browse at end of summer lost due to leaf fall; and

F = individual moose forage requirement (kg dry weight/day).

The vegetation submodel provides the area (A_j) and amount of browse available at the end of the summer (B_j) for each land class. Available browse is defined as the standing crop of plant material of species, height, and size (measured to the average diameter at which browsing stops) suitable for moose forage. The amount of browse available in the winter is the amount available at the end of the summer reduced by a proportion representing leaf fall. If browse is measured without leaves, L can be set to zero. Division of a daily forage requirement produces the number of moose-days of winter forage available.

3.4.6 Winter Mortality

Winter mortality rates for moose can be calculated in two ways:

1) as a function of the winter carrying capacity with an additional availability component depending on snow accumulation; or

2) directly as a function of snow accumulation.

3.4.6.1 Winter Mortality as a Function of Carrying Capacity

The amount of browse available in the 1200 mi^2 herd area is calculated as discussed above. Proportions of each land class in this area were estimated from the proportions measured in a 16 km band surrounding the impoundment areas. When development is initiated in the model, the amounts of vegetation inundated are subtracted from the available range and hence from the available browse. Browse availability is further modified by snow accumulation (Figure 3.23). The total amount of browse available is then divided by the number of moose in the post-harvest population and the number of days in the winter period (180) to arrive at the forage available per moose per day. Winter mortality rates are then determined from Figures 3.24 and 3.25 using forage available per moose per day as the independent variable.

This approach to determining winter mortality has the virtue of attempting to relate mortality to the most obvious project impact (i.e. vegetation removal). It must be used with caution, however, since both the relationship between snow accumulation and the proportion of forage available, as well as the relationships between forage availability and mortality, are poorly understood in a quantitative sense.

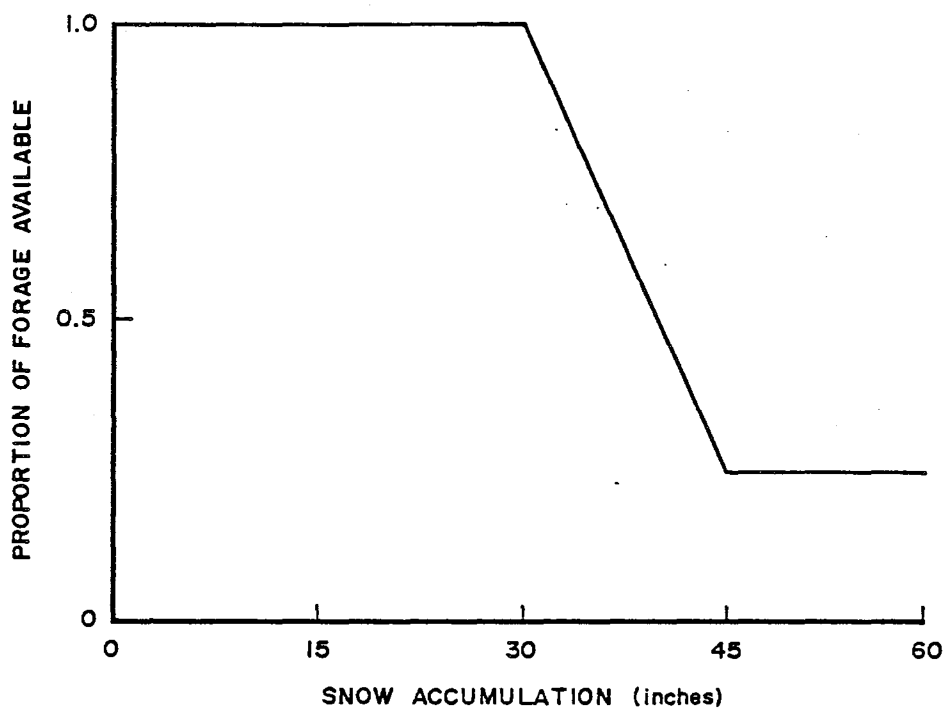


Figure 3.23: Forage availability as a function of snow accumulation.

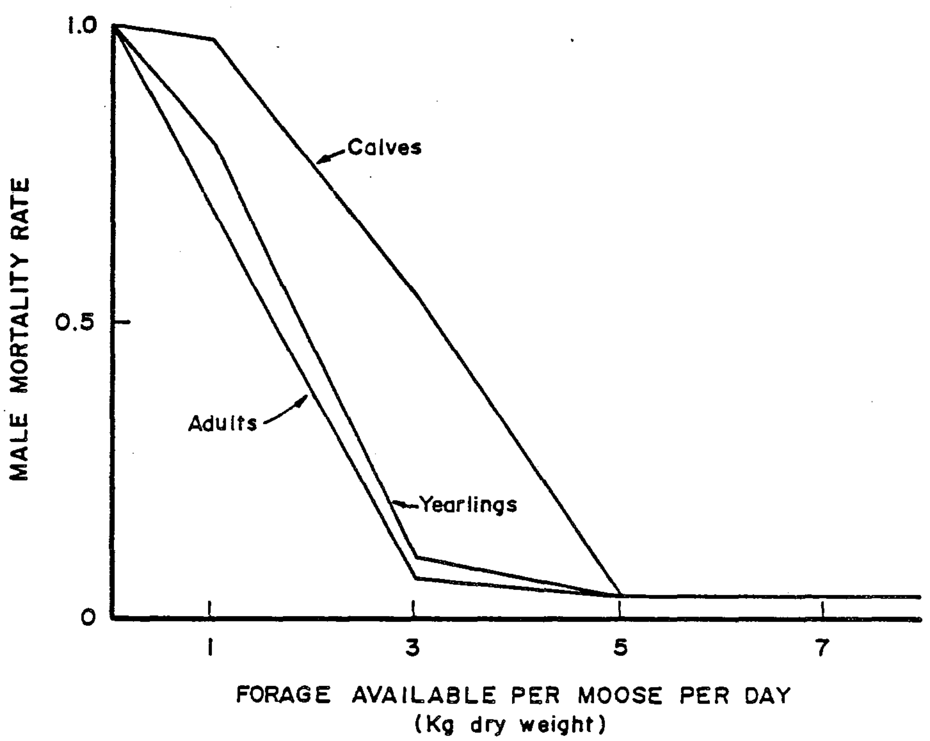


Figure 3.24: Male winter mortality rates as a function of forage availability.

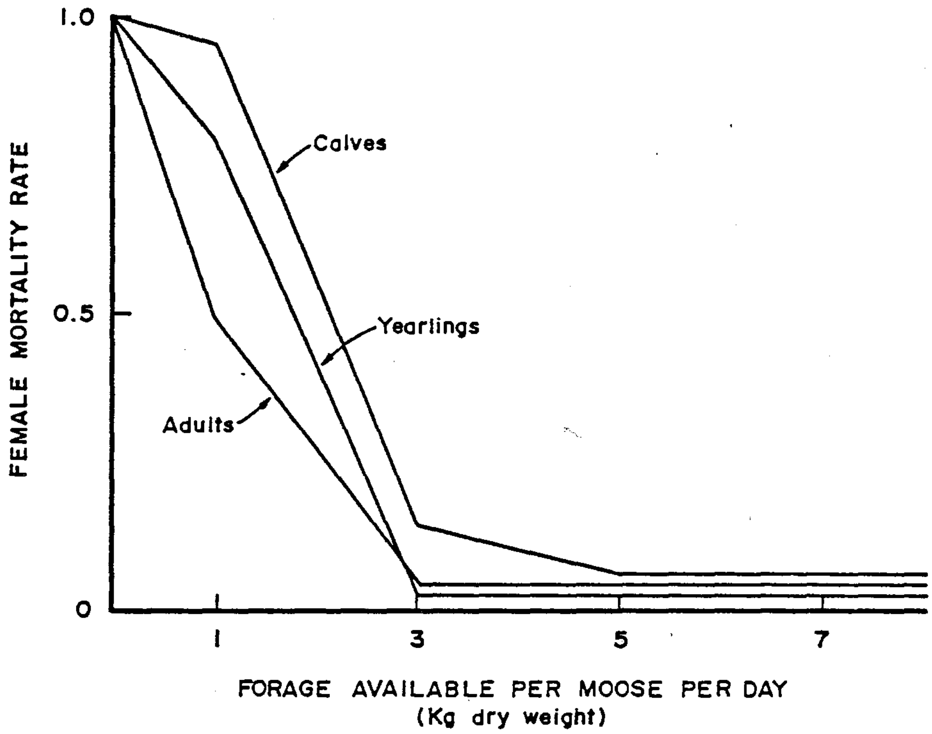


Figure 3.25: Female winter mortality rates as a function of forage availability.

3.4.6.2 Winter Mortality as a Function of Snow Accumulation

As noted above, winter mortality rates may also be calculated directly as a function of snow accumulation. Three levels of mortality are distinguished for three ranges of snow accumulation (Table 3.11).

This approach to the winter mortality calculation has the virtue of being more directly related to field observations. Mortality rates for the first two levels of snow accumulation were determined from radiotelemetry data (Ballard, et al., 1983). However, the actual snow accumulations at the time the radiotelemetry data were obtained are unknown. Second, snow accumulations and mortality rates for the third level (> 39 in) are purely hypothetical at this time. And finally, of course, this approach does not relate mortality to any project impacts.

3.5 Bear Submodel

The bear submodel relates population responses of black and brown bears to changes in habitat structure and to the more direct human influences of hunting and dispersal from disturbance. Due to the limited time available at the first workshop, only female bears were considered and hunting was not included in the first modelling attempt. Subsequent technical meetings have corrected these simplifications as well as adding substantial complexity to the structure of the model. Field data upon which some of the parameters of this submodel are based are presented in Miller and McAllister (1982) and Miller (1983).

3.5.1 Population Structure

The brown bear population in the study area is stratified into two groups: those using the area that will be directly affected by the impoundment (vulnerable population), and those that will not (non-vulnerable population) (Figure 3.26).

Table 3.11: Moose mortality rates at various depths of snow accumulation (modified from Ballard, et al., 1983 and Appendix I).

SNOW ACCUMULATION	MORTALITY RATE (%)					
	MALES			FEMALES		
	CALVES	YEARLINGS	ADULTS	CALVES	YEARLINGS	ADULTS
> 32 in	6	6	3.6	6	2.4	3.6
32 - 39 in	57	10	7.2	14	2.4	3.6
> 39 in	95	80	70	95	80	50

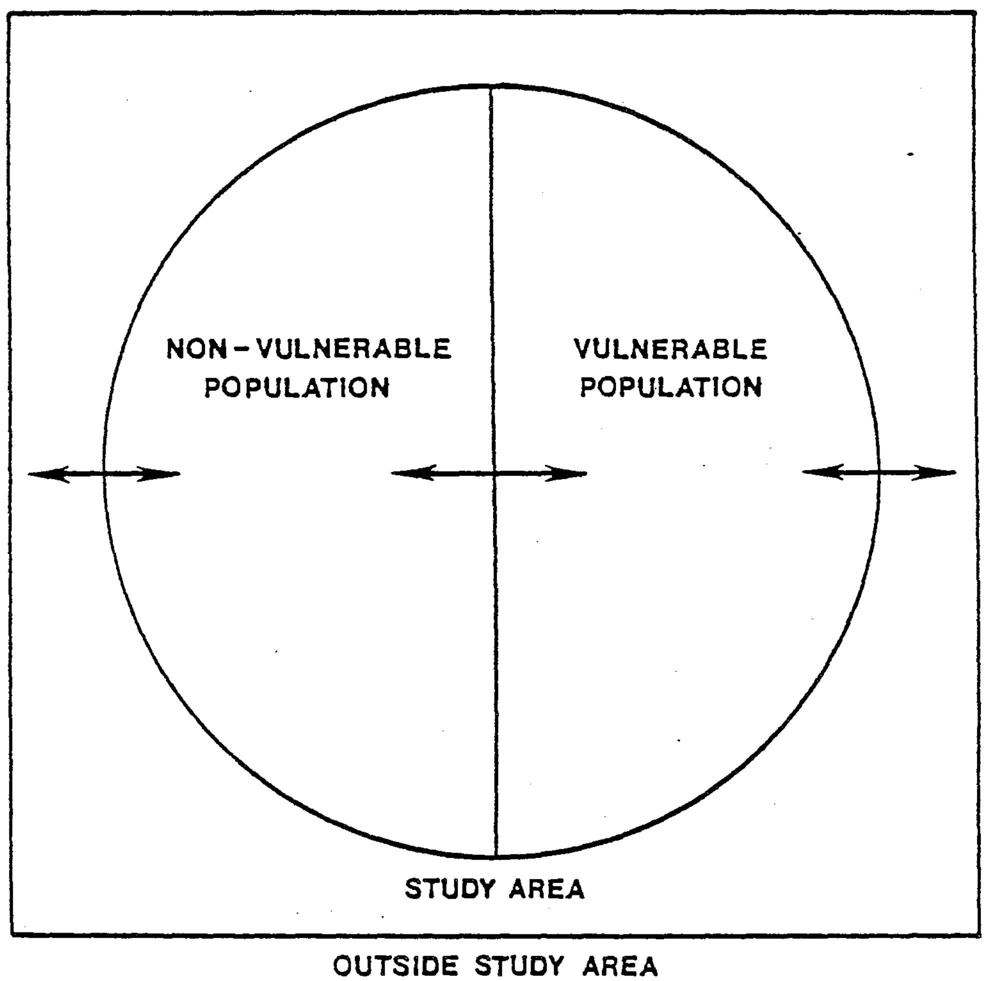


Figure 3.26: Diagrammatic representation of the division of the bear population into vulnerable and non-vulnerable numbers.

Dispersal between the vulnerable and non-vulnerable population and between a population outside the study area (i.e. a "buffer" population) is allowed. A similar structure is utilized for black bears, however, the entire population in the study area is considered to be vulnerable. This structure is used to mimic the idea that specific geographical regions may be net producers (i.e. sources) or sinks for bears. The resulting population in any given area depends, in part, on the rate at which the area "leaks" bears to less productive areas or acquires bears from more productive surrounding areas.

The submodel relates the underlying processes of reproduction, hunting mortality, natural mortality and dispersal to changes in conditions and food supplies which operate on specific maturity, age and sex classes of the vulnerable and non-vulnerable populations. These classes are linked in the form of a simple life table and are portrayed in Figures 3.27 through Figure 3.30 for brown female, brown male, black female and black male bears respectively. Mature females are partitioned into groups based on the presence or absence of offspring (three groups for brown bears (Figure 3.27), two groups for black bears (Figure 3.29)). Immature black bears are partitioned into four age classes and immature brown bears are partitioned into six age classes.

The proportion of bears in a given age class that have reached maturity (Table 3.12) is assumed constant. For example, a three year old immature female brown bear that survives the year must become either a mature animal with no offspring or a four year old immature animal (Figure 3.27). Mature animals without offspring either remain in that condition or produce cubs.

The sequence of calculations for the submodel is diagrammed in the form of a flowchart in Figure 3.31. Each calculation is described in further detail below.

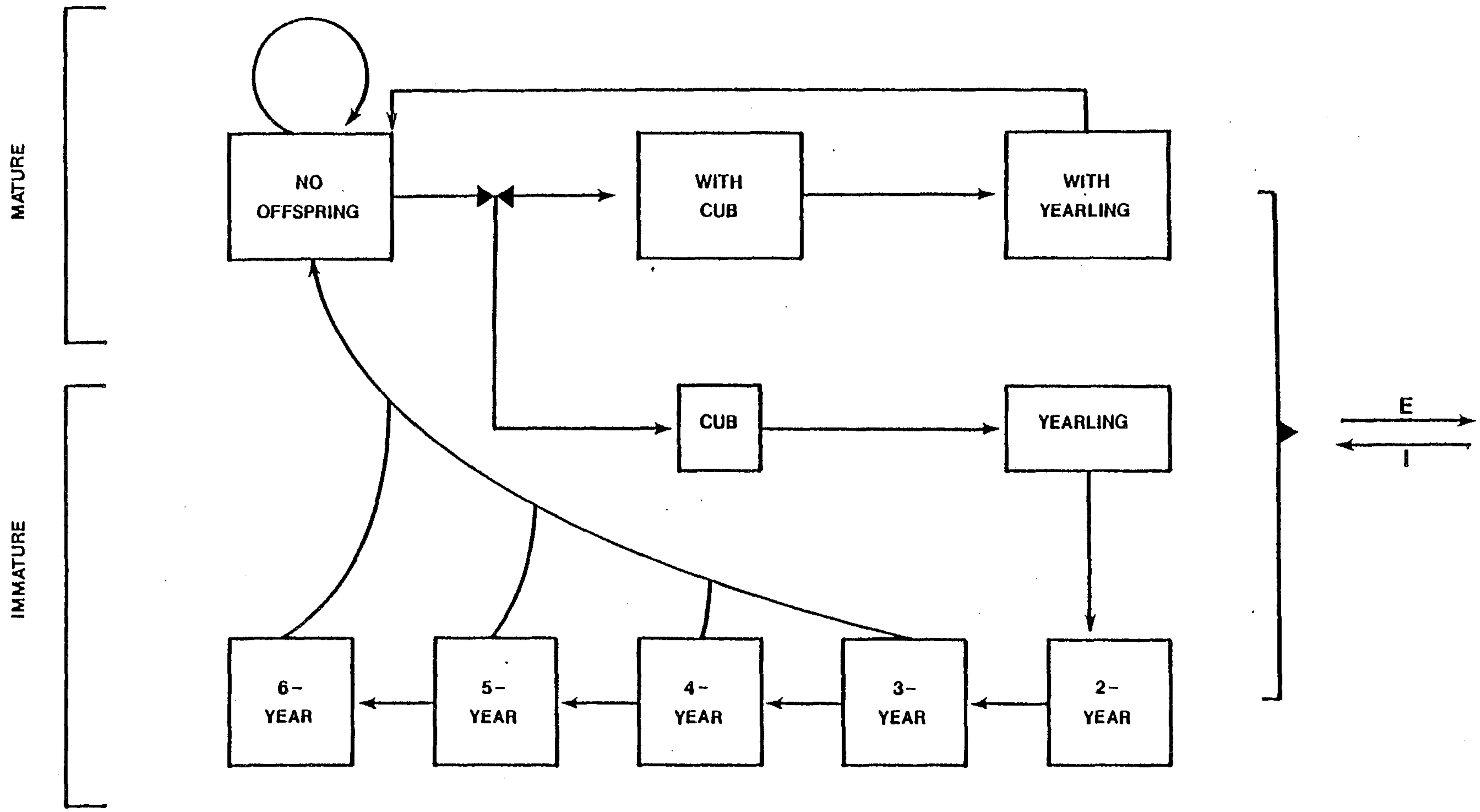


Figure 3.27: Life structure of female brown bear. Each arrow represents a time step of one year.

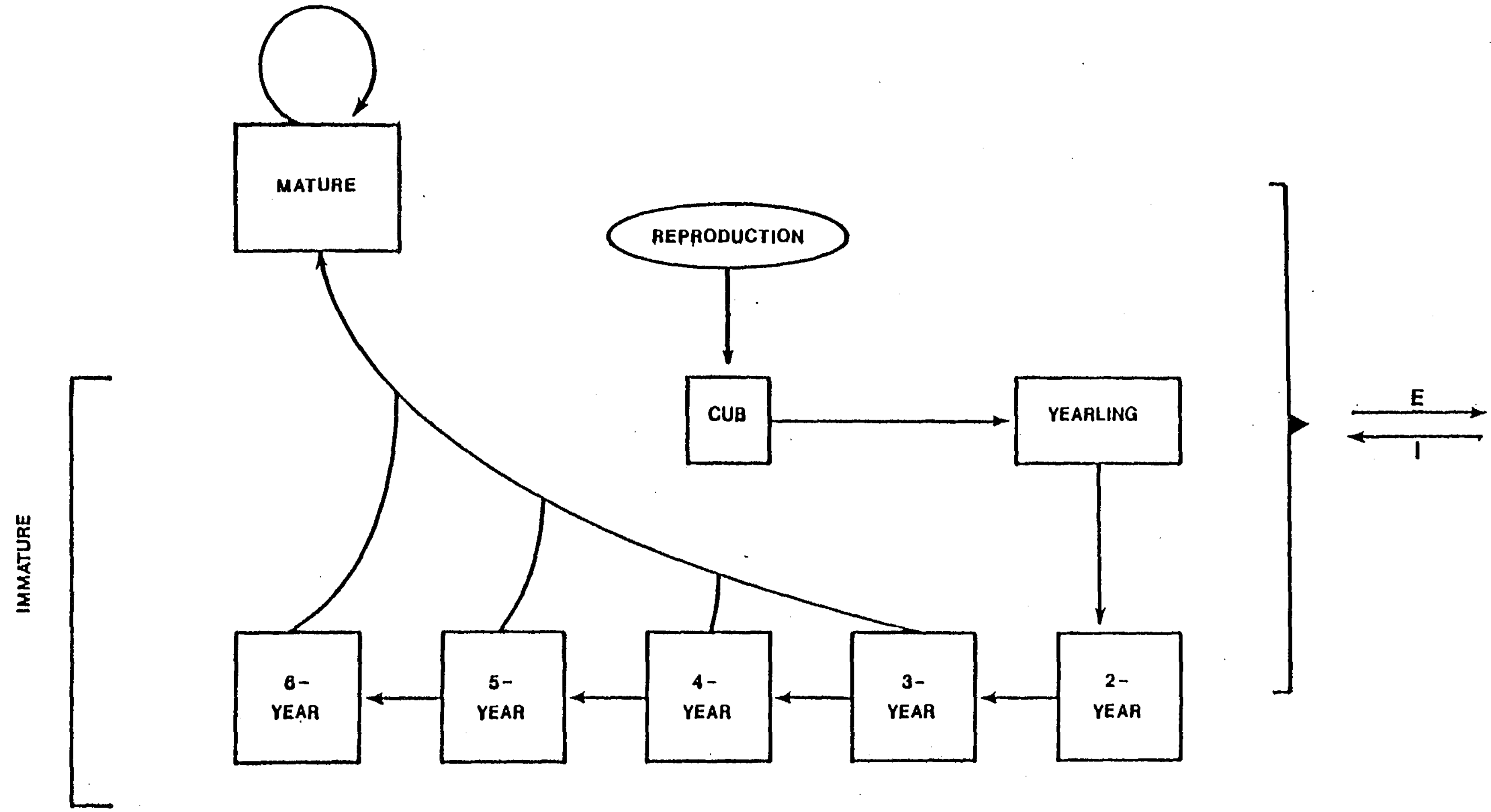


Figure 3.28: Life structure of male brown bear. Each arrow represents a time step of one year.

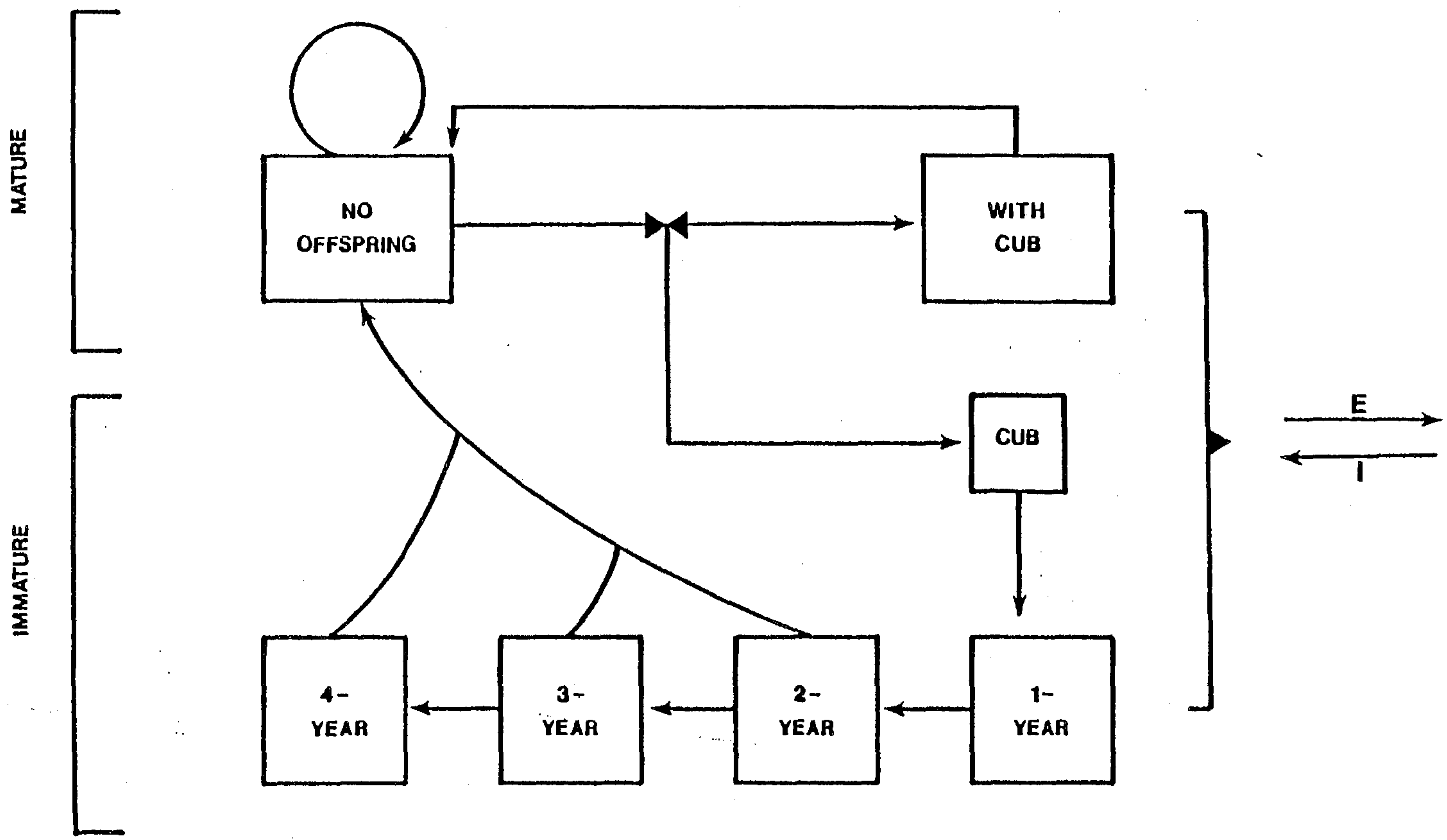


Figure 3.29: Life structure of female black bear. Each arrow represents a time step of one year.

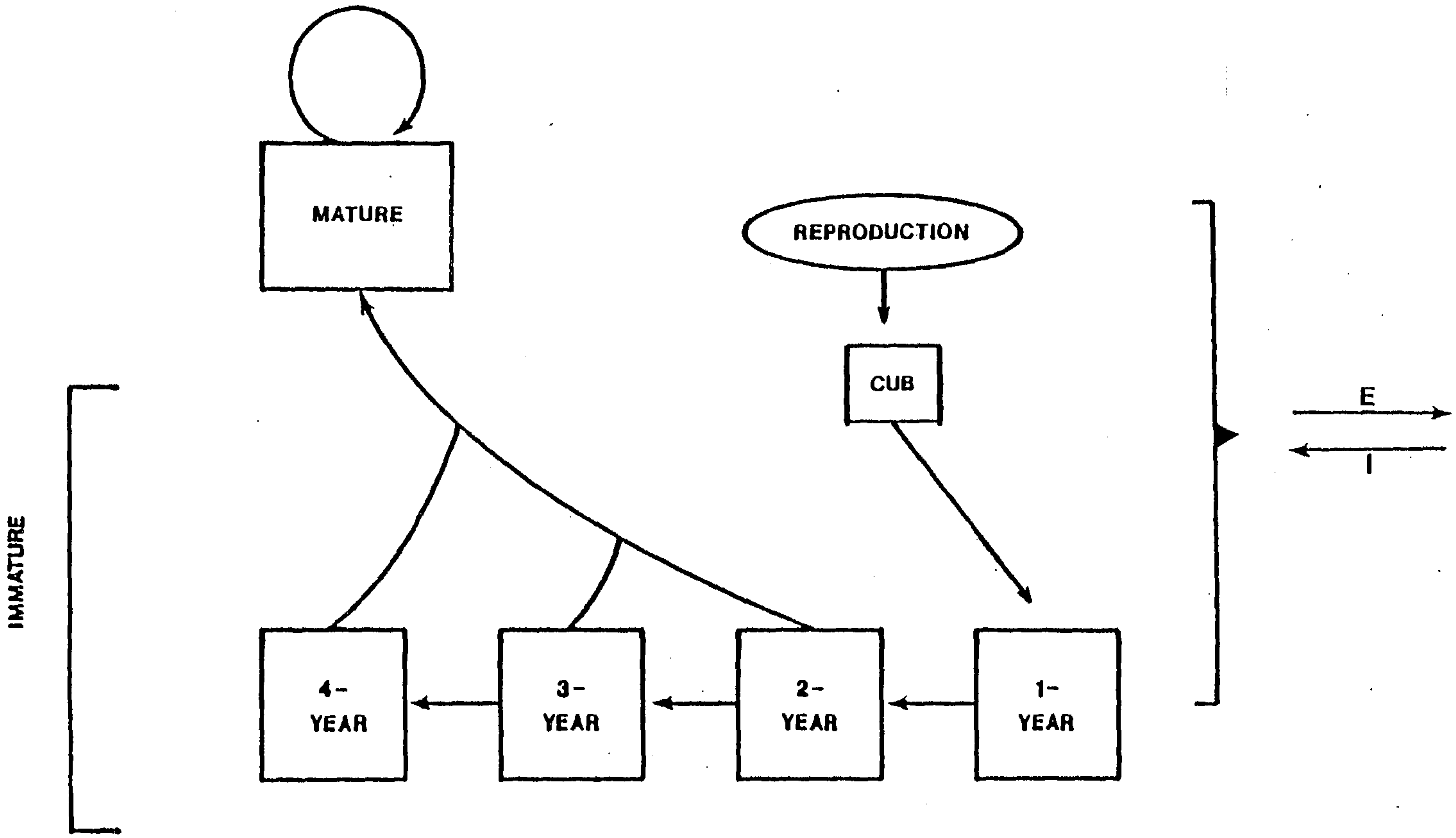


Figure 3.30: Life structure of male black bear. Each arrow represents a time step of one year.

Table 3.12: Assumed proportion of bears reaching maturity by age.

	PROPORTION REACHING MATURITY	
AGE	BLACK	BROWN
2	0.5	--
3	0.75	0.44
4	1.0	0.76
5	--	0.9
6	--	1.0

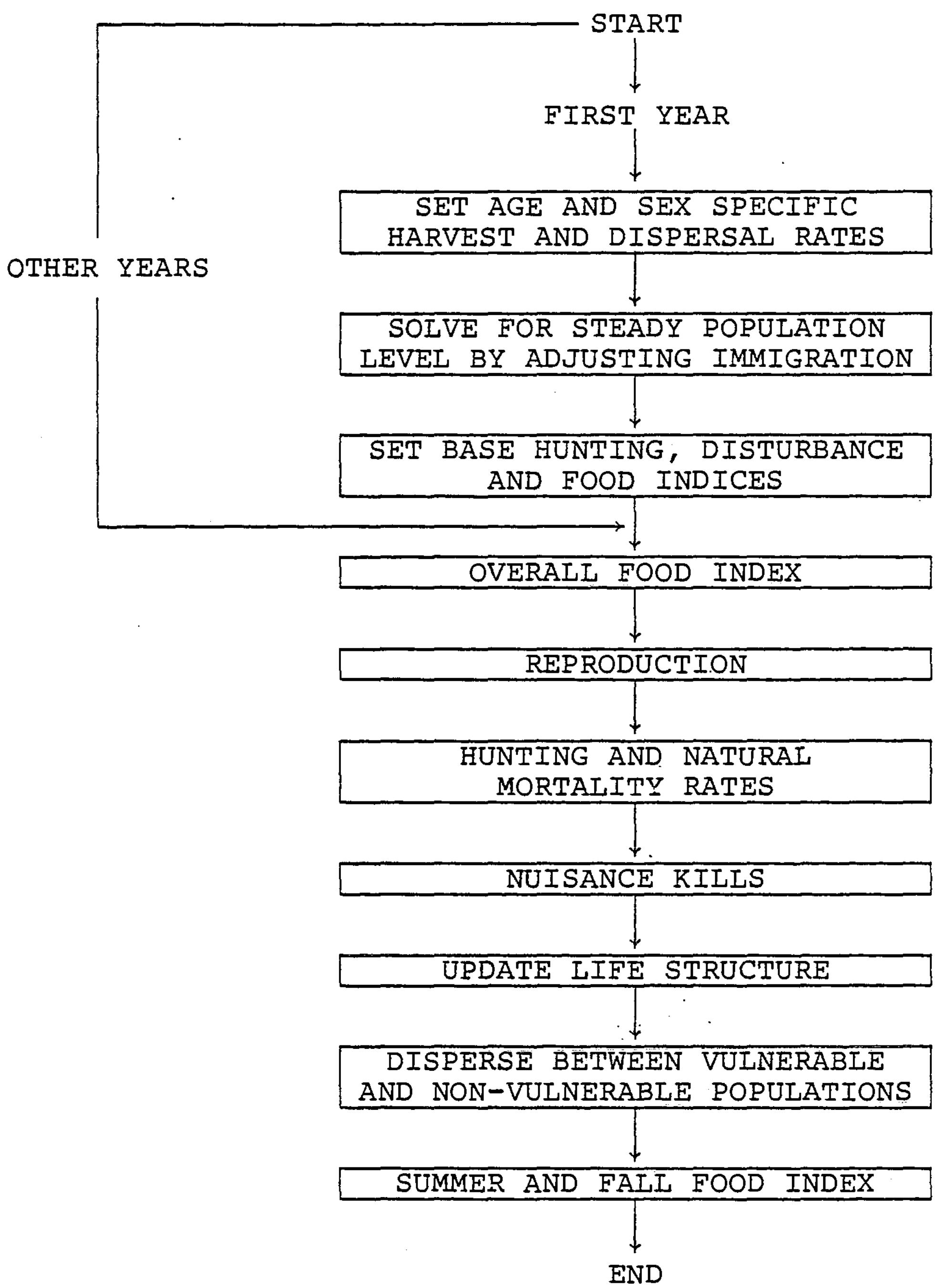


Figure 3.31: Sequence of bear submodel operations.

3.5.2 Initial Population Equilibrium

During the first modelled year (1980), the population is assumed to be in equilibrium with the surrounding populations such that if all factors that affect bears were to remain the same, the total population size after each cycle of the life table (i.e. 10 years for brown bears and 7 years for black bears) would reamin constant. In other words, immigration and recruitment are in balance with losses due to natural mortality, hunting mortality and immigration. This assumption may be unrealistic if populations in the surrounding areas are in fact declining.

To obtain the above conditions, all factors, with the exception of immigration, were preset and a constant immigration level was found by utilizing a non-linear algorithm (Simplex varying step size). Recruitment was obtained by letting half the females without offspring produce a litter size of two (one male, one female) the following year. The natural mortality constants are presented in Tables 3.13 and 3.14 for brown and black bears. On the other hand, hunting mortality and dispersal rates were set through a more cumbersome method. A generalized formulation was used to determine both the hunting mortality and dispersal rates:

$$R_{ij} = \bar{R}\, w_{ij} \frac{\Sigma\Sigma\, G_{ij}}{\Sigma\Sigma\, G_{ij}\, w_{ij}}$$

where,

i = the age class;

j = the sex;

R_{ij} = the specific rate;

$\bar{R}$ = an overall mean rate;

Table 3.13: Brown bear base natural mortality estimates.

CLASS	FEMALE	MALE
Mature (no offspring)	.05	.04
Mature (with cub)	.05	--
Mature (with yearling)	.05	--
Cub	.15	.15
Yearling	.1	.1
Immature (2-year)	.08	.07
Immature (3-year)	.06	.05
Immature (4-year)	.05	.05
Immature (5-year)	.05	.05
Immature (6-year)	.05	.05

Table 3.14: Black bear base natural mortality estimates.

CLASS	FEMALE	MALE
Mature (no offspring)	.08	.07
Mature (with cub)	.08	--
Cub	.15	.15
Immature (1-year)	.1	.1
Immature (2-year)	.08	.08
Immature (3-year)	.08	.08
Immature (4-year)	.08	.08

w_{ij} = a relative unitless weight; and

G_{ij} = a population level from which the overall mean was derived.

In other words, an overall mean rate is partitioned into the various classes according to a set of weights consistent with an initial population level.

Tables 3.15 and 3.16 depict the initial population levels, Tables 3.17 and 3.18 the relative weights for dispersal, and Tables 3.19 and 3.20 the relative weight for hunting. The relative weights can be viewed as the propensity for that event to occur. For example, Table 3.17 declares that an immature three year old male brown bear is 10 times more likely to disperse than a mature animal.

3.5.3 Indices

The primary factors that affect the processes of reproduction, mortality and dispersal of bears can be identified. However, quantitatively little is known about the functional form and parameter values for these relationships. Therefore, indices relative to 1980 (assumed to be an "average year") are utilized for each of the primary factors (summer and fall food, spring food, disturbance, and hunting effort).

3.5.3.1 Summer and Fall Food Index

Since summer and fall foods are thought to be primarily blueberries, the index for any year t is defined as:

$$\frac{\text{total berry production in year t}}{\text{total berry production in 1980}}$$

Table 3.15: Assumed brown bear initial population size.

CLASS	FEMALE	MALE
Mature (no offspring)	30	50
Mature (with cub)	13	--
Mature (with yearling)	12	--
Cub	12	12
Yearling	12	12
Immature (2-year)	10	11
Immature (3-year)	9	9
Immature (4-year)	4	6
Immature (5-year)	1	3
Immature (6-year)	1	1

Table 3.16: Assumed black bear initial population size.

CLASS	FEMALE	MALE
Mature (no offspring)	39	54
Mature (with cub)	16	--
Cub	16	15
Immature (1-year)	17	18
Immature (2-year)	14	24
Immature (3-year)	8	14
Immature (4-year)	4	6

Table 3.17: Brown bear dispersal weight by class and sex.

CLASS	FEMALE	MALE
Mature (no offspring)	1	1
Mature (with cub)	1	--
Mature (with yearling)	1	--
Cub	1	1
Yearling	1	1
Immature (2-year)	2	5
Immature (3-year)	3	10
Immature (4-year)	3	9
Immature (5-year)	2	8
Immature (6-year)	1	1

Overall dispersal rate = .1

Table 3.18: Black bear dispersal weight by class and sex.

CLASS	FEMALE	MALE
Mature (no offspring)	1	1
Mature (with cub)	1	--
Cub	1	1
Immature (1-year)	2	3
Immature (2-year)	3	10
Immature (3-year)	3	7
Immature (4-year)	2	3

Overall dispersal rate = .2

Table 3.19: Brown bear harvest weight by class and sex.

CLASS	FEMALE	MALE
Mature (no offspring)	4	5
Mature (with cub)	1	--
Mature (with yearling)	3	--
Cub	1	1
Yearling	3	3
Immature (2-year)	4	10
Immature (3-year)	8	10
Immature (4-year)	8	9
Immature (5-year)	8	9
Immature (6-year)	7	8

Overall hunting mortality = .1

Table 3.20: Black bear harvest weight by class and sex.

CLASS	FEMALE	MALE
Mature (no offspring)	4	5
Mature (with cub)	1	--
Cub	1	1
Immature (1-year)	6	8
Immature (2-year)	8	10
Immature (3-year)	7	9
Immature (4-year)	6	8

Overall hunting mortality = .1

The total berry production for a given year is the sum of total berry production in each vegetation type. The vegetation submodel provides berry production per hectare for each vegetation type and the area in each vegetation type which allows calculation of total production. For brown bears, the total study area is utilized, while for black bears, only the two impoundment areas and the 60 km strip from Devil Canyon Dam to Talkeetna are used.

The summer food index for brown bears is modified by use of the salmon resource from Prairie Creek. Twenty-five percent of brown bears in the study area are assumed to use this resource during one-third of their summer feeding periods. It is assumed that future recreational developments or material sites in the area will preclude bear use of this resource. Because the level of disturbance (number of recreational use days per year) necessary to preclude use could not be determined, it was arbitrarily assumed that this resource would be lost if recreational use doubles the 1980 level. If this recreational use level is reached, the summer food index is reduced by 8%.

3.5.3.2 Spring Food Index

Spring food (which includes such items as Equisetum, moose calves, small mammals, skunk cabbage, roots, and cottonwood buds) is more vulnerable to inundation than summer food. The index relates preference of vegetation types utilized per bear to the base year 1980 and is calculated as:

$$\frac{\text{total area of vegetation in year } t \text{ weighted by preference}}{\text{total area of vegetation in year 1980 weighted by preference}}$$

$$* \frac{\text{\# of bears in 1980}}{\text{\# of bears in year } t}$$

The assumed relative preference weights are depicted in Table 3.21 for brown and black bears. For brown bears, the total study area is utilized, while for black bears, only the two impoundment areas and the 60 km strip from Devil Canyon Dam to Talkeetna are used.

Table 3.21: Assumed relative preference of vegetation types.

VEGETATION TYPE	BROWN BEAR	BLACK BEAR
Conifer Woodland	5	8
Conifer Open	5	8
Deciduous and Mixed	7	10
Tundra	5	0
Tall Shrub-Alder	3	3
Medium Shrub	3	2
Low Birch	5	2
Low Willow	5	3
Low Mixed	5	3
Water	0	0
Rock/Snow/Ice	0	0
Temporary (Disturbed)	0	0
Permanent (Disturbed)	0	0
Pioneer	8	10

3.5.3.3 Disturbance and Hunting Effort Indices

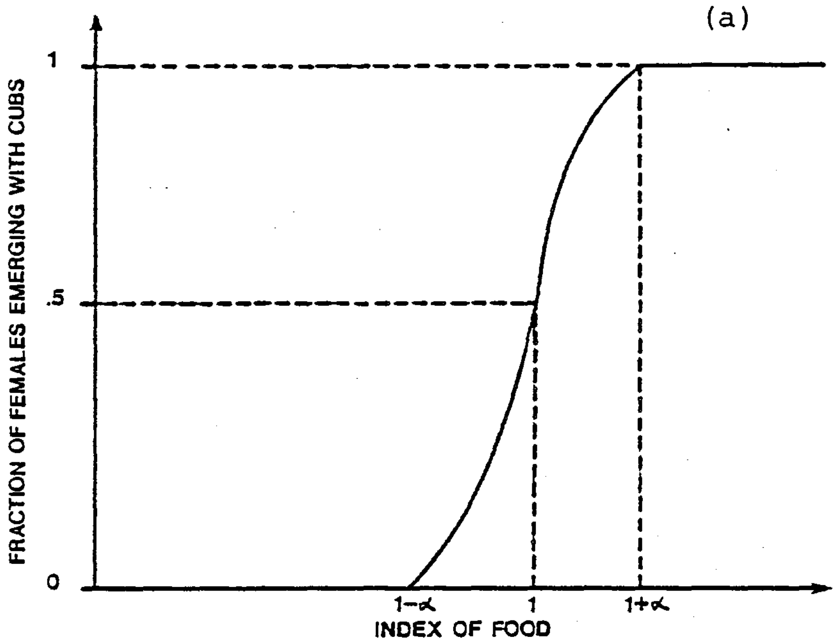
Total disturbance and hunting effort in user days are provided directly by the recreational submodel. The indices are the simple ratio with the base 1980 year.

3.5.4 Reproduction

The proportion of females emerging with cubs is a function of the previous summer's food index while cub survivorship is a function of the current spring food index. In the model, the combined effect of these processes is simulated as a function of a composite index of the previous summer's food and the current spring food. For vulnerable populations, the composite index consists of 80% summer food and 20% spring food. For the non-vulnerable brown bear populations, the index consists of 80% summer food with a constant 20% added on to represent mean spring food.

The proportion of females emerging with cubs as a function of the composite index is shown in Figure 3.32a. Fifty percent of the females emerge with cubs when the food index is 1.0, representing an average year. The α parameter governs the sensitivity of pregnancy rate to food availability. When the food index (Figure 3.32a) is near $1 - \alpha$, the proportion with cubs is near 0; when it is near $1 + \alpha$, the proportion is close to 1.0. In the current version of the model, α is 0.2 for black bears and 0.5 for brown bears; black bears are assumed more sensitive to changes in berry production.

At present, the model employs a constant litter size of two. However, an option is available for mean litter size to be determined as a function of the food index (Figure 3.32b). The maximum mean litter size is 2.5 for brown bears and 2.7 for black bears. The number of cubs is the product of the number of females emerging with cubs and the mean litter size. It is assumed that 50% of the cubs are male and 50% are female.



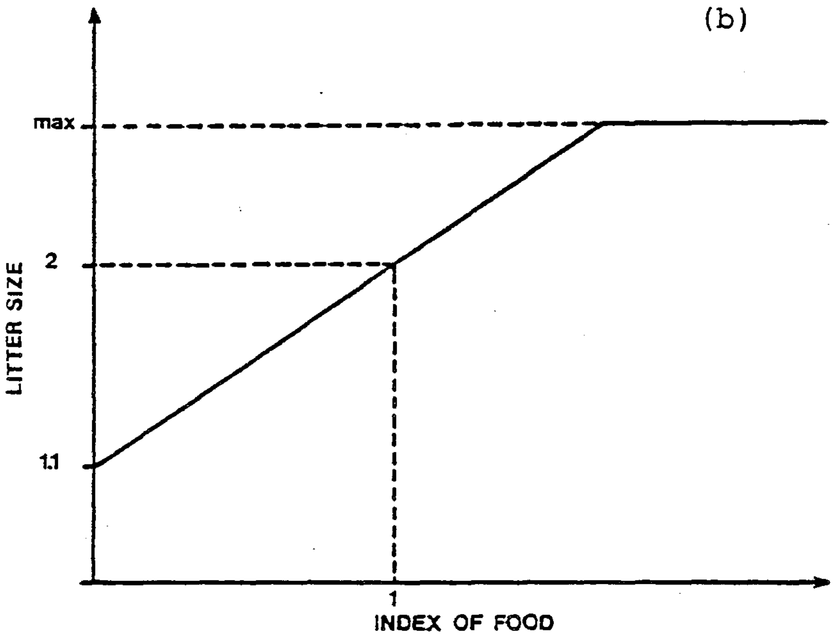


Figure 3.32: Reproduction relationships as a function of the index of food:

(a) proportion of females emerging with cubs;

(b) mean litter size.

3.5.5 Mortality

3.5.5.1 Hunting Mortality

The method for devising the hunting mortality rate is discussed in detail in this section since the same rationale is utilized for natural mortality and dispersal rates.

Mortality rates can always be expressed in terms of the complement survivorship; i.e.:

$$HM_t = 1 - HS_t$$

where,

HM_t = hunting mortality; and

HS_t = survival from hunting in any year t.

Suppose that the effective hunting effort doubled over the base year (1980) with all bears in a population remaining equally vulnerable. Then, the fraction of bears surviving is:

$$HS_t = (1 - HM_B)^2$$

where,

HM_B = the base hunting mortality.

In other words, the bears must be subjected to the base hunting rate exactly twice since the effective hunting effort doubled. This scheme may be generalized to any increase or decrease in hunting effort; i.e.:

$$HM_t = 1 - (1 - HM_B)^{EV}$$

where,

EV = the effective hunting vulnerability.

However, a change in hunting effort may not translate into an equal vulnerability of bears. An increase in hunters may produce interference of an individual hunter's effectiveness, a portion of the bear population may become wary because of disturbance, or regulation may introduce inefficiency. This phenomenon can be mimicked by multiplying any increase or decrease of the hunting index from the base year (1980) by a sensitivity constant:

$$EV = (\text{Hunting Index} - 1)\ \text{Sensitivity Constant} + 1$$

Thus, a sensitivity of 1 produces a direct relationship between the number of hunters and the vulnerability of bears to hunting, while a sensitivity of 0 results in no change from the base rate, regardless of the number of hunters. Figure 3.33 depicts the effect upon the mortality rate from a decrease in sensitivity.

The base rates partitioned by age, maturity and sex were those obtained for the equilibrium conditions. All populations (vulnerable and non-vulnerable) are assumed to be subjected to hunting. However, at present, the sensitivity of brown bears to hunting is set to 0.02 to reflect the workshops participants' belief that hunting of brown bears can be largely controlled through regulation. Similarly, the sensitivity of black bears is also small (0.2, i.e. a five-fold increase in hunters only doubles the effective vulnerability), but somewhat larger than for brown bears since their range is restricted and kills are often the result of chance encounters by hunters while targeting upon other species.

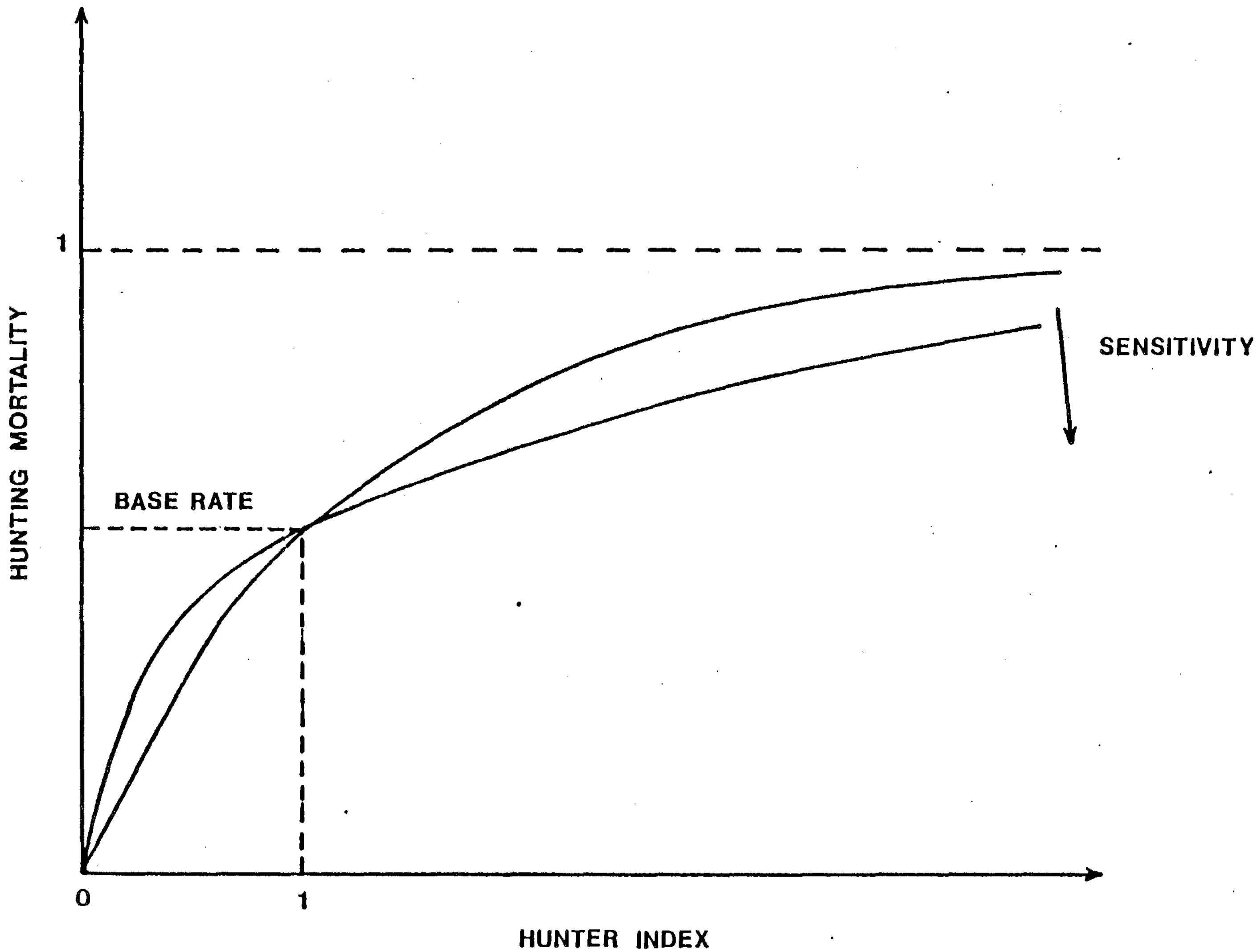


Figure 3.33: Hunting mortality rate as a function of the hunter index with the effect of a lower sensitivity illustrated.

3.5.5.2 Natural Mortality

All animals of the non-vulnerable populations and animals of the vulnerable populations two years of age or greater are assumed to have a constant natural mortality rate (see Tables 3.13 and 3.14). The mortality rates of the remaining cubs and yearlings of the vulnerable population are calculated in the same manner as hunting mortality with the reciprocal of the spring food index replacing the hunting index in the mortality equation, since spring food is more vulnerable to inundation than summer food, and the base rates presented in Tables 3.13 and 3.14. The cubs and yearlings are considered to be completely susceptible to changes in spring food availability (i.e. sensitivity).

3.5.5.3 Nuisance Kill

Only nuisance kills associated with construction work are considered explicitly. At maximum activity, it is assumed that five brown bears and seven black bears will be killed each year. For construction activity less than maximum, a simple proportionate number of animals are killed (Figure 3.34). The total kill is then partitioned into the appropriate sex, maturity and age classes according to the relative weights given in Tables 3.22 and 3.23.

3.5.6 Dispersal

Brown bears disperse between vulnerable and non-vulnerable populations at a constant relative rate of 15% each year. There is no such dispersal of black bears since all are considered vulnerable to inundation. In addition, all bears can disperse to the "buffer" population outside the study area. Base dispersal rates, as calculated for initial population equilibrium conditions, are assumed to be constant for the non-vulnerable bear populations.

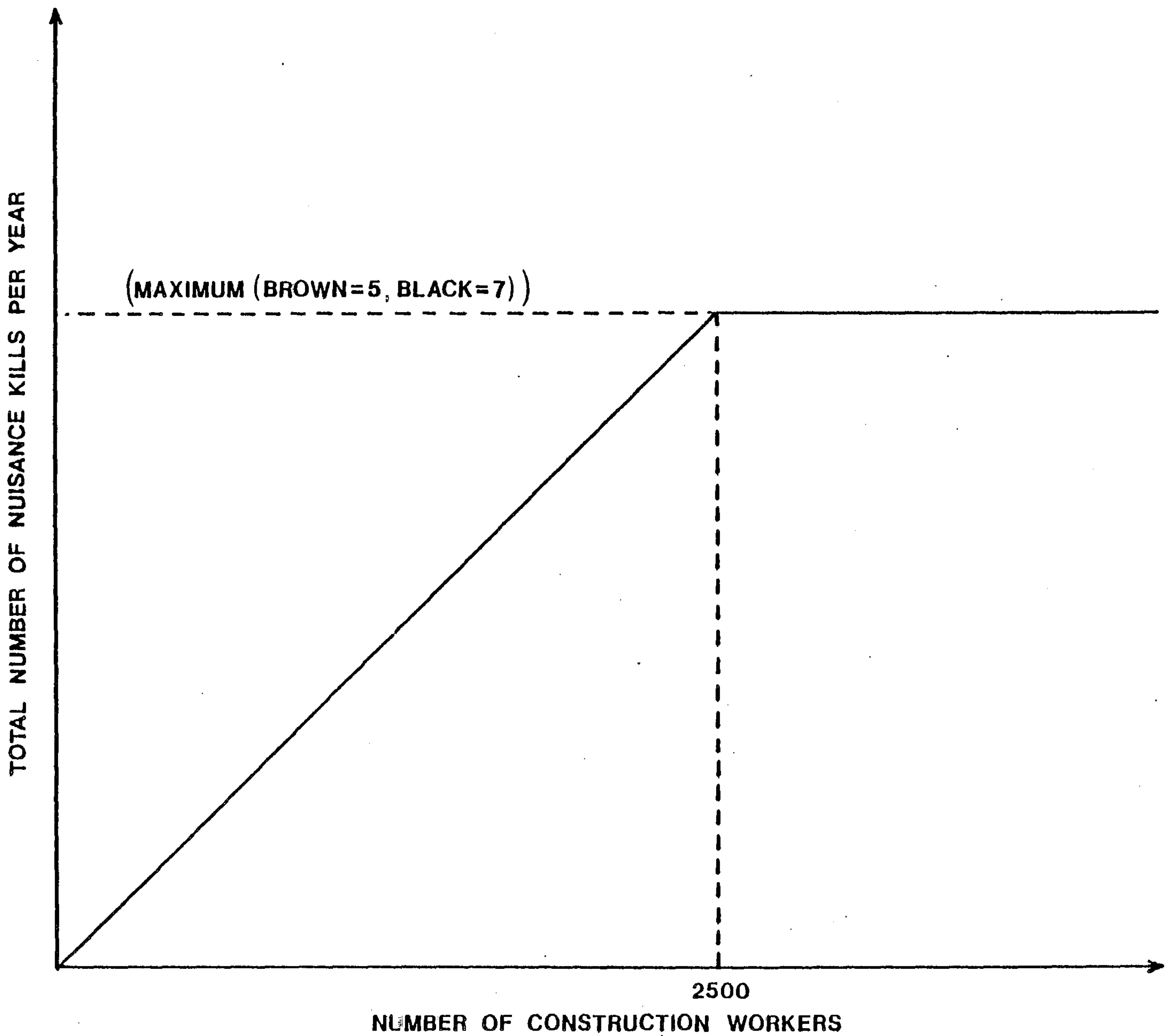


Figure 3.34: Number of nuisance kills as a function of construction activity.

Table 3.22: Brown bear nuisance kill weights by class and sex.

CLASS	FEMALE	MALE
Mature (no offspring)	7	2
Mature (with cub)	7	--
Mature (with yearling)	7	--
Cub	7	7
Yearling	7	7
Immature (2-year)	4	4
Immature (3-year)	4	4
Immature (4-year)	4	4
Immature (5-year)	4	4
Immature (6-year)	4	4

Table 3.23: Black bear nuisance kill weights by class and sex.

CLASS	FEMALE	MALE
Mature (no offspring)	4	2
Mature (with cub)	4	--
Cub	4	4
Immature (1-year)	7	7
Immature (2-year)	7	7
Immature (3-year)	7	7
Immature (4-year)	7	7

For the vulnerable populations, the base rates and the disturbance index are used in the same manner as hunting mortality to calculate dispersal rates of sex, maturity and age classes each year. The sensitivity of brown bears (0.4) to disturbance is assumed to be much greater than for black bears (0.1).

While the dispersal of bears is modelled explicitly, other mortality factors, such as the result of disturbance (e.g. nuisance kills), are implicitly included since the bears that do disperse are no longer members of the study area population.

3.6 Model Results

The model, in its current state, consists of numerous functional relationships of the biophysical processes operating in the Susitna Basin. Lack of data and understanding forced an overly simplistic representation of many of these processes. As a result, great care must be taken in evaluating the results presented in this section. We caution against considering the results to be valid projections of what might happen in the Susitna Basin.

Two scenarios (sets of actions) to be simulated were developed:

a) a baseline or no project scenario; and

b) the full project, Case C, power generation scenario with little mitigation.

The major differences between scenarios (Table 3.24) relate to flow regime, number of dams constructed, choice of access route, and control of access.

Table 3.24: Scenarios used in the simulations.

	NO PROJECT	FULL PROJECT
Flow Regime	preproject	case C (optimum power generation)
Access Route	none	plan used in FERC license application
Access Control	no increased access	open access
Dams Constructed	none	Watana, Devil Canyon

The following figures compare indicators for the two scenarios. It may ultimately be desirable to compare the quantitative results but, at present, only the qualitative results should be considered. It is more appropriate to examine the general temporal differences in the indicators among the scenarios, rather than to focus on their actual values.

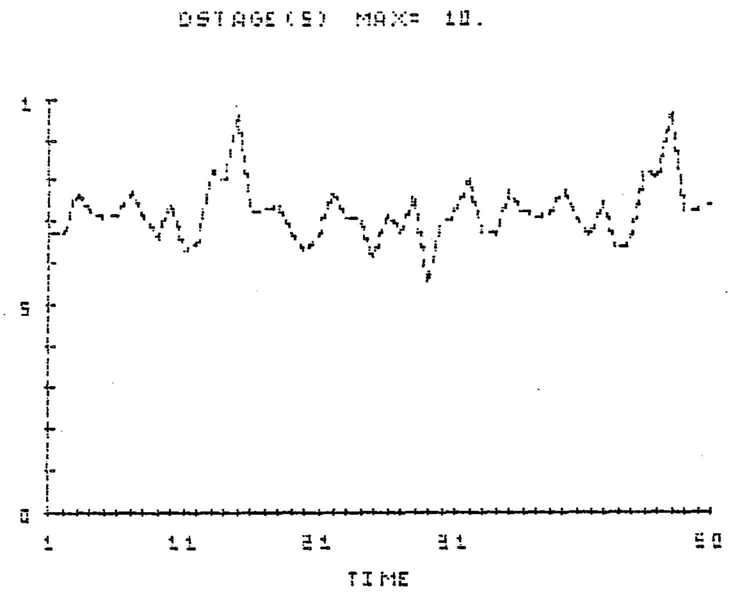
3.6.1 Physical Processes/Development/Recreation

The maximum annual change in stage measured at Gold Creek Station (Figure 3.35) is considerably less under the regulated scenario (Figure 3.35b). The drop that occurs at simulation year 12 is associated with the commencement of the operation of the dams.

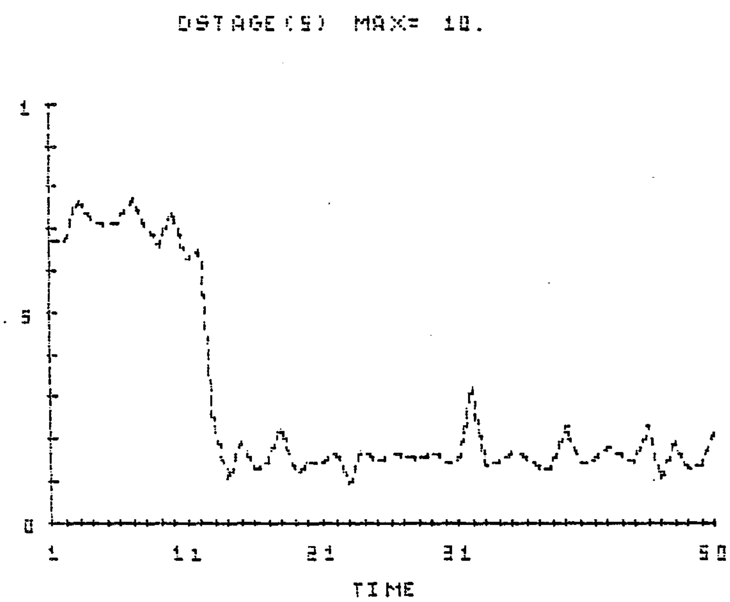
The amount of reservoir clearing in a year (Figure 3.36) follows the schedules outlined in Table 3.1. The large jump in reservoir clearing in the development scenario (Figure 3.36b) is associated with the clearing for Watana; the smaller jump later in years 21 - 24 is associated with clearing for the Devil Canyon impoundment.

Influx of construction personnel is associated with dam construction (Figure 3.37). In the model, this influx is simulated using the schedule outlined in Table 3.3. The large peaks are associated with the construction of Watana (Figure 3.37b); the lesser peak is associated with the construction of Devil Canyon (Figure 3.37b).

Recreational use of the area is assumed to increase gradually without the project (Figure 3.38a). Under the full project scenario with no restriction on access (Figure 3.38), there is a steeper increase in recreational use for ten years after construction of Watana is completed.

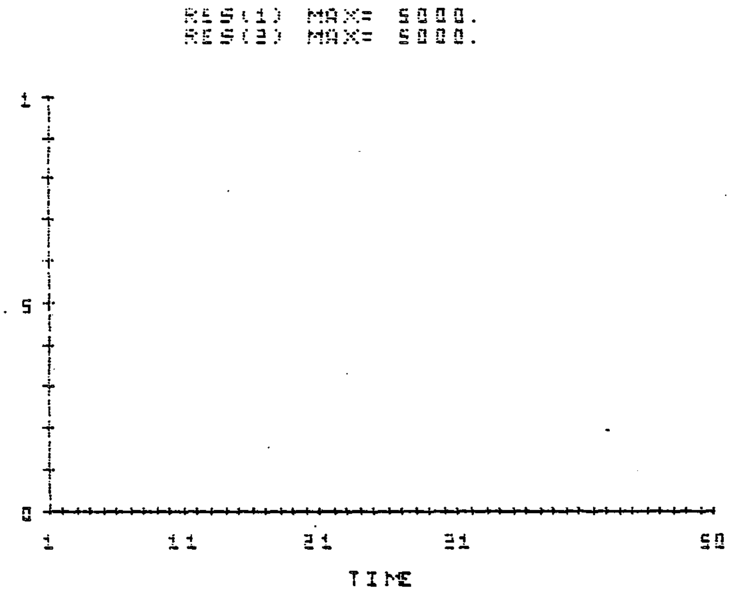


(a) No Project

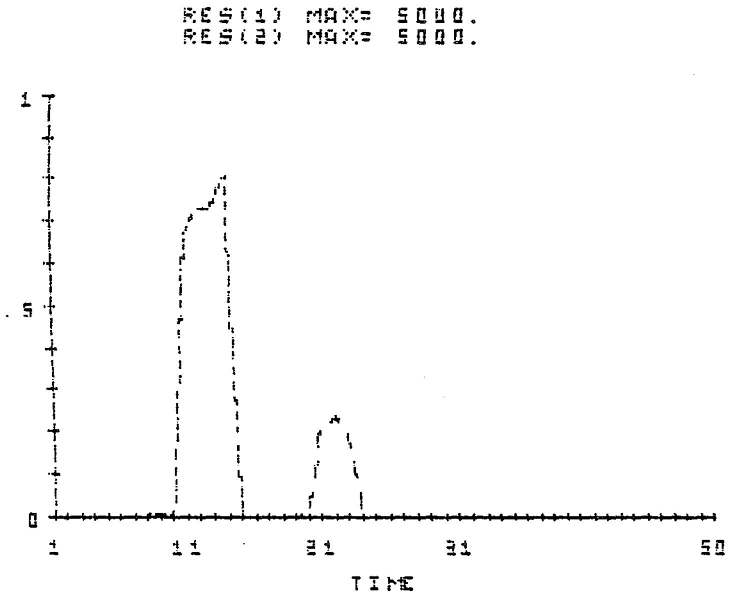


(b) Full Project

Figure 3.35. Maximum annual change in stage at Gold Creek Station. The maximum value on y-axis is 10 feet.

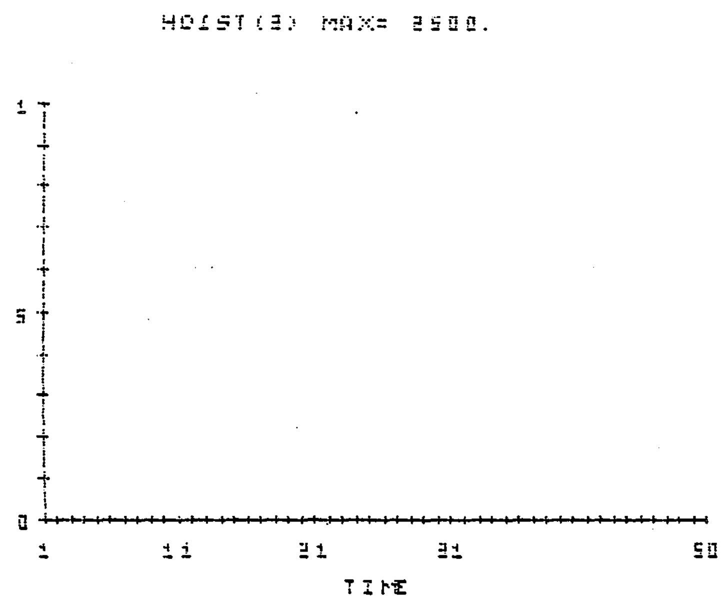


(a) No Project

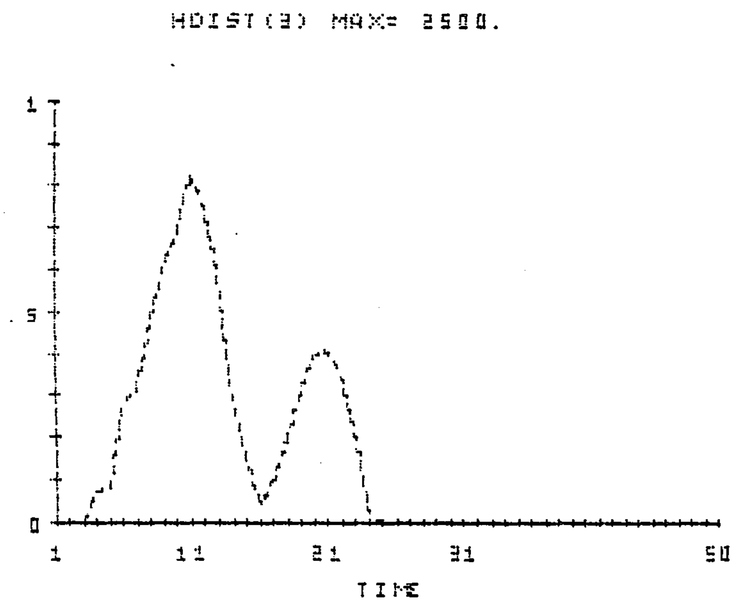


(b) Full Project

Figure 3.36: Amount of reservoir clearing (ha) per year. The maximum value on the y-axis is 5000 ha.

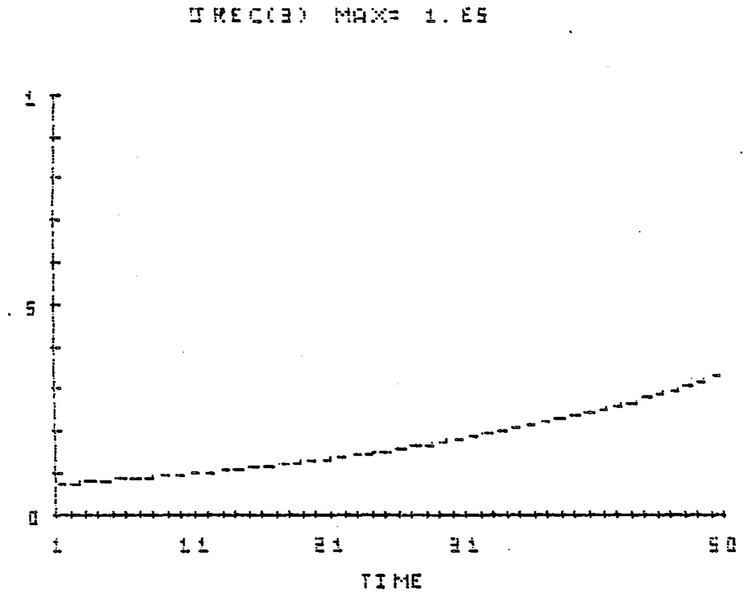


(a) No Project

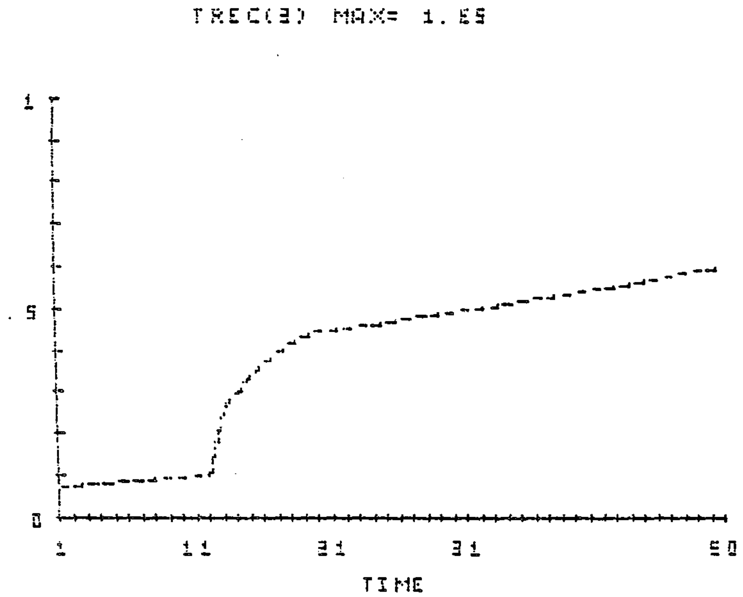


(b) Full Project

Figure 3.37: Construction personnel on site at any one time. The maximum on the y-axis is 2500 workers.



(a) No Project



(b) Full Project

Figure 3.38: Recreational use days in the Upper Susitna Basin. The maximum on the y-axis is 100,000 use days.

Potential overwintering habitat for beaver (Figure 3.39) appears to show a slight decrease after the project is introduced. This small decline occurs in the model because of the lower hydraulic head between the open water section of the downstream reach and adjacent slough and side channel habitat. However, this relationship is a candidate for refinement (c.f. Section 5.1.1).

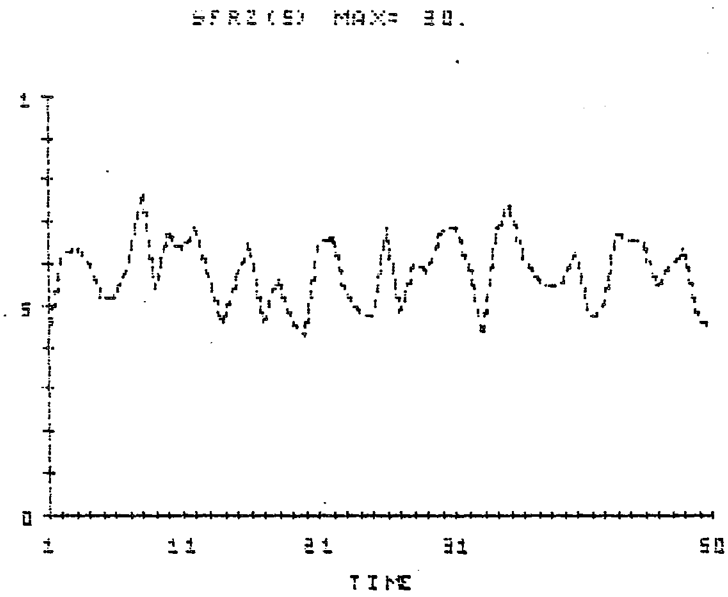
The area of the downstream reach subjected to ice scouring (Figure 3.40) shows considerable variation under the natural hydrological regime (Figure 3.40a). With the project, the frequency of ice scouring is reduced as a result of the ice melting in place before the high tributary inflows have an opportunity to trigger break-up.

The minimum surface area covered by water during the growing season (Figure 3.41) is an important determinant of the process of riparian succession. The introduction of the project reduces the amount and variability of the flooded area (Figure 3.41b).

3.6.2 Vegetation

In the Upper Susitna Basin, available winter range for moose is assumed to be located at 4,000 feet in elevation. Changes in two vegetation types that make up much of the food available on the winter range are illustrated in Figures 3.42 (deciduous and mixed forest) and 3.43 (low mixed shrub). The deciduous and mixed forest shows a substantial decline (Figure 3.42b), while the low mixed shrub (Figure 3.43b) shows only a slight decline.

While the deciduous and mixed forest declines, it has a low browse value. As a result, the change in available forage for moose (Figure 3.44) is difficult to discern from the natural variability. However, much of the deciduous and mixed forest that will be inundated occurs at lower elevations in the valley bottoms. It is believed that during severe winters (high snow accumulation), moose will utilize the valley bottoms during the early spring.



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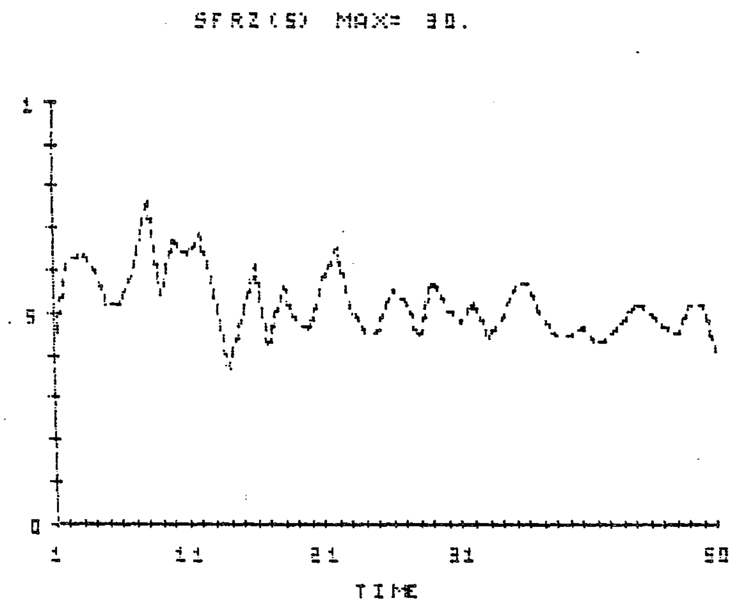


(b) Full Project

Figure 3.39: Potential overwintering habitat for beaver in sloughs and side channels. The maximum on the y-axis is 30 km.

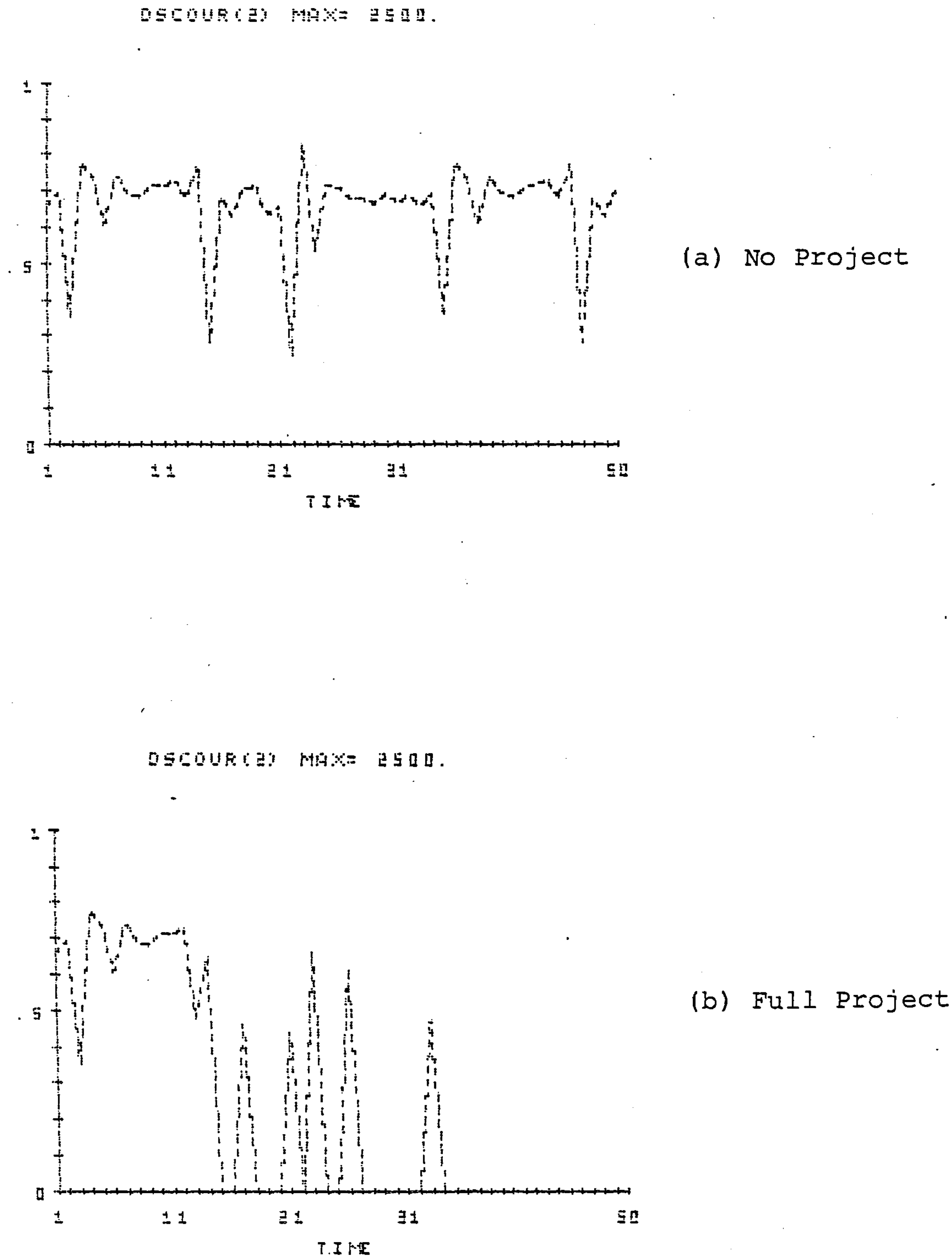
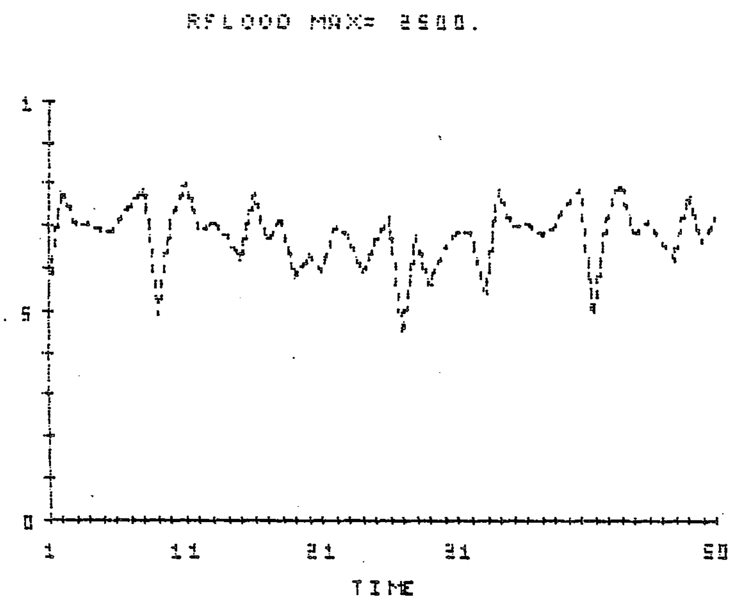
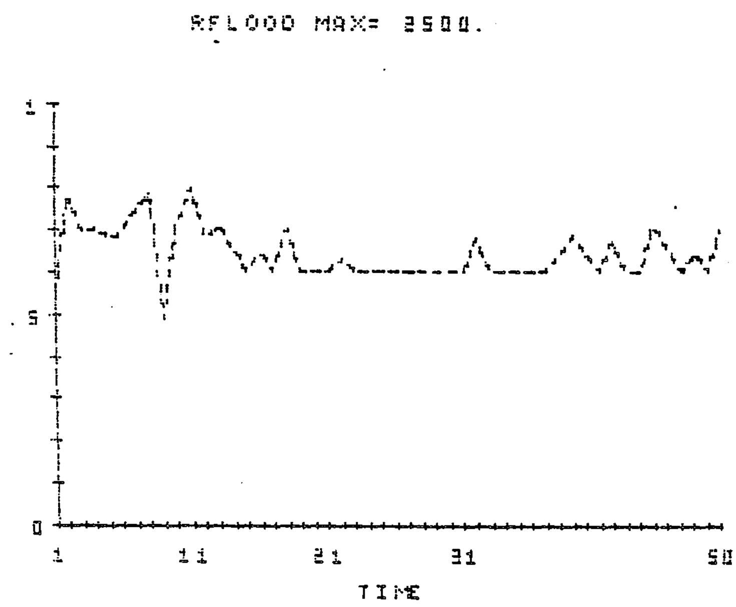


Figure 3.40: Area subject to ice scouring in the downstream reach. The maximum on the y-axis is 2500 ha.

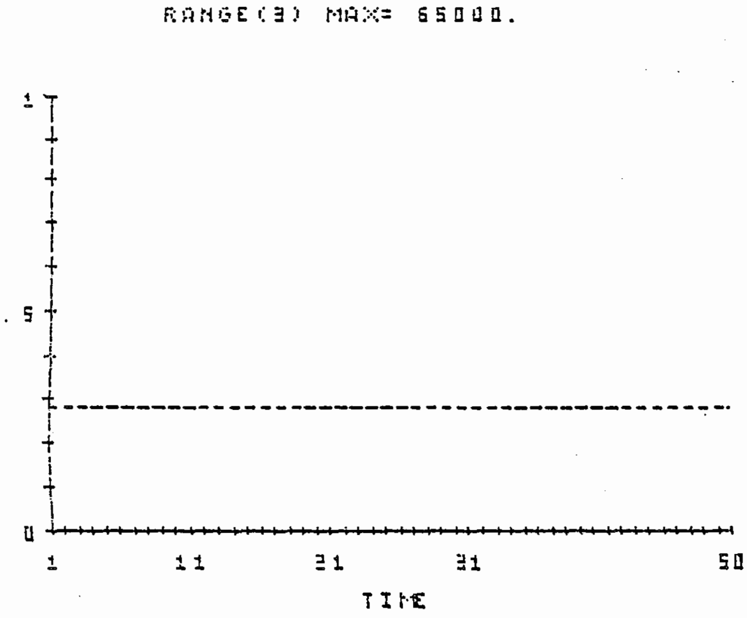


(a) No Project

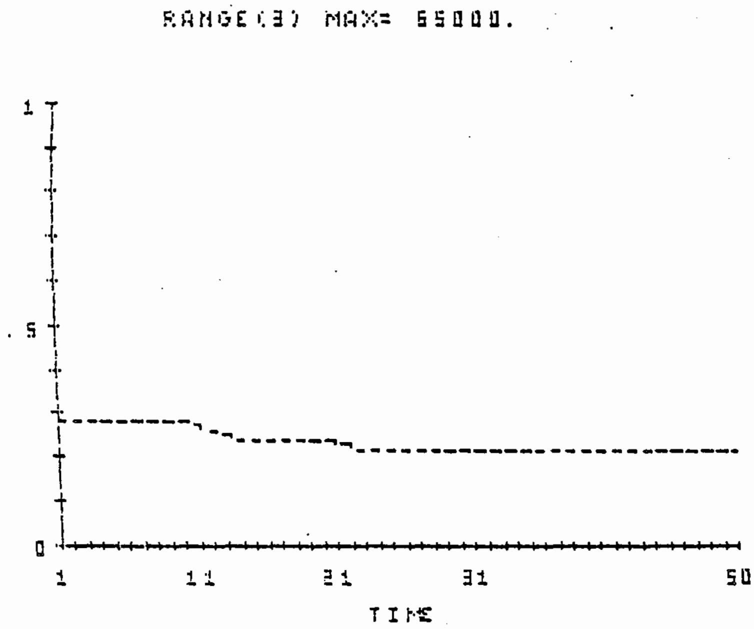


(b) Full Project

Figure 3.41: Minimum surface area covered with water in the downstream reach. The maximum on the y-axis is 2500 ha.

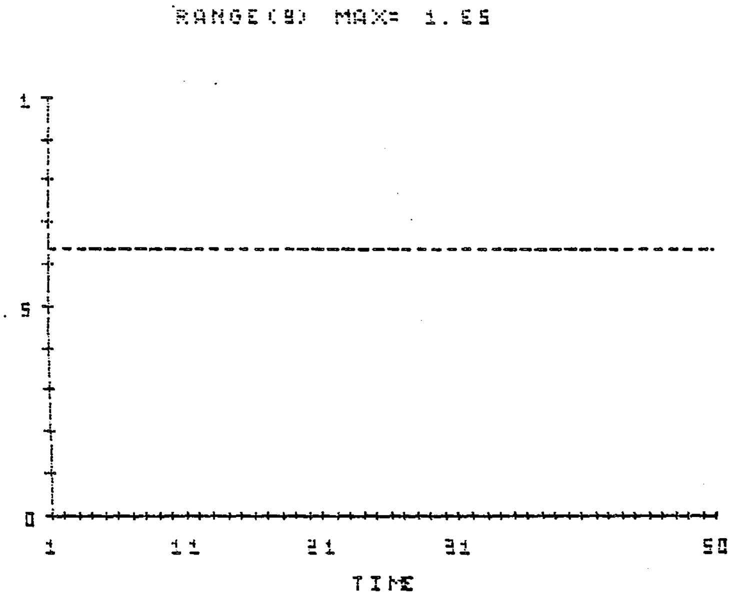


(a) No Project

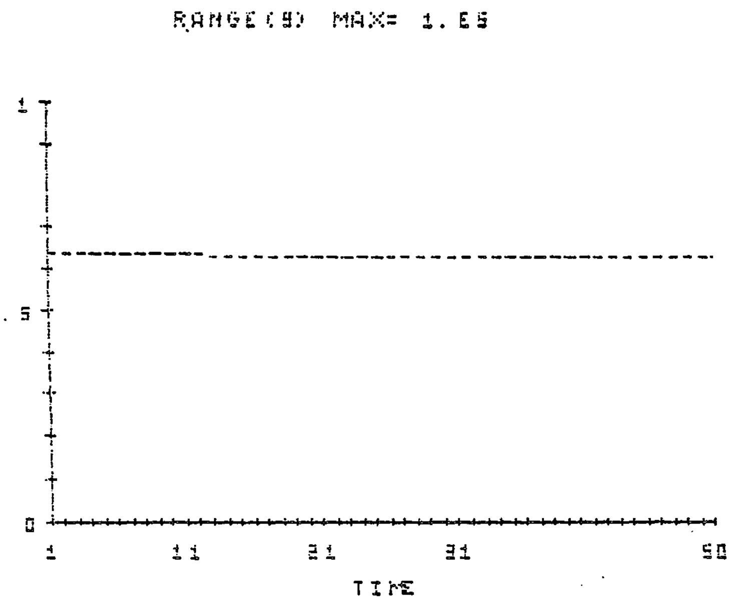


(b) Full Project

Figure 3.42: The areal extent of deciduous and mixed forest (less than 4000 feet elevation in the Upper Susitna Basin). The maximum on the y-axis is 65,000 ha.

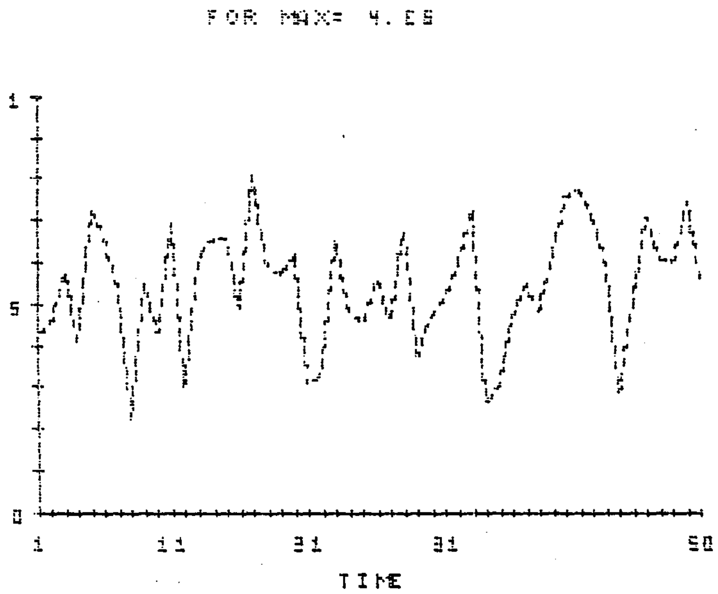


(a) No Project



(b) Full Project

Figure 3.43: The areal extent of low mixed shrub (less than 4,000 feet elevation) in the Upper Susitna Basin. The maximum on the y-axis is 100,000 ha.



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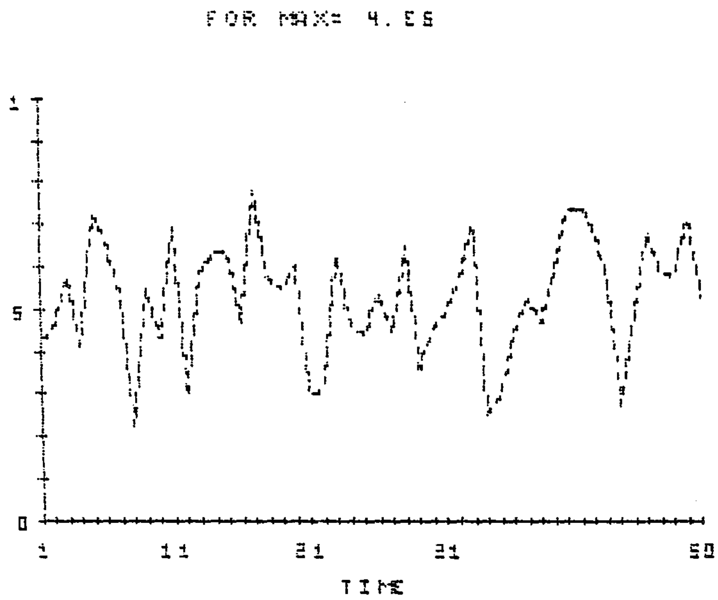


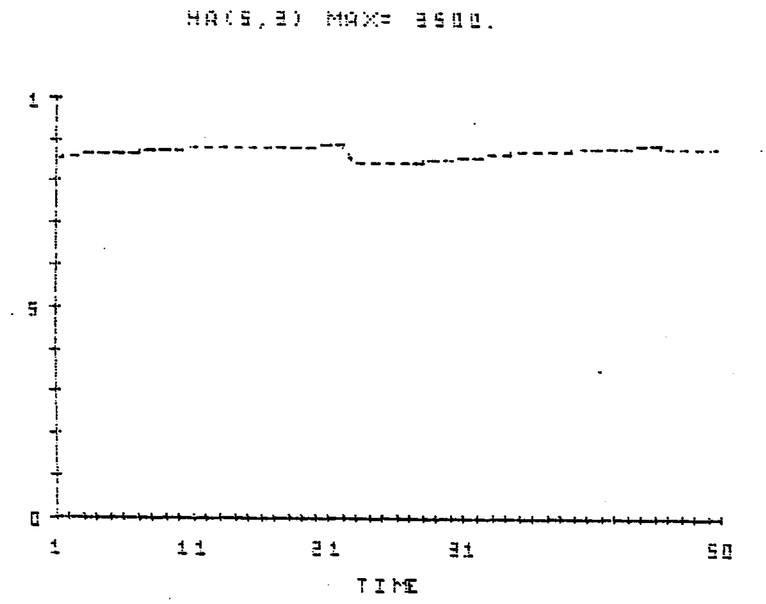
(b) Full Project

Figure 3.44: Winter forage availability for moose in the Upper Susitna Basin. The maximum on the y-axis is 4,000,000 ha.

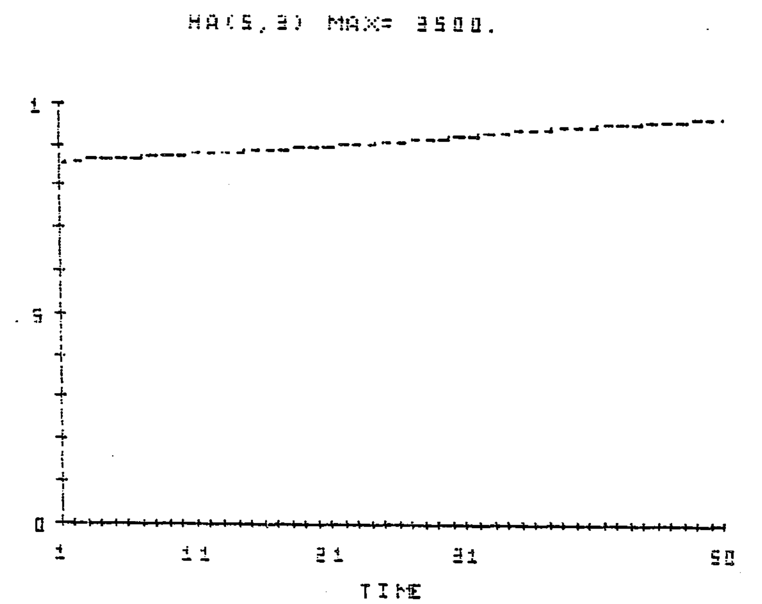
In the downstream reach (Devil Canyon to Talkeetna), the within year variability (Figure 3.34) and maximum stage will be significantly reduced as a result of the project. The effect on riparian succession is to move the vegetation types to a new, much less variable, dynamic equilibrium. In summary, the deciduous and mixed forest shows a constant increase (Figure 3.45b); tall shrub shows an initial increase and then gradually decreases as it succeeds to deciduous and mixed forest (Figure 3.46b); low mixed shrub shows a gradual decline as it succeeds to tall shrub (Figure 3.47b); and the pioneer species which are subjected to considerable variability (Figure 3.48a) under natural conditions show a constant decline to very low levels once the project is introduced (Figure 3.48b).

3.6.3 Furbearers and Birds

Under the current assumptions in the model, the number of beaver colonies associated with sloughs and side channels in the downstream riparian zone oscillate about the carrying capacity for both scenarios (Figure 3.49). A major reason for the population being nearly equal to the carrying capacity is the way in which carrying capacity is defined. Since the hydrology group provides the length of shoreline with greater than .5 m of ice free water under the maximum ice cover, a major source of overwinter mortality (i.e. beaver colonies frozen out due to insufficient water depth) is incorporated in the determination of carrying capacity. In reality, the carrying capacity during the den construction period (i.e. late summer) is likely much higher, although the effective carrying capacity (which the model generates) is decreased substantially by the ice free depth criteria. Therefore, the only process which could result in a substantial drop in the population from the carrying capacity is a severe scouring event; and, in fact, the model predicted drops in population are a consequence of ice scouring events (Figures 3.49a and 3.49b).

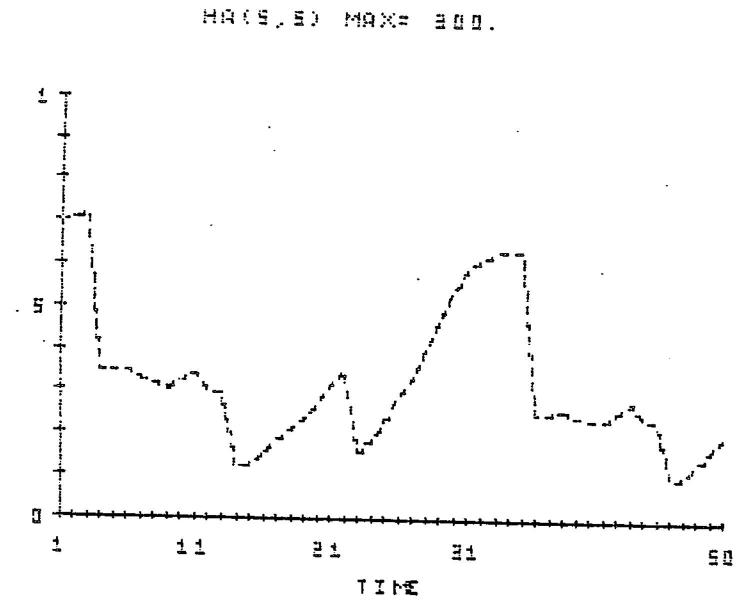


(a) No Project

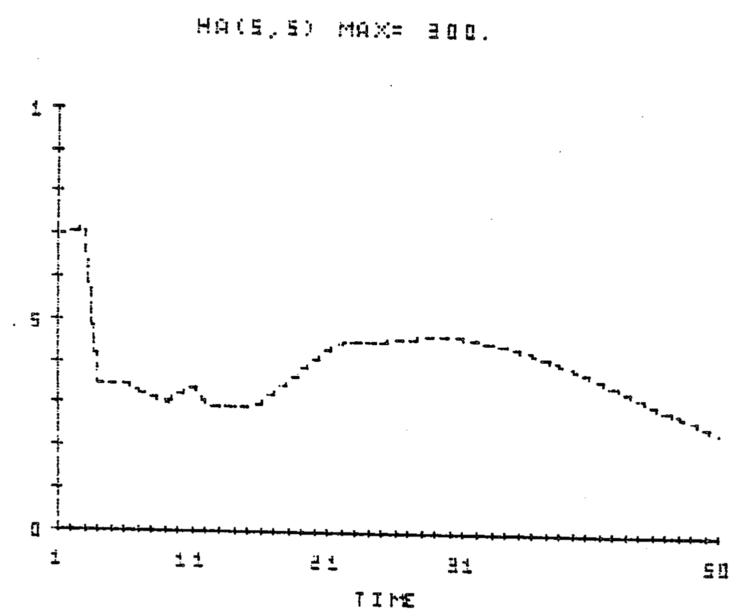


(b) Full Project

Figure 3.45: The areal extent of deciduous and mixed forest in the downstream floodplain. The maximum value on the y-axis is 3,500 ha.

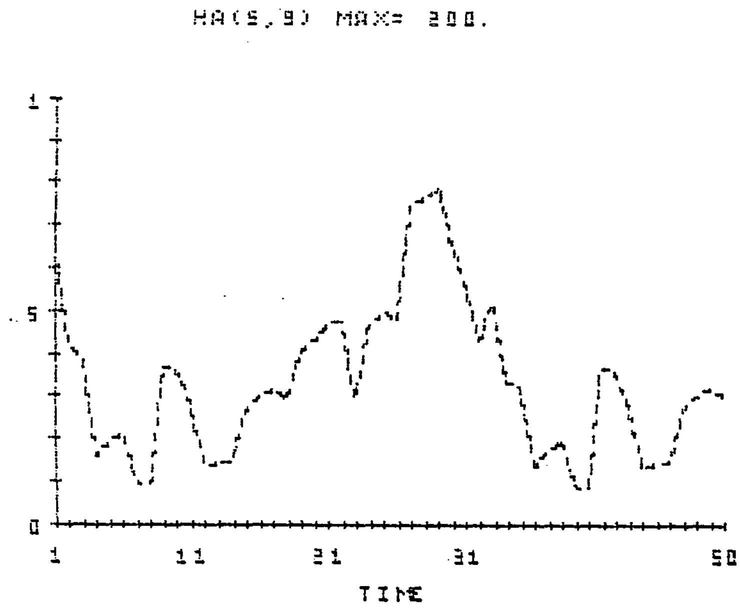


(a) No Project



(b) Full Project

Figure 3.46: The areal extent of tall shrub in the downstream floodplain. The maximum value on the y-axis is 300 ha.



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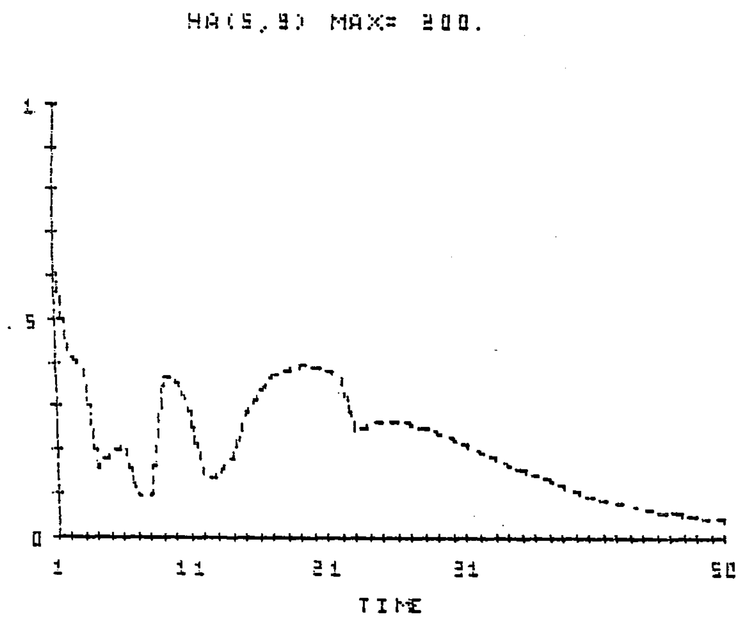
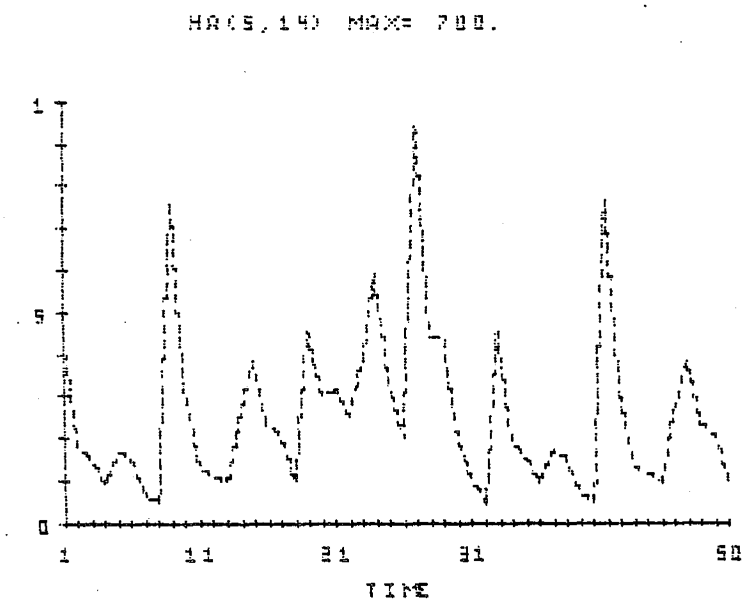


(b) Full Project

Figure 3.47: The areal extent of low mixed shrub in the downstream floodplain. The maximum on the y-axis is 200 ha.



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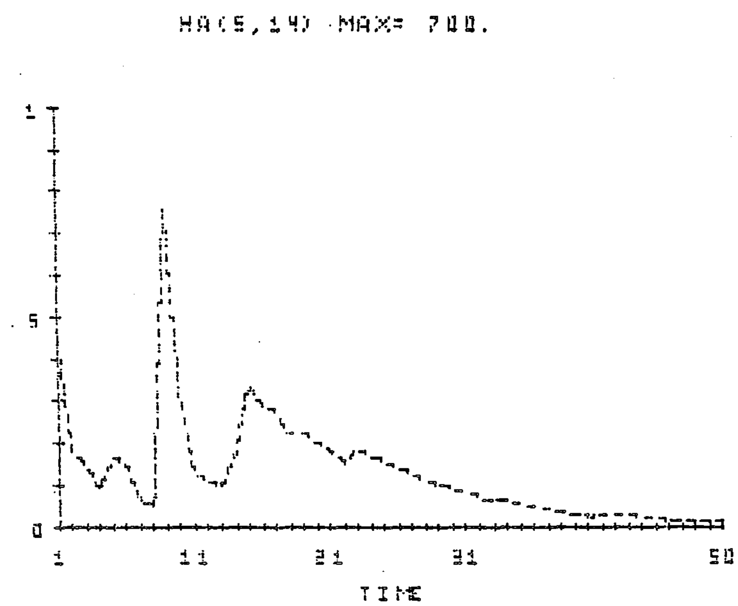
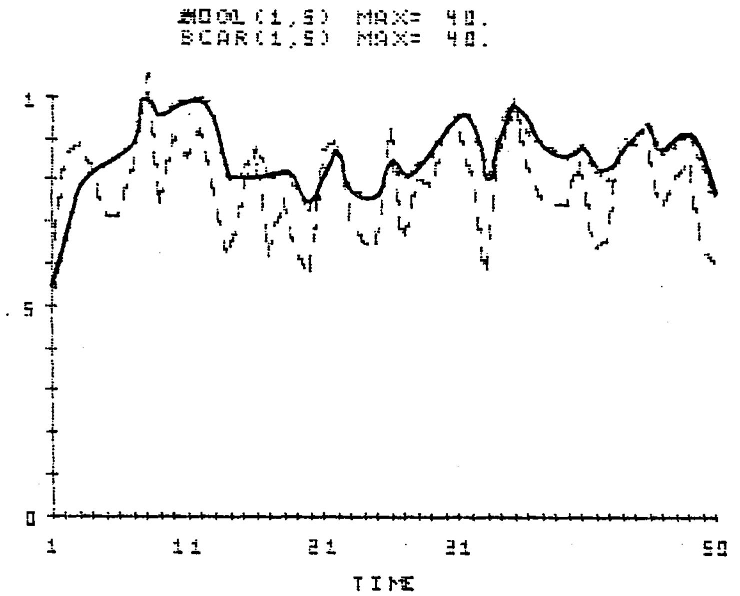


(b) Full Project

Figure 3.48: The areal extent of pioneer vegetation in the downstream floodplain. The maximum on the y-axis is 700 ha.



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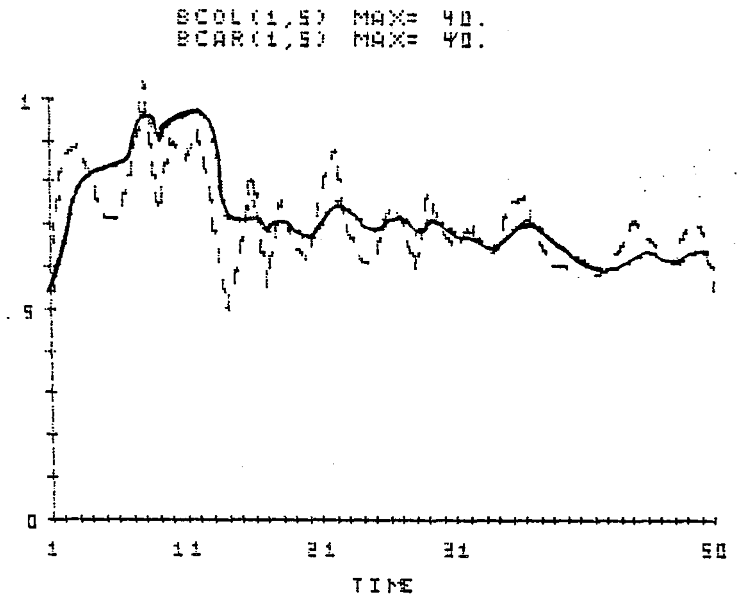


(b) Full Project

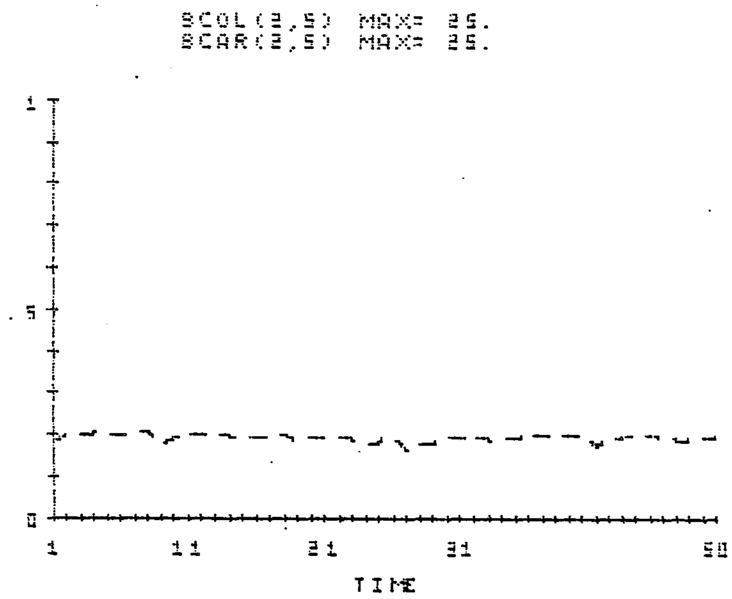
Figure 3.49: Beaver colonies utilizing the sloughs and side channels (solid line) and the corresponding carrying capacity (broken line) in the downstream riparian zone. The maximum on the y-axis is 40 colonies.

The apparent stabilization in the beaver population after project construction in year 12 (Figure 3.49b) is a direct consequence of the reduction in ice scouring events. It is interesting to note the "stable" population is lower, on average, with the full project situation (i.e. 25 colonies versus 35 colonies), although with a less dramatic shift from year to year. This is a direct consequence of a reduction in the number of shoreline miles meeting the ice free depth criteria, as determined by the hydrology submodel (see Figure 3.39).

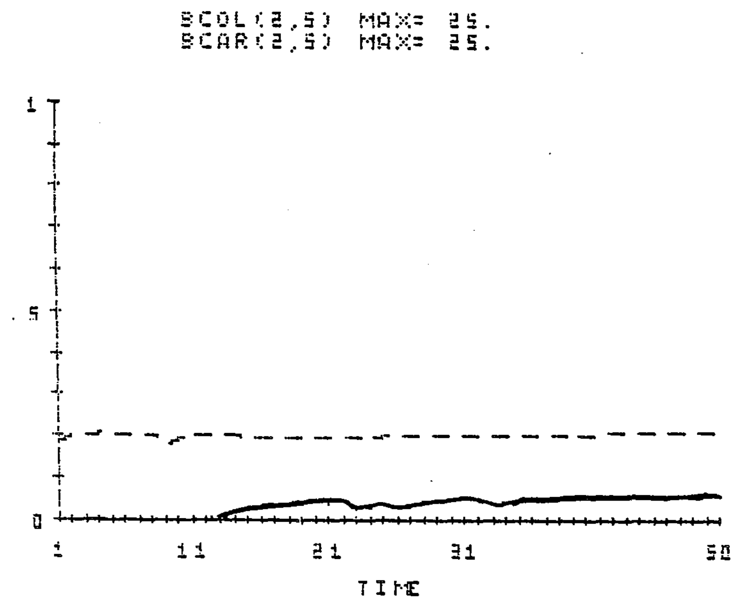
The main channel colonies, despite a viable carrying capacity, are not in evidence for the no project scenario. This is a consequence of both ice scouring and wide fluctuations in stage, which, in concert, result in a zero beaver colony population in the spring. (What is not shown here is the fact that beaver colonies are established along the main channel in the summer, but are destroyed by the above mentioned hydrologic events.) For the full project scenario, the reduction in the magnitude of the scouring event, as well as the reduction in stage fluctuation over the year, result in a viable, although small, main channel population (about two colonies - Figure 3.50). It is significantly lower than the carrying capacity since the model prediction shown is for after the impact of stage fluctuation on the colonies.

The model predictions for marten are essentially the same for both scenarios (Figure 3.51). The population quickly reaches its maximum density and, as such, is directly dependent on changes in the amount of forest habitat. The loss of forest habitat, due to the project impoundments, accounts for the slight drop in the population after year 11 (Figure 3.51b).

As described in the submodel description, the prediction of bird territories is a direct function of habitat availability. Therefore, any change in any one of the habitats identified as important to a particular bird species (see Table 3.9) will result in a proportionate change in the predicted number of bird territories.

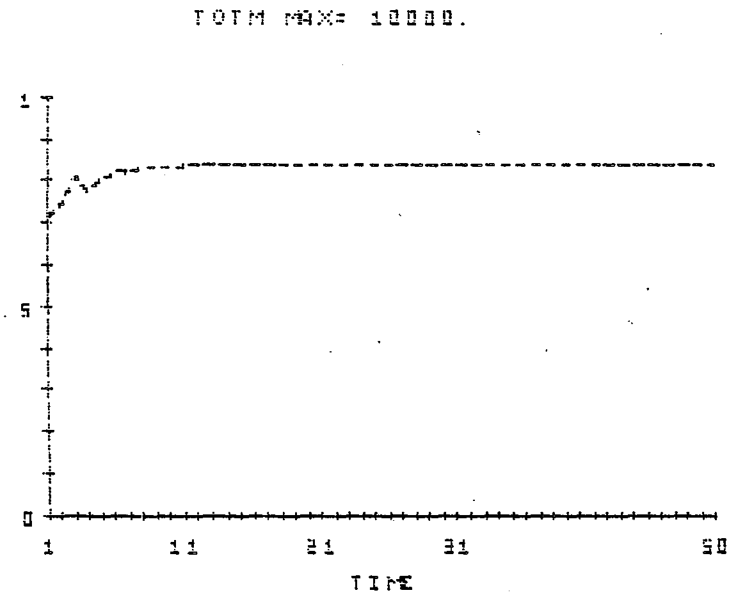


(a) No Project



(b) Full Project

Figure 3.50: Beaver colonies utilizing the main channel (solid line) and their carrying capacity (broken line) in the downstream riparian zone. The maximum on the y-axis is 25 colonies.



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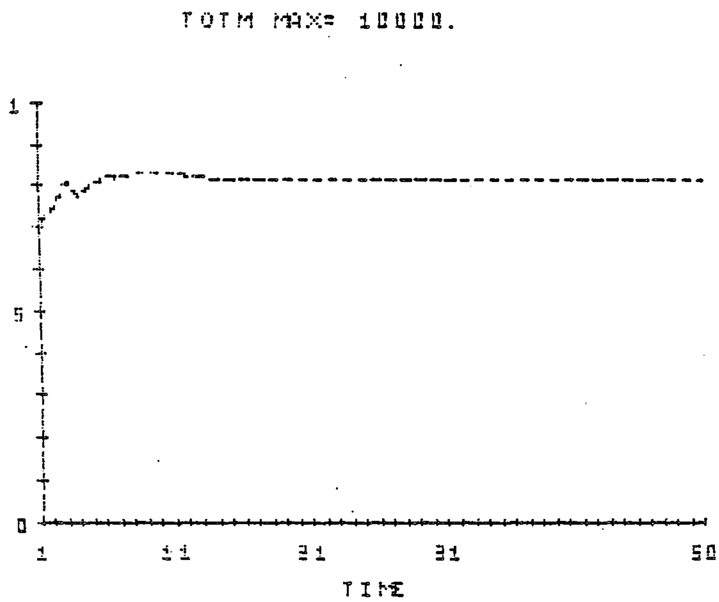


(b) Full Project

Figure 3.51: Total marten population in the modelled project area. The maximum on the y-axis is 10,000.

This is evidenced for brown creeper (Figure 3.52), northern water thrush (Figure 3.53), and the total number of bird territories (Figure 3.54). These figures are nothing more than a cumulative surrogate indicator appropriate to birds demonstrating cumulative changes in the various land classifications as a consequence of the project. It should be noted that although the drop in bird territories is small relative to the maximum of 4×10^6 (Figure 3.54), that drop does represent tens of thousands of birds and should not be viewed as insignificant.

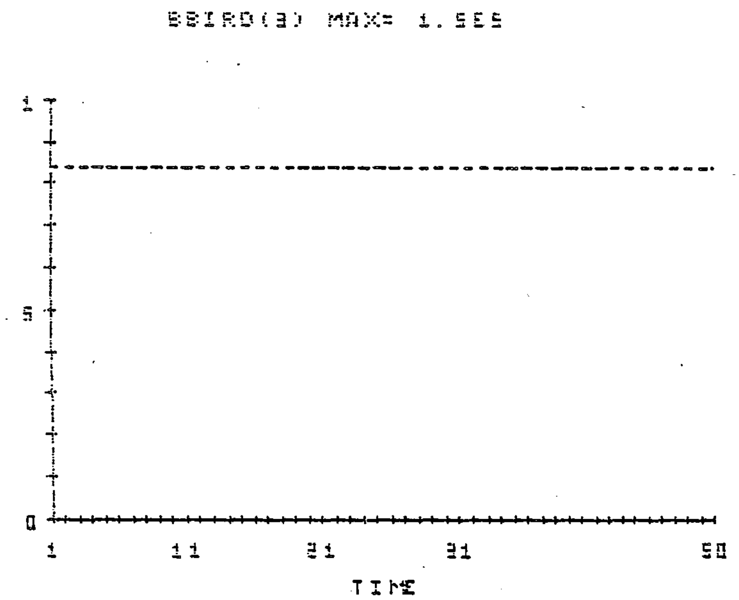
3.6.4 Moose

The post harvest fall moose population appears to increase with the project (Figure 3.55b). This occurs because the simulated grizzly bear population shows a decline (Figure 3.61). This apparently results in the reduction of bear predation on moose (Figure 3.57b). In the model, the simulated wolf population is unaffected by the project (Figures 3.56a and 3.56b). Wolf predation on moose is also unaffected (Figure 3.57).

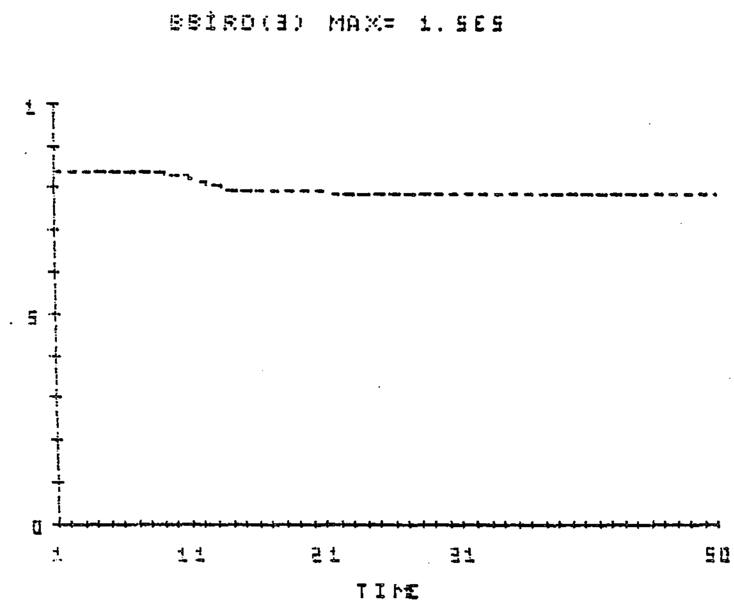
The age ratio (calves/100 cows) shows a more rapid increase under the full project scenario (Figure 3.58), indicating that while the population numbers remain unchanged, there is a shift to younger age distribution. The moose harvest shows a slightly different pattern between scenarios, but the absolute numbers are similar (Figure 3.59).

3.6.5 Bears

The total population of bears in the study area over the first 50 years of the simulation with no project remains stable (Figure 3.60). However, under full development, there is a marked drop of the black bear population and a lesser drop for brown bears (Figure 3.61).

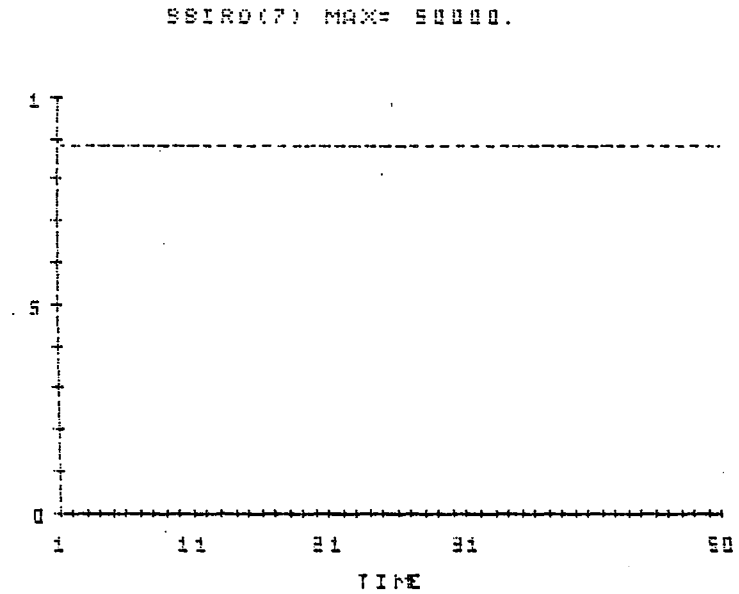


(a) No Project



(b) Full Project

Figure 3.52: Number of bird territories associated with brown creeper in the total modelled area. The maximum on the y-axis is 150,000.



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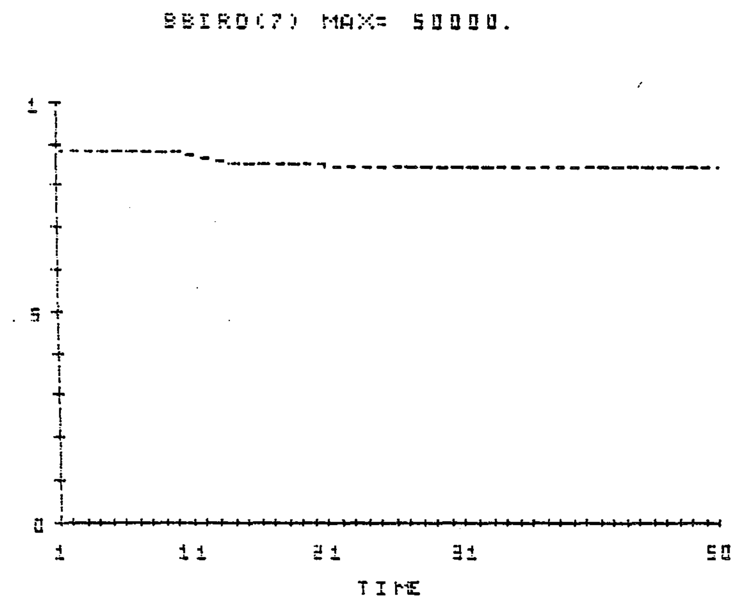
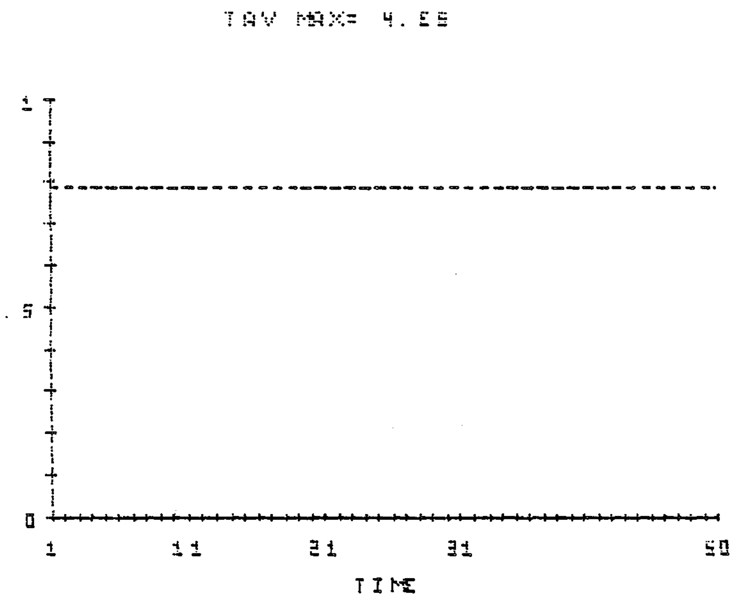


(b) Full Project

Figure 3.53: The number of bird territories associated with northern water thrush in the total modelled area. The maximum on the y-axis is 50,000.



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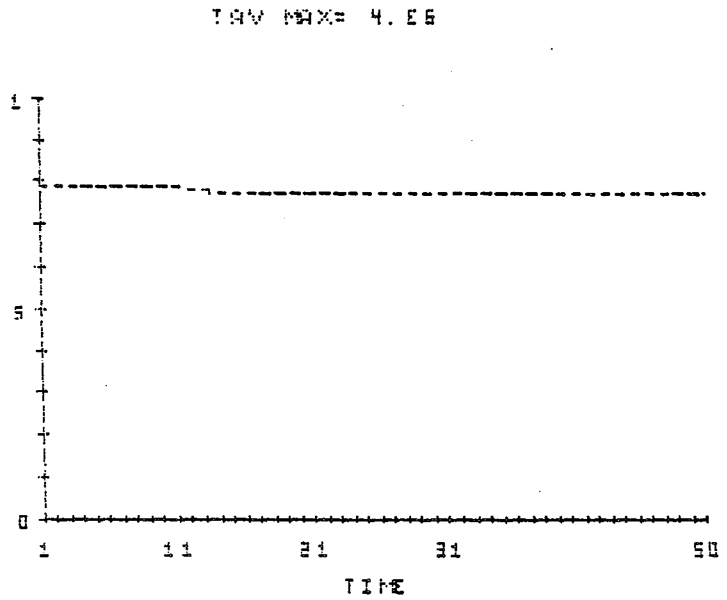
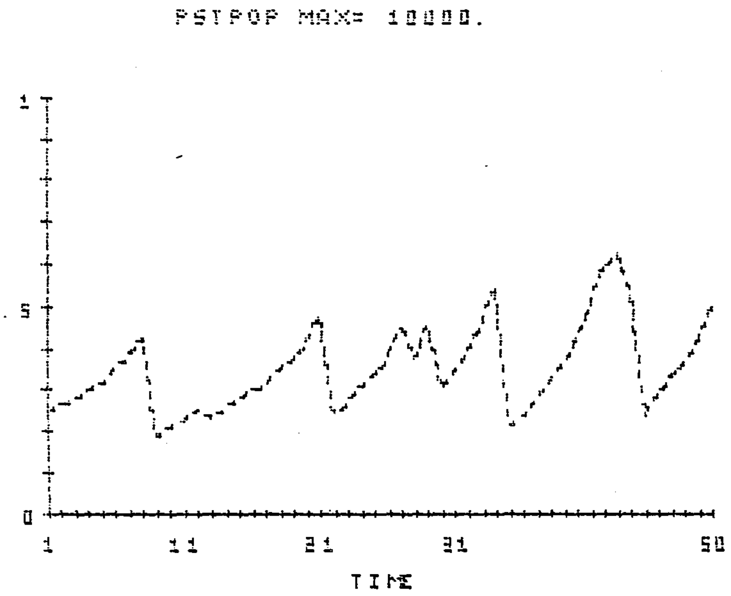


(b) Full Project

Figure 3.54: The total number of bird territories associated with the area represented by the model. The maximum on the y-axis is 4×10^6.



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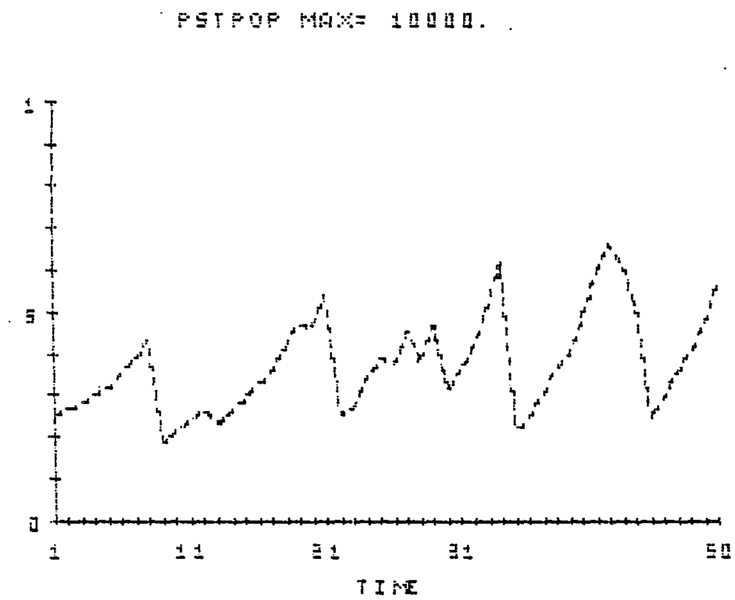
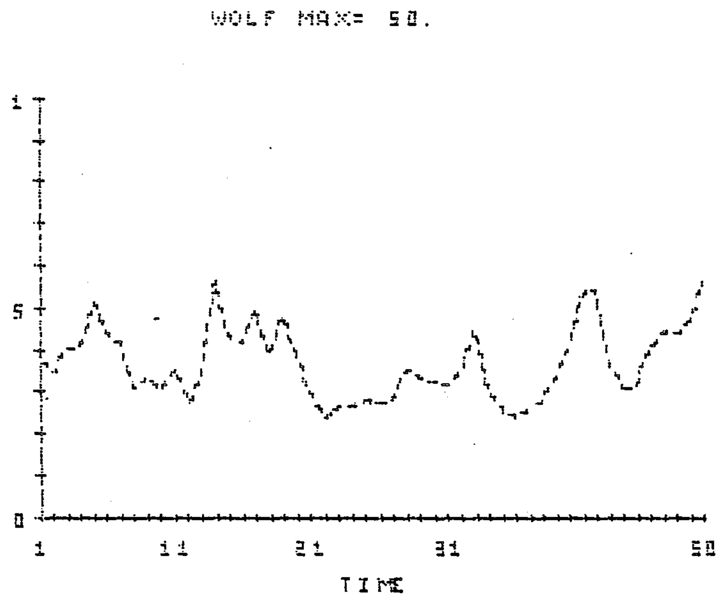


(b) Full Project

Figure 3.55: Post harvest fall moose population. The maximum on the y-axis is 10,000 animals.



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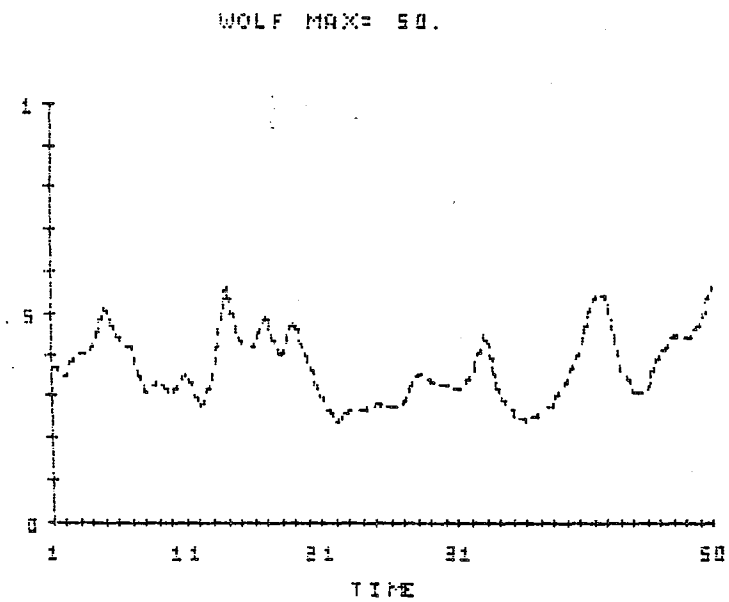
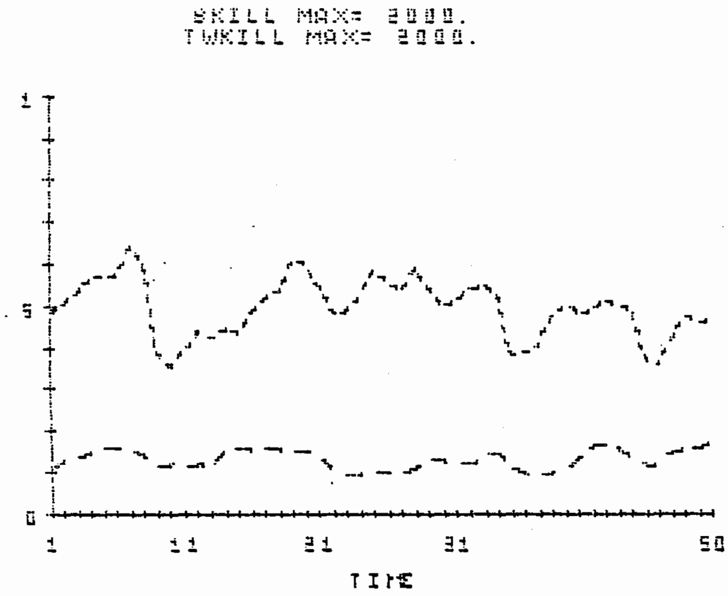
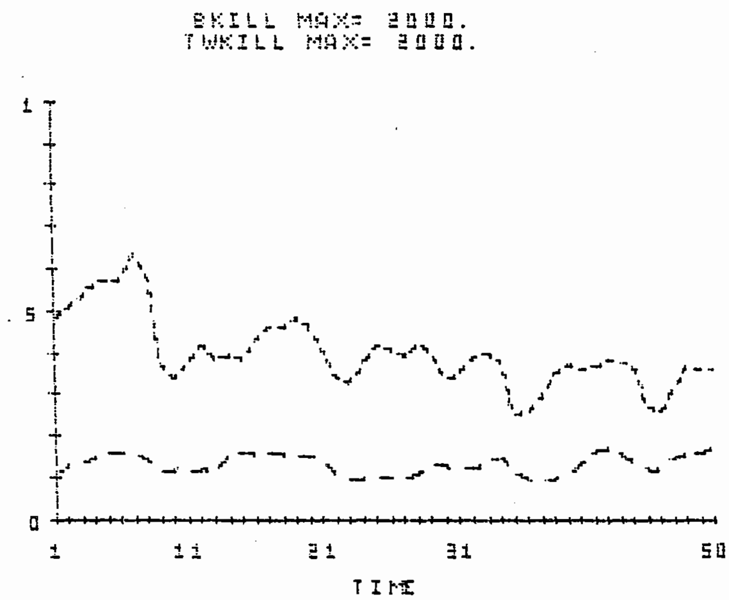


(b) Full Project

Figure 3.56: Wolf population. The maximum on the y-axis is 50.

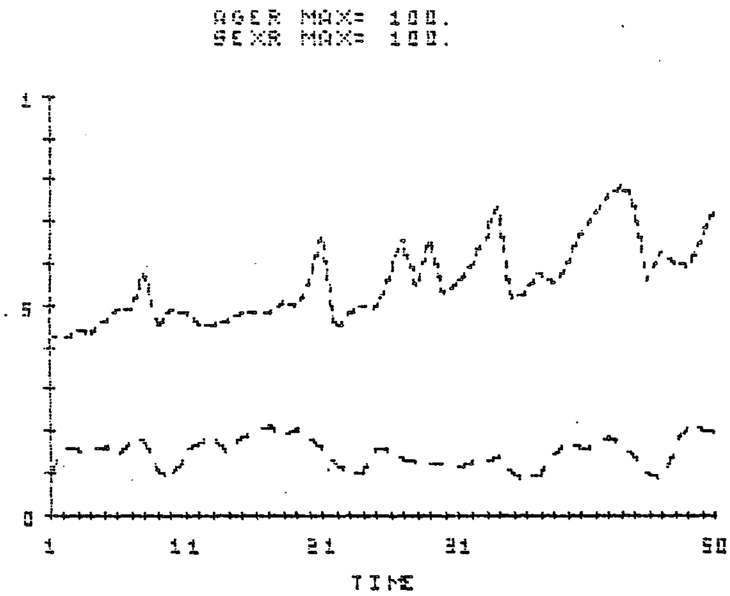


(a) No Project



(b) Full Project

Figure 3.57: Bear kills (upper line) and wolf kills (lower line) of moose. The maximum on the y-axis is 2,000 animals.



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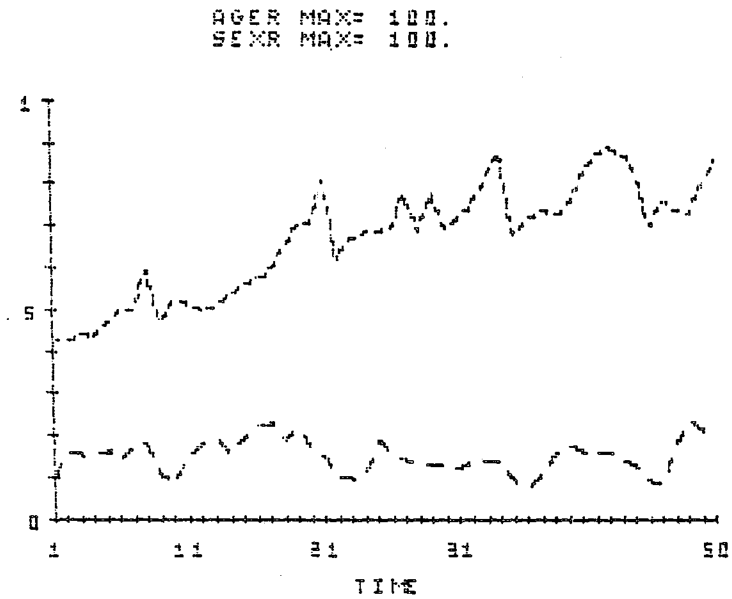
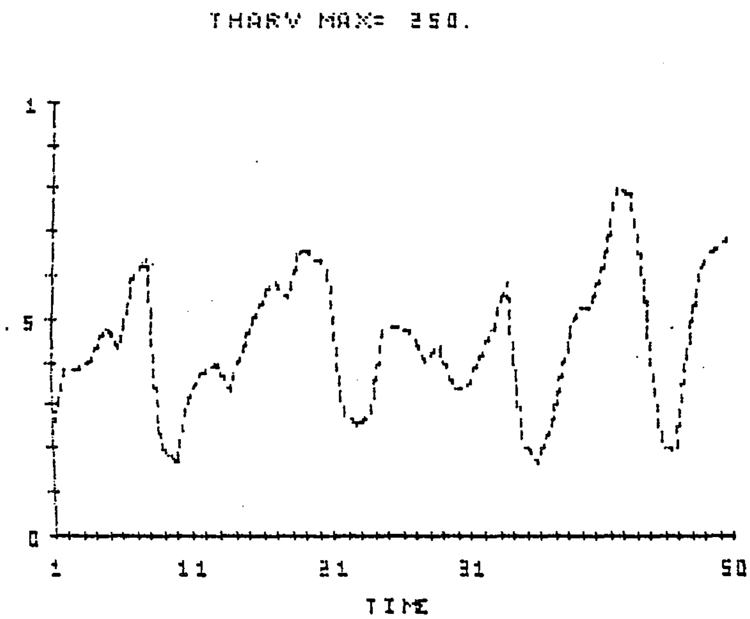


(b) Full Project

Figure 3.58: Age ratio (calves/100 cows) and sex ratio (males/100 females). The maximum on the y-axis is 100.



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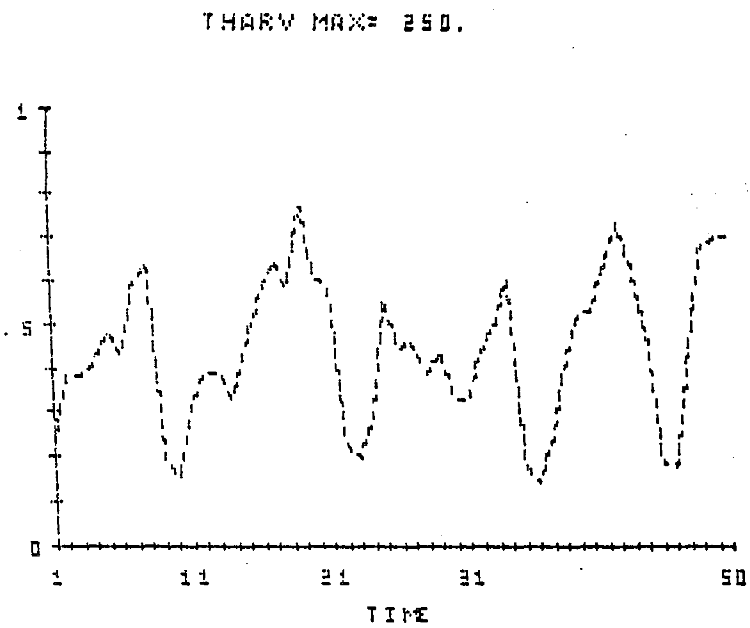
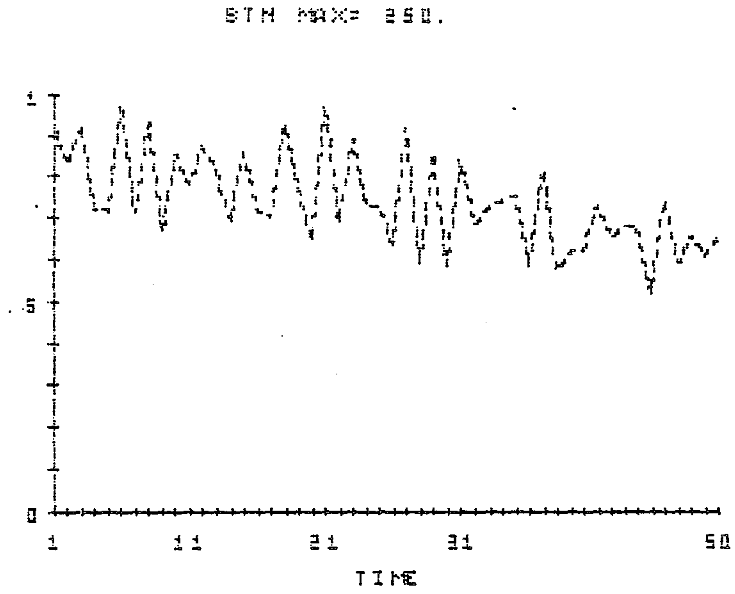


(b) Full Project

Figure 3.59: Moose harvest. The maximum on the y-axis is 250 animals.



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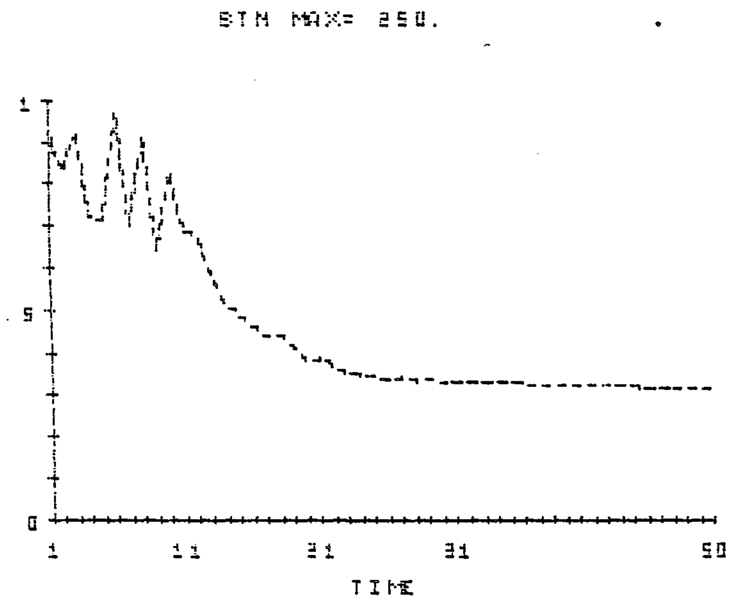
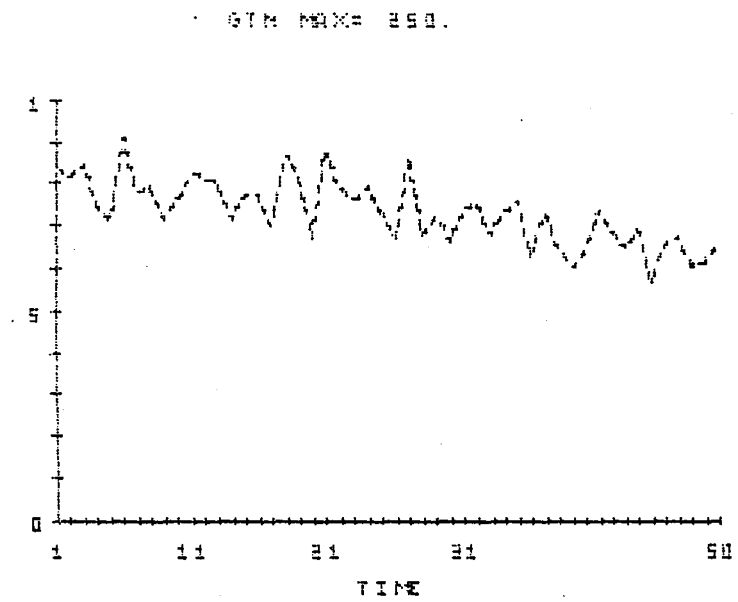


(b) Full Project

Figure 3.60: Black bear populations. The maximum on the y-axis is 250 animals.



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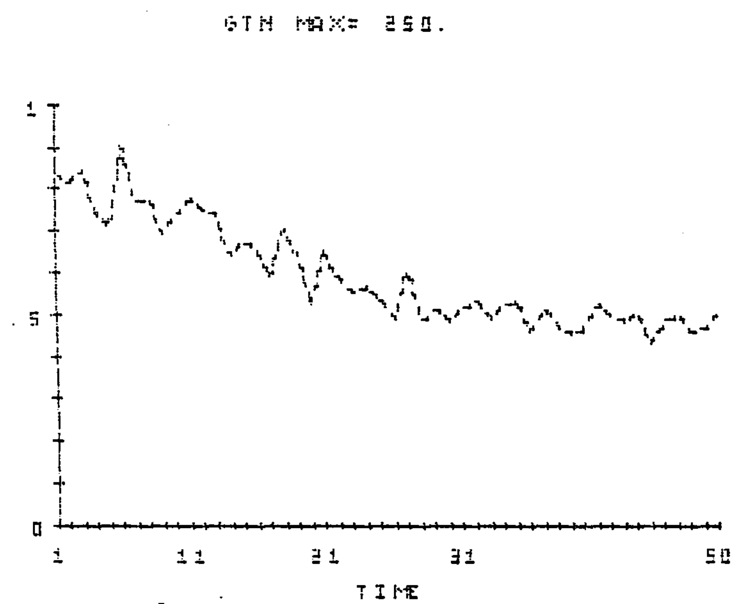
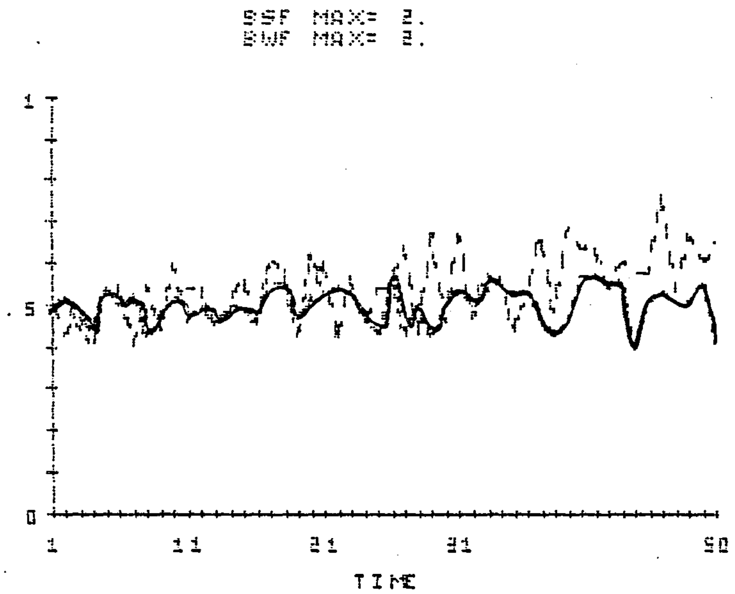


(b) Full Project

Figure 3.61: Brown bear populations. The maximum on the y-axis is 250 animals.

For black bears, the decrease in population is mostly attributable to decreased reproduction (an increase in the reproductive interval) and increased mortality of cubs and yearlings. Both these processes are controlled by the food indices; however, the reduction in spring food availability from inundation shows a more dramatic response (Figure 3.62).

For brown bears, the slight decrease in population is attributable to the increased dispersal from disturbance. There is a marked increase in recreational use (Figure 3.38b) resulting in an increase in the dispersal rate, leading to a decline in total population (Figure 3.61).



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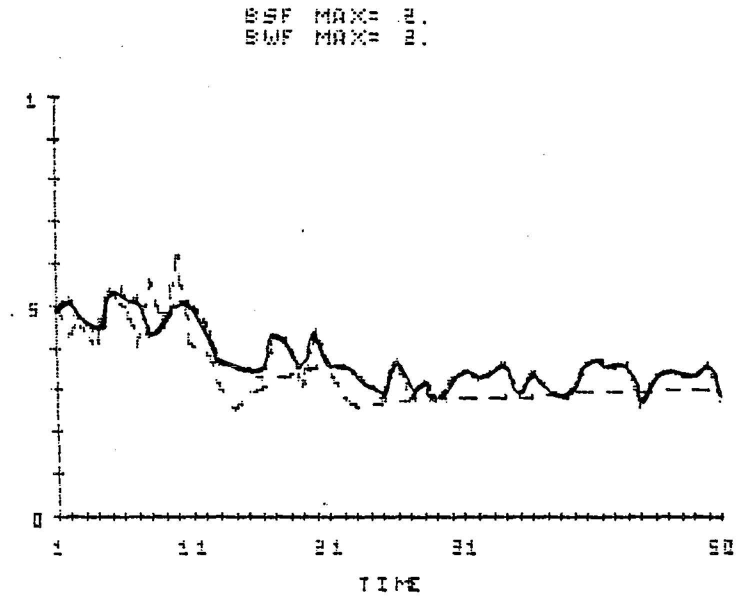

(b) Full Project

Figure 3.62: Index of summer (solid line) and winter (broken line) black bear food. The maximum on the y-axis is 2.0.

4.0 CONCEPTUAL MODEL

The looking outward matrix (Table 2.5) provides the framework for linking the component submodels. The completely integrated model is a complex set of relationships within and between submodels. To gain a broad understanding of the major processes included in the model, the simulation model has been translated through a process of simplification and compression into a conceptual model of the terrestrial environment in the Susitna Basin (Figure 4.1).

In the conceptual model, the major components (boxes) and the major linkages (arrows) represent the processes and information transfers considered to be important to understanding the biophysical system in the Susitna Basin. In the diagram (Figure 4.1), solid lines represent linkages that are included in the numerical simulation model; broken lines represent critical linkages that are not presently included into the numerical simulation model.

The model depicted in Figure 4.1 represents an interdisciplinary perspective of the potential impact of the Susitna hydroelectric project on the terrestrial environment in the Susitna Basin. As such, it provides an overall framework for assessing deficiencies in our current understanding.

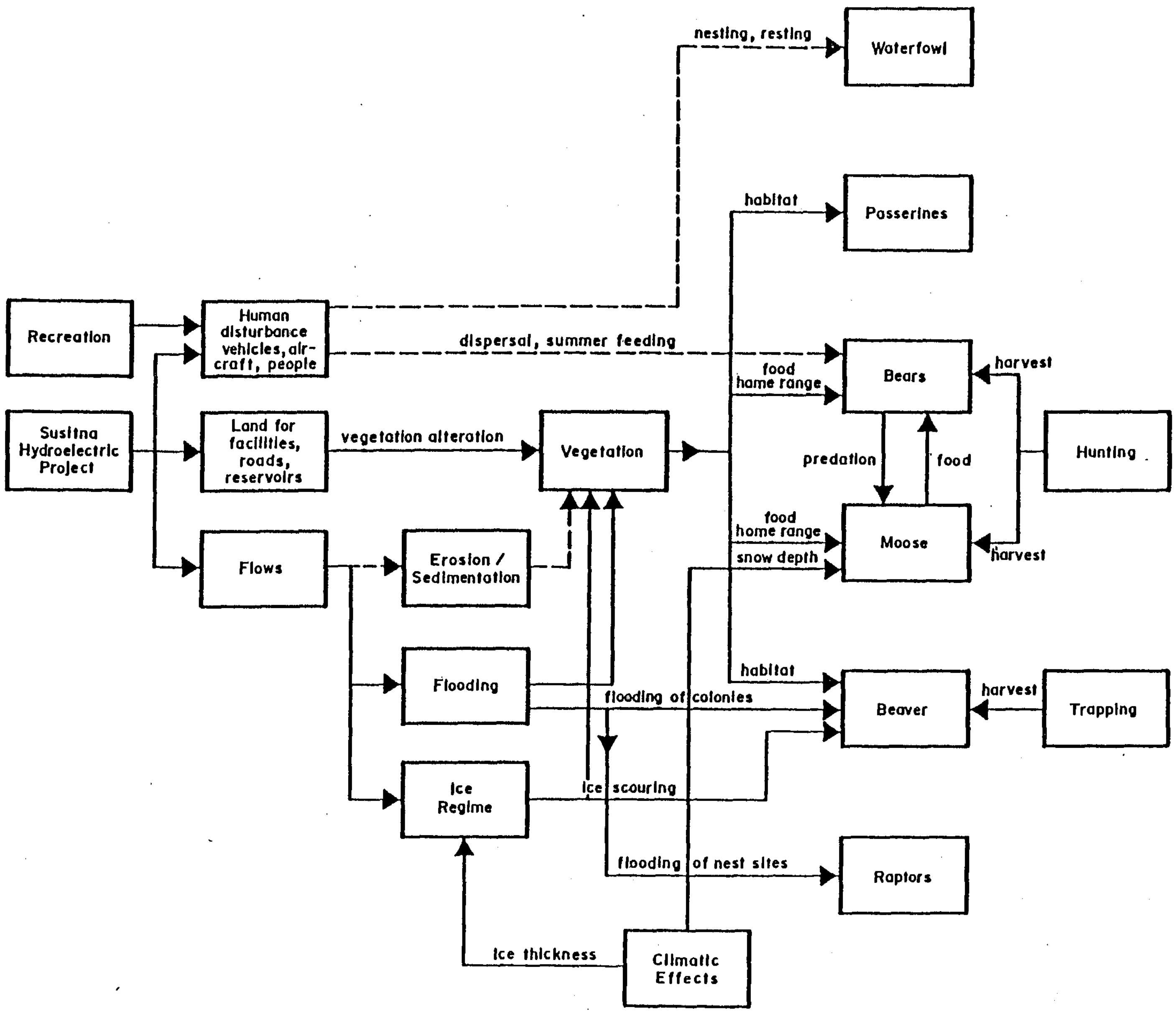

Figure 4.1: Conceptual model of major components and linkages included in the model of the terrestrial environment in the Susitna Basin.

5.0 MITIGATION PLANNING

At the mitigation planning workshop held February 28 to March 2, 1983, discussion centered around five major areas: mitigation, monitoring, information needs, planned studies, and model refinements. This section reports the discussion that took place in each of the subgroups.

5.1 Physical Processes/Development/Recreation

5.1.1 Model Refinements

5.1.1.1 Recreation

Currently, the model contains little credible information with respect to recreation. Information available (in FERC License Application, Exhibit E, Chapter 7) on existing or future recreational use in terms of numbers of use days or amounts of land needed appears to be unreliable. Data on current use and credible projections of future use and need are critical to better understanding of the impact of recreation on wildlife in the Susitna Basin.

5.1.1.2 Development and Land Use

To adequately reflect habitat disturbance and loss, the model must use accurate up to date information about various project features. This is particularly true of access road locations, areas alienated by the activities described in Table 3.1, and air, road, and train traffic estimates. Current estimates are based on data from the FERC License Application, Exhibit E, Chapter 3.

At present, the model contains only scanty information about current land use patterns in the study area. Because of the dynamic nature of land ownership in the area brought about primarily by the Alaska Native Claims Settlement Act, it is extremely difficult to make projections about future land use patterns. However, a credible development scenario requires that the model make projections about changing land use patterns with and without the project. This is inadequately represented in the present model.

5.1.1.3 Physical Processes

Restructuring of Ice Processes:

The model contains a simplistic representation of the positioning of the ice front, the formation of ice cover, spring break up, and ice scouring with its subsequent impact on vegetation. While this part of the model must be refined, there is still considerable uncertainty surrounding the mechanisms affecting the ice processes. As the uncertainty is resolved through further hydrologic, hydraulic, and ice studies, the model will be refined.

Spatial Resolution in the Downstream Reach (Devil Canyon to Talkeetna)

At present, the downstream reach is represented in the model by a single spatial unit. It is now clear that this is inadequate. This reach needs to be divided into a number (not less than five) of smaller reaches. In addition, it appears desirable to represent the sloughs explicitly within each of the smaller reaches.

Overwinter Habitat for Beaver

At present, the suitability of slough, side channel, and mainstem habitats for beaver is indirectly related to flow. In the model, the amount of suitable overwintering habitat is functionally related to stage. However, this relationship is a crude hypothesis and does not adequately represent the underlying hydraulic processes. A more realistic representation requires a more detailed spatial resolution of sloughs and the dynamics of groundwater inflow as influenced by main channel stage.

Climatic Effects

The importance of climatic effects to understanding processes that might be affected by the project can not be overstated. The most important climatic influences are snow and ice. The interrelationship between the ice regime, flow, and vegetation was discussed earlier.

Snow, or rather the amount of snow on the ground, affects the ability of moose and caribou to utilize winter range. In the model, the amount of snow on the ground is stochastically generated and does not provide a realistic representation of what actually occurs. What is required is the amount of snow on the ground by elevation class. An alternate approach is to use a more robust snow model similar to one developed by McNamee (1982) for simulating the effect of snow in elk dynamics. Such a model consists of three components: snowfall, snowmelt, and snow interception. In the simplest version of the model, snow is assumed to be general in nature, such that snow depth (not density, crusting, etc.) would be the only influence on ungulate dynamics. The general model would be:

$$SN_{s,t} = SN_{s,t-1} - MR * SR_s * f(CC_s) + SO_t * f(CC_s)$$

where,

$SN_{s,t}$ = snow depth on site s in time step t;

MR = maximum snowmelt;

SR_s = snowmelt factor specific to site characteristics (e.g. elevation);

SO_t = snowfall; and

CC_s = crown closure.

In simple terms, the model suggests that the snow depth in a given time step is equal to what was there the time step before less what has melted plus what has fallen through to the ground. Work of Harestad and Bunnell (1981) relates the level of snow interception to snowfall and canopy closure; the work of Haverly et al. (1978) and Leaf and Brink (1973) can provide guides for defining snowmelt. A similar model needs to be developed to better understand how moose and caribou will adapt to the loss of winter range as a result of the impoundments.

5.1.2 Information Needs

There are four major information needs related to the model refinements:

a) better estimates of current and future recreational use;

b) better estimates of the maximum amount of suitable overwintering habitat for beaver in each of the slough, side channel, and mainstem habitats;

c) data on snow accumulation by elevation in the Upper Susitna Basin; and

d) data on river morphology in relation to water surface area.

Of these needs, the last is of critical importance. Currently, the model represents fourteen vegetation types, one of which is designated water. In its simplest division, the water is made up of three qualitatively different aquatic habitats: slough, side channel, and mainstem. For a given stage at any transect along the river, the model needs to predict the proportion of the transect that is comprised of each of the terrestrial vegetation and aquatic habitat types. Both the data and the conceptual understanding to do this are currently lacking.

5.1.3 Mitigation

For recreation, concern centers around the maintenance and enhancement of recreational opportunities. Specific concern is focused on canoeing and kayaking.

Existing and future land use pattern may conflict with proposed mitigation measures. Two examples are: potential bear mitigation at Prairie Creek may conflict with private development, and the burning and clearing for moose may be prevented if there are competing land uses.

It is also possible that the plans to set aside twelve sloughs for aquatic mitigation may conflict with beaver utilization of the same areas.

5.2 Vegetation

Workshop discussions concerning model refinements and information needed to represent vegetation changes associated with the project, studies planned or required to provide that information, and additional work with respect to mitigation and monitoring activities are summarized below. While the studies described are vegetation oriented, much of the work is being done to provide information to assess project impacts on moose and to better plan mitigation activities for those impacts.

5.2.1 Model Refinements/Information Needs

Information needs associated with vegetation can be divided into two major categories: information required to better define project related impacts, and information required to determine appropriate mitigation activities. Impact related information includes:

1) what vegetation do wildlife need and use;

2) what vegetation is currently available; and

3) what vegetation will be lost as a result of project construction and subsequent operation.

Mitigation related information includes:

1) what areas in the Susitna Basin do wildlife use that could be manipulated in some way; and

2) how will browse production and wildlife use increase with different types of manipulation in various vegetation types.

A number of refinements to the current vegetation submodel have been discussed. The two major refinements involve better spatial representation of the project area (especially the riparian zone below Devil Canyon), and a better representation of ice processes and their effects on riparian succession. Less important model refinements include better representations of development activities, wildlife food, and dynamics of upland vegetation.

5.2.1.1 Spatial Resolution

The spatial units and land classification system in the model are compromises. Clear suggestions for improvement emerged at the workshop with respect to birds (more detailed resolution of vertical stratification in the land classification system) and beaver (more detailed spatial resolution of vegetation in areas close to channels and sloughs). The need for spatial units more appropriate for moose (e.g. winter range) was also discussed at the workshop. These issues must be resolved before proceeding to a more precise estimate of variables within various spatial units and vegetation types.

5.2.1.2 Ice Processes and Riparian Succession

The model currently represents riparian vegetation and succession and the effects of ice processes very simplistically. The assumptions incorporated in the model represent hypotheses about ice process effects but they are largely untested. The representation of these succession/disturbance processes could be greatly improved if the riparian vegetation and channel morphology were incorporated in more detail spatially and if work was initiated to study ice processes. The aquatic assessment of the Susitna project is utilizing hydraulic simulation models and supporting channel cross section data for instream flow studies and also has need to conduct ice process related studies. A cooperative effort between the aquatic and terrestrial assessment groups could be mutually beneficial and should be considered.

5.2.1.3 Resolution of Development Activities

Land is removed for development activities from various land classes based on the relative proportions in the respective spatial units or, in the case of roads, based on proportions specific to a given route. The model could be refined to provide additional activities or to provide a finer resolution of the land class changes associated with an activity given its specific location within a spatial unit. An example is the transfer of land in the impoundment spatial areas to the water class. This transfer is currently based on the development submodel's calculation of land cleared for vegetation, rather than on a calculation of the amount of area actually covered by water.

5.2.1.4 Wildlife Food

Currently, the model simulates the variation in browse standing crop and berry production as a random process. This simple representation could be improved by adding mechanisms that incorporate the effects of consumption of vegetation by wildlife. This is particularly true in the case of moose consumption of browse and to some extent, beaver alteration of habitat in the riparian zone. Further improvements in the model would result if the productivity of browse and berries can be functionally related to climatic variables such as temperature, snowfall, or total precipitation. However, current understanding of the determinants of productivity in the area may not be sufficient to fully develop these relationships.

5.2.1.5 Dynamics of Upland Vegetation

The current hypothesis is that the areas in various upland land classes are constant except for changes associated with specific development activities or vegetation manipulation actions. While this is a weak assumption, current understanding of upland successional processes is not sufficient to suggest a more dynamic approach.

The most serious drawback of this approach may be an underestimate of the importance of natural fire in the area along with its consequent effects on the natural variability of wildlife habitat. Van Cleve and Viereck (1981) have stated that:

> "The taiga of interior Alaska is dominated by young stands in various stages of succession - mature stands of over 200 years in age are rare. Fire is the main cause of the young ages of the stands - in some areas fire that kills all of the above ground vegetation can be expected every 50 - 100 years."

If this is the situation in the study area, the natural fire regime needs to be represented in a 50 year simulation. The long-term habitat value of inundated areas may not be fairly represented by their current species composition if fire periodically converts them to earlier successional stages in the absence of inundation.

5.2.2 Planned Studies

Vegetation studies planned for the coming field season address the information needed to better define impacts of the project above the Devil Canyon site (i.e. not changes in riparian vegetation resulting from project operation) and associated mitigation measures.

5.2.2.1 Phenology

It has been hypothesized that early green-up of vegetation at lower elevations is a primary reason why a lot of moose are found in the proposed impoundment area in early spring. It has been further hypothesized that inundation of this area could result in a shortage of moose browse during this period. The study would consist of running transects down elevational gradients to the river and noting phenological stage by species and utilization by moose if evident. Results of the study should better define project impacts on early spring food supply for moose.

5.2.2.2 Food Habits

This study will help define what vegetation moose are eating at different times of the year. The study involves fecal samples for percent composition by vegetation species. Some fecal samples collected during the winter and early summer are already available for analysis. Additional samples will be collected this spring and in late summer. This information will be used to define project impacts and as a basis for designing mitigation activities.

5.2.2.3 Browse Sampling

The purpose of this study is to determine the amount of browse in different vegetation types and the energy content of that browse. A pilot project will be conducted during the upcoming field season to determine the best techniques to use with the full study to be conducted the following summer. Prior to the pilot project, the people doing this study will meet with several moose biologists to determine the appropriate measure of browse (e.g. current year's growth, to point of average browse, etc.). This information will be used in conjunction with the carrying capacity work described below.

5.2.2.4 Browse Mapping

Browse mapping will be done to evaluate how much browse (areal extent of vegetation types) is currently available and how much will be lost as a result of project activities. A core area around and including the impoundment area will be mapped at a scale of 1:24,000 and a larger area will be mapped at a scale of 1:63,360. The mapping contractor will work with vegetation specialists, and moose and bear biologists to identify appropriate vegetation mapping categories.

5.2.2.5 Energetics Modelling

An energetics model for moose will be developed from an existing model and validated with information from the Kenai Peninsula. The modelling will help define browse requirements for a moose in this area. Results of the modelling will be used in the carrying capacity work described below.

5.2.2.6 Carrying Capacity

The browse sampling, browse mapping, and energetics modelling results will be integrated to determine current carrying capacity of the Susitna area for moose and the reduction in carrying capacity caused by project activities. These results will help define mitigation needs.

5.2.2.7 Monitor BLM Burn Site

The BLM is planning to conduct a control burn in the Alphabet Hills area. Vegetation sampling pre-burn will be done to initially characterize the area with respect to canopy cover, tree and shrub density, and browse production. Repeated sampling following the burn will provide information on successions and browse production following different severities of burns in different vegetation types. This information should be very useful for evaluating the potential of using burning as a mitigation measure for lost moose habitat. If burning is shown to be an effective mitigation tool, this study should also help determine what vegetation types should be burned and how severe a burn should be planned to achieve a maximum increase in browse production.

5.2.3 Needed Studies

In addition to the studies already planned, a number of additional studies were discussed which would help to better define project impacts and possible mitigation alternatives.

5.2.3.1 Monitor Other Vegetation Manipulations

A number of areas downstream from Devil Canyon have been disturbed in the past for different reasons. Some vegetation sampling in these areas would provide information on succession and browse production subsequent to these disturbances. In addition, ADF & G is planning a chaining operation in the Palmer area. If pre- and post-chaining sampling could be arranged at this site, it would provide information to evaluate chaining as a possible mitigation alternative.

5.2.3.2 Ice Processes and Riparian Vegetation

The effects of ice processes on riparian vegetation and the potential impact of regulated flows (and associated changes in ice processes) on riparian succession are not well understood. Prediction of project impacts downstream from Devil Canyon and design of suitable mitigation measures requires a better understanding and representation of these processes. Currently, available geomorphological cross section information with associated vegetation information could be used to better represent what vegetation gets scoured at different flow and ice levels. Periodic surveying of data at these cross sections could be used in conjunction with ice surveys to define how ice processes affect different vegetation types.

Aquatic and terrestrial environmental assessment studies of the Susitna project, which are currently being conducted independently, require much of the same information. This is especially true of the hydraulic, hydrologic, and geomorphological information produced by Acres American and R & M Consultants. The two studies also have similar information needs, such as effects of ice processes on fish and wildlife habitat and changes in these processes post-project. Some coordination between these groups to cooperatively develop and use this information could be mutually beneficial and would result in analyses which are more logically consistent and compatible with each other and therefore more useful to APA.

5.2.4 Mitigation and Monitoring

Mitigation and monitoring activities for vegetation losses which are addressed in the FERC license application are justified primarily as they pertain to impacts on moose. The studies discussed above should better define these impacts and provide valuable information for designing mitigation.

A concern was expressed, however, that the independent aquatic and terrestrial assessment studies may result in inconsistent mitigation recommendations (e.g. fish mitigation release scenarios, which are detrimental to downstream vegetation and wildlife). While these conflicts may ultimately be unavoidable, a cross analysis of mitigation options by the other assessment group would at least indicate potential areas of conflict early in the mitigation process while a variety of mitigation options are still available. If all major environmental impacts are to be adequately considered in the design, licensing, and operation of the project, an integration of aquatic and terrestrial analysis and design of mitigation activities should be started.

5.3 Furbearers and Birds

The following section summarizes workshop discussions concerning model refinements and information needed to represent the biology of the furbearer and bird system, studies needed to provide some of that information, suggested mitigation strategies to minimize potential impacts, and monitoring procedures that would help evaluate the impact of a mitigation or other action.

5.3.1 Beaver

5.3.1.1 Model Refinements

Habitat Definition

Currently, beaver habitat is structured as a function of two major criteria: proportion of sloughs and side channels with greater than .5 m of ice-free water below the maximum ice cover; and the proportion of shoreline length with balsam poplar and birch vegetation adjacent to it.

The first criteria is the key determinant in the appropriateness of an area for beaver habitation. Reduction in the amount of ice-free water would almost certainly result in a direct reduction in the number of colonies that could be supported in any given area.

The vegetation criteria lacks any firm hypothesis about what aspects of vegetation (i.e. type, quality, quantity, and location) make one area more suitable than another. To more clearly define this criteria it was suggested that the vegetation and furbearer subgroups take a detailed look at the available river cross sections and attempt to better establish the proportion of the various vegetation types that are found within 40 m of the shoreline. The result will be a more precise representation of the appropriate vegetation (i.e. balsam poplar and birch) as it is now defined for beaver habitat, thereby improving the vegetation submodel's prediction of how the adjacent vegetation characteristics might change after impoundment. This will, in turn, improve the model's capability to predict how beaver colonies might be impacted by alterations in vegetative structure. It should be noted that it may be necessary to complement the analysis of the available cross sections with some ground truthing.

There is also a need for refinement of the hydrology aspect of the beaver habitat criteria. Evidently, beaver will not build a den adjacent to water with velocities greater than approximately 4.4 ft/sec between mid-August and freeze-up; this velocity being the maximum a beaver can effectively swim against for any prolonged period. This added criteria will require the hydrology and furbearer groups to coordinate their field programs to ensure some velocity information is obtained for critical reaches of the river.

Price Index

In the model, a potential major source of beaver mortality is trapping success which is a direct result of an externally set price index. A high price index could conceivably result in a complete decimation of the beaver population in one year. Historically, the price for beaver pelts has oscillated regularly with a period on the order of 15 years. Since a period of high trapping intensity in conjunction with a shift in the hydrology of the region could result in a severe impact on beaver, the participants suggested an oscillating price index be introduced into the model.

5.3.1.2 Information Needs/Research

Overwinter Survival

Currently, one of the major data needs is actually determining how many beaver colonies there are along the Susitna River Basin and their overwinter survival. Therefore, a concerted effort should be made to count the number of caches in the fall, and the following spring (before and after break-up) to establish what proportion of the colonies survived the winter. This survival would be related to three major factors:

1) the degree of ice scouring during break-up;

2) maintenance of ice-free water under the ice cover; and

3) the change in quality of the food cache over the winter period.

The impact of all three of these factors could be assessed through the above proposed site visits. However, a first step in this direction could be made this year by coordinating a planned April - May visit by the hydrologists with one or two of the researchers in the furbearer study.

The third factor is of special interest since it directly relates to the need to better understand the relationship between the beaver and the nearby vegetation. Different vegetation types have very different overwintering qualities and could be a determining factor in a beaver colony's survival.

Characterize Habitat

The quality of the food cache is directly related to the availability of appropriate vegetation. There is a definite need to better characterize what it is that makes an area good for beaver. Therefore, site visits designed to count beaver colonies and/or caches should also measure:

1) the vegetation available to the colony and of that available, how much was utilized (i.e. what is actually found in the cache);

2) the characteristics of the adjacent water body (i.e. bank structure, water depths, depth of ice cover, water velocity, etc.); and

3) is there any evidence of trapping?

5.3.1.3 Mitigation

Besides trapping control, mitigation specifically for beaver was judged to be a minor issue for the region between Devil Canyon and Talkeetna. Generally, it was felt that changes due to impoundment in this reach of the river would have a positive impact on beaver and would likely increase the number of potential beaver colonies. However, in light of this prediction, there was considerable concern expressed regarding proposed destruction of beaver dams in the 12 sloughs which have been selected as optimal salmon rearing habitat by the fisheries studies. The furbearer group felt other control options should be explored and requested some coordination between the fisheries and furbearer studies.

Given the predicted increase in beaver, it was also suggested that this might be viewed as compensation out of kind for the probable loss of marten due to impoundment.

Monitoring

The monitoring recommendations were very much related to enhancing the information needs and research described earlier. Specifically, these are:

a) cache counts in the fall;

b) determination of the overwinter colony survival by counting the viable colonies pre- and post break-up;

c) continual observation and evaluation of the nearby vegetation and its utilization;

d) interactions between beaver and salmon, specifically in rearing areas - does the existence and persistence of a beaver dam have an identifiable impact on salmon rearing success?; and

e) the level of trapping in the region - this requires a survey coordinated with the Alaska Department of Fish and Game to obtain better information on the intensity of beaver trapping and associated harrassment.

5.3.2 Marten

5.3.2.1 Model Refinements

As it now stands, the marten population model is a simplistic representation based on very little information. Therefore, refinement of the model is not practical until some of the critical information gaps are addressed.

5.3.2.2 Information Needs

Marten Habitat

Marten generally depend on the availability of forest habitat for both cover and food and it is suspected that the forest lost due to impoundment is prime habitat. However, this suspicion is based on very qualitative information that requires further investigation. The recommended first step is to coordinate a marten specialist with the vegetation group to better characterize marten habitat and then direct themselves to improving the methodology for detecting that habitat. Determination of how much habitat is available in the region is important to taking a first step at predicting the impact of impoundment on marten.

Population

Once the habitat types have been identified, the marten densities associated with each type should be established, possibly expressed as high/low estimates. This would then permit a first cut estimation of the probable loss due to impoundment. In the longer term, there is a need to improve our understanding on how marten relate functionally to the available habitat (i.e. fecundity, mortality, dispersal, density dependence, etc.).

Trapping

Marten are very vulnerable to trapping. As with beaver, there is a need to get better information on trapping intensity and projections of future levels of effort.

5.3.2.3 Mitigation

Given marten's dependence on forested lands, attempts should be made to minimize the reduction in forest land due to impoundment. Once more information on the expected losses in numbers is available, it should be brought to the attention of ADF & G and the Alaska Board of Game. High losses may require exploration of enhancement strategies or trapping regulations. There was also a concern expressed regarding the proposed burning of forest to generate more moose browse in the area. This would definitely have a negative impact on marten and, if implemented, should be monitored before and after the event.

5.3.3 Birds

5.3.3.1 Information Needs

For the raptors (primarily golden eagle), there is a need for more information of the location and elevation of potential nesting cliffs and existing nesting sites, primarily around the

Watana reservoir, on or near the water's edge. Also, there is a need to confirm the location of the bald eagle nests downstream of Indian River. Currently, it is not clear which of the documented sites are actual nest locations and which are alternate nest locations. Also, there are some discrepancies between the documented information and more recent observations.

For the purposes of possible mitigation, there is a need to document the location, distribution, and number of cliffs and exposed bedrock above the maximum reservoir level available for possible modification to make additional potential nesting sites. These cliffs need to be typified as to suitability for modification and level of effort to do so.

There is also a need to refine the available information on location and extent of potential bald eagle nesting sites, primarily in riparian poplar stands and hillside white spruce. These should also be assessed for current suitability and potential for modification.

5.3.3.2 Mitigation/Monitoring

The major mitigation strategies for the raptors have already been identified, namely the creation of new nesting sites to compensate for losses due to construction and/or impoundment. The success of this approach is not predictable since it depends greatly on how the birds react both to the new site and the actual disturbance activity. Therefore, it is important that the nests and nest sites be monitored each spring to assess the effectiveness of the modification (i.e. are the new sites utilized?) and determine what further action might be necessary, if any.

For swans, mitigation involves at least minimization of the disturbance to the nesting and staging areas, if not total avoidance of those areas. Monitoring would involve annual observation of the swan's utilization of those areas as well as conformance of the public and project staff to established disturbance criteria.

5.4 Moose

The following section summarizes workshop discussions concerning additional model refinements and information needed to adequately represent the biology of moose in the Susitna area, studies either planned or needed to provide that information, and additional work that requires planning as mitigation and monitoring proceeds. It is important to note that much of the corresponding discussion concerning the vegetation submodel is directly applicable to moose.

5.4.1 Model Refinements

5.4.1.1 Spatial Definition

The present moose model represents an ill-defined area of 1200 mi^2 with an assumed distribution of vegetation types. This representation can be improved quite easily in the following way. Existing radiotelemetry data can be used to define a herd area by drawing a line connecting the outermost (farthest from the impoundment) radiotelemetry locations for each moose whose home range ovelaps the impoundment area. Amounts of each vegetation type within this herd area can then be determined from the vegetation mapping that is to be done this spring and summer.

5.4.1.2 Bear Predation

There are three fundamental deficiencies in the representation of bear predation. First, the model assumes that only brown bears prey on moose. While it is known that black bear can and do take moose, the extent to which this actually occurs in the Susitna area is uncertain.

Second, while a mechanism is incorporated in the model to alter vulnerability of moose calves to bear predation as a function of severity of the previous winter, this mechanism is not presently used. Studies in the Susitna area indicate lower calf/cow ratios in years following heavy snowfall. The relationship is fairly consistent except in one year during which there was a bear removal program. In that year, the fall calf/cow ratio was high despite a hard previous winter. These observations thus seem to indicate a relationship between winter severity and vulnerability of moose calves to bear predation. Unfortunately, the observations are not sufficiently well quantified at this time to allow incorporation in the model.

Finally, the brown bear submodel considers a population that occupies a spatial area somewhat larger than the moose herd area described above. A method is needed to determine what proportion of the brown bears in the model should be considered effective predators on moose in the defined herd area. Radio-telemetry information from the bear studies may be useful in this regard.

5.4.1.3 Wolf Predation

The current representation of wolf dynamics has similar deficiencies. The spatial area occupied by the wolf population represented in the model may not completely coincide with that for moose. More careful definition of the proportion of the wolf population actually preying on moose in the herd area described above is needed.

The model wolf population is presently not affected by any model variables pertaining to development. Mechanisms of impact on the wolf population need to be considered more carefully.

Finally, wolf predation rates on moose in the model are unaffected by moose density, caribou density, or winter severity, all of which are thought to be important in determining the number of moose taken.

5.4.1.4 Winter Mortality

Winter Severity

Both methods of calculating winter mortality in the moose submodel use snow accumulation as an index of winter severity. At the present time, the value for snow accumulation is estimated by the physical processes submodel from the mean and standard deviation of accumulations reported at 12 stations in 4 months (January, February, March, and April) for varying (by station) numbers of years. These records need to be examined carefully in the context of known historic patterns of moose mortality to see if other combinations of months and/or stations might provide a better estimate of winter severity. For example, the sum of snow accumulations for the 4 month period may be a better index of severity than the average value for the 4 months. Methods for incorporating other factors (e.g. hardness of snow, temperature) that contribute to winter severity should also be examined.

Winter Mortality as a Function of Snow Accumulation

The above examination of historic snow accumulation patterns with respect to observed moose mortality should provide information useful in constructing a more realistic relationship between winter severity and winter mortality rates (Table 3.11).

Winter Mortality as a Function of Carrying Capacity

The second method of calculating winter mortality rates for moose uses snow accumulation to modify forage availability.

The present relationship (Figure 3.23) is largely hypothetical and needs to be refined to represent explicitly two aspects of this phenomenon. First, snow accumulation influences the availability of forage in the vertical dimension; that is, different snow depths cover different proportions of potentially available forage. The currently planned browse studies (see vegetation submodel) will provide information useful in this regard through vertical stratification of browse samples.

Second, snow accumulation influences the availability of forage in the horizontal dimension; that is, different snow depths restrict moose to different altitudes and/or cover types. More intensive monitoring of radio-collared moose in the impoundment area should provide additional information useful in better defining habitat use relationships under different snow conditions.

Given the availability of certain proportions of the total browse present, the moose model then requires two additional types of information: the utility of the available browse in supporting moose, and relationships between consumption rates and mortality. The utility of the available browse to the moose population is currently estimated on a biomass (kg dry weight) basis. The total available biomass of browse species is divided by the number of moose use days (moose population times number of days on the winter range) to obtain daily consumption rates per moose (assuming that all available forage can be found and consumed). Digestible energy and nitrogen are probably better estimates of diet suitability than biomass. The browse sampling program to be initiated this summer will provide plant materials that will be analyzed for digestible energy and nitrogen, which will then be used in the model in place of biomass as a measure of the quality and quantity of forage available.

The second step, estimating mortality rates from consumption rates, is more problematic. One possibility is to use a bio-energetics model along with the above data on forage quantity and quality to estimate weight loss at different consumption levels.

Mortality rates would then be estimated for various levels of weight loss. Note that this approach may also be useful if the desired output from the model is simply an estimate of carrying capacity. The bioenergetics model can be used to estimate daily forage consumption rates (assuming that moose foraging is bulk limited by rumen volume, rather than by forage availability). Estimates of available nitrogen and digestible energy can then be divided by the daily consumption rates to obtain the number of moose use days available.

5.4.1.5 Model Testing and Evaluation

The above needs for information and model refinement were identified in the absence of extensive experience with the present formulation of the model. Additional model testing and evaluation by ADF & G personnel will likely identify other refinements. The current version of the workshop model has been made available to ADF & G for this purpose.

5.4.2 Planned Studies

5.4.2.1 Moose

Moose radiotelemetry studies to date have been aimed at better definition of the subpopulations using the Susitna Basin. In response to the need for better habitat use information and better definition of the home ranges of animals using the impoundment areas, monitoring schedules are presently being changed. Radio-collared moose whose home ranges overlap the impoundment areas will be monitored twice weekly. Other radio-collared animals will be located less frequently. In addition, monitoring of radio-collared animals in the proposed burn area in the Alphabet Hills will be continued. Studies of the utilization of this area pre- and post-burning should provide valuable insights into the effectiveness of burning as a mitigation technique. A late winter census of the number of moose in the proposed burn area is also planned.

In addition to these studies, most of the planned work dealing with vegetation mapping and browse sampling is directly applicable to moose (see vegetation submodel).

5.4.2.2 <u>Wolves</u>

As mentioned above, one of the principal information needs regarding wolves is more careful definition of the numbers preying on moose in the herd area being modelled. Radiotelemetry studies aimed at better population definition will be continued. Additional food habits information directed toward better estimates of predation rates will also be collected. Finally, results of a separate study examining relationships between presence of prey items in the wolf diet and occurrence of those same items in fecal samples will be useful in estimating predation rates.

5.4.3 <u>Needed Studies</u>

In addition to the work briefly outlined above, the following studies would be very useful in more carefully estimating the potential impacts of Susitna hydroelectric development on moose and in evaluating the potential effectiveness of various mitigation measures.

1) A fall census of moose in the composition count areas in the Upper Susitna Basin would provide a useful check on parameter values currently used in the moose submodel. Many of the current parameters were estimated from a single census conducted in the fall of 1980.

2) More intensive study of calves of cows that are already radio-collared would be useful in refining estimates of the sources and magnitude of calf mortality (e.g. predation by both bear species), as well as the importance of dispersal from the Susitna area. Preliminary results from radiotelemetry work suggest that movement out of the

area is more common than movement into the area. If this is so, the Susitna area may serve as a source of individuals for a region much broader than that expected to be directly impacted by hydroelectric development.

3) Additional information on moose utilization of so-called "rehabilitation" areas downstream of the dam sites would be useful in evaluating the potential effectiveness of various possible mitigation measures.

4) Plans need to be formulated to allow more intensive monitoring of moose behavior during a severe winter, should one occur.

5.4.4 Mitigation and Monitoring

A variety of other factors will eventually be important in the specification of an adequate plan for mitigation and monitoring of the impacts of hydroelectric development on moose. First, it is important that mitigation options other than vegetation manipulation continue to be given adequate consideration. Second, successful use of vegetation manipulation techniques will require additional information on the relative merits of options such as burning and crushing. These techniques need to be evaluated more carefully with respect to site-specific criteria influencing their probable success in producing additional browse at times and places where it can be utilized by moose. Finally, it must be remembered that impacts on forage availability may not be the principal effect on downstream moose. Destruction or modification of critical habitats, such as islands used for calving, may be more important for these animals. Additional work is needed in assessing both the probable impacts of development on these areas, as well as their importance to moose.

5.5 Bears

5.5.1 Model Refinements

5.5.1.1 Bioenergetics and Foraging

Reproduction and natural mortality of cubs and yearlings, which are food related, are two important factors influencing the population dynamics of bears. To completely represent these processes, the bioenergetic requirements and foraging behavior of bears must be understood better than is currently possible. For instance, the prediction of fat reserves (i.e. condition) for a bear would involve the knowledge of at least the search efficiency, handling time, and digestibility of the major food items in the bear's diet. Unfortunately, the expense of bear research precludes this level of knowledge in the near future.

5.5.1.2 Initial Equilibrium

The tactic of assuming an initial population equilibrium and relating indices to this equilibrium level effectively reduces the number of processes to be quantified. The drawback, however, is that the assumed equilibrium condition is, at best, tenuous. A concrete suggestion made at the workshop, that partially addresses the drawback, was to explore the sensitivity of the bear population in the study area (with and without the project) to changes over time of the immigration from the outside "buffer" population. Then, sensitivity to <u>absolute</u> changes in immigration was explored at the workshop with the conclusion that impacts will be more severe (i.e. greatest relative change in population level with and without the project) when immigration is minimal. Nevertheless, the ability to increase or decrease immigration over time should be incorporated into the model.

5.5.1.3 Berry Production

Another shortcoming of the model is the portrayal of fluctuations in berry production. At present, the production in each vegetation type is subject to random variation each year. A more realistic approach would be to simulate a berry failure every few years.

However, the information used to predict berry production was derived indirectly from data on stems. Stems do not have a direct relationship to berries in any particular year. As such, the data currently available on vegetation types and berry production cannot be used with any confidence.

5.5.1.4 Spatial Resolution

The current spatial resolution is gross in comparison to the finer scale processes that may impact bears. In particular, disturbance of brown bears will not occur evenly over the entire study area. For instance, localized areas of disturbance would likely disperse more brown bears out of the study area (or deplete them through nuisance kills) than a more diffuse disturbance.

While it may be desirable to develop a finer spatial resolution in the Upper Susitna Basin, it may be possible to disregard the downstream reach in the analysis. The downstream area is markedly different in terms of patterns of bear use and vegetation. For example, it is suspected that downstream black bears use predominantly salmon and Devil's club berries in the late summer, both of which are unavailable to bears in the Upper Susitna Basin impoundment areas, assuming that this habitat in the downstream may understate the project's impacts.

5.5.1.5 Prairie Creek Salmon Resource

Another spatial problem is the portrayal of Prairie Creek as a food source outside the study area. If development at Prairie Creek can indeed be attributed to the project, then it can be argued that all bears that utilize the resource should be included in the model and not only those that chiefly reside in the study area.

The assumption that a doubling of 1980 recreational use would mean that the salmon resource would be completely eliminated is much too conservative. However, the assumption that the Prairie Creek salmon represent only one-third of the summer energy intake for bears that use the resource could easily be understated. Both assumptions are highly speculative.

The model currently distributes the loss over the entire bear population by reducing the summer food index. A refined approach would be to reduce the reproductive potential of a significant proportion of the female bears that use Prairie Creek. This would cause the number of females that use Prairie Creek to decline and the population as a whole would also be reduced.

5.5.1.6 Dispersal and Harvesting

The weights for dispersal and harvesting presented in Tables 3.17 to 3.20 are, at best, educated guesses of the relative propensities of the various classes to disperse or be harvested. It would be valuable to test the sensitivity of the model to the assumed weights.

5.5.1.7 Composite Food Index

The composite food index does not adequately portray the importance of both spring and summer food to bear reproduction; both foods must be adequate in a given year or bears will be unable to reproduce the following spring. Another reason for treating spring and summer food separately is because the importance of predation on moose calves (spring food) is unknown. The availability of moose calves in the spring may be impacted by the project as much as vegetation.

5.5.2 Mitigation and Monitoring

The model demonstrates that the major mechanisms of impacts for black bears is the loss of spring habitat from inundation which results in a larger reproductive interval and increased mortality of cubs and yearlings. Obviously, habitat manipulation as a mitigation measure should target upon the production of spring foods that can be enhanced (Equisetum, small mammals, skunk cabbage, roots and cottonwood buds) through increased acreage of forest and pioneer vegetation types.

Further, monitoring during the construction and post-project stages should focus upon these predictions. In addition, inundation will displace black bears from traditional denning sites which, in the model, either experience a longer reproductive interval or disperse from the study area. Monitoring of these displaced bears should present a research opportunity to document their behavior.

For brown bears, the major impact mechanism is dispersal or associated mortality from disturbance generated by increased human usage (e.g. recreational, hunting) of the study area. Therefore, the model would indicate that such mitigation measures as controlled access and the minimization or limitation of disturbance would be effective. Unfortunately, the model does not have sufficient spatial resolution to aid in the specific design of these measures. However, the planned development of the Prairie Creek area may serve as an opportunity to monitor the effects of both dispersal from disturbance and the subsequent effect upon reproduction of the lost salmon food resource. On the other hand, Prairie Creek is viewed by many participants as a potential site for out-of-kind (preservation) mitigation.

6.0 FUTURE WORK

The model that existed at the completion of the second workshop held February 28 - March 2, 1983 was greatly improved over the preliminary model constructed during the first workshop. In particular, the moose submodel has a much sounder empirical basis and the bear submodel has a more realistic structure. The hydrology submodel has been improved to incorporate linkages between the vegetation and furbearer submodels. The vegetation submodel itself has a more reasonable representation of riparian succession in the downstream reach.

The discussions in the subgroups were fruitful, as evidenced by the material presented in the previous section (5.0) on mitigation planning. The workshops allowed for examination of current and future study programs in the context of the model and mitigation planning.

Future modelling and mitigation planning is dependent upon a reevaluation of the spatial and temporal structure. The geographical areas into which the model is currently divided are too large to address some of the critical questions regarding moose, bears, beaver, and riparian succession. A new spatial representation must be developed before much more effort is put into model refinement.

Future modelling and mitigation planning now depends upon a program of effective coordination between the aquatic and terrestrial programs. At meetings held in late March, a program of coodination was proposed by LGL, ESSA, AEIDC, and R & M Consultants. One of the first priorities of this program is to develop a common spatial and temporal structure for the aquatic and terrestrial models.

It is currently planned to hold a workshop in the fall of 1983 to integrate the results of the 1983 summer field season into the mitigation planning and modelling. The workshops and the modelling will continue to be the focus for the terrestrial mitigation planning by adapting to new information and enhancing collective understanding.

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APPENDIX I

UPPER SUSITNA RIVER BASIN

MOOSE POPULATION MODELLING

by

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Introduction

The Upper Susitna River Basin of Game Management Unit 13 (GMU-13) has received considerable attention in recent years by the Alaska Department of Fish and Game (ADF & G). Information on the distribution, abundance, and sex and age characteristics of moose (Alces alces) populations have been routinely collected since the early 1950s for harvest management. Since 1975, research on the population status and food habits of two important predators, brown bears (Ursus arctos) and wolves, has been in progress. In addition, several other intensive research projects have been conducted in the area to identify predator-prey relationships and other moose and predator population dynamics parameters. The availability of such information presents a unique opportunity to examine the structure and dynamics of the moose population occupying the Upper Susitna River Basin and GMU-13.

ADF & G is currently developing a computer simulation model to synthesize historical information related to the Upper Susitna River Basin and GMU-13 moose populations. Development of the model has been motivated by several factors:

1) the model should recreate as closely as possible the historical data base; and

2) analysis of model results should lead to the basis for a predictive model which can be utilized in the Susitna Hydroelectric Project Big Game Studies.

The model has, therefore, concentrated on explaining existing historical information, rather than future predictions. Increased understanding of the historical conditions can then be used to develop a satisfactory relational model for examining potential development impacts.

Because information and analyses presented in this report are of a preliminary nature, they should not be used in scientific technical publications without the approval of the authors.

Simulation Model - General Format

The preliminary version of the computer simulation model was designed to provide maximum flexibility with regard to both structure and parameter estimation. This was accomplished by dividing the annual dynamics of the moose population into a series of discrete events. These events describe the birth and death processes of the population. The birth process is described by a single component, whereas the death process consists of four different components - death by:

1) natural causes;

2) hunting;

3) wolf predation; and

4) bear predation.

These events can be arranged in any sequence to describe the annual cycle of the population. In addition, detailed printouts of the modelled population can be requested at any time to compare with historical field data.

The simulation model divides the moose population into six sex-age categories: calves, yearlings, and adults of each sex. This reflects the level of classification attainable in the field. Each time an event is invoked, the standing population resulting from the previous event (or the initial population) is subjected to the changes described by that event. The specific changes for each event are as follows:

A. Reproduction

The reproduction component involves two changes in the following order:

1. New calves are created by the following equations:

$$\text{TOTAL CALVES} = \text{FECUNDITY (YEARLINGS)} * \text{FEMALE YEARLINGS} + \text{FECUNDITY (ADULTS)} * \text{FEMALE ADULTS}$$

MALE CALVES = (SEX RATIO AT BRITH) * TOTAL CALVES

FEMALE CALVES = TOTAL CALVES - MALE CALVES

2. The standing population is advanced one year in age:

ADULTS = ADULTS + YEARLINGS

YEARLINGS = CALVES

CALVES = TOTAL NEW CALVES (from step 1)

Parameters necessary for reproduction are:

1. Fecundity rate for yearling females.
2. Fecundity rate for adult females.
3. The sex ratio at birth.

B. Death by Natural Causes

A natural mortality rate for each sex-age category is used to determine the number of deaths by natural causes:

$$\text{DEATHS (SEX, AGE)} = \text{MORTALITY RATE (SEX, AGE)} * \text{NUMBER (SEX, AGE)}$$

The number of survivors is simply:

NUMBER (SEX, AGE) = NUMBER (SEX, AGE) - DEATH (SEX, AGE)

Parameters necessary for natural mortality are:

1. Mortality rate for each sex-age category.

C. Death by Hunting

Since historical harvest information is available, the number of deaths by hunting is an input parameter and is simply subtracted from the standing population.

NUMBER (SEX, AGE) = NUMBER (SEX, AGE) - HARVEST (SEX, AGE)

D. Death by Wolf Predation

Most of the information on moose mortality due to wolf predation has been gathered through food habits studies of wolf populations. This information, coupled with estimates of the numbers of wolves occupying the same area as the moose population, is used by the model to estimate the number of deaths due to wolf predation.

The following equations constitute the wolf predation component:

$$\begin{array}{c}\text{Total kgs prey}\\ \text{Consumed by wolves}\end{array} = \begin{array}{c}\text{Daily consumption}\\ \text{rate per wolf}\end{array} * \begin{array}{c}\text{Number of}\\ \text{wolves}\end{array} * \begin{array}{c}\text{Number}\\ \text{of days}\end{array}$$

$$\begin{array}{c}\text{Number of}\\ \text{calves killed}\end{array} = \begin{array}{c}\text{Total kg}\\ \text{prey consumed}\end{array} * \begin{array}{c}\text{Proportion of}\\ \text{diet consisting}\\ \text{of moose calves}\end{array} \div \begin{array}{c}\text{Average weight}\\ \text{of moose calf}\end{array}$$

$$\begin{array}{c}\text{Number of}\\ \text{yearlings and}\\ \text{adults killed}\end{array} = \begin{array}{c}\text{Total kgs}\\ \text{prey consumed}\end{array} * \begin{array}{c}\text{Proportion of}\\ \text{diet consisting}\\ \text{of moose yearlings}\\ \text{and adults}\end{array} \div \begin{array}{c}\text{Average}\\ \text{weight of}\\ \text{yearlings}\\ \text{and adults}\end{array}$$

The number of deaths due to wolf predation is subtracted from each sex category in proportion to their availability in the population.

Parameters necessary for the wolf predation component are:

1) Number of wolves.

2) Daily consumption rate per wolf.

3) Number of days of wolf predation.

4) Proportion of wolf diet consisting of moose calves.

5) Proportion of wolf diet consisting of moose yearlings and adults.

6) Average weights of moose calves.

7) Average weight of yearlings and adults.

E. Death by Bear Predation

Bear predation rates have been estimated from studies on both moose populations and bear populations. Preliminary estimates of daily consumption rates were judged too high to be realistic. In an effort to limit bear predation within realistic bounds, a relationship between daily consumption rates and moose abundance was hypothesized. The bear predation component of the model adjusts the daily consumption rates for both calves, and yearlings and adults using the following relationship:

$$\text{Adjusted consumption rate} = \left(\text{Maximum consumption rate} \div \begin{array}{c}\text{Moose abundance} \\ \text{at which maximum} \\ \text{rate occurs}\end{array} \right) * \text{Moose abundance}$$

The adjusted consumption rates are then utilized in the following equations:

$$\text{Number of calves killed} = \text{Adjusted daily calf consumption rate} * \text{Number of days of predation} * \text{Number of bears}$$

$$\text{Number of yearlings and adults killed} = \text{Adjusted daily yearling and adult consumption rate} * \text{Number of days of predation} * \text{Number of bears}$$

The number of deaths due to bear predation is subtracted from each sex category in proportion to their availability in the population.

Parameters necessary for the bear predation component are:

1) Number of bears.

2) Maximum daily consumption rate on calves.

3) Abundance of calves at which maximum daily consumption rate occurs.

4) Maximum daily consumption rate on yearlings and adults.

5) Abundance of yearlings and adults at which maximum daily consumption rate occurs.

6) Number of days of predation.

The number of events, and the specific sequences of events, needed to define an annual moose population cycle can be changed at any time during a simulation run. Similarly, the parameters necessary for any event can be changed. This allows the modeller to use historical information to recreate conditions as they appear to have existed.

In specifying the sequence of events and the event parameters, it is important to remember that the events are independently processed. This is not a problem for events that in nature occur at distinct and separate time periods (spring reproduction and fall hunting, for example). For those events that occur simultaneously or that overlap in time (early summer wolf predation and early summer bear predation, for example), care must be taken to ensure the proper order of events and the event parameters may need to be altered.

Upper Susitna River and GMU-13 Simulation Moose Model

Because longer, more intense moose population studies to assess the impacts of predation on moose were previously conducted in an adjacent portion of GMU-13 (Ballard, et al., 1981 a,b), that area was used as the basis for the Upper Susitna River model. Boundaries of the area were previously described by Ballard, et al. (1981a). Briefly, the boundaries are the Alaska Range on the north, Brushkana and Deadman Creeks on the west, Susitna River on the south and the Maclaren River on the east. Although this area extends beyond the impact zones, we believe that the biological characteristics of the area are representative of the project area. Also, an attempt was made to model the entire GMU-13 moose population as well, in an effort to provide a comparison to the Susitna model and allow assessment of the percentage of the GMU-13 moose population to be impacted by the project. Both models will be published elsewhere (Ballard, et al., In prep.).

Both population models start with an estimate of population size, and sex and age structure, and proceed through an annual cycle of reproduction and mortality factors which, for these models, are termed "events" (Figure 1). Population estimates are calculated for each year at calving and subsequently the population declines as mortality factors act on the population.

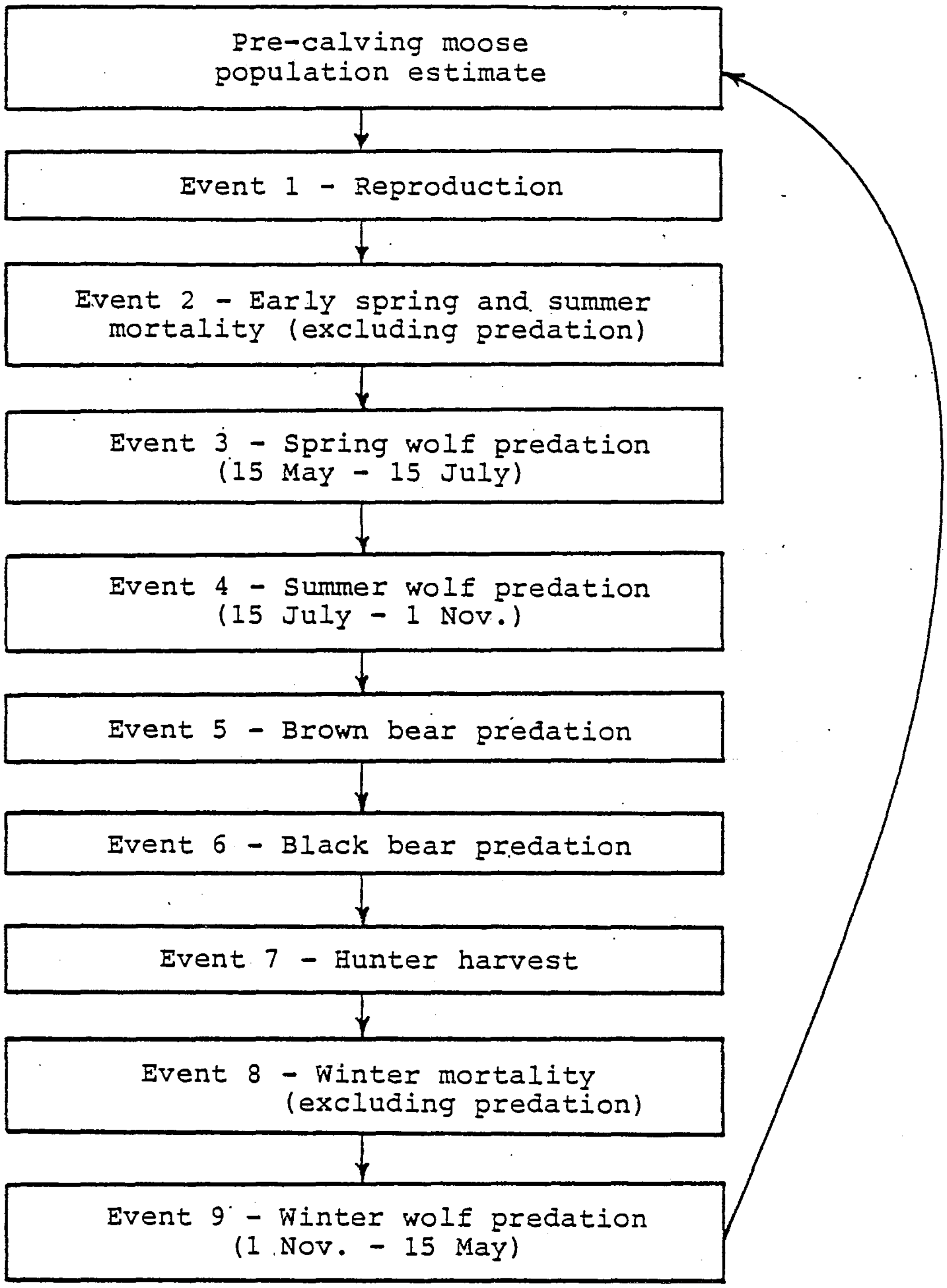


Figure 1: Timing and sequence of factors used in the models to determine the annual population dynamics of moose in the Susitna River Study Area and the entire GMU 13 in southcentral Alaska.

Population Estimates

Population Size

The starting 1975 population size estimate (X) for each model was derived from the following formula:

$$X = \frac{(A)\ (B)}{C}$$

where,

A = the number of moose observed/hour during the 1975 autumn composition counts;

B = the 1980 area population estimate for either the study area or GMU-13; and

C = the number of moose observed/hour during the 1980 autumn composition counts which were conducted immediately before the census.

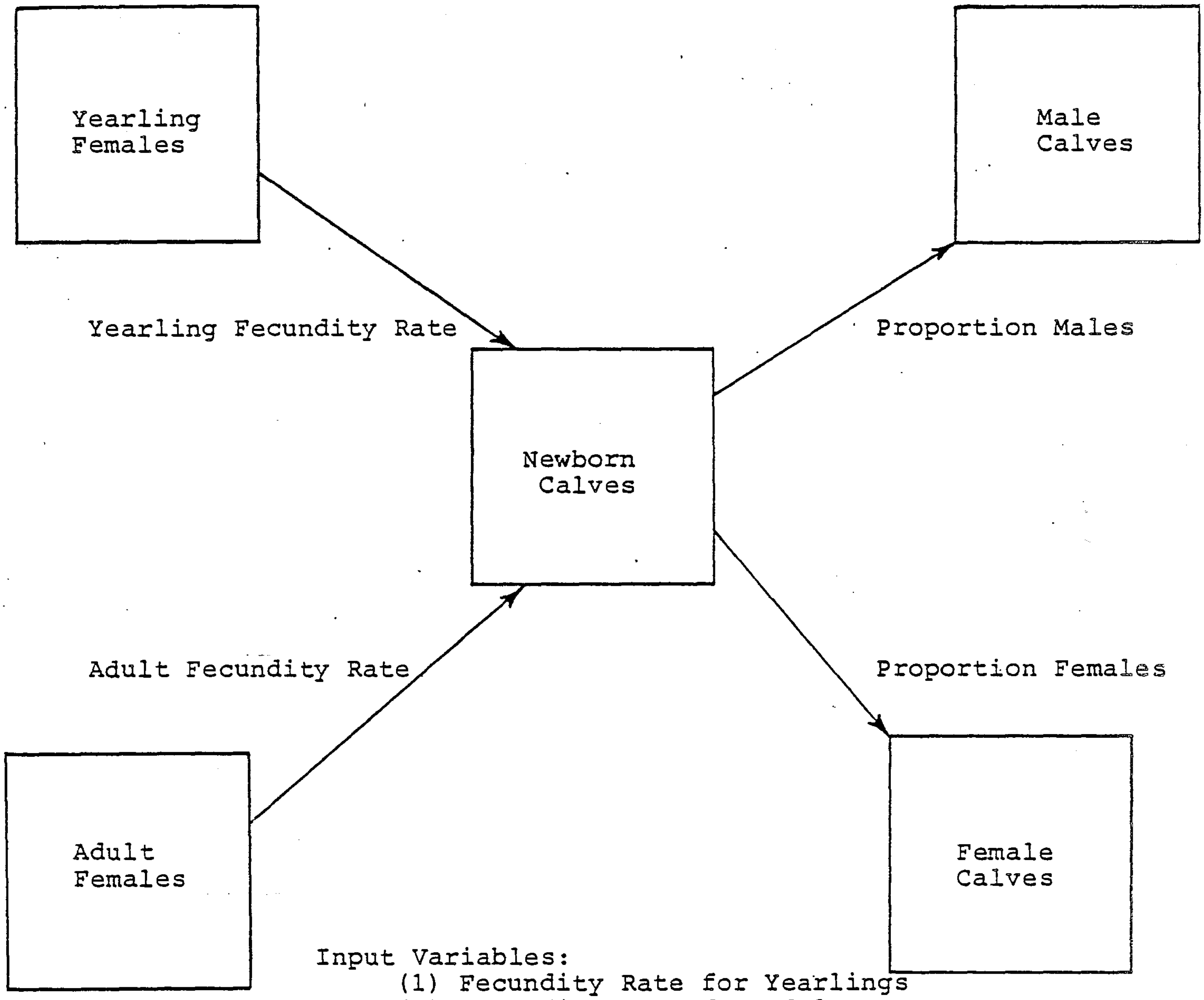
We assumed that the numbers of moose observed/hour during fall composition counts reflected annual changes in moose density. Variable B was estimated from a census during November, 1980. Approximately 8,142 km^2 of GMU-13, which included all of the 7,262 km^2 wolf removal area, were stratified and censused to determine the number of moose, using quadrat sampling techniques described by Gasaway (1978) and Gasaway, et al. (1979). Moose density estimates derived during the census in 1980 were used as the basis for grossly estimating numbers of moose within the Susitna Study Area and within GMU-13 from 1975 - 1981. The actual moose population estimate in fall, 1980 was used as a check for the population size generated by the project model. It was assumed that for the model to be valid, the fall, 1980 population estimate derived from the model should closely coincide with the census estimate.

A different approach was used for the GMU-13 model. Those portions of GMU-13 not censused in 1980 were stratified into 4 density categories (none, low, moderate, and high). The stratification was based upon a combination of distribution and numbers of moose observed during composition counts conducted from 1975 - 1981, and the knowledge of 5 biologists with experience in this area (more than 24 man-years). Density estimates for the 4 categories derived from sampling were then applied to the non-sampled area to arrive at a GMU-13 population estimate of 23,000 moose for fall, 1980. The GMU-13 model was modified so that the fall, 1980 population size generated by the model would conform with the estimate derived from censusing and stratification.

Event 1 - Reproduction and Sex and Age Structure

The sex ratio of calves at birth was assumed to be 50:50 while the sex ratio of yearlings and adults was determined by the previous year's estimate of reproduction and mortality. In the case of year 1 (1975), the sex ratio was determined by the fall moose composition count and back-calculated to correspond with population size at calving (Figure 2). All age classifications were directly extrapolated from sex and age composition count data except for the percent of calves in the herd. This was adjusted upward by 5% because calves are often located away from large groups of moose and are usually underestimated in composition counts (Ballard, et al., 1982 a,b; and Gasaway, pers. comm.). Also, because preliminary runs revealed that in both models, populations declined to extinction, initial estimates of numbers of yearlings were doubled. Estimates of yearlings based upon composition counts were drastically underestimated, probably because they were incorrectly aged as adults.

Pregnancy rates of cow moose were determined from rectal palpation of captured animals in 1976, 1977, and 1980 (VanBallenberghe, 1978; Ballard and Taylor, 1980; and Ballard, et al., 1982a,b). Although some minor variations in rates were noted, we assumed that 88% of the sexually mature cows ($\geq$ 2 yr age) were pregnant each year.



Input Variables:
(1) Fecundity Rate for Yearlings
(2) Fecundity Rate for Adults
(3) Sex Ratio at Birth

Figure 2: Schematic diagram of Event 1 (reproduction) for the moose model.

Estimates of moose productivity were determined during calf collaring programs from 1977 - 1979 (Ballard, et al., 1980; 1981a) and were estimated at 135 calves/100 pregnant cows or 1.19 calves/adult cow. Productivity of 2 year olds was estimated at 0.29 calves/cow (from Blood, 1973). For the models, we assumed that productivity remained constant each year (which was probably not the case). In fact, in that portion of the Susitna River Study Area where brown bears were transplanted, there was a significant ($P < 0.01$) negative relationship between the preceding winter's snow depth and the following fall's calf:cow ratio (Ballard, et al., 1980), suggesting that some fluctuations in productivity occur due to winter severity. However, because of large variations in snow depth between drainages, and because calf survival has been significantly increased by predator reduction programs following severe winters, we were unable to modify productivity estimates based on available data.

Event 2 - Early Spring and Summer Mortality (Excluding Predation)

Following birth, both calf and adult mortality estimates (Figure 3) were subtracted from the population. Immediately after birth, 6% of the calves were assumed to die from natural factors other than wolf and bear predation, such as stillbirth, drownings, and other accidents (from Ballard, et al., 1981a).

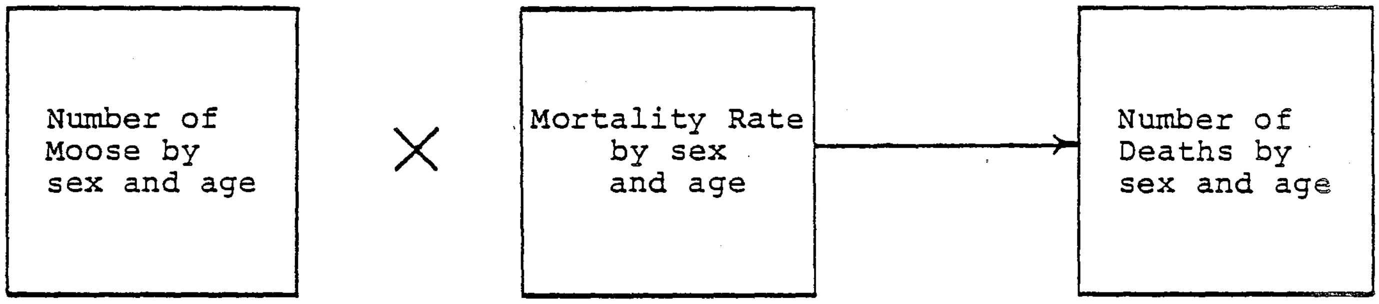
Events 3, 4, 9 - Wolf Predation

Estimates of annual moose mortality due to wolf predation for each model were divided into 3 time periods to correspond with pup production, human exploitation and natural mortality, and changes in diet composition (Figure 4). The time periods were as follows:

#1) May 15 - July 15 (Event 3);

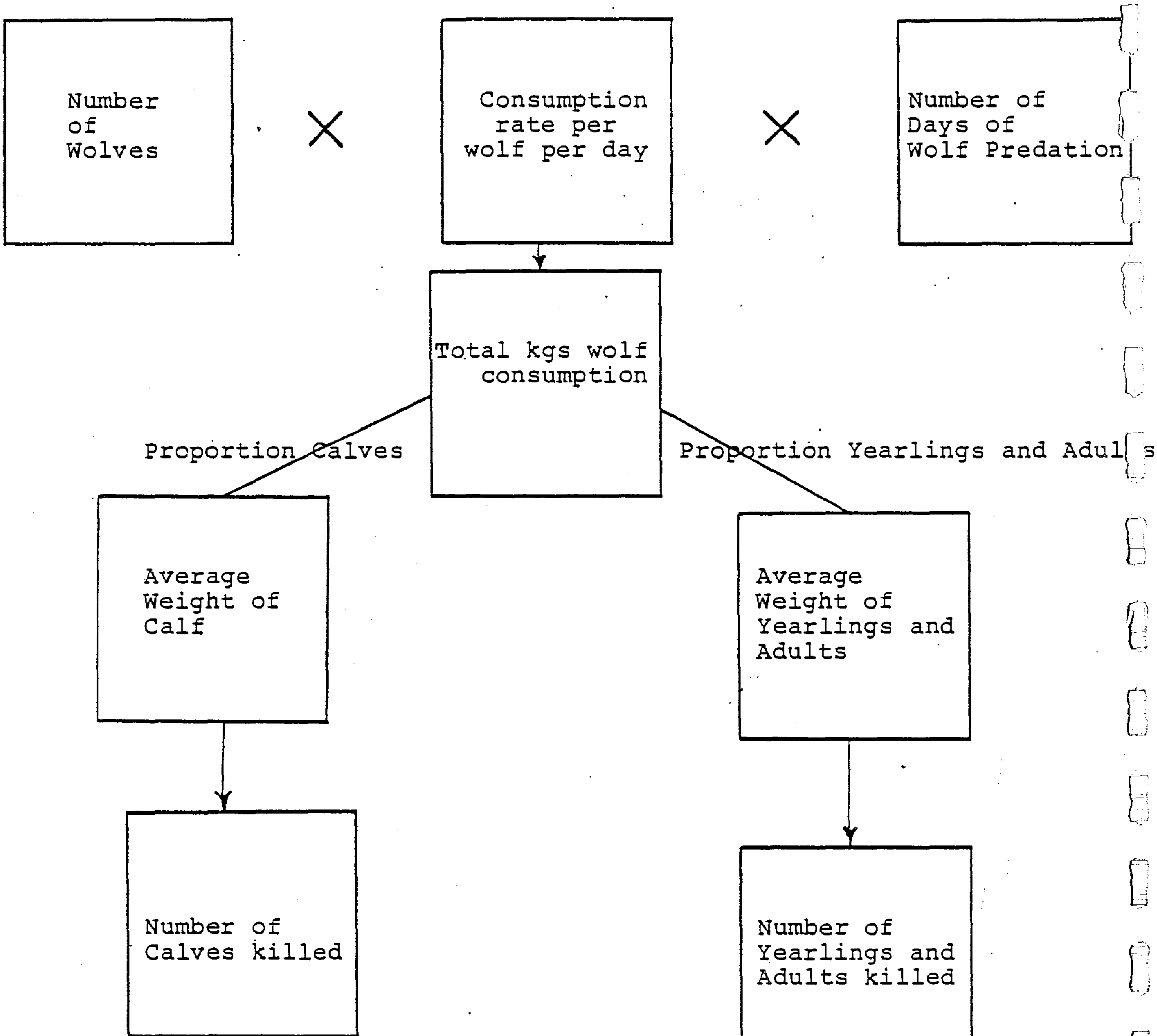
#2) July 15 - November 1 (Event 4); and

#3) November 1 - May 15 (Event 9).



Input Variables:
(1) Mortality Rate for each sex and age group

Figure 3: Schematic diagram of Events 2 and 8 (early spring and winter mortality) for the moose model.



Input Variables:

(1) Number of Wolves
(2) Consumption Rate of Wolves
(3) Number of Days of Wolf Predation
(4) Proportion of Wolf Kill Consisting of Calves
(5) Proportion of Wolf Kill Consisting of Yearlings and Adults
(6) Average Weight of Calves
(7) Average Weight of Yearlings and Adults

Figure 4: Schematic diagram of Events 3, 4 and 9 (wolf predation) for the moose model.

Period #1 encompasses the wolf denning period and represents the annual low in the wolf population. Because pups are quite small during this time period, no food consumption was allocated for them. Period #2 encompassed the post-denning period and represents the highest level of the wolf population (adults plus pups prior to hunting and trapping season) during the year. For this latter time period, we assumed that pups had similar food requirements as adults. Period #3 encompassed both the population's highest level during the year (prior to hunting and trapping season) but also the lowest level (post-hunting and trapping season). Consequently, we used the mid-point between the two population estimates to provide an average number of wolves for the winter. Wolf population levels were derived from Table 30 from Ballard, et al. (In Prep.) for the Susitna River Study Area while the GMU-13 estimates were derived from Tables 22 and 30 (op. cit.).

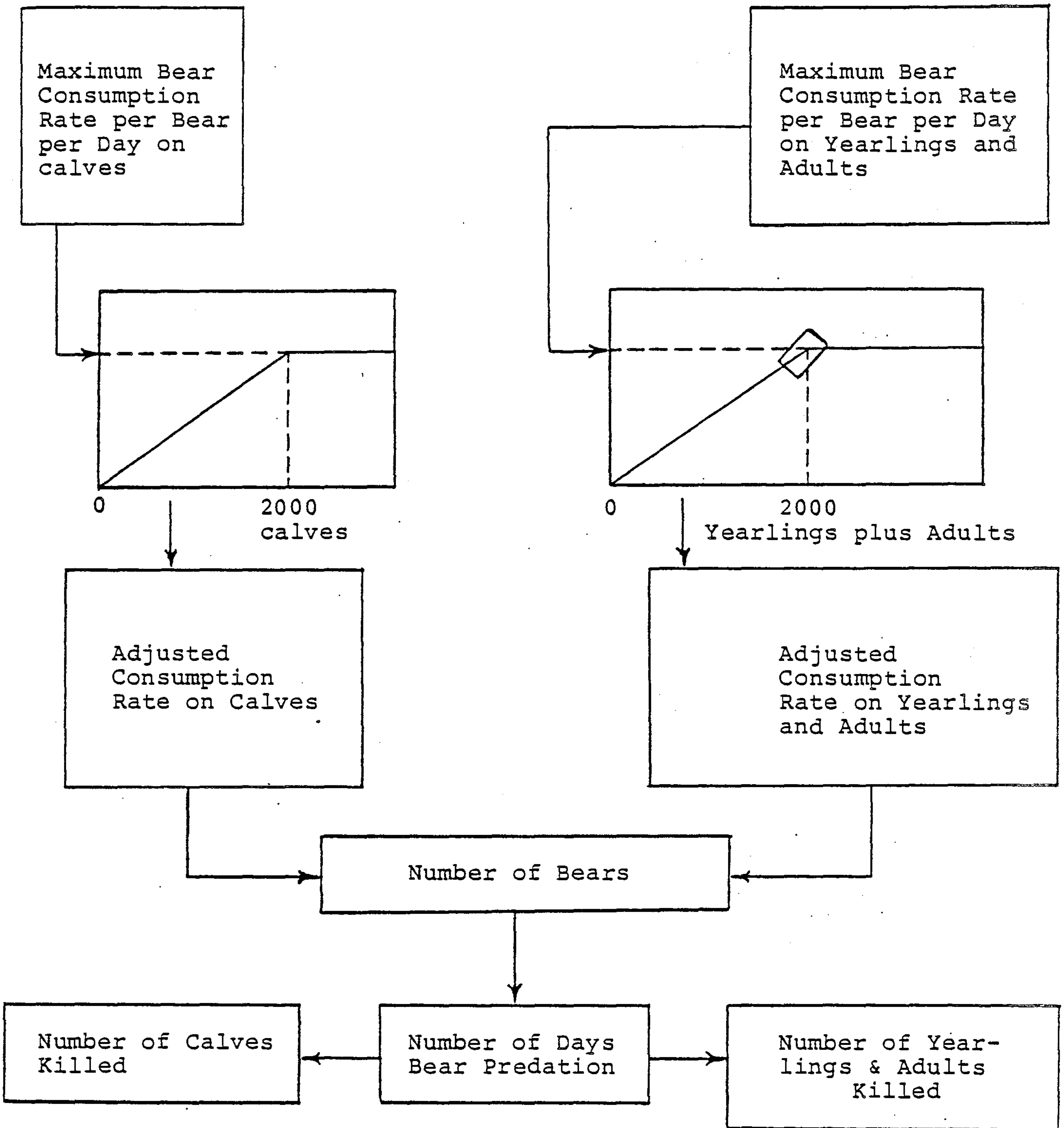
Estimates of percent biomass of moose consumed by wolves for Period #1 were based entirely on scat analyses according to methods described by Floyd, et al. (1978). The analyses indicated that 91% of the biomass of prey consumed by wolves from May 15 - July 15 was comprised of ungulates, with calf and adult moose comprising 35% and 47%, respectively, of the total biomass consumed. Estimates of percent biomass of calf and adult moose consumed by wolves during Periods #2 (July 15 - November 1) and #3 (November 1 - May 15) were determined from kills observed while monitoring radio-marked packs. The estimates for the study were divided into 2 time periods to correspond with the increased importance of caribou as wolf prey from 1979 - 1981. From 1975 - 1978, we estimated that from July 15 - November 1 (Period #2), calf and adult moose comprised 12% and 78%, respectively, of the prey biomass, while from November 1 - May 15 (Period #3), calf and adult moose comprised 18% and 73%, respectively, of the biomass. During Period #2 from 1979 - 1981, percent biomass of adult moose declined to 73%, while the percent of calf moose remained constant. Percent biomass declined to 17% and 68% calf and adult moose, respectively, during Period #3 from 1979 - 1981.

The estimated biomass of calf and adult moose killed by wolves during each time period per year was extrapolated from wolf population estimates for each period multiplied by the numbers of days in each period multiplied by the estimates of wolf daily consumption rates. For all 3 time periods, it was assumed that wolves consumed 7.1 kgs prey/wolf/day (Table 20 op. cit.). Estimates of percent biomass by prey species were then multiplied to derive estimated biomass. For each time period, the number of moose killed was estimated by dividing the average weight of each age class for each period derived from literature and field studies into the estimated biomass. The wolf daily consumption rate used is relatively high in relation to that reported in the literature and thus, we consider the estimates of number of moose killed per year to be inflated.

Event 5 - Brown Bear Predation

Predation rates of brown bear on both adult and calf moose were derived from observations of kills during daily relocation flights of 23 adult radio-collared bears (Ballard, et al., 1981a and Table 35 from Ballard, et al., In Prep.). The relocation flights were done between May 15 and July 15, the period of most brown bear predation on moose (Ballard, et al., 1981a). Kill rates of adult moose were calculated by assuming that all adult moose killed by the 23 radioed bears between May 15 and July 15 were observed (N = 28), and after this time, no adult moose were killed. Observed rates of calf moose killed were 1 calf/ 9.4 days/adult bear. These kill rates were extrapolated to the adult bear population estimates for the Susitna Study Area and GMU-13 (derived from Miller and Ballard, 1982). No information was available on annual bear population fluctuations, so for these models, we assumed a stable population from 1975 - 1981 (Figure 5).

Preliminary runs of the model indicated that kill rates of calf moose were too high. It seems more likely that estimates of bear kill rates on calf moose would be underestimated even from daily relocation flights because many bears remained on calf



Input Variables:
(1) Maximum Consumption Rate on Calves
(2) Maximum Consumption Rate on Yearlings and Adults
(3) Number of Bears
(4) Number of Days of Bear Consumption

Figure 5: Schematic diagram of Events 5 and 6 (brown bear and black bear predation) for the moose model.

kills less than 24 hours (Ballard, unpub. data) . Therefore, we modified the estimates of calf kill rate by assuming that the magnitude of bear predation was partially dependent on the density of moose calves. For the study area model, it was assumed that bears preyed upon 50% of the estimated number of calves produced for 1977 and 1978. This was based upon estimates derived from moose composition counts (0.14 calves/bear/day for 60 days and 0.02 adults/bear/day, for 60 days). At higher levels of calf production than the 1977 and 1978 levels, we assumed that the numbers preyed upon remained constant. At lower levels of calf production, we assumed that a linear relationship existed between percent calves taken by bears and calves produced. During 1979 only, we reduced brown bear predation on calves to 0.10 calves/bear/day to correspond with removal of 47 transplanted bears from the Susitna Study Area for a 2 month period in late spring and early summer (Miller and Ballard, 1983).

Preliminary runs of the project model suggested that our estimates of bear predation on adults were also too high. The original kill estimates meant than an excess of 20% annual adult moose mortality occurred from brown bear predation alone. Such estimates, compared with all of the other mortality factors, were obviously greatly exaggerated. Because many bears remain with adult moose kills for 5 - 6 days, periodic relocation of bears could tend to overestimate kill rates, similar to overestimation of wolf kill rates (Fuller and Keith, 1980). However, most of our data were collected during contiguous daily flights and because individual carcasses and bears could usually be identified, the rates should not have been greatly exaggerated. Possibly the 23 adult radio-collared bears had kill rates greater than the rest of the bear population, but we have no evidence to support this idea. Predation estimates on adult moose were modified in a similar way to those for calf moose except that we assumed that at the 1977 and 1978 moose population estimates, brown bears were responsible for 7% adult mortality.

Preliminary runs of the GMU-13 model suggested that the estimates of bear predation derived for the Susitna area were also too high for the entire unit. This was not unexpected since we originally applied bear density estimates obtained for the Susitna area (Miller and Ballard, 1983) to the entire unit. Undoubtedly, variations in both brown bear density and predation on calves occur within the unit. Consequently, both the number of bears and predation rates were subjectively adjusted downwards to 708 adult bears preying on calf and adult moose at a rate of 0.10 calves/bear/day and 0.01 adult moose/bear/day during May 15 - July 15.

Event 6 - Black Bear Predation

Although black bears (Ursus americanus) occur in GMU-13 and they have been observed preying on moose (Ballard and Miller, unpub. data), they were rare and were considered an insignificant source of mortality within the Susitna River Study Area. However, because black bears were quite numerous in other portions of GMU-13, they were incorporated into the GMU-13 model (Figure 5).

Based on existing density estimates and observed rates of predation from one portion of the unit, we originally estimated that 1,650 black bears occur in the unit and that they were preying on calf and adult moose at a rate of 0.021 and 0.012/bear/day, respectively. Similar to brown bear predation rates, preliminary runs suggested that perhaps both the population estimates and the predation rates for black bear were too high. Consequently, they were subjectively reduced to a population of 1,000 black bears preying on moose at 0.003 calves/bear/day and 0.001 adults/bear/day for 60 days following birth.

Event 7 - Hunter Harvest

Annual hunting mortality, which during this study affected bulls only, was determined for each year of study from "mandatory harvest reports" (Figure 6). Harvest reports from successful and

Number of Moose by sex and age	minus	Number of Moose Harvested by sex and age

Input Variables:
(1) Number of Moose Harvested by sex and age

Figure 6: Schematic diagram of Event 7 (hunting mortality) for the moose model.

unsuccessful moose hunters are required by law in GMU-13, however, this is not enforced and compliance is less than 100%. To encourage moose hunters to report results of their hunt, reminder letters are sent to all those who took a harvest ticket but did not report their hunt results. Because no reminder letters were sent in 1980, the harvest for that year was determined by extrapolating from return and non-return reports in previous years to reports returned in 1980.

Antler measurements on harvest reports since 1978 provided a basis for grossly estimating the number of yearlings killed, although some measurements were undoubtedly false. Antler measurements of ≤ 30 inches were considered to be yearlings or younger. Beginning in 1980, only bulls with antler spreads of 36 inches, or at least 3 brow tines, were legal for harvest. For the 1978 and 1979 hunting seasons, 55.4% of the measured moose had antlers of 30 inches or less; therefore, we assumed that annually from 1975 - 1979 half of the harvest was comprised of yearling bulls.

The annual hunting mortality rate for adult bulls was estimated at 25% based on radio-collar data (N = 28).

Event 8 - Winter Mortality (Excluding Predation)

Estimates of winter mortality in the model (Figure 3) were subtracted from the estimated number of moose present each November following hunter harvest. The magnitude of winter mortality (usually by starvation) was initially estimated from radio-collared moose by methods described by Hayne (1978) and Gasaway, et al. (In press). Winter mortality was calculated as follows (from Gasaway, et al., In press):

$$\text{Percent mortality} = \frac{a}{b}$$

where,

a = number of winter mortalities of radio-collared moose; and

b = estimated number of collared animal months.

b estimated as follows: $\frac{(c)\ (d)}{e}$

where,

c = mean # months collars transmitting (exluding dead moose);

d = total # radio-collared moose (including dead moose); and

e = time interval for annual mortality.

Winter mortality data was available from 1977 - 1981 for calf moose and from 1979 - 1982 for yearling moose (Table 1).

For modelling, it was assumed that during mild winter (1975 - 1976 through 1977 - 1978 and 1979 - 1980) calf mortality was 6%. Winter 1978 - 1979 was considered relatively severe (Eide and Ballard, 1982) with high rates of calf mortality during late winter (Table 1). These higher rates for males and female calves were used for 1978 - 1989 in the models. For yearling females, we utilized the calculated rate of 2.4%, and for yearling bulls, we utilized the calculated mortality rate of 6% (Table 1). Even though the yearling bull mortality rate was attributable to hunting, which theoretically would have been illegal, it was used because bulls usually suffer proportionately larger natural mortality than females and we suspected the calculated rate was low.

Table 1. Mortality rates due to winter starvation of radio-collared calf and yearling moose in the Nelchina and Susitna River Basins, 1977-1982.

	Calves				Yearlings	
	1977-78 1/ 1979-80 1/ 1980-81		1978-79 2/		1979-80 1/ 1980-81 1981-82	
Sex	F	M	F	M	F	M
# mortalities	1	1	3	8	1	2 3/
$\bar{x}$ mos. collars transmitting (excluding mortalities)	5.0	5.6	2.6	2.7	9.9	10.5
Total # radio-collared moose (including mortalities)	25	26	41	26	50	37
Time interval (# mos.)	7	7	5	5	12	12
% mortality	5.6	4.8	14.1	57.1	2.4	6.2

1/ Mild winters
2/ Severe winters
3/ Both mortalities from hunting

Annual winter mortality rates for adult cows varied from 0 to 5.6% during 1976 - 1982 (Table 2). Overall, the winter mortality rate was estimated at 3.6% and this was used for each year of the study. Apparently the winter of 1978 - 1979 was severe enough to cause significant increases in calf mortality but not for adults.

It was assumed that during mild winters, adult bulls suffered rates of winter mortality identical to that of cows (3.6%). During severe winters, we assumed that adult bulls would suffer higher rates of mortality than cows, so the 1978 - 1979 winter mortality was subjectively estimated at 7.2%.

Project Population Model Analyses

Population Size Estimates

Between 1975 and 1981, estimates derived from fall composition counts and the model suggest that the area's moose population increased (Figure 7). The model indicates that the fall moose population increased by 24%, while population estimates based on the composition counts indicated a much larger increase of 101%. Projected population estimates beyond May, 1981 (Figure 7) assume that all mortality factors remain identical to those of 1980 - 1981.

Each year's independent moose population estimate based upon composition counts were compared to those generated by the model (Figure 8). From this comparison, it becomes quite evident that the annual population estimates based on composition counts were not accurate. Using both the 1975 and 1976 data with documented levels of productivity and mortality, the population eventually becomes extinct. Based upon the 1980 census estimate and the composition of the population at that time, no winter mortality could have occurred for the moose population to have increased up to the 1981 or 1982 estimates based on the composition counts. Because this is highly unlikely, it suggests that the

Table 2. Mortality rates of adult (>2 yr.) radio-collared cow moose due to winter starvation and unidentified mortality in the Nelchina and Susitna River Basins of southcentral Alaska from 1976-1982.

Year	1976-77	1977-78	1978-79	1979-80	1980-81	1981-82	Total
# Mortalities	0	1	1	1	2	4	9
$\bar{x}$ mos. collars transmitting (excluding mortalities)	5.5	11.5	10.6	6.0	10.0	10.4	24.1
Total # radio-collared moose (including mortalities)	36	42	45	52	80	82	126
Time Interval (# mos.)	12	12	12	12	12	12	12
% Mortality	0	2.5	2.5	3.9	3.0	5.6	3.6

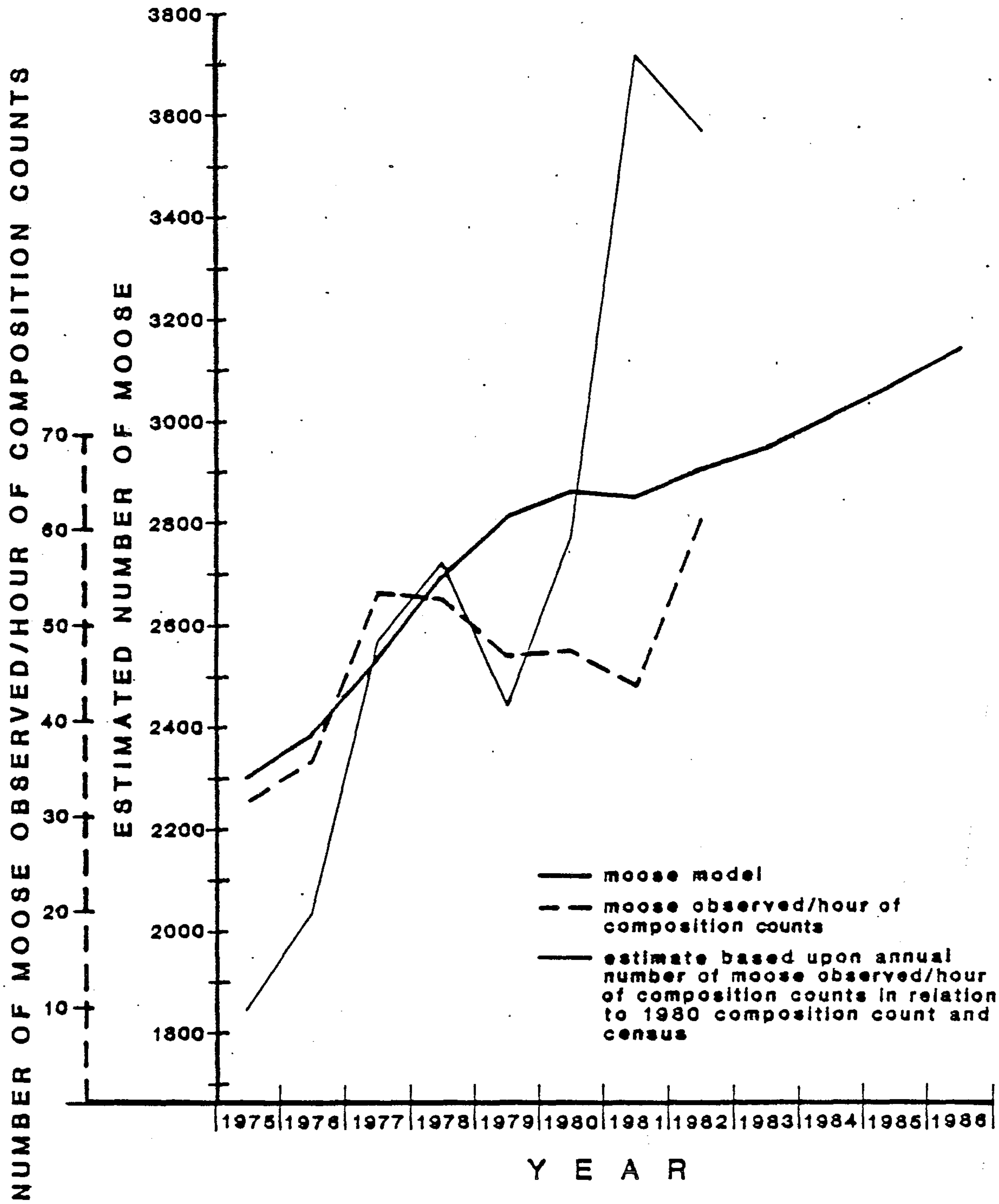


Figure 7. November moose population estimates as derived from modeling versus composition counts for the Susitna River Study Area of southcentral Alaska, 1975–1986.

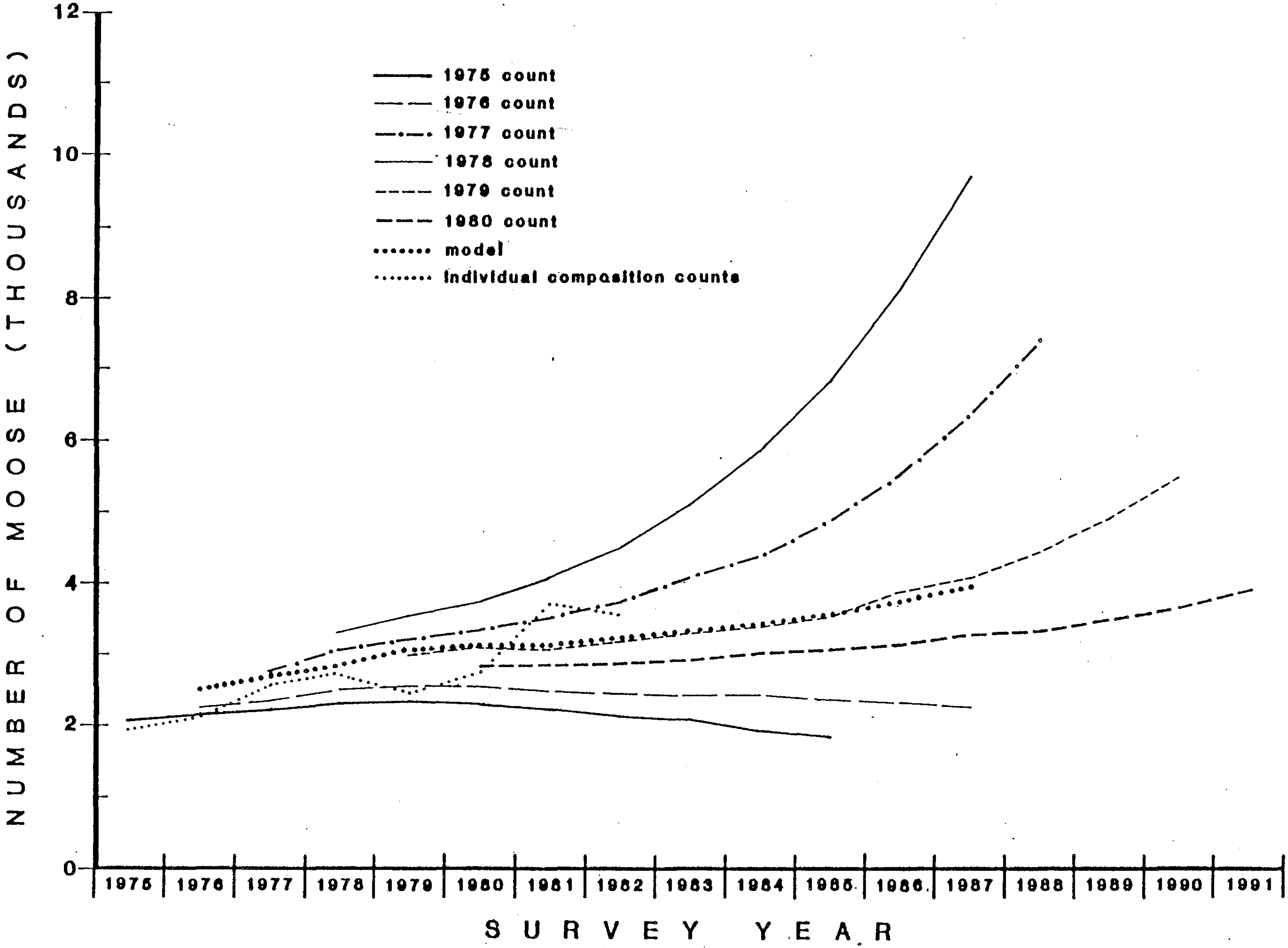


Figure 8. Fall moose population trends derived from modeling using annual composition count data for initial population size for the Susitna River Study Area, 1975-1991.

number of moose observed/hour in composition counts is probably not an accurate index of change in annual moose density. Also, it suggests that the relationship between moose observed per hour in composition counts versus population estimates obtained from censusing may be quite variable from year to year. All other population estimates suggested an increasing population trend although the rates of increase were quite different.

Sex and Age Structure

Comparison of several sex-age parameters between the model and composition counts suggest that at least three sex-age classifications are underestimated during composition counts. Calf:cow ratios, as estimated from the model, were higher than those obtained from composition counts (Figure 9). Even though composition count ratios were adjusted upward based upon observed differences between composition surveys and census data, the model suggests that the discrepancy between these two counts may be larger than existing data suggest (Gasaway, et al., 1982; Ballard, et al., 1982). The discrepancy occurs because cow:calf pairs are often segregated from larger groups of moose and have a lower probability of being observed with either survey method.

Also, the model suggests that both survey estimates tend to underestimate the proportions of yearling bulls (Figure 10) and cows present in the population. This could occur for at least 3 reasons:

1) counts are often made following hunting mortality, so that usually an unknown proportion of yearling bulls has been removed and remains unaccounted for;

2) an unknown proportion of the yearling bulls cannot be identified from fixed-wing aircraft because antlers are comprised of either buttons or short spikes; and

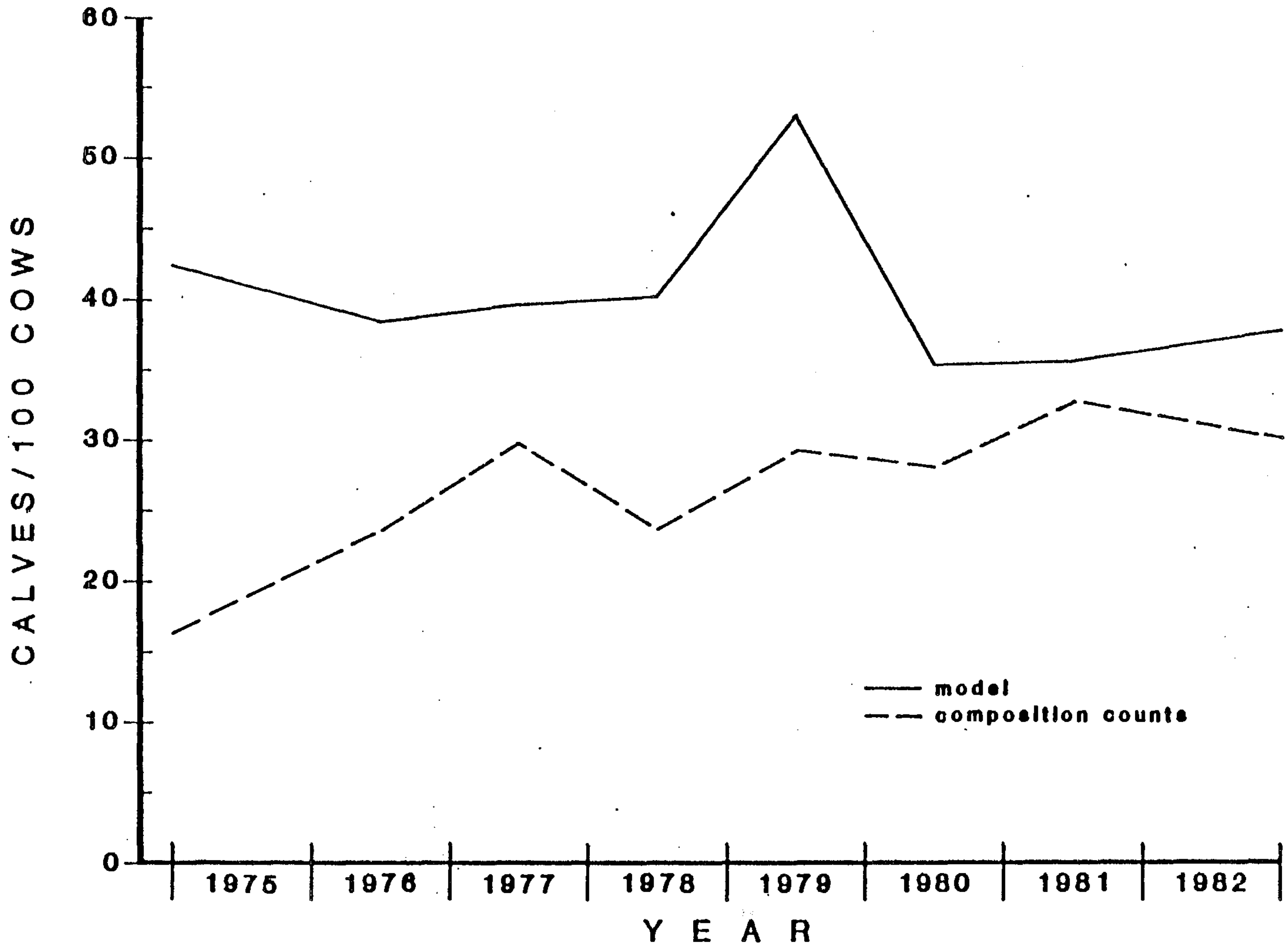


Figure 9. Estimated moose calf:cow ratios derived from modeling versus calf:cow ratios obtained from annual composition counts in the Susitna River Study Area, 1975–1982.

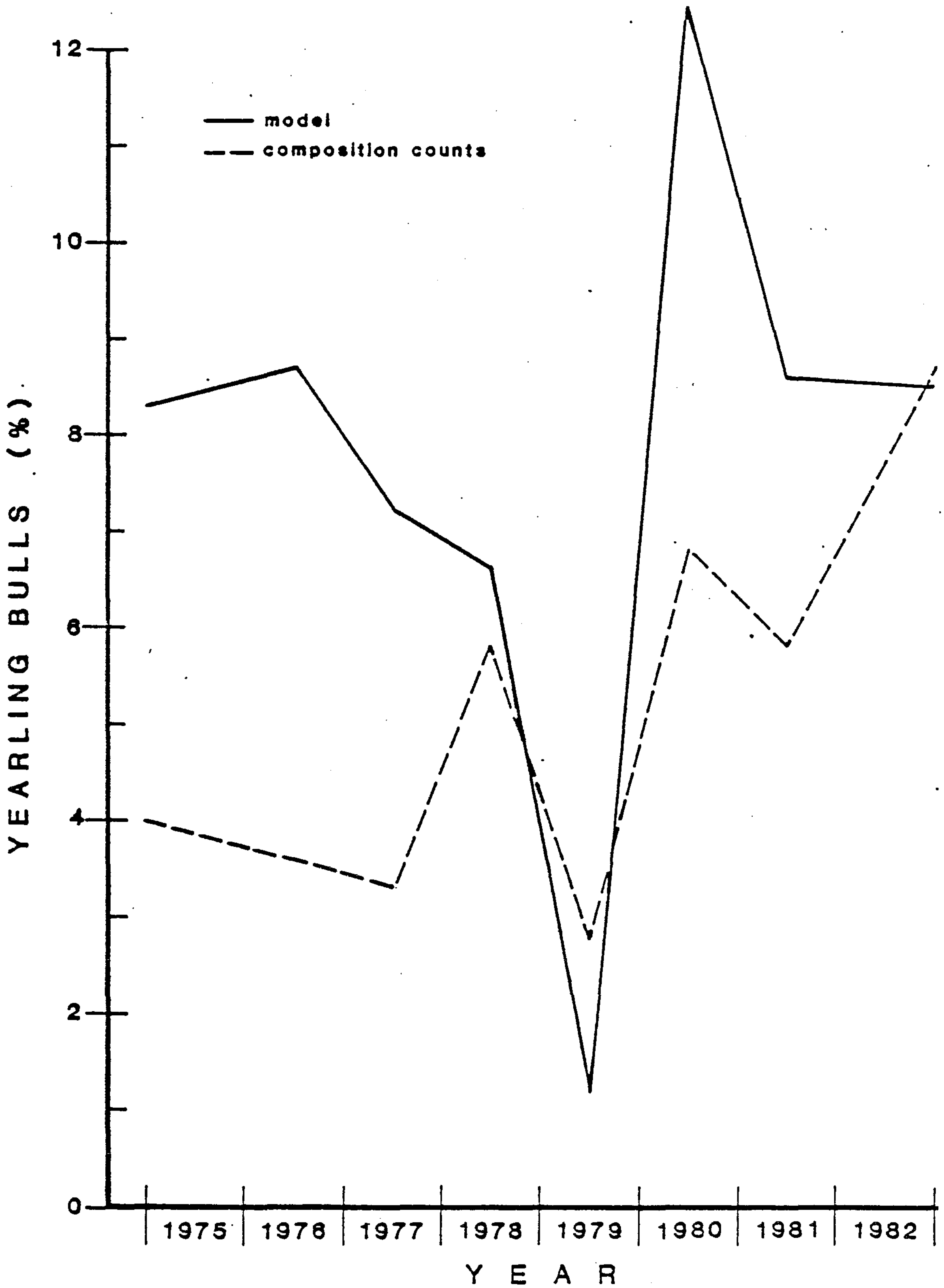


Figure 10. Percent yearling bulls in moose populations each fall as determined from modeling versus composition counts for the Susitna River Study Area, 1975–1982.

3) during the 1975 and 1976 composition surveys, the criteria utilized for estimating ages of yearling bulls were not accurate according to antler configuration data (Gasaway, pers. comm.).

Because the proportion of yearling females is based upon the estimates of yearling males, this sex-age class would also be underestimated.

Calf Mortality

Predation by brown bears was the single most important calf mortality factor during the study period. Because of the manner in which brown bear mortality was calculated, the numbers of calves killed by bears each year varied (Figure 11), but the actual percentage of calves killed remained constant each year, except in 1979 when bears were temporarily transplanted from the area.

Calf mortality attributable to wolf predation declined from 9.1% in 1975 to 4.1% in 1978 (Table 3). This suggests that during the years that wolves were experimentally killed (1976 - 1978), calf survival increased slightly. Following termination of wolf control and repopulation of the area by wolves, calf mortality attributable to wolf predation increased and slightly exceeded precontrol levels by 1981. During the same period, starvation accounted for 1.9 - 3.2% of the total calf mortality except during the winter of 1978 - 1979. This was considered a moderately severe winter, and at least 14.9% of the calves died of starvation.

Yearly Mortality

Trends in yearling moose mortality were similar to those of calves, except the magnitude of the mortality was substantially less (Table 3). From 1975 - 1979, hunting mortality (assuming that half of the bull harvest was comprised of yearlings) was the

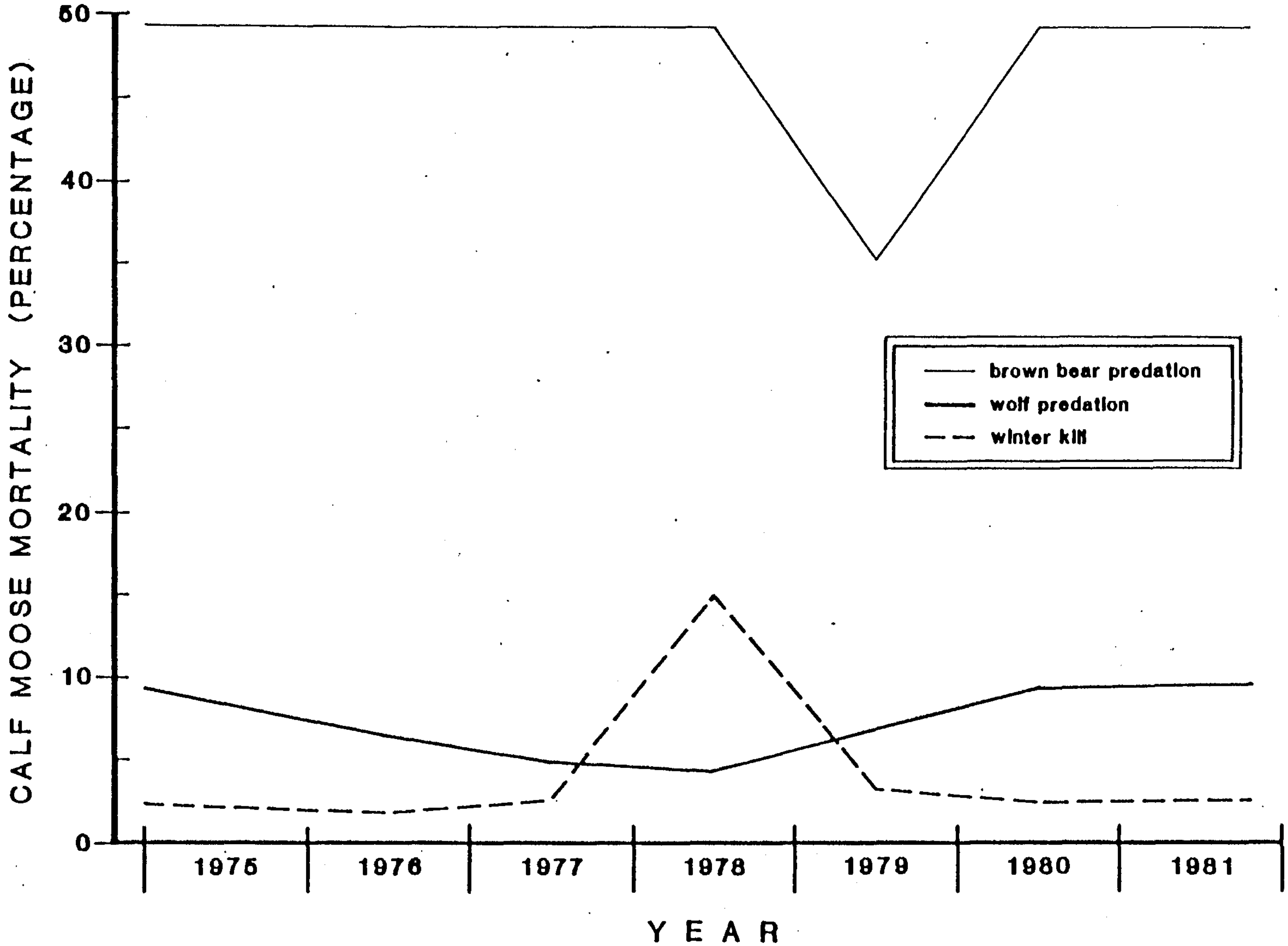


Figure 11. Annual rates of calf moose mortality due to predation and winter kill as determined from modeling the Susitna River Study Area moose population, 1975-1981.

Table 3. Estimates of spring moose population size, and causes and magnitude of mortality by sex and age class as determined from modeling the Susitna River Study Area moose population from 1975-76 to 1981-82.

Year 1975-76	Calves		Yrlgs.		Adults		Total
Age Class / Sex	M	F	M	F	M	F	Both
Spring Population Est.	811	811	274	274	93	1365	3628
Mortality							
Early Spring and Summer	48	48	0	0	0	0	96
Spring Wolf Predation	36	36	2	2	1	8	85
Summer Wolf Predation	18	18	9	9	3	46	103
Brown Bear Predation	399	399	19	19	7	96	939
Hunting	0	0	51	0	52	0	103
Winter Wolf Predation	20	20	10	10	4	52	116
Winter Kill	18	18	11	5	1	43	60
Subtotal	539	539	102	45	68	245	1502
% of Population	66.5	66.5	37.2	16.4	73.1	17.9	41.4

Year 1976-77	Calves		Yrlgs.		Adults		Total
Age Class / Sex	M	F	M	F	M	F	Both
Spring Population Est.	699	699	272	272	197	1349	3488
Mortality							
Early Spring and Summer	41	41	0	0	0	0	82
Spring Wolf Predation	21	21	1	1	1	4	49
Summer Wolf Predation	10	10	5	5	4	24	58
Brown Bear Predation	343	343	18	18	13	91	826
Hunting	0	0	41	0	42	0	83
Winter Wolf Predation	13	13	6	6	4	31	73
Winter Kill	17	17	2	5	4	44	89
Subtotal	445	445	67	35	68	194	1254
% of Population	63.7	63.7	24.6	12.9	34.5	14.4	36.0

Year 1977-78	Calves		Yrlgs.		Adults		Total
Age Class / Sex	M	F	M	F	M	F	Both
Spring Population Est.	721	721	254	254	318	1392	3660
Mortality							
Early Spring and Summer	43	43	0	0	0	0	86
Spring Wolf Predation	17	17	1	1	1	4	41
Summer Wolf Predation	7	7	3	3	4	18	42
Brown Bear Predation	354	354	16	16	20	88	848
Hunting	0	0	52	0	52	0	104
Winter Wolf Predation	10	10	4	4	5	24	57
Winter Kill	18	18	10	5	8	46	105
Subtotal	449	449	86	29	90	180	1283
% of Population	62.3	62.3	33.9	11.4	28.3	12.9	35.1

Year 1978-79	Calves		Yrlgs.		Adults		Total
Age Class / Sex	M	F	M	F	M	F	Both
Spring Population Est.	753	753	272	272	396	1437	3883
Mortality							
Early Spring and Summer	45	45	0	0	0	0	90
Spring Wolf Predation	15	15	1	1	1	3	36
Summer Wolf Predation	6	6	3	3	4	14	36
Brown Bear Predation	370	370	16	16	23	85	880
Hunting	0	0	74	0	74	0	148
Winter Wolf Predation	10	10	4	4	6	23	57
Winter Kill	181	44	17	16	21	48	317
Subtotal	627	490	115	30	129	173	1564
% of Population	83.3	65.1	42.3	11.0	32.6	12.0	40.3

Table 3. (cont'd)

Year	1979-80						
Age Class	Calves		Yrlgs.		Adults		Total
Sex	M	F	M	F	M	F	Both
Spring Population Est.	787	787	126	263	424	1506	3893
Mortality							
Early Spring and Summer	47	47	0	0	0	0	94
Spring Wolf Predation	21	21	0	1	1	4	48
Summer Wolf Predation	14	14	3	6	9	33	79
Brown Bear Predation	276	276	8	16	26	91	693
Hunting	0	0	82	0	82	0	164
Winter Wolf Predation	18	18	4	8	12	44	104
Winter Kill	25	25	1	5	11	49	116
Subtotal	401	401	98	36	141	221	1298
% of Population	51.0	51.0	77.8	13.7	33.3	14.7	33.3

Year	1980-81						
Age Class	Calves		Yrlgs.		Adults		Total
Sex	M	F	M	F	M	F	Both
Spring Population Est.	796	796	386	386	311	1512	4187
Mortality							
Early Spring and Summer	47	47	0	0	0	0	94
Spring Wolf Predation	32	32	2	2	1	6	75
Summer Wolf Predation	18	18	9	9	8	37	99
Brown Bear Predation	391	391	21	21	17	82	923
Hunting	0	0	0	0	134	0	134
Winter Wolf Predation	23	23	13	13	10	50	132
Winter Kill	18	18	21	8	5	49	119
Subtotal	529	529	66	53	175	224	1576
% of Population	66.5	66.5	17.1	13.7	56.3	14.8	37.6

Year	1981-82						
Age Class	Calves		Yrlgs.		Adults		Total
Sex	M	F	M	F	M	F	Both
Spring Population Est.	814	814	267	267	456	1621	4239
Mortality							
Early Spring and Summer	48	48	0	0	0	0	96
Spring Wolf Predation	40	40	1	1	2	8	92
Summer Wolf Predation	18	18	7	7	11	40	101
Brown Bear Predation	400	400	14	14	25	87	940
Hunting	0	0	0	0	153	0	153
Winter Wolf Predation	20	20	8	8	13	46	115
Winter Kill	18	18	14	5	9	53	117
Subtotal	544	544	44	35	213	234	1614
% of Population	66.8	66.8	16.5	13.1	46.7	14.4	38.1

largest source of overall mortality (Figure 12), even though only affecting males. Beginning with the 1980 season, yearlings were theoretically protected by antler regulations and, therefore, hunting mortality declined to insignificant levels. Mortality attributable to wolf predation declined from 7.6% in 1975 to a low of 3% while wolf control was in effect. Following termination of wolf control, yearling mortality attributable to wolf predation increased. Yearling mortality attributable to brown bears declined during the study period primarily because the model assumed a stable bear population and the moose popualation was increasing. Winter mortality (starvation) was quite variable even during mild winters. The highest winter mortality occurred during the severe winter of 1978 - 1979.

Adult Mortality

Trends in adult mortality were quite similar to those of yearlings because for both types of predation, it was assumed that the sex-age class of kills was dependent on availability (Figure 13).

GMU-13 Population Model Analyses

Population Size Estimates

The 1978 - 1982 GMU-13 post-calving moose population trend (15.8% increase) was similar in many respects to that of the Susitna River Study Area (16.8%). However, the population declined between 1975 - 1976 and 1976 - 1977 and again in 1978 - 1979 (Table 4). The largest increases occurred between 1979 - 1980 (7.5%) and 1980 - 1981 (9.9%). The estimated fall population size based on the model differed considerably from the population estimate derived from composition counts, particularly for 1975 and 1976 (Figure 14). This was believed due to underestimation of both yearlings and calves during composition counts.

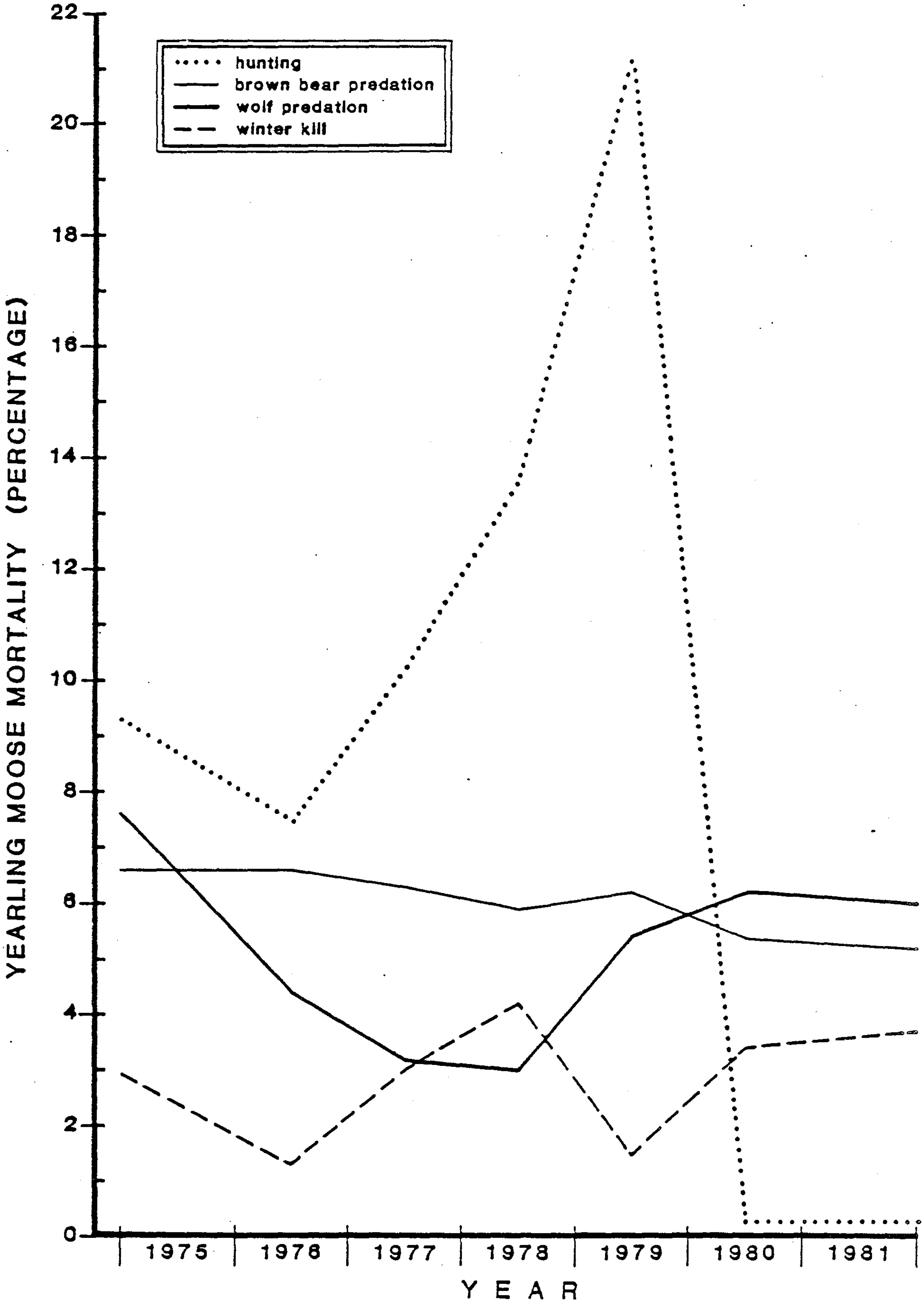


Figure 12. Annual percent yearling bull moose mortality due to several mortality factors as determined from modeling the Susitna River Study Area in southcentral Alaska, 1975-1981.

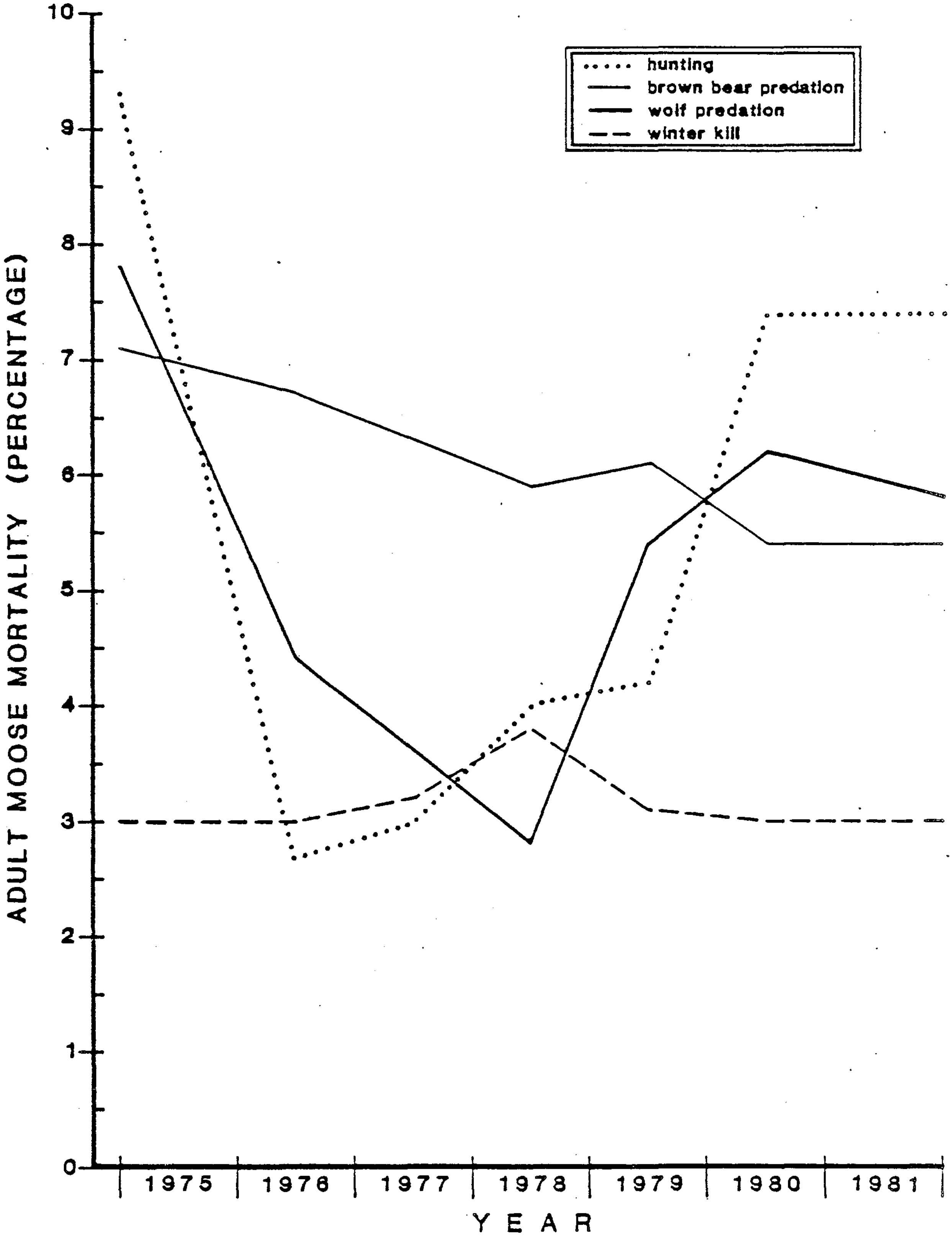


Figure 13. Annual adult moose mortality rates by cause as determined from modeling the Susitna River Study Area moose population in southcentral Alaska, 1975-1981.

Table 4. Estimates of spring moose population size, and causes and magnitude of mortality by sex and age class as determined from modeling the moose population in GMU 13 of southcentral Alaska from 1975-76 to 1981-82.

1975-76	Calves		Yrlgs.		Adults		Total
	M	F	M	F	M	F	Both
Spring Population Est.	7230	7230	1098	1098	1269	11822	29807
Mortality							
Early Spring and Summer	433	433	0	0	0	0	866
Spring Wolf Predation	486	486	11	11	13	123	1130
Summer Wolf Predation	209	209	57	57	66	615	1213
Brown Bear Predation	2124	2124	61	61	70	658	5098
Black Bear Predation	90	90	4	4	5	46	239
Hunting	0	0	358	0	358	0	716
Winter Wolf Predation	299	299	80	80	92	865	1715
Winter Kill	233	233	36	23	27	375	927
Subtotal	3874	3874	607	236	631	2682	11904
% of Population	53.6	53.6	55.3	21.5	49.7	22.6	39.9

1976-77	Calves		Yrlgs.		Adults		Total
	M	F	M	F	M	F	Both
Spring Population Est.	5598	5598	3356	3356	1129	10062	29099
Mortality							
Early Spring and Summer	335	335	0	0	0	0	670
Spring Wolf Predation	535	535	33	33	11	98	1245
Summer Wolf Predation	156	156	111	111	37	333	904
Brown Bear Predation	2124	2124	159	159	54	477	5097
Black Bear Predation	90	90	11	11	4	34	240
Hunting	0	0	366	0	366	0	732
Winter Wolf Predation	250	250	176	176	59	526	1437
Winter Kill	141	141	160	73	23	328	866
Subtotal	3631	3631	1016	563	554	1796	11191
% of Population	64.9	64.9	30.3	16.8	49.1	17.9	38.5

1977-78	Calves		Yrlgs.		Adults		Total
	M	F	M	F	M	F	M F
Spring Population Est.	5322	5322	1657	1967	2915	11059	28552
Mortality							
Early Spring and Summer	319	319	0	0	0	0	638
Spring Wolf Predation	333	333	12	12	18	67	775
Summer Wolf Predation	157	157	65	65	97	368	909
Brown Bear Predation	2124	2124	93	93	138	525	5097
Black Bear Predation	90	90	7	7	10	37	241
Hunting	0	0	428	0	428	0	856
Winter Wolf Predation	190	190	78	78	116	440	1092
Winter Kill	137	137	81	42	80	362	839
Subtotal	3350	3350	764	297	887	1799	10447
% of Population	62.9	62.9	38.8	15.1	30.4	16.3	36.6

1978-79	Calves		Yrlgs.		Adults		Total
	M	F	M	F	M	F	Both
Spring Population Est.	5751	5751	1972	1972	3231	10930	29607
Mortality							
Early Spring and Summer	345	345	0	0	0	0	69
Spring Wolf Predation	247	247	9	9	14	49	575
Summer Wolf Predation	128	128	53	53	87	294	743
Brown Bear Predation	2124	2124	93	93	152	513	5099
Black Bear Predation	90	90	7	7	11	36	241
Hunting	0	0	432	0	432	0	864
Winter Wolf Predation	173	173	70	70	115	390	991
Winter Kill	1608	397	137	43	182	361	2728
Subtotal	4652	4652	801	275	993	1643	11868
% of Population	80.9	60.9	40.6	13.9	30.7	15.0	40.5

Table 4. (cont'd)

1979-80	Calves M	Calves F	Yrlgs. M	Yrlgs. F	Adults M	Adults F	Total Both
Spring Population Est.	5571	5571	1036	2247	3409	10984	29218
Mortality							
Early Spring and Summer	346	346	0	0	0	0	692
Spring Wolf Predation	281	281	5	12	18	57	654
Summer Wolf Predation	88	88	18	40	61	195	490
Brown Bear Predation	2124	2124	50	108	164	528	5098
Black Bear Predation	90	90	4	8	12	37	241
Hunting	0	0	500	0	500	0	1000
Winter Wolf Predation	117	117	25	55	83	267	664
Winter Kill	170	170	27	49	95	366	877
Subtotal	3216	3216	629	272	933	1450	9716
% of Population	55.7	55.7	60.7	12.1	27.4	13.2	33.3

1980-81	Calves M	Calves F	Yrlgs. M	Yrlgs. F	Adults M	Adults F	Total Both
Spring Population Est.	5958	5958	2555	2555	2833	11509	31418
Mortality							
Early Spring and Summer	337	337	0	0	0	0	674
Spring Wolf Predation	258	285	11	11	12	50	600
Summer Wolf Predation	123	123	57	57	65	258	683
Brown Bear Predation	2124	2124	111	111	126	501	5097
Black Bear Predation	90	90	8	8	9	35	240
Hunting	0	0	0	0	557	0	557
Winter Wolf Predation	106	106	51	51	58	231	603
Winter Kill	180	180	142	56	76	383	1017
Subtotal	3218	3218	380	294	903	1458	9471
% of Population	54.0	54.0	14.9	11.5	31.3	12.7	30.1

1981-82	Calves M	Calves F	Yrlgs. M	Yrlgs. F	Adults M	Adults F	Total Both
Spring Population Est.	6307	6307	2720	2720	4155	12312	34521
Mortality							
Early Spring and Summer	378	378	0	0	0	0	756
Spring Wolf Predation	218	218	9	9	13	40	507
Summer Wolf Predation	97	97	43	43	66	195	541
Brown Bear Predation	2124	2124	105	105	161	477	5096
Black Bear Predation	90	90	7	7	11	34	239
Hunting	0	0	0	0	794	0	794
Winter Wolf Predation	123	123	56	56	86	255	699
Winter Kill	204	204	153	61	111	416	1149
Subtotal	3234	3234	373	281	1242	1417	9781
% of Population	51.3	51.3	13.7	10.3	29.9	11.5	28.3

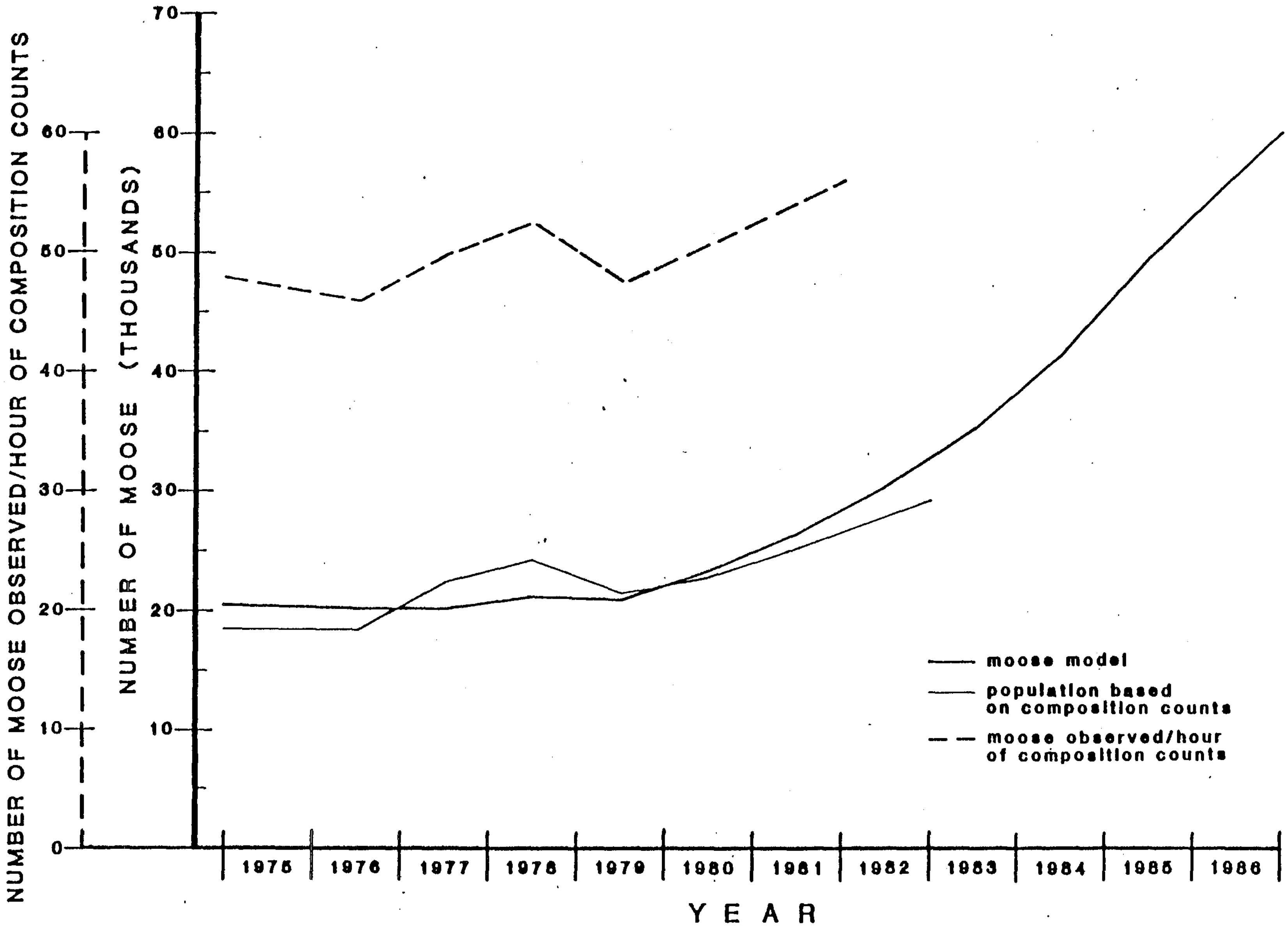


Figure 14. Fall moose population estimates as derived from modeling versus annual composition counts for Game Management Unit 13 of southcentral Alaska, 1975–1986.

Calf Mortality

Brown bear predation was responsible for more calf mortality than wolf predation or winter mortality (Figure 15). Except during the severe winter of 1978 - 1979, wolf predation was the second most important cause of calf mortality (Figure 15). Mortality of calf moose was higher in the GMU-13 than in the wolf control area, particularly in 1976 - 1977 when wolves preyed upon 17.3% of the estimated number of calves produced. As wolf densities declined in the unit, primarily from hunting and trapping activities, the estimated percentage of calves preyed upon by wolves declined each year, reaching a low of 7.0% during 1981 - 1982. Calf mortality studies conducted in 1977 and 1978 suggested that 3% of the calf mortalities during the first 6 weeks following birth were attributable to wolf predation (Ballard, et al., 1981). Independent modelling estimates suggested that calf mortality attributable to wolf predation ranged from 4.3 to 6.3% during the same years. Therefore, both approaches suggested that wolf predation on newborn moose calves was a secondary source of calf mortality.

Adult Mortality

Wolf predation on adult moose in the GMU-13 also declined during the study period (Figure 16), ranging from 13.5% in 1975 to 4.0% in 1981. The decline in wolf-related adult mortality was due to a decrease in the wolf population and concurrent increases in the moose population. Similarly, percent annual adult mortality from brown bear predation also declined (5.5 to 4.8%) but this was primarily the result of increases in the moose population since we assumed that bear populations were stable during the study.

During the study, adult mortality attributable to hunting increased primarily because of changes in hunting regulations in 1980 which placed all harvest pressure on adult bulls only.

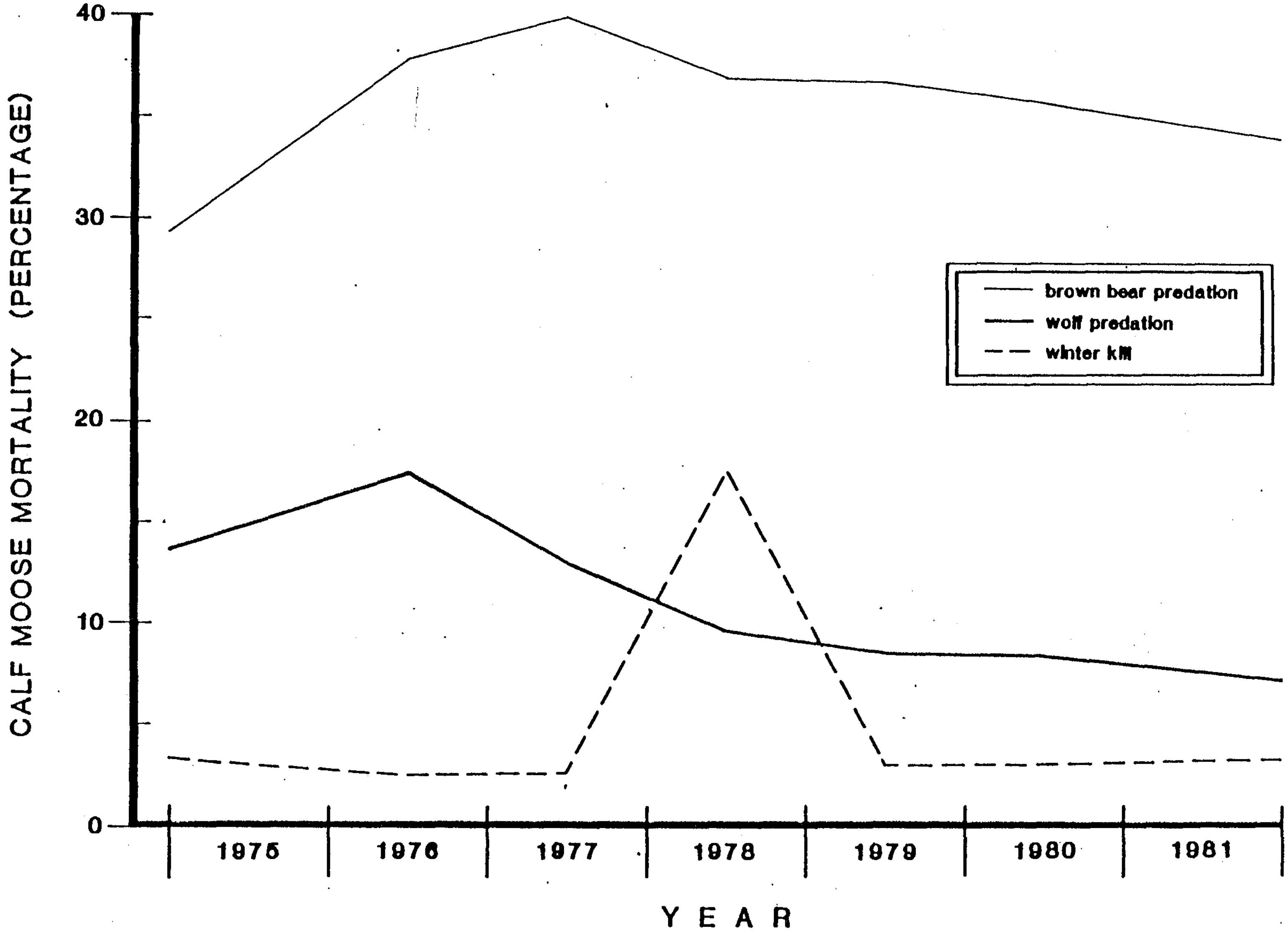


Figure 15. Estimated annual rates of calf mortality from predation and winter kill determined from modeling the Game Management Unit 13 moose population of southcentral Alaska, 1975-1981.

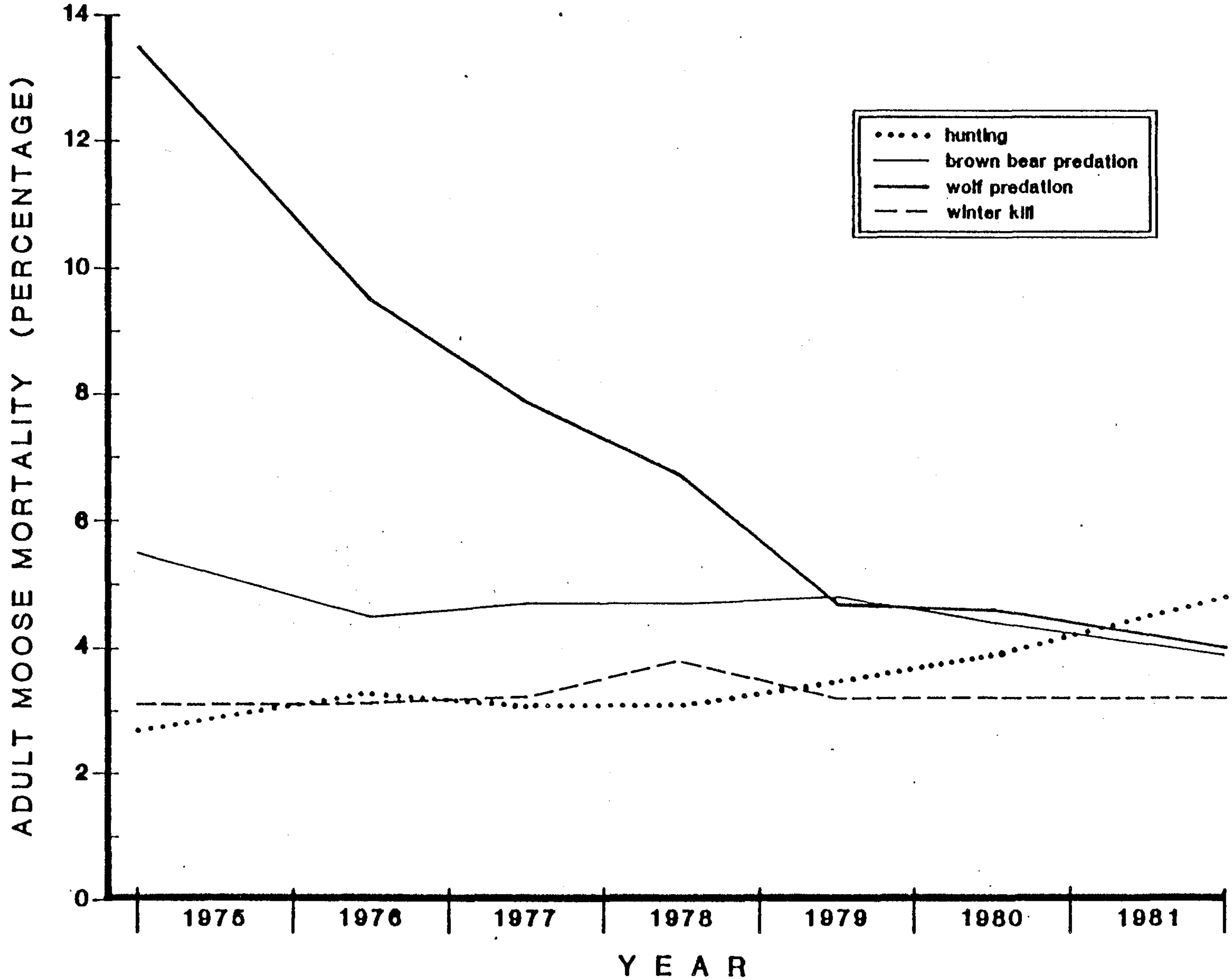


Figure 16. Annual Game Management Unit 13 adult moose mortality rates from four factors estimated from modeling, 1975–1981.

Wolf Predation

Earlier analyses of the effects of decreased wolf densities (from wolf control) on moose calf survival suggested that no significant increases had occurred because ratios of various sex and age classifications had fluctuated similarly between control and non-control areas (Ballard, et al., 1981). Although the reductions in wolf density were substantially larger in the wolf control area, wolf densities in both the wolf control area and GMU-13 decreased from 1975 levels, while moose populations in both areas increased (Figure 17). Reductions in both calf mortality from 9 - 17% annual mortality to 4 - 7%, and adult moose mortality from 8 - 10% to 3 - 4% annual mortality probably contributed to the increases in the moose populations. Because wolf densities declined in both areas, it would be expected that the sex-age ratios would fluctuate similarly. Although wolf predation was not the primary source of moose mortality, its reduction, in combination with several mild winters, appears to have allowed both moose populations to increase. Substantially larger increases could probably be anticipated if the level of bear predation was also reduced.

From November 1 through May 15 each year, mortality of moose from wolf predation is relatively high on a superficial basis, but on a population level, is relatively minor. For example, in both the experimental area and GMU-13, wolf predation accounted for 6.5 and 7.7% mortality, respectively, of the calves present on November 1, 1975. However, of the total calves produced, this source of mortality represented only 2.3 and 4.1% respectively. From this comparison, it would be easy to conclude from flights made during winter when wolf kills are most noticeable that wolf predation was a much more important source of moose mortality than what it actually represents on a population basis.

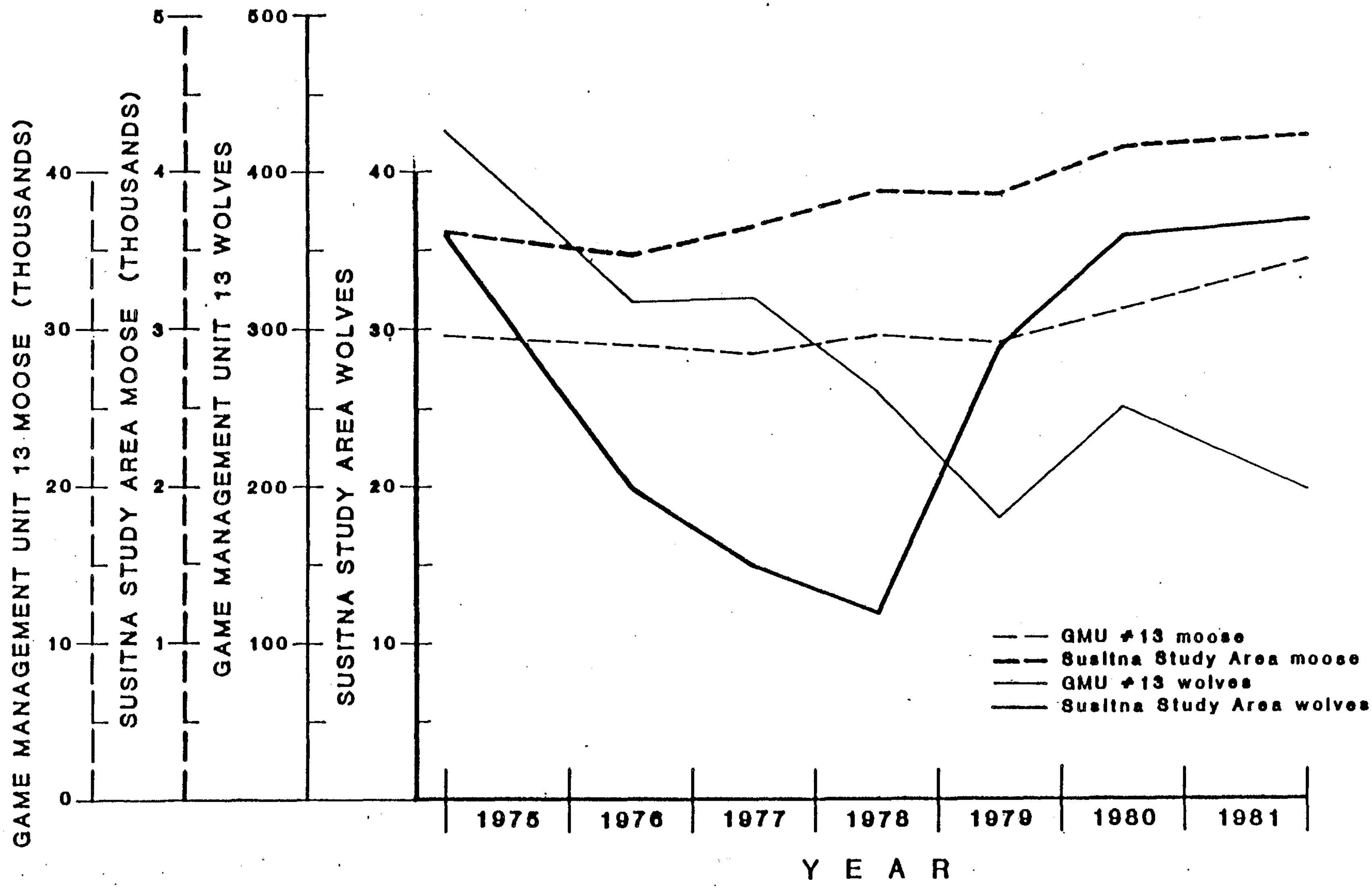


Figure 17. Annual fall moose and wolf population trends between Game Management Unit 13 and the Susitna River Study Area of southcentral Alaska, 1975-1981.

Summary

Development and refinement of the models has identified a number of areas where our understanding of moose population dynamic processes is incomplete. Probably the most important data gaps relate to the importance of various types of predation. Although black bears are quite numerous in the western half of the hydroelectric project study area, their importance as predators of moose has not been investigated. If black bears are in fact significant predators of moose, the addition of this factor to the model could greatly alter our interpretations of the potential impacts of the project on moose. Also, it became quite evident that our 1978 estimates of brown bear predation on moose were much too high, requiring additional study. Although a considerable volume of information has been collected on wolf populations, additional refinement of the relationships between snow conditions and wolf population processes is needed.

Both models relied heavily on the moose population estimates derived in 1980. To provide a validation of the model, the areas should be recensused in 1983 or 1984. Moose studies should be continued up to and through a severe winter. Currently, our estimates of starvation mortality during severe winter conditions are little more than guesses.

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