thanks t.j.

AN ABSTRACT OF THE THESIS OF

James Allen McNutt for the degree of DOCTOR OF PHILOSOPHY

in FOREST MANAGEMENT presented on January 30, 1976

Title: A Stochastic Analysis of Erosion and Economic Impacts Associated with Timber Harvests and Forest Roads

Abstract approved: John H. Beuter
Dr. John Beuter

A complex and sometimes serious problem facing modern day forest managers is that of estimating and analyzing potential on-site impacts which result from forest activities. A major type of adverse impact is man-initiated forest erosion. This consequence can be substantially magnified when forest harvest and road activities are implemented in steep, sometimes unstable terrain, characteristic of much of our Western forest land.

The objective of this study was to develop an analysis methodology and a decision model which will assist in evaluation of timber harvest and forest road alternatives and the potential scope of concomitant erosion consequences. The study effort consisted of four distinct parts: 1) development of probability functions for seven individual erosion events; 2) structuring a system model which simulates timber harvest and forest road alternatives in terms of several model products; 3) building an economic model which evaluates added capital costs associated with the erosion potential of each harvest and road

for expected road and slope erosion events.

The basic goal of this forest system study was to provide land managers with a tool for obtaining additional measurement parameters for proposed harvest and road alternatives. In order to illustrate how such a tool may be applied, the study concluded with an application of the complete methodology for ten well specified harvest and road alternatives. These alternatives ranged from highlead clearcutting to helicopter partial cutting to no harvesting at all. Output of system analysis for these alternatives demonstrated that harvest and road capital components and erosion consequences can be integrated jointly into the decision making process.

A Stochastic Analysis of Erosion and Economic Impacts Associated With Timber Harvests and Forest Roads

by

James Allen McNutt

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

June 1976

APPROVED:

Associate Professor of Forest Management in charge of major

Head of Department of Forest Management

Dean of Graduate School

Date thesis is presented January 30, 1976

Typed by Terry J. McNutt for James A. McNutt

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

A STOCHASTIC ANALYSIS OF EROSION AND ECONOMIC IMPACTS ASSOCIATED WITH TIMBER HARVESTS AND FOREST ROADS

I. INTRODUCTION

Man's growing use of forest resources is creating increased potential for adverse site impacts. A major type of adverse impact is man related erosion events. Building road networks to provide forest access and managing land for activities such as timber harvesting can result in increased erosion levels. This reality magnifies as man begins to utilize more forest acreage that is both very steep and highly unstable. Such increased erosion potential may have severe consequences for any management entity responsible for land being so treated. Erosion events can reduce site productivity, delay area treatment, destroy capital investments, disrupt multiple use objectives, and create severe public reactions.

Current methodology for analyzing the costs and benefits of a projected forest use is not adequate for considering several of these key impacts. In many cases, managers do not have either the knowledge or the tools necessary to weigh properly alternative harvest and road plans. Due to a combination of reasons, there has been a surprisingly small amount of systematic and quantitative research of harvest returns, road costs, and potential erosion impacts. Because harvesting is a major source of capital and roads a major source of capital investment, as well as forest erosion, managers require more refined knowledge and analytical tools to evaluate costs and benefits of various alternatives.

The limiting alternative constraints are: road construction costs; maintenance costs; forgone access cost; harvest costs; silvicultural systems employed; or erosion potentials anticipated. How can these be identified, quantified, and integrated into the decision making process? Can potential access and harvest requirements be analyzed in terms of each user's best set of harvest constraints? When some, or all, of such perplexing questions can be answered, more sound timber management decisions will be made. Such decisions will lead to better capital investment and more stable environmental conditions. The appropriate knowledge, tools, and analysis methodology would seem to be critical inputs into the decision making process.

Study Objective

The purpose of this study is to develop and demonstrate a methodology which will integrate potential erosion consequences into the bundle of costs and benefits associated with a projected forest use. I selected timber harvesting and associated road activities, with their concomitant erosion potentials, as the forest use/erosion impact combination for analysis. The relatively high level of quantitative understanding of harvest and road operational costs and benefits was the determining factor in selection of timber harvesting as a basis for analysis. Any other specified forest use could be studied in a similar manner.

Study Scope

Aristotle's famous syllogism:

All men are mortal.
Socrates is a man.
Therefore: Socrates is mortal.

is an application of science which produces deductions on the particular from hypotheses about the general. The hypothesis that all men are mortal is an "a priori" first principle that leads to the conclusion on Socrates' mortality. The deduction depends on non-rejection of the hypothesis, the definition of Socrates as being a man, and the rule that all members of a class have like characteristics. That Socrates is a mortal is a prediction you should be able to observe in the real world. Hence, a major product of science is the conclusion <u>on the particular</u> derived <u>from</u> the perception <u>of the general</u> in which <u>both</u> are <u>tentative</u>, relying directly on the reliability of the general (Warner, 1958 and Larabee, 1964).

I initiate discussion on my study scope with this apparent tangent to underscore a significant, but very subtle point. Most related forest eco-system research involves study of the particular with no, or extremely cautious, inference to the general. The rationale for this approach is that the very complex nature of the forest eco-system and man's interaction with it prevents one from formulating general hypotheses and deducing to the most unique particular. I believe, on the contrary though, that common factors abound that will allow us to apply the Aristotlean method. Our task is to identify these factors and hypothesize about their binding relationships. Once such hypotheses are proffered we must attempt to refute them by then testing them against observations on the particular (Popper, 1957). For example, we may deduce and test relationships between specified erosion events and selected on-site variables in the following manner:

Define: slope "A" as a non-cohesive soiled, steep slope ,
Rule: All members of a class have like characteristics,
Syllogism:

"a priori" first principle:
All non-cohesive, steep slopes are debris avalanche prone.
Slope "A" is a non-cohesive soiled, steep slope.
Therefore: Slope "A" is debris avalanche prone.

Our task is then to observe slopes of type "A" over time and observe whether or not they are prone to the designated event. If they are, we do not reject the hypothesis; if they are not (at some level of significance) we do reject the hypothesis and begin again.

With this philosophy as a guiding method I divided my study into four general areas. The first two allowed for formulating the "a priori" first principles regarding hypotheses relating certain erosion events and specific on-site variables. The second two areas helped determine the form of deductions for a specific site,based on the appropriate hypotheses, rules and definitions.

My initial step involved identification of on-site variables that appeared at the outset to be generally related to certain well defined erosion events. This was accomplished by careful review of previous erosion research and close personal contact with a series of noted erosion specialists.

Secondly, I developed probability functions relating the on-site variables and the specified erosion events. This was accomplished by utilizing special survey/interview techniques to obtain empirical estimates of erosion probability schedules from a composite set of specialists: materials engineers, hydrologists, soil scientists, fisheries biologists, geologists, logging engineers, road engineers, and forest managers. These schedules were used in conjunction with a hydrologic model of a selected Western Oregon watershed to develop the family of "a priori" first principles: the appropriate probability functions.

My third step involved structuring a system model which simulated harvest and road alternatives over a rotation of nearly 90 years. The products from this model included annual: timber removals, road miles constructed/reconstructed, and estimates of sizes and numbers of each erosion event. These outputs were all "expected" values and they were determined for a variety of harvest and road alternatives.

Finally, I applied economic analysis techniques to estimate net costs and benefits associated with products of the simulation model. Estimates obtained included annual and present net worth values for: timber revenues, direct harvest costs, direct road construction and maintenance costs, site preparation and regeneration costs, reconstruction costs (due to erosion damage to roads and road structures), and site productivity costs (due to volume and growing time losses). Significantly different in this economic valuation was the inclusion of formerly unspecified estimates of capital expenses to the land manager and his timber production system due to erosion events affecting that system over a rotation.

The scope of my project ranged from formulating "a priori" first principles relating defined erosion events and selected on-site variables to deductions on what we should observe in the real world for a particular site. Because of the time element involved with the stochastic nature of geological phenomena, I was not able to submit these deductions to an adequate test for refutation. Long periods of time and periodic observations are necessary to provide reasonable tests. I, and hopefully my colleagues, will include this as a part of future research efforts.

Study Procedure

Accomplishing the purpose of this study within the scope outlined involved eight steps:

1) selecting a set of erosion events and appropriate on-site variables,
2) obtaining empirical probability schedules,
3) determining a study area and acquiring a physical data base,
4) developing a hydrologic model for the study area,
5) establishing the form of erosion probability functions tailored to the study area,
6) identifying and outlining the harvest and road alternatives,
7) building a simulation model for the alternative set,
8) estimating the cost/benefit bundle for each alternative.

II. DEFINING THE PROBLEM TYPE AND METHOD SELECTED FOR ANALYSIS

Initial study efforts were directed at developing a method for determining the probability relationships for several types of erosion events and a wide variety of possible on-site eco-system conditions. The problem encountered was the classical "uncertain, no-data" type described by Halter and Dean (1971). A recommended approach for solving this problem employs Bayesian analysis through use of "Bayes' Theorem":

$$P(EV_j|SS) = \frac{P(EV_j)\ P(SS|EV_j)}{P(EV_1)P(SS|EV_1) + \ .\ .\ .\ + P(EV_n)P(SS|EV_n)}$$

where:

EV_j--------------erosion event j,

SS --------------on-site eco-system condition,

$P(EV_j|SS)$--------posterior probability of erosion event j occurring on sites with eco-system condition SS,

$P(EV_j)$-----------prior probability of event j occurring <u>anywhere</u>,

$P(SS|EV_j)$--------likelihood of forest site with eco-system condition of SS being associated with all historical events j: called conditional probability of SS given EV_j has <u>already</u> occurred.

This chapter defines the types of erosion events and on-site variables and variable states selected for this study. Subsequent chapters develop the probabilistic relationships based on these event sets and on-site variable states which are required for application of "Bayes' Theorem". This theorem and the conditional probability relationships specified then serve as the key components of the forest erosion model developed in this study.

Selecting Erosion Events and Appropriate Physical Variables

The process of analyzing erosion events was divided into two distinct parts: 1) erosion events associated with or caused by forest roads; and 2) slope erosion not associated with forest roads. Forest road erosion was defined to consist of four mutually exclusive and exhaustive events (McNutt, 1974):

1) Off road erosion - any erosion event occurring due to the presence of a forest road but not affecting that road bed or surface (travelway cross section).

2) Road damage - any erosion event occurring due to the presence of a forest road that disrupts up to 50 percent of that road bed or surface (travelway cross section),

3) Road failure - any erosion event occurring due to the presence of a forest road that disrupts more than 50 percent of that road bed or surface (travelway cross section),

4) Nothing - actually a non-event, but occurring whenever none of the three "events" are present.

Slope erosion was defined to consist of five mutually exclusive and exhaustive events (Bailey, 1971):

1) Rockslide - downward and usually rapid movement of newly detached segments of the bedrock sliding on bedding, joint or fault surfaces or any other plane of seperation.

2) Debris avalanche/flow - sudden downslope movement of the soil mantle on steep slopes (such as headwalls). Usually leaves a gully like erosion scar,

3) Slump/earthflow - combination of processes of sliding and flowing. Upper part slides downward in one or more blocks that commonly rotate slightly about the axes that are horizontal and parallel to the slope. Lower part flows as a viscous fluid,

4) Creep - slow (very) more or less continuous downward and outward movement of slope forming soil or rock. Movement produces deformation and shifting of slope mantle, but does not result in failure,

5) Nothing - actually a non-event, but occurring whenever none of the four "events" are present.

Eight independent variables were identified to represent the key physical factors related to road erosion events:

1) Road Age - there are four variable states:

    a) 0-5 years,
    b) 6-10 years,
    c) 11-20 years,
    d) 21-+ years.

2) Road Standard - there are two variable states:

    a) Secondary --- usable width - 12 feet
    maximum subgrade width - 16 feet
    maximum curve radius - 50 feet
    maximum favorable grade - 25 percent
    maximum adverse grade - 20 percent
    average number of curves/mile - 20
    average number of cleared acres/mile

    b) Primary --- usable width - 20 feet
    maximum subgrade width - 24 feet
    minimum curve radius - 100 feet
    maximum favorable grade - 18 percent
    maximum adverse grade - 12 percent
    average number of curves/mile - 10
    average number of turnouts/mile - 0
    average number of cleared acres/mile - 16

3) Road Surface - there are two variable states:

    a) Gravel - designed for all weather use,
    b) Spot Stabilized - designed for dry weather use.

4) Slope Class - there are four variable states:

    a) 0-20 percent,
    b) 21-50 percent,
    c) 51-70 percent,
    d) 71-+ percent.

5) Soil Type - there are four variable states:

    a) Shallow non-cohesive ---- 0-20 inches of unconsolidated soil materials (potential effective rooting zone) in unified soil classification system categories: GW, GP, GM, GC, SW, SP, SM, and SC,

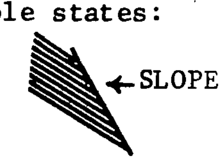
b) Deep non-cohesive ---- 21-+ inches of unconsolidated soil materials (potential effective rooting zone) in unified soil classification system categories: GW, GP, GM, GC, SW, SP, SM, and SC,
c) Shallow cohesive ---- 0-40 inches of unconsolidated soil materials (potential effective rooting zone) in unified soil classification system categories: ML, CL, OL, MG. CH, OH, and PT,
d) Deep Cohesive ---- 41-+ inches of unconsolidated soil materials (potential effective rooting zone) in unified soil classification system categories: ML, CL, OL, MG, CH, OH, and PT.

6) Landform Class - there are four variable states:

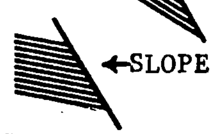
a) Headwall slope ---- bowl shaped area with slopes usually in excess of 75-80 percent at or near the ridgetop in the upper reaches of a drainage,
b) Hummocky slope ---- area with warped appearance, usually associated with past slumps, many small lakes and or undrained depressions,
c) Streamside slope ---- any slope that is neither a headwall nor a hummocky slope and is inclusive of all acreage 150 feet either side of Class I and II streams and 50 feet either side of Class III and IV streams (USFS stream classification),
d) Normal slope ---- any slope that is neither a headwall, a hummocky, nor a streamside slope.

7) Bedding Plane categories - there are five variable states:

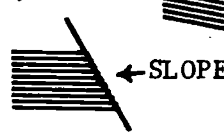
a) Dips steeply with the slope,



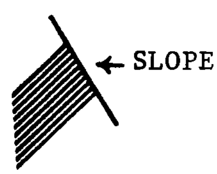
b) Dips gently with the slope,



c) Horizontal bedding,



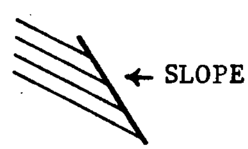
d) Dips gently against the slope,



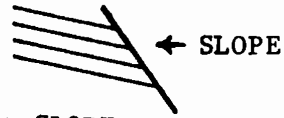
e) Dips steeply against the slope.

8) Slope Structure categories (relating to fracturing or jointing angles) - there are five variable states:

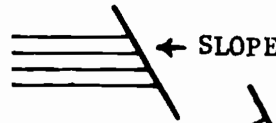
a) Fractured steeply with the slope,



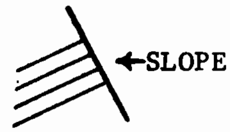
b) Fractured gently with the slope,



c) Horizontal fracturing,



d) Fractured gently against the slope,



e) Fractured steeply with the slope.

Eight independent variables were identified to represent the key physical factors related to slope erosion events.

1) Average Age Main Timber Type - there are five variable states:

   a) 0-5 years,
   b) 6-10 years,
   c) 11-20 years,
   d) 21-40 years,
   e) 41-80(+) years.

2) Harvest Method - there are four variable states:

   a) Skyline (one-end suspension),
   b) Helicoptor,(complete suspension),
   c) Highlead(full-length skidding),
   d) No harvesting (previous 20 years).

3) Silvicultural Method - there are three variable states:

   a) Clearcut (includes patch cut),
   b) Partial cut (less than 70 percent removal),
   c) Natural forest (<u>never</u> harvested).

4) through 8) are the same variables (4-8) as identified for road erosion, but are tailored to slope erosion events.

Selection of the four road erosion events, five slope erosion events, and eleven different on-site physical variables does not imply that these are closed sets. On the contrary, an infinite number of events, physical variables and variable states could be employed. However analytical and practical considerations dictated selection of the sets indicated. In all cases, the events defined have been illustrated to be highly visible and apparently important in the forest eco-system. The eleven physical variables have been regularly associated with the events defined, and as such appear initially to be important factors related to event occurences. Other variables may be important and can be added to the methodology by any interested analyst. But, the practical consideration for this study was that for the road erosion eight variable set and associated variable states there is a possible 25,600 different combinations, and for the slope erosion eight variable set and appropriate variable states, a possible 96,000.[1] For an initial analysis and new methodology development, I believed that the event, variable, and variable state sets utilized were theoretically adequate and practically manageable.

---

[1] For roads: 25,600 = (4) x (2) x(2) x (4) x (4) x (4) x (5)x (5), or the product of the number of unique variable states. For slope conditions: 96000 = (5) x (4) x (3) x (4) x (4) x (4) x (5) x (5).

III. OBTAINING EMPIRICAL PROBABILITY SCHEDULES

The appropriate erosion probability schedules were obtained by conducting a survey of selected specialists. Table 1 is a summary of biographical data for all respondents. The key to the professional codes is:

"TENS"	"UNITS"	
10 - Academic	1 - Soil Scientist	5 - Logging Engineer
20 - Industrial	2 - Hydrologist	6 - Forester
30 - State	3 - Geologist	7 - Fisheries/Biologist
40 - Federal	4 - Road Engineer	8 - Materials Engineer

(For example: 43 - federal geologist).

I selected this particular sample based on knowledge of professional reputation for each respondent. Other professionals could have been added to the sample, but because the true population size is unknown, justification of a 'large' or a 'small' sample is not relevant. Because I was able to contact most known specialists of repute in a general region from Northern California north to British Columbia and from Western Oregon east to the Rocky Mountains, I believe my sample is as representative as reasonably required for this level of analysis.

The type of analysis to be applied to this "uncertain, no-data problem" (Bayesian analysis) required information on two different relationships: 1) estimates of the probability an event occurrence will be associated with a particular variable state; and 2) estimates of event frequency probabilities for each selected erosion event (Halter and Dean, 1971). The method I chose to acquire this subjective probability information involved "game playing" suggested by work done in Halter and Dean (1971) and Payne (1951). As noted

Table 1. Summary data for the Road and Slope Erosion Survey

Respondent Number	Years experience	Hydrologic	Harvesting	Road engineering	Geological	Soil & stability	Professional Code
		* * * * * * Percent time spent on these Problems[a] * * * * * *					
1	10	70	5	0	5	20	12
2	8	60	0	0	5	35	42
3	14	5	5	5	10	75	43
4	13	4	3	3	20	70	41
5	18	20	30	5	5	40	41
6	13	10	10	10	40	30	43
7	15	10	30	5	0	55	41
8	13	10	10	30	30	20	43
9	3	30	20	20	10	20	22
10	10	50	20	5	10	15	22
11	10	20	0	10	5	65	11
12	15	60	20	10	0	10	12
13	5	5	0	30	5	60	48
14	15	5	89	1	0	5	45
15	6	0	5	5	0	90	41
16	15	20	10	5	0	50	48
17	8	35	15	0	0	50	41
18	19	15	15	15	5	50	42
19	13	5	1	30	24	40	48
20	23	25	25	15	10	25	11
21	9	60	20	0	0	20	12
22	15	0	5	5	5	85	21
23	14	0	15	25	0	60	41
24	13	60	20	0	0	20	12
25	11	5	75	5	5	10	46
26	8	0	30	20	20	30	41
27	4	55	0	5	5	35	42
28	4	0	0	0	0	100	46
29	4	10	0	0	50	40	33
30	7	33	0	33	1	33	37
31	15	10	10	10	10	60	42
32	17	20	10	0	30	40	42
33	28	5	10	65	5	15	14
34	4	50	5	5	10	30	47
35	3	5	5	20	20	50	43
Averages	11.486	22.057	14.800	11.343	9.857	41.514	

[a] When working on the five problem areas shown, each respondent's time is divided accordingly.

previously, the problem was divided into road erosion and slope (non-road related) erosion components.

Under each of these problem segments a series of questions was asked that related a specific erosion event and all variable state sets, one variable at a time. The "idea" behind each question was to estimate what variable state is more likely to be associated with a specific erosion event. Respondents were asked to draw upon all of their past experience (a composite) and not to refer to any particular erosion event or special problem. An example of the specific approach follows.

> Instructions: Answer the following questions by drawing upon all of your past experience. For each question consider only the two variable states noted in that question and estimate where the designated erosion event is more likely and least likely to occur. For each question you will be allocated $1000 to wager. The entire sum must be wagered for a complete response to each separate question.

Begin:

Assume - A debris avalanche/flow has just occurred on an acre of forest land

Variable - Slope class

Directions - Answer the three questions circled from the first six. Answer the seventh question.

1. I wager $_______the acre of forest affected was on a slope of 0-20%, and I wager $_______it was on one of 21-50%.

(2) I wager $__300__the acre of forest affected was on a slope of 51-70%, and I wager $__700__it was on one greater than 71%.

3. I wager $_______the acre of forest affected was on a slope of 21-50% and I wager $_______it was on one of 51-70%.

(4) I wager $__10__the acre of forest affected was on a slope of 0-20%, and I wager $__990__it was greater than 71%.

(5) I wager $__150__the acre of forest affected was on a slope of 21-50%, and I wager $__850__it was one greater than 71%.

6. I wager $______the acre of forest affected was on a slope of 0-20%, and I wager $______it was one of 51-70%.

7. Rank the following according to the most likely category of occurrence of the designated erosion event. A ranking of 1 is most likely and a ranking of 4 least likely.

21-50% Slope	51-70% Slope	0-20% Slope	71-+ Slope
1 2 (3) 4	1 (2) 3 4	1 2 3 (4)	(1) 2 3 4

(circle the appropriate number for ranking)

The particular sequence answered by each respondent was randomly assigned for all question sets. No two questionnaires (90 questions on road erosion and 136 on slope erosion answered) were identical. The reader will note that in the example there is a common denominator relating the three circled questions. The three slope class variable states: 51-70 percent, 0-20 percent, and 21-50 percent are all compared with the state: 71-+ percent, one at a time. All questionnaires included randomly assigned circled sets which had this type of common denominator property. Possible combinations for this example encompass circled sets: 1,4,6 (0-20%); 1,3,5 (21-50%); 2,3,6, (51-70%); and 2,4,5 (greater than 71%). Two key assumptions governed this approach and the consequent interpretation. First, the Aristotelean method moves from the general to the particular. I hypothesized that all on-site variable states may have a general relationship with each other within a class and with the specified erosion event. I then assumed that by obtaining information on several general relationships, all on-site variables separately, one could identify the particular relationship by specifying the appropriate variable state combinations which describe a certain forest site.

Secondly, I assumed that the variable states within a single on-site variable class were mutually exclusive and exhaustive. Therefore, a wager set as shown in the example indicates the following:

Question

2. 300/700 is the ratio of the probabilities a debris avalanche/flow will affect either a 51-70 percent slope or a 71-+ percent slope,

4. 10/990 is the ratio of the probabilities a debris avalanche/flow will affect either a 0-20 percent slope or a 71-+ percent slope,

5. 150/850 is the ratio of the probabilities a debris avalanche/flow will affect either a 21-50 percent slope or a 71-+ percent slope.

When a debris avalanche/flow <u>has</u> occurred, the following holds:

$$Pr(0\text{-}20)+Pr(21\text{-}50)+Pr(51\text{-}70)+Pr(71\text{-}+) = 1.00$$

Or, the sum of the probabilities that a debris avalanche/flow affects one of the slope classes must equal one. Therefore if we divide both sides of this equation by Pr(71-+) we have:

$$\frac{Pr(0\text{-}20)}{Pr(71\text{-}+)} + \frac{Pr(21\text{-}50)}{Pr(71\text{-}+)} + \frac{Pr(50\text{-}70)}{Pr(71\text{-}+)} + \frac{Pr(71\text{-}+)}{Pr(71\text{-}+)} = \frac{1.00}{Pr(71\text{-}+)}$$

and substituting:

$$\frac{10}{990} + \frac{150}{850} + \frac{300}{700} + 1 = \frac{1.00}{Pr(71\text{-}+)}$$

Then solving first for Pr(71-+) then the other probabilities yields:

Pr(0-20) = .006   Pr(21-50) = .110

Pr(51-70) =.267   Pr(71-+) = .623

All respondents' replies were set forth in this context and manipulated as indicated. The results for the example are interpreted:

> when a debris avalanche/flow occurs, the wagering indicates the subjective probabilities for it to affect a 0-20 percent, 21-50 percent, 51-70 percent or 71-+ percent slope class are respectively: .006, .110, .267, and .623. These are called conditional probabilities; given the condition that a debris avalanche <u>has</u> occurred, what is the probability it struck each state.

The means and standard deviations for the 35 sample survey on road erosion and slope erosion events and all noted on-site variables and variable states are illustrated in Tables 3-6. A complete data listing for each respondent's replies and sample questionnaires are on file in the Forest Engineering Department at Oregon State University(OSU). Data results on the ranking questions (question type number seven of the example) are not reported. This question type was a "blind question" utilized to avoid obvious inconsistencies and data manipulation errors.

Table 7 reports the results obtained for the second major category of information required to apply Bayesian analysis: estimates of event frequency probabilities. A similar approach to that demonstrated in the previous example was employed. Respondents were given a precondition of general climatic situation: 1) dry, 2) normal wet, and 3) abnormal wet. A temporal and space constraint of per month, per mile and per month per acre was established for the road erosion and slope erosion events respectively. The "idea" behind each question was to estimate for all possible road miles (forest acres) conceivable, what proportion would experience a specified erosion event in a one month period under the designated climatic conditions. Note that one possible outcome in each event set - road and slope erosion - is "nothing". Because not every forest mile, nor every forest acre, experiences an "active" eventevery month, this "non-event" type was included to provide mutually exclusive, exhaustive event sets. A typical question was:

Table 2. Key to Parameter Identification.

Road Erosion Events
T1 - Nothing
T2 - Off Road Erosion
T3 - Road Damage
T4 - Road Failure

Slope Erosion Events
D1 - Nothing
D2 - Rockslide
D3 - Debris Avalanche Flow
D4 - Slump Earthflow
D5 - Creep

Road Standard
S1 - Secondary
S2 - Primary

Road Surface
M1 - Gravel
M2 - Spot Stabilized

Road Age (years)
R1 - 0-5
R2 - 6-10
R3 - 11-20
R4 - 21- +

Slope Class (percent)
U1 - 0-20
U2 - 21-50
U3 - 51-70
U4 - 71 - +

Soil Type
V1 - Shallow non-cohesive
V2 - Deep non-cohesive
V3 - Shallow cohesive
V4 - Deep cohesive

Landform (Slope)
W1 - Normal
W2 - Streambank
W3 - Hummocky
W4 - Headwall

Bedding Plane Dip
X1 - Steeply with slope
X2 - Gently with slope
X3 - Horizontal
X4 - Gently against slope
X5 - Steeply against slope

Bedding Plane Fracture Angle
Y1 - Steeply with slope
Y2 - Gently with slope
Y3 - Horizontal
Y4 - Gently against slope
Y5 - Steeply against slope

Average Age Main Timber (Years)
E1 - 0-5
E2 - 6-10
E3 - 11-20
E4 - 21-40
E5 - 41-80- +

Harvest Method
H1 - Skyline
H2 - Helicopter
H3 - Highlead
H4 - No harvest (20 years)

Silvicultural Method
C1 - Clearcut
C2 - Partial cut
C3 - Natural Forest (never cut)

Table 3. Probability Table for Road Erosion Events and Four On-Site Variables.

Road Age	EVENTS T2 $\bar{x}/\hat{\sigma}$	T3 $\bar{x}/\hat{\sigma}$	T4 $\bar{x}/\hat{\sigma}$
R1	.58/.16	.49/.15	.48/.17
R2	.24/.10	.25/.08	.25/.11
R3	.10/.06	.14/.08	.14/.11
R4	.08/.06	.12/.06	.13/.07
Σ	1.00	1.00	1.00

Slope Class	EVENTS T2 $\bar{x}/\hat{\sigma}$	T3 $\bar{x}/\hat{\sigma}$	T4 $\bar{x}/\hat{\sigma}$
U1	.06/.06	.07/.06	.06/.04
U2	.13/.07	.16/.09	.16/.09
U3	.26/.11	.28/.07	.28/.11
U4	.55/.19	.49/.15	.50/.17
Σ	1.00	1.00	1.00

Road Standard	EVENTS T2 $\bar{x}/\hat{\sigma}$	T3 $\bar{x}/\hat{\sigma}$	T4 $\bar{x}/\hat{\sigma}$
S1	.36/.12	.38/.18	.40/.21
S2	.64/.12	.62/.18	.60/.21
Σ	1.00	1.00	1.00

Road Surface	EVENTS T2 $\bar{x}/\hat{\sigma}$	T3 $\bar{x}/\hat{\sigma}$	T4 $\bar{x}/\hat{\sigma}$
M1	.44/.11	.45/.14	.43/.13
M2	.56/.11	.55/.14	.57/.13
Σ	1.00	1.00	1.00

$\bar{x}$ = mean

$\hat{\sigma}$ = standard deviation

Table 4. Probability Table for Road Erosion Events and Four On-Site Variables.

Soil Type	EVENTS T2 $\bar{x}/\hat{\sigma}$	T3 $\bar{x}/\hat{\sigma}$	T4 $\bar{x}/\hat{\sigma}$
V1	.35/.17	.30/.18	.24/.13
V2	.24/.11	.24/.12	.28/.15
V3	.20/.09	.20/.09	.19/.11
V4	.21/.13	.26/.16	.29/.18
Σ	1.00	1.00	1.00

Land-form	EVENTS T2 $\bar{x}/\hat{\sigma}$	T3 $\bar{x}/\hat{\sigma}$	T4 $\bar{x}/\hat{\sigma}$
W1	.11/.08	.11/.07	.12/.10
W2	.24/.14	.25/.14	.23/.13
W3	.21/.13	.25/.14	.26/.15
W4	.44/.17	.39/.18	.39/.19
Σ	1.00	1.00	1.00

Bedding Plane Dip	EVENTS T2 $\bar{x}/\hat{\sigma}$	T3 $\bar{x}/\hat{\sigma}$	T4 $\bar{x}/\hat{\sigma}$
X1	.40/.17	.40/.15	.46/.19
X2	.20/.06	.21/.07	.19/.08
X3	.17/.08	.17/.09	.15/.09
X4	.12/.05	.12/.10	.11/.05
X5	.11/.07	.10/.07	.09/.06
Σ	1.00	1.00	1.00

Fracture Angle	EVENTS T2 $\bar{x}/\hat{\sigma}$	T3 $\bar{x}/\hat{\sigma}$	T4 $\bar{x}/\hat{\sigma}$
Y1	.41/.19	.44/.17	.43/.16
Y2	.21/.08	.20/.07	.22/.08
Y3	.14/.06	.13/.06	.13/.07
Y4	.13/.07	.11/.05	.11/.05
Y5	.11/.08	.12/.08	.12/.08
Σ	1.00	1.00	1.00

$\bar{x}$ = mean

$\hat{\sigma}$ = standard deviation

Table 5. Probability Table for Slope Erosion Events and Four On-Site Variables.

Average Age Main Timber Type	EVENTS D2 $\bar{x}/\hat{\sigma}$	D3 $\bar{x}/\hat{\sigma}$	D4 $\bar{x}/\hat{\sigma}$	D5 $\bar{x}/\hat{\sigma}$
E1	.29/.13	.36/.16	.28/.16	.35/.14
E2	.26/.08	.33/.12	.28/.14	.25/.10
E3	.18/.05	.15/.06	.20/.08	.17/.06
E4	.15/.06	.09/.05	.13/.07	.12/.05
E5	.12/.07	.07/.05	.11/.06	.11/.08
Σ	1.0	1.0	1.0	1.0

Slope Class	EVENTS D2 $\bar{x}/\hat{\sigma}$	D3 $\bar{x}/\hat{\sigma}$	D4 $\bar{x}/\hat{\sigma}$	D5 $\bar{x}/\hat{\sigma}$
U1	.02/.04	.03/.04	.11/.10	.05/.05
U2	.09/.07	.10/.09	.20/.11	.14/.09
U3	.25/.11	.25/.13	.32/.18	.26/.10
U4	.64/.16	.62/.18	.37/.24	.55/.18
Σ	1.0	1.0	1.0	1.0

Harvest Method	EVENTS D2 $\bar{x}/\hat{\sigma}$	D3 $\bar{x}/\hat{\sigma}$	D4 $\bar{x}/\hat{\sigma}$	D5 $\bar{x}/\hat{\sigma}$
H1	.23/.06	.25/.07	.27/.05	.26/.09
H2	.19/.07	.20/.09	.20/.08	.21/.09
H3	.45/.16	.46/.16	.41/.12	.39/.15
H4	.13/.08	.09/.07	.12/.07	.14/.17
Σ	1.0	1.0	1.0	1.0

Silvi-cultural Method	EVENTS D2 $\bar{x}/\hat{\sigma}$	D3 $\bar{x}/\hat{\sigma}$	D4 $\bar{x}/\hat{\sigma}$	D5 $\bar{x}/\hat{\sigma}$
C1	.50/.18	.67/.16	.56/.14	.57/.17
C2	.28/.09	.23/.11	.28/.06	.27/.09
C3	.22/.10	.10/.08	.16/.10	.16/.14
Σ	1.0	1.0	1.0	1.0

$\bar{x}$ = mean

$\hat{\sigma}$ = standard deviation

Table 6. Probability Table for Slope Erosion Events and Four On-Site Variables ,

Soil Type	EVENTS D2 $\bar{x}/\hat{\sigma}$	D3 $\bar{x}/\hat{\sigma}$	D4 $\bar{x}/\hat{\sigma}$	D5 $\bar{x}/\hat{\sigma}$
V1	.52/.24	.47/.20	.10/.10	.33/.22
V2	.18/.12	.21/.12	.18/.13	.24/.13
V3	.19/.12	.21.14	.17/.12	.21/.14
V4	.11/.10	.11/.09	.55/.25	.22/.19
Σ	1.0	1.0	1.0	1.0

Land-form	EVENTS D2 $\bar{x}/\hat{\sigma}$	D3 $\bar{x}/\hat{\sigma}$	D4 $\bar{x}/\hat{\sigma}$	D5 $\bar{x}/\hat{\sigma}$
W1	.12/.10	.11/.10	.14/.10	.16/.13
W2	.21/.18	.23.18	.20/.12	.28/.22
W3	.07/.08	.09/.09	.51/.21	.24/.21
W4	.60/.23	.57/.23	.15/.15	.32/.24
Σ	1.0	1.0	1.0	1.0

Bedding Plane Dip	EVENTS D2 $\bar{x}/\hat{\sigma}$	D3 $\bar{x}/\hat{\sigma}$	D4 $\bar{x}/\hat{\sigma}$	D5 $\bar{x}/\hat{\sigma}$
X1	.53/.24	.45/.19	.42/.23	.41/.16
X2	.17/.09	.20/.10	.20/.06	.21/.07
X3	.13/.08	.15/.07	.16/.08	.16/.06
X4	.09/.07	.10/.06	.12/.09	.11/.06
X5	.08/.08	.10/.08	.10/.07	.11/.06
Σ	1.0	1.0	1.0	1.0

Fracture Angle	EVENTS D2 $\bar{x}/\hat{\sigma}$	D3 $\bar{x}/\hat{\sigma}$	D4 $\bar{x}/\hat{\sigma}$	D5 $\bar{x}/\hat{\sigma}$
Y1	.46/.20	.42/.20	.37/.20	.39/.16
Y2	.21/.11	.20/.08	.22/.08	.22/.05
Y3	.12/.07	.13/.07	.15/.07	.15/.06
Y4	.11/.07	.13/.08	.12/.06	.13/.06
Y5	.10/.10	.12/.11	.14/.12	.11/.07
Σ	1.0	1.0	1.0	1.0

$\bar{x}$ = mean

$\hat{\sigma}$ = standard deviation

Table 7. Event Frequencies for Road and Slope Erosion Events.

ROAD EROSION EVENTS

Climatic Condition	T1 $\bar{x}/\hat{\sigma}$	T2 $\bar{x}/\hat{\sigma}$	T3 $\bar{x}/\hat{\sigma}$	T4 $\bar{x}/\hat{\sigma}$	Σ
Dry	.95/.06	.02/.03	.02/.03	.01/.02	1.00
Wet	.58/.31	.22/.19	.13/.12	.07/.09	1.00
Very Wet	.32/.30	.32/.21	.22/.15	.14/.14	1.00

SLOPE EROSION EVENTS

Climatic Condition	D1 $\bar{x}/\hat{\sigma}$	D2 $\bar{x}/\hat{\sigma}$	D3 $\bar{x}/\hat{\sigma}$	D4 $\bar{x}/\hat{\sigma}$	D5 $\bar{x}/\hat{\sigma}$	Σ
Dry	.93/.06	.02/.03	.01/.02	.01/.01	.03/.03	1.00
Wet	.53/.29	.07/.08	.11/.11	.10/.08	.19/.15	1.00
Very Wet	.36/.27	.19/.18	.19/.18	.15/.13	.23/.20	1.00

$\bar{x}$ = mean

$\hat{\sigma}$ = standard deviation

> Given a dry climatic state, a perspective of per acre, per month, $1000 to wager, and the knowledge that one of the two events noted in each question has occurred --
>
> > I wager \$ 995 nothing occurred and I wager \$ 5 that a debris avalanche occurred.

A total of 27 questions of this type, 12 on road erosion and 15 on slope erosion events, was asked each survey respondent. All respondents' replies were manipulated exactly as described for the variable state question sets previously discussed. The resultant probability entries in the matricies in Table 7 are interpreted:

> when the monthly climatic condition is "wet" (pre-condition), each mile of road has a probability of 0.58, 0.22, 0.13, and 0.07 for nothing, off road erosion, road damage, or road failure to occur respectively. Each acre of forest land has a probability of 0.36, 0.19, 0.19, 0.15, and 0.23 of being affected by nothing, a rockslide, a debris avalanche flow, a slump earth flow, or a creep acceleration. These are "universal" or "average" probabilities for what one would expect for all road miles and all forest acres.

The output from the 18 probability matricies in Tables 3-7 provide the "a priori" first principles regarding road and slope erosion. That is to say they provide the hypotheses on the general, variable states taken individually, which can be utilized to deduce outcomes on the particular, variable state combinations. The purpose of the remaining portion of this study is to demonstrate a process of deduction and an estimate of consequences of the deductive sets.

IV. DETERMINING A STUDY AREA AND ACQUIRING A PHYSICAL DATA BASE

After careful reconnaissance, I selected a study area on United States Department of Agriculture, Forest Service (USDA FS) land in Western Oregon assigned to the Smith River Ranger District, Siuslaw National Forest. The specific study site is a 3500 acre tract located in the Smith Umpqua land block just east of the confluence of the Smith and Umpqua rivers. The tract, called Harvey Creek Drainage, is annotated on the map in Figure 1.

The topography is highly variable and the soils are fragile and unstable. Burroughs, et al (1973) have characterized the erosion problem as one dominated by debris avalanche/flows. The basic formation is that of bedded sediments found in the form of sandstone bedrocks. The basic soil formations are Tyee and Yamhill, and the area is characterized by steep slopes, and sharp ridges overlain with these shallow non-cohesive soils. The landscape is highly dissected by many stream channels that are very steep near ridge tops. Headwalls are present throughout the drainage. The tract is quite homogeneous in these characteristics, and Figure 2 illustrates the general landform conditions found throughout the drainage (Burroughs, et al, 1973).

The climate is typical of Coast Range sites. Precipitation ranges from 75 to 150 inches annually and averages nearly 100 inches. Almost all precipitation is delivered as rainfall during the period from October through May.

FIGURE 1. Harvey Creek Drainage Near Reedsport.

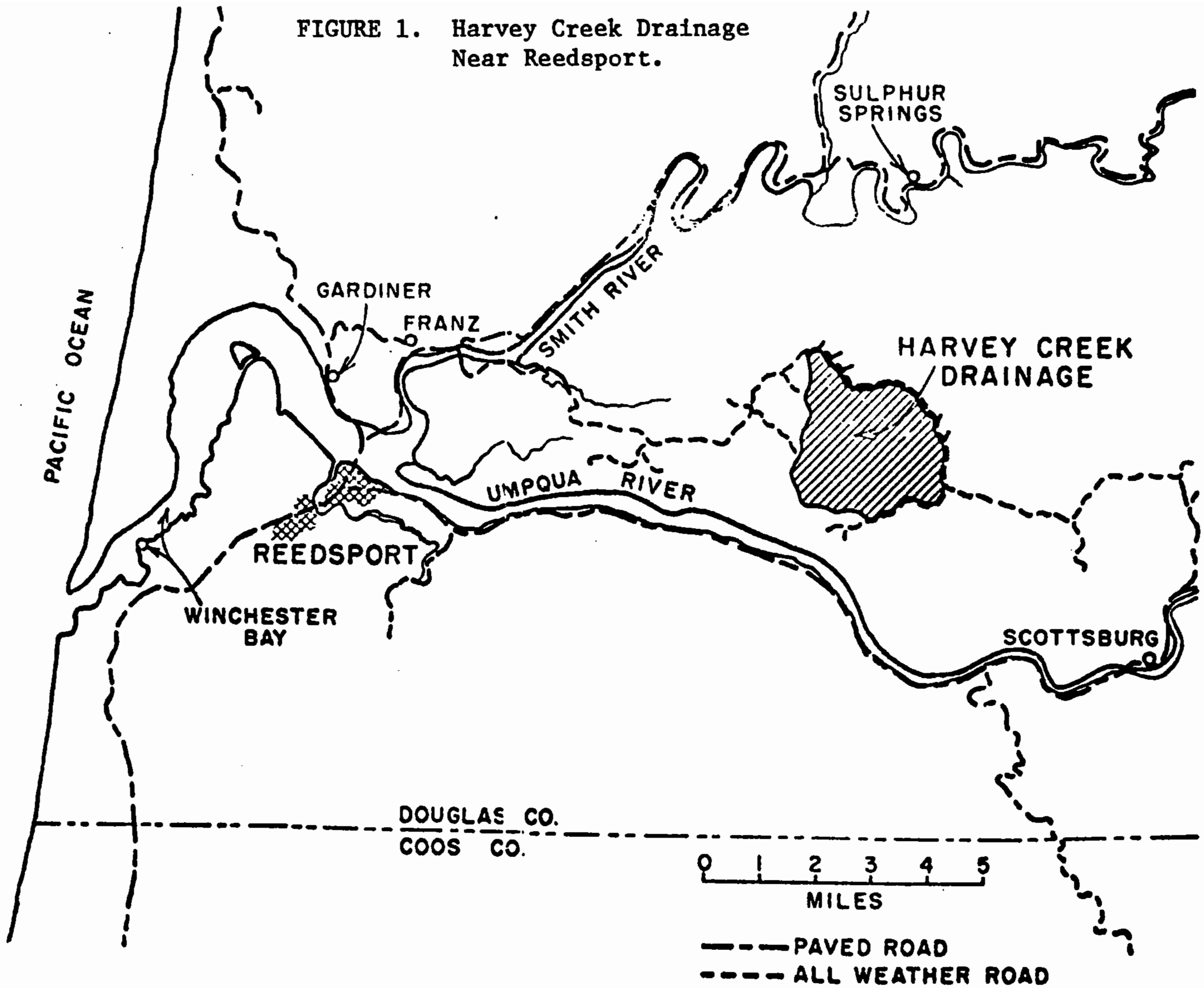
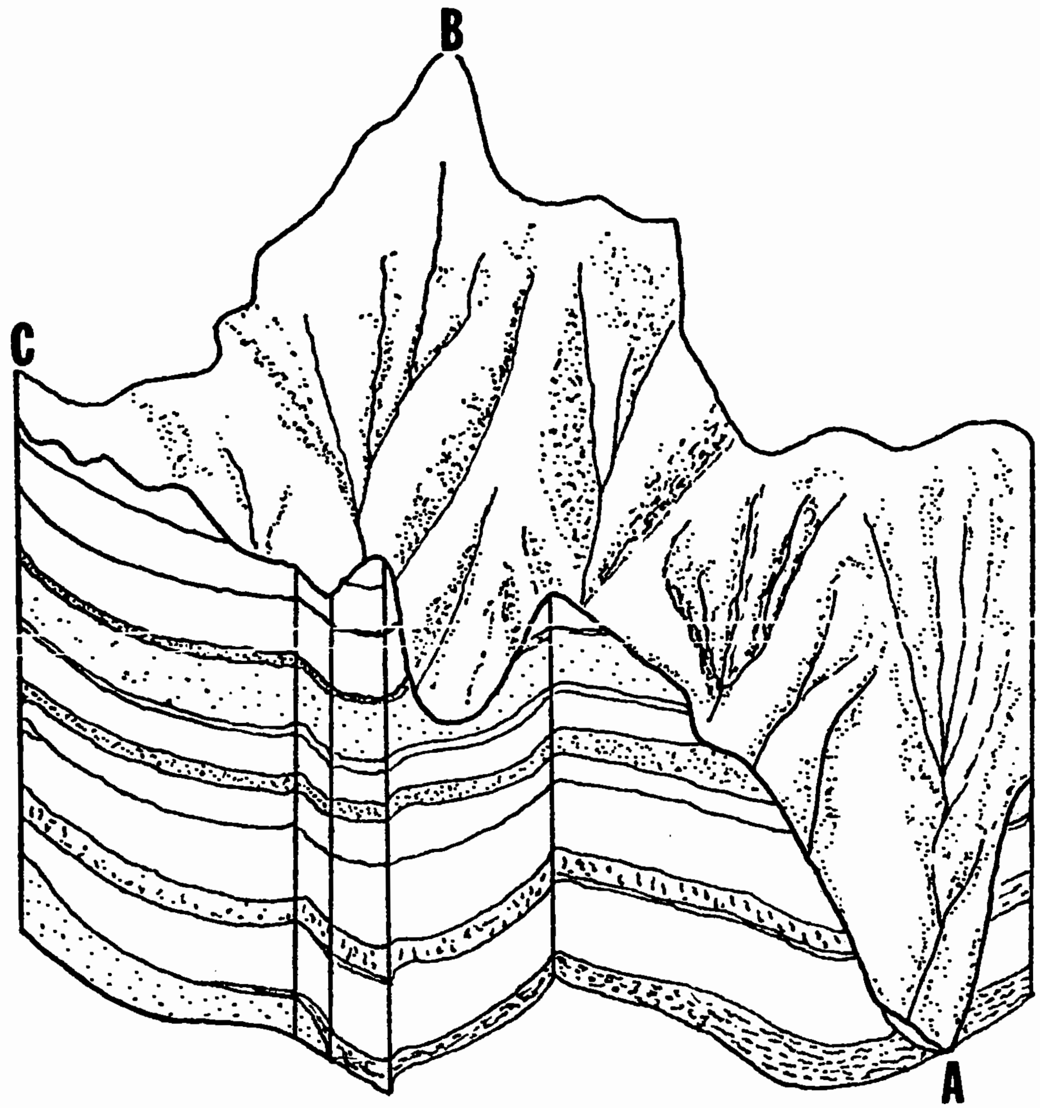


FIGURE 2. Block Diagram of Typical Landform Conditions for the Harvey Creek Drainage (after Burroughs, et al, 1973)



A - Mouth of the basin, and steep headwall area.

B - Steep headwall area below basin highpoint.

C - A basin highpoint with no headwall below.

The timber is primarily large second growth Douglas-fir (resulting from numerous area fires). This 75-150 year old timber serves as a potentially very valuable standing component of the Siuslaw National Forest timber resource. However, due to area instability, many erosion problems have emerged during and following recent efforts to remove some of this prime timber. Because of these problems, the Siuslaw National Forest suspended temporarily all harvest operations in 1970.

In consonance with this action is a more recent Siuslaw National Forest decision to conduct a forest wide "Land Suitability Analysis." The goals of this analysis are threefold (USDA FS, 1974):

1) Determine immediate needs of the land manager to understand potential risks and hazards to specific land areas from current timber sale decisions,

2) Develop a Forest Timber Management Plan which stratifies the timber growing base into land suitable and unsuitable for harvesting under current logging system techniques,

3) Determine the important factors affecting the suitability and availability of the land for timber production and the consonant effects upon other interrelated resources.

These goals are somewhat synonomous with projected outputs of my study, hence a close working relationship was established with Siuslaw National Forest personnel. Satisfying the three analysis goals required collection and organization of an indepth physical data base for all Siuslaw National Forest lands. Forest personnel concentrated their initial efforts in this task on and around my study area. This led to the compilation of detailed soil surveys, topographic chartings, and hydrologic and vegetative surveys for the Harvey Creek Drainage. I have had complete access to this physical data base. Additionally, I have supplemented the basic data with numerous field trips into the study area. These trips have helped to acquire more information on road conditions, specific road and slope failures, and general site conditions related to recent harvest activities. The data provided by forest personnel was assumed to be accurate except where on-site inspections dictated significant changes.

V. DEVELOPING A HYDROLOGIC MODEL FOR THE HARVEY CREEK DRAINAGE

Water plays a key role in determining erosion potential. The rationale for building a hydrologic model was to simulate monthly values of selected watershed variables which would help describe this role. These variables were subsequently used to develop a set of erosion index populations which establish the joint climatic-hydrologic on-site condition each month. The erosion index population values are used to calculate the "universal" monthly probabilities for each road and slope erosion event. The "universal" monthly probabilities, the conditional probabilities in Tables 3-7, and "Bayes' Theorem" are used to calculate expected monthly erosion probabilities for all drainage sites.

The hydrologic model employed was based on a simple water balance equation (see page 42) and two key assumptions. Monthly values of precipitation, runoff, evapotranspiration, subsurface soil water fluxes, and soil water content are indicators of general hydrologic and storm activity levels. And, erosion potentials are related to storm sizes, frequencies, and soil water conditions. Validity of these assumptions has neither been conclusively supported nor refuted by previous hydrologic and geologic research. They are employed here for two practical reasons. Geologic phenomena are long term by nature; to rely on small time increments to explain activity levels would be quite costly. The assumptions are logical consequences of, and do not conflict with, previous hydrologic and geologic findings.

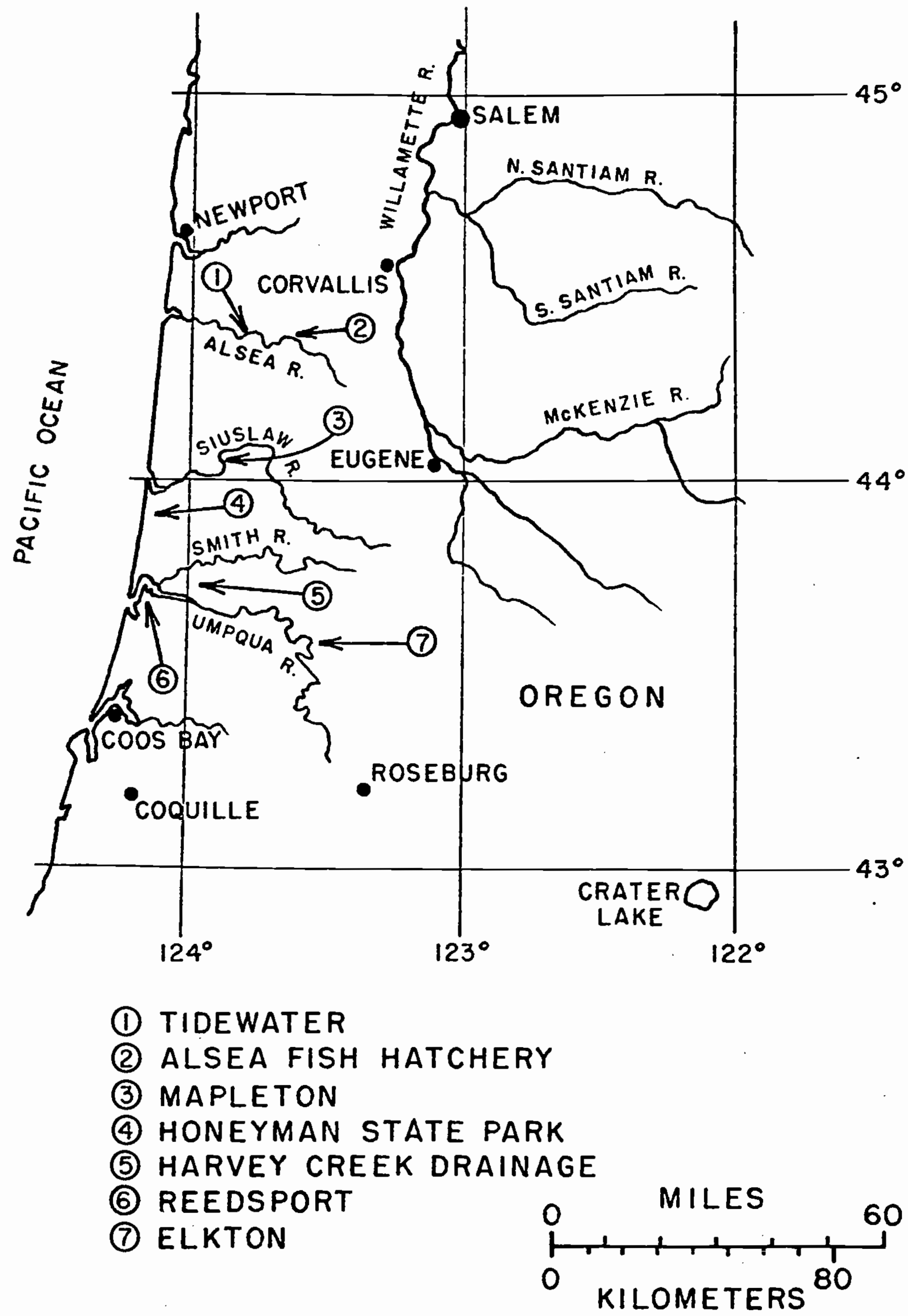
A typical problem encountered was the lack of hydrologic and climatologic data available for the Harvey Creek Drainage. Statistical procedures employed in this study require 40 to 50 years of monthly information for selected watershed variables. Since this information was not available, statistical techniques and regression analysis were applied to other area hydrologic and climatologic station data to construct an artificial data base. Six station information bases were examined for use: Elkton, Mapleton, Reedsport, Honeyman State Park (formerly Canary), Alsea Fish Hatchery, and Tidewater (on the Alsea River) (see Figure 3). Examination of key geophysical and climatologic factors for each locale led to the decision to utilize climatologic information from Alsea Fish Hatchery, and streamflow data from Tidewater.

The USDA and U.S. Weather Bureau precipitation Isohyetal maps for Alsea Fish Hatchery and Harvey Creek Drainages indicate both are in the 95-100 inch annual precipitation category (USDA and US Weather Bureau,1964). Similar maps for precipitation intensities show that both sites experience identical levels for the (USDA and US Department of Commerce, 1971) following:

Two year six hour precipitation - 0.22 inches,
Five year six hour precipitation - 0.26 inches,
Ten year six hour precipitation - 0.30 inches,
Fifty year six hour precipitation - 0.35 inches,
100 year six hour precipitation - 0.40 inches,
Two year 24 hour precipitation - 0.50 inches,
Five year 24 hour precipitation - 0.60 inches,
100 year 24 hour precipitation - 0.90 inches.

The US Department of Interior (USDI) Geological Survey(1970) reports that the Alsea River Basin and Harvey Creek Drainage both have annual runoff of 60-70 inches. Orwig (1973) identified seven independent basin variables as keys to monthly runoff in the Oregon Coast Range: airmass lift, basin aspect, soils index, mean basin elevation, drainage density, normal annual precipitation, and rainfall intensity. These properties were extremely similar for both drainage basins.

FIGURE 3. Six Climatological Stations Considered for Correlation with Harvey Creek Drainage Geophysical and Climatological Factors.



This is indicative of highly related runoff as well as precipitation patterns at monthly levels. Based on these findings, and the assumption that runoff measured at Tidewater is a response of basin precipitation measured at the Alsea Fish Hatchery, Harvey Creek was assumed to have a monthly precipitation pattern similar to historical records for Alsea Fish Hatchery, and a monthly runoff response similar to that recorded at Tidewater. With this as a base, a hydrologic model was built which treats five main variables: monthly precipitation, runoff, evapotranspiration, subsurface soil water fluxes, and soil water content.

Precipitation

Modeling monthly precipitation required fitting continuous distributions for each month of the year. Measuring goodness of fit (Chi-square test) and fitting procedures generally require a sample size of 40 or greater for statistical reliability (Weatherill, 1972). Because Alsea Fish Hatchery data was to be used for predicting runoff, this data was necessarily the basis for fitting the 12 monthly precipitation distributions. Only 22 years of data existed for this station, therefore, best possible fitting and fit testing procedures required expansion of this data base. Regression analysis and 42 years of data from the Honeyman State Park Station were used to predict an additional 20 years of monthly Alsea data. The regression basis was the 22 common years of data for the stations. Predicted precipitation values were based on the remaining 20 years of Honeyman State Park data. Table 8 describes regression results. Appendix A reports monthly precipitation data for Alsea Fish Hatchery, Honeyman State Park, and predicted data for Alsea Fish Hatchery.

Key to Table 8 (After Draper and Smith, 1968).

Sample size - n = 22
* - indicates value is in natural logarithmic units
P_i , i = 1, 12 - the dependent variable, Alsea Fish Hatchery precipitation for month i (inches).
X_i., i = 1, 12 - the independent variable, Honeyman state precipitation for month i (inches)
F - Value & ν_1 & ν_2 - Test of model variable significance and the appropriate degrees of freedom ν_1 and ν_2
R^2 - a measure of the proportion of total variation about the mean of P_i explained by the regression.
MSE - mean square error, an estimate based on n-2 degrees of freedom of the variance about the regression of the predicted variable.
Y - symbol for the original dependent random variable
$\hat{Y}$ - or YHAT - symbol for the predicted value of Y based on the current regression equation.
$\hat{\sigma}$ - standard deviation estimate for the indicated samples, not for the regression "equation."

All regression results were examined in a number of different ways to evaluate reliability of six basic regression assumptions (Kmenta, 1971):

1) Error term is normally distributed,
2) Expected value of the error term is zero,
3) Variance of the error term is a constant,
4) Error terms are not correlated in time and/or space,
5) Each explanatory variable is non-stochastic,
6) No explanatory variable has an exact linear relation with any other explanatory variable or any set of other explanatory variables.

Note that assumption six is not applicable in simple linear regression; later multiple regression employs all six assumptions.

In every case, the regression equations maintained basic monthly distribution shapes. Use of regression functions to create an additional 20 years of monthly precipitation data for the Alsea Fish Hatchery station appeared to be a reasonable application. Combined with the existing 22 years of data, this provided a total of 42 sample

Table 8. Precipitation Regression Models and Statistics [a]

Month	Models	F-Value (ν_1, ν_2)	R^2 (MSE)	MAX - $\hat{y}$ - (y)	MIN - $\hat{y}$ - (y)	RANGE - $\hat{y}$ - (y)	MEAN - $\hat{y}$ - (y)	σ - $\hat{y}$ - (y)
January	$P1 = 1.313\ X1^{.984}$	85.4 (1, 21)	0.80 (.056*)	30.99 (34.45)	6.34 (5.70)	24.64 (28.75)	18/37 (18.72)	7.36 (7.99)
February	$P2 = 1.365\ X2^{.960}$	142.7 (1, 21)	0.87 (.025*)	20.78 (25.10)	4.27 (3.79)	16.52 (21.31)	12.18 (12.33)	4.20 (4.82)
March	$P3 = 1.391\ X3^{.933}$	142.6 (1, 21)	0.87 (.034*)	21.04 (20.22)	2.69 (1.93)	18.35 (18.29)	12.40 (12.46)	4.43 (4.28)
April	$P4 = 1.355\ X4^{.901}$	139.1 (1, 21)	0.87 (.050*)	12.88 (13.17)	1.84 (1.63)	11.05 (11.54)	6.57 (6.65)	3.08 (3.16)
May	$P5 = 1.033 + .755\ X5$	51.9 (1, 21)	0.72 (1.38)	8.66 (9.01)	1.86 (1.47)	6.80 (7.54)	3.82 (3.82)	1.81 (2.14)
June	$P6 = 1.023\ X6^{.711}$	30.9 (1.21)	0.60 (.133*)	3.47 (3.22)	0.68 (0.57)	2.79 (2.65)	1.96 (2.05)	0.77 (0.92)
July	$P7 = .003 + .743\ X7$	342.8 (1, 21)	0.94 (.003)	2.35 (2.43)	0.01 (0.01)	2.34 (2.42)	0.55 (0.55)	0.69 (0.71)
August	$P8 = .045 + .801\ X8$	152.5 (1, 21)	0.88 (.260)	5.82 (5.81)	0.06 (0.01)	5.77 (5.80)	1.14 (1.14)	1.34 (1.43)
September	$P9 = -.350 + 1.277\ X9$	50.0 (1, 21)	0.71 (2.12)	9.30 (11.48)	0.20 (0.09)	9.10 (11.39)	3.22 (3.22)	2.19 (2.61)
October	$P10 = .875\ X10^{1.075}$	72.6 (1, 21)	0.78 (.159*)	13.70 (13.86)	1.00 (0.45)	12.70 (13.41)	6.56 (6.69)	3.60 (3.44)
November	$P11 = 4.273 + .855\ X11$	48.6 (1, 21)	0.71 (9.06)	20.52 (23.13)	5.34 (4.15)	15.18 (18.98)	13.40 (13.40)	4.58 (5.44)
December	$P12 = 1.317\ X12^{.981}$	212.5 (1, 21)	0.91 (.017*)	26.37 (32.20)	6.49 (6.64)	19.88 (25.56)	17.66 (17.78)	6.04 (6.46)

/a See page 34 for key to table use

points of monthly data for fitting and fit testing.

All distribution fitting and fit testing were based on statistical procedures outlined in Fishman (1973), Brownlee (1965), Wetherill (1972), and presentations by Scheurman (1974). Dennis Dykstra, Department of Forest Engineering at OSU, provided assistance through collaberation on computer programming for distribution fitting. Three continuous distributions were fit where appropriate to each month's precipitation data: 1) Normal; 2) Exponential; and 3) Weibull.

	Probability Density Function (pdf)	Limits	Cumulative Distribution Function (CDF)
1)	$f(x) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-(x-\mu)^2/2\sigma^2}$	$-\infty \leq x \leq \infty$	$F(x) = \frac{1}{\sqrt{2\pi}\,\sigma}\int_{-\infty}^{x} e^{-(t-\mu)^2/2\sigma^2} dt$
2)	$f(x) = \begin{cases} \frac{1}{\lambda} e^{(x/\lambda)} & \text{if } 0 \leq x \leq \infty \\ 0 & \text{if } x \leq 0 \end{cases}$		$F(x) = 1-e^{-(x/\lambda)}$
3)	$f(x) = \begin{cases} \frac{\alpha}{\beta^{\alpha}} x^{(\alpha-1)} e^{-(x/\beta)^{\alpha}} & \text{if } 0 \leq x \leq \infty \\ 0 & \text{if } x \leq 0 \end{cases}$		$F(x) = 1-e^{-(x/\beta)^{\alpha}}$

Symbol	Explanation	Symbol	Explanation
x	Random variate	e	Value≃ 2.7183·····
μ	Mean	λ	Mean and shape parameter
σ^2	Variance	α	Shape paramater
π	Value ≃ 3.1416·····	β	Scale parameter

Table 9 illustrates results of fitting and fit testing. In all instances, the χ^2 test for the two parameter Weibull distributions yielded non-significant (only poor fits are significant) results. In only two cases, March and April, did either the normal or exponential produce a better χ^2 goodness of fit result. Due to closeness of March and April

Table 9. Precipitation Distribution Fitting .

Month	Weibull Parameters $\hat{\alpha}$	$\hat{\beta}$	Weibull χ^2_ν	Normal χ^2_ν	Exponential χ^2_ν
January	2.609	18.967	$\chi^2 = 1.286$ $\nu = 3$	$\chi^2 = 9.240$ $\nu = 3$	NOT FIT
February	2.804	14.052	$\chi^2 = 1.104$ $\nu = 3$	$\chi^2 = 2.360$ $\nu = 3$	NOT FIT
March	3.150	13.156	$\chi^2 = 1.623$ $\nu = 3$	$\chi^2 = 1.243$ $\nu = 3$	NOT FIT
April	2.257	7.116	$\chi^2 = 2.582$ $\nu = 3$	$\chi^2 = 2.053$ $\nu = 3$	NOT FIT
May	1.811	4.590	$\chi^2 = 4.070$ $\nu = 3$	$\chi^2 = 10.480$ $\nu = 3$	NOT FIT
June	1.759	2.190	$\chi^2 = 2.906$ $\nu = 3$	$\chi^2 = 4.220$ $\nu = 3$	$\chi^2 = 16.283$ $\nu = 3$
July	0.845	0.565	$\chi^2 = 5.020$ $\nu = 3$	NOT FIT	$\chi^2 = 7.582$ $\nu = 3$
August	0.792	0.815	$\chi^2 = 1.553$ $\nu = 4$	NOT FIT	$\chi^2 = 3.047$ $\nu = 4$
September	1.262	3.408	$\chi^2 = 7.880$ $\nu = 3$	$\chi^2 = 9.409$ $\nu = 3$	NOT FIT
October	1.681	7.869	$\chi^2 = 3.072$ $= 4$	$\chi^2 = 4.769$ $\nu = 4$	NOT FIT
November	2.551	16.135	$\chi^2 = 1.077$ $\nu = 3$	$\chi^2 = 1.699$ $\nu = 3$	NOT FIT
December	3.084	18.674	$\chi^2 = 3.702$ $\nu = 3$	$\chi^2 = 4.912$ $\nu = 3$	NOT FIT

n = 42 ν = degrees of freedom = (# of cells)-(# parameters)-(1)

All Chi-square (χ^2) test intervals contained at least five observations

All Weibull fits are "not significant", e.g. do not reject hypotheses that Weibull distributions fit the respective sample populations

The level of significance was: $\gamma = 0.05$

Weibull and Normal fits, and because of difficulties of simulating accurately from Normal distributions, as well as the ease of simulating responsively from Weibull distributions, Weibull distributions were selected for modeling all twelve months' precipitation data. Estimation of the two Weibull parameters was accomplished by employing an algorithm based on Maximum Likelihood Estimation (MLE), presented by Fishman (1973), and through the aid of a FORTRAN IV program which can be found in Appendix B.

Runoff

Similar to precipitation modeling, monthly runoff prediction required development of twelve functional relationships. Regression analysis was applied to 20 years of monthly precipitation data from the Alsea Fish Hatchery and the available 20 years of data for monthly runoff from Tidewater.

All regression analysis involved regressing a dependent variable (monthly runoff) on seven independent variables (monthly precipitation and the three previous months' precipitation and runoff). The basic approach used was a "modified backstep" regression analysis. A full model is specified and least significant variables are dropped one at a time in each backstep. At each juncture, t-values of previously dropped variables were scanned. Any departed variable which had a t-value that climbed back above $\pm$ 1.80 (γ = .05) was reentered the specified model. The goal of modeling was to minimize the MSE at a selected level of significance (e.g. γ=.05), not to maximize R^2. This approach allows for development of more significant models than does "stepwise regression" or maximization of the R^2 value alone (Draper and Smith, 1968). Table 10 reports regression analysis results.

Key to Table 10 (after Draper and Smith, 1968).

Sample size - n = 20.
* - indicates value is in natural logarithmic units.
R_i, i = 1, 12 - the Alsea River at Tidewater runoff values for month i.
P_i, i = 1, 12 - the Alsea Fish Hathery precipitation values for month i.
γ - level of significance.
F - value & ν_1, ν_2 - Test of model variables 'joint' significance and the appropriate degrees of freedom ν_1 and ν_2
R^2 - a measure of the proportion of total variation about the mean of the dependent variable explained by regression.
MSE - mean square error, an estimate based on n-2 degrees of freedom of the variance about the regression of the predicted variable.
Y - symbol for the original dependent variable.
$\hat{Y}$ - or YHAT - symbol for the predicted value of Y based on the current regression equation.
$\hat{\sigma}$ - standard deviation estimate for the indicated samples, not for the regression "equation."

The twelve functions were analyzed for the reliability of the six basic regression assumptions specified by Kmenta (1971) and listed previously. All models were significant, generally highly predictive, and stable relative to initial base modeling assumptions. Twenty years of Tidewater Runoff data can be found in Appendix A.

Evapotranspiration

A more general approach was utilized to develop evapotranspiration functions. Gerald Swank, USFS, Region 6 Hydrologist provided estimates of monthly lake evaporation (LE) for the Harvey Creek area. Combined with two regression equations developed by Mustonen (1968), for estimating evapotranspiration in a humid environment, this yielded evapotranspiration functions for the 12 months. Mustonen presented two main equations:

$$ET_i = .88LE_i \ (P_i + .40)^{.20} \quad \text{for the growing season,}$$
$$R^2 = .76 \qquad \hat{\sigma} = .75,$$

Table 10. Runoff Regression Models and Statistics.[a]

Month	RUNOFF REGRESSION MODELS	Least Significant Variable	F-Value (ν_1, ν_2)	R^2 (MSE)	MEAN $\hat{y}$ ($\bar{y}$)	σ $\hat{y}$ ($\bar{y}$)	MAX 20 year Error (in.)
January	$R_i = .37P_i^{1.98} P_{i-1}^{0.20}$	$\gamma = 0.04$ P_{i-1}	124.8 (2, 17)	0.94 (.0277*)	13.68 (13.78)	6.74 (6.83)	− 4.56
February	$R_i = -.70 + .80P_i + 1.05P_{i-1} - 1.03R_{i-1} - .35R_{i-3}$	$\gamma = 0.01$ R_{i-3}	23.6 (4, 15)	0.88 (2.97)	10.34 (10.15)	4.06 (4.29)	− 2.79
March	$R_i = -4.80 + .95P_i + 1.64P_{i-3}$	$\gamma = 0.0075$ P_{i-3}	58.3 (2, 17)	0.88 (2.32)	9.73 (9.73)	3.88 (4.14)	+ 3.20
April	$R_i = .25 + .57P_i + .36P_{i-2} - .29R_{i-2}$	$\gamma = 0.03$ R_{i-2}	13.9 (3, 16)	0.74 (2.27)	5.41 (5.41)	2.29 (2.67)	+ 2.37
May	$R_i = .39P_i^{0.39} P_{i-1}^{0.37} P_{i-3}^{0.31}$	$\gamma = 0.02$ P_{i-3}	16.3 (3, 16)	0.77 (.0538*)	2.58 (2.67)	0.93 (1.40)	− 2.31
June	$R_i = .48P_{i-1}^{0.46} P_{i-3}^{0.13}$	$\gamma = 0.075$ P_{i-3}	13.6 (2, 17)	0.63 (.0416*)	1.16 (1.18)	0.30 (0.40)	− 0.28
July	$R_i = .50P_i^{0.05} R_{i-1}^{0.51} R_{i-3}^{0.12}$	$\gamma = 0.02$ R_{i-3}	29.9 (3,16)	0.86 (.0095*)	0.60 (0.60)	0.13 (0.14)	− 0.16
August	$R_i = .03 + .07P_i + .47R_{i-1} + .02P_{i-2} - .01P_{i-3}$	$\gamma = 0.03$ P_{i-3}	59.7 (4, 15)	0.94 (.0012)	0.38 (0.38	0.13 (0.13)	+ 0.05
September	$R_i = .05 + .09P_i + .07P_{i-1} + .04P_{i-2}$	$\gamma = 0.03$ P_{i-2}	78.7 (3, 16)	0.94 (.0045)	0.45 (0.45)	0.24 (0.25)	+ 0.13
October	$R_i = -1.26 + .21P_i + .06P_{i-1} + 1.70R_{i-2} + .18P_{i-3}$	$\gamma = 0.05$ P_{i-3}	24.3 (4, 15)	0.87 (.116)	1.20 (1.20)	0.80 (0.85)	− 0.53
November	$R_i = -7.66 + .68P_i + .54P_{i-1}$	$\gamma = 0.001$ P_{i-1}	66.5 (2, 17)	0.89 2.944	6.40 (6.29	4.66 (5.01)	+ 2.60
December	$R_i = -7.85 + .83P_i + .23P_{i-1} + 1.92R_{i-2}$	$\gamma = 0.001$ P_{i-1}	120.6 (3, 16)	0.96 1.941	12.26 (12.27)	6.24 (6.37)	− 2.21

[a] See page 39 for key to table use

$ET_i = LE_i$ for the dormant season,

$$R^2 = .83 \quad \hat{\sigma} = .37.$$

ET_i is evapotranspiration for month i in inches and LE_i and P_i are month i lake evaportation and precipitation, respectively. The growing season is April through September, and dormant season October through March. These functions provided measures of evapotranspiration required for modeling.

Subsurface Soil Water Losses

A simple water balance equation was used as the overall model integrating function. All variables are measured in inches of water.

$$S_i = S_{i-1} + P_i - R_i - ET_i + AL_i - I_i$$

where: S_i, i = 1, 12 = soil water content for month i,
S_{i-1}, i=1, 12 = soil water content for month i-1,
P_i, i =1, 12 = precipitation for month i,
R_i, i = 1, 12 = runoff for month i,
ET_i, i=1, 12 = evapotranspiration for month i,
and AL_i, i = 1, 12 = net subsurface inflow and outflow for month i.

Interception losses, I_i, are accounted for by utilizing regression equations based on precipitation levels to calculate monthly runoff. Therefore, this term is eliminated. Additionally, the long term change in soil water content ($S_i - S_{i-1} = \Delta S$) equals zero. Because average values reflect long term conditions, where the subscript 'a' denotes annual averages and P_a, R_a, and ET_a are known:

$$\Delta S = 0.0 = P_a - R_a - ET_a + AL_a,$$

$$AL_a = R_a + ET_a - P_a$$

$$AL_a = 64.11 + 25.56 - 98.81, \quad \text{therefore: } AL_a = -9.14 \text{ inches.}$$

The minus sign indicates average ground water flux is out of the system: a water loss. With greater losses during high rainfall periods than low assumed, the following function was utilized to calculate the monthly flux:

$$AL_i = AL_a \left[\left(\frac{P_i}{P_{ai}} \right) \left(\frac{R_{ai}}{R_a} \right) \right]$$

where:

AL_i, i = 1, 12 = subsurface water loss for month i,
AL_a = annual average subsurface water loss,
P_i, i = 1, 12 = precipitation for month i,
P_{ai}, i = 1, 12 = average precipitation for month i,
R_{ai}, i = 1, 12 = average monthly runoff for month i,
and R_a = average annual runoff.

This equation provides dynamic subsurface soil water fluxes for modeling purposes.

Soil Water Content

Soil water content determination is straight forward. Everything on the right hand side of the water balance equation except the initial value of S_{i-1} is accounted for:

$$S_i = S_{i-1} - P_i - R_i - ET_i + AL_i \ .$$

This initial value can be set at any reasonable arbitrary level to initiate model operations. A value of S_{i-1} equal to 10.0 inches was employed.

Yee (1975), reports that soil and topography similar to that of the Harvey Creek Drainage, seldom exceeds a volumetric soil water content of 50 to 55 percent. Here:

$$\Theta_\nu = S/s.d., \text{ where}$$

Θ_ν is volumetric soil water content, S soil water content in inches, and s.d. soil depth in inches. The weighted average of soil depth for the study area is nearly 48 inches; this was the assumed soil depth employed. Consequently a maximum limit of 25 inches of water (Θ_{ν} = 25/48 = 52 percent) for soil water content was established. A minimum level of 0.0 inches was also utilized.

The Hydrologic Model

Based on noted hydrologic functional relationships and all stated assumptions, a FORTRAN IV simulation model was constructed for the Harvey Creek Drainage. A copy of this program can be found in Appendix C. The model was run on a "water year basis," October through September. The model was operated more than one dozen times for runs totaling over 1500 separate years. No apparent instabilities or inconsistencies were noted. Table 11 reports a comparative summary **for** variable averages from a 150 year model run and actual recorded long term averages. Note the high level of agreement between model variable averages and actual variable averages in this table.

The Erosion Indices

Output from the hydrologic model was used to create a family of erosion potential index distributions. These distributions were based on the fact: water plays a key role in determining erosion potential, and the assumption: potential levels can be indexed by frequency distributions for various combinations of monthly precipitation and soil water content.

In conjunction with the erosion probability survey conducted to acquire empirical estimates for probability relationships, a separate seven question hydrology oriented questionnaire was submitted to the 35 respondents. The premise was:

Table 11. Comparative Summary of Variable Averages from a 150 Year Hydrologic Model Run and Actual Recorded Long-term Averages.

Month	Avg. Precipitation Records	Avg. Precipitation Model	Avg. Runoff Records	Avg. Runoff Model	Avg. Evapotranspiration Records	Avg. Evapotranspiration Model
October	6.69	7.61	1.20	1.32	1.94	1.94*
November	13.40	14.25	6.29	6.29	0.66	0.66*
December	17.78	17.66	12.27	12.93	0.16	0.16*
January	18.72	16.64	13.78	13.33	0.00	0.00*
February	12.33	12.41	10.15	10.75	0.46	0.46*
March	12.46	12.19	9.73	10.38	0.77	0.77*
April	6.65	6.19	5.41	5.12	2.16	2.19
May	3.82	4.36	2.67	2.67	3.08	3.21
June	2.05	2.09	1.18	1.29	3.86	3.90
July	0.55	0.59	0.60	0.64	4.41	4.18
August	1.14	1.09	0.38	0.40	4.13	4.09
September	3.22	3.44	0.45	0.45	3.72	3.70
Annual Averages	98.81	98.52	64.11	65.57	25.35	25.26

(data all in inches of water)

* Exact values used for dormant season evapotranspiration in the model for these six months, reason for exact equality.

Two main hydrologic variables are directly related to erosion potentials. They are: precipitation and soil water content. The following functional relationship relating erosion potentials to these two variables is to be considered:

$$\text{Erosion Potential} = b\ (\text{Precipitation index}) + a\ (\text{Soil water content index})$$

Here 'b' and 'a' are proportionality constants that represent the proportional roles precipitation and soil water content play in creating an erosion potential. This survey examines seven well defined erosion events. Precipitation and soil water content may play different roles in each erosion event. The purpose of this survey is to establish estimates of 'b' and 'a' for these seven events:

The instructions and a sample question were:

Instructions: Answer the following questions by drawing upon all of your past experience. For each question consider all possible events of that type and estimate how important precipitation was in triggering the event and how important the soil water content level was in triggering the event. In each case you will be allocated 100 points and all 100 points should be assigned b & a each time. In other words, in the infinite scheme of things how important is precipitation and how important is the soil water content level in triggering a specific type of erosion event?

Example:

Assume a debris avalanche/flow has just occurred.
Let b + a = 100

b = 70 (role of precipitation in causing the debris avalanche/flow event)

a = 30 (role of soil water content in causing the debris avalanche/flow event).

The allocation of 70 points to 'b' and 30 to 'a' indicates that both variables are important in triggering debris avalanche/flows, however, the weights indicate that precipitation amount and intensity is thought to be more important for this event type. Table 12 reports means and standard deviations for each b/a pair for three road erosion

Table 12. Hydrologic Variable Coefficients for Road and Slope Erosion.

Road Erosion Events

Coefficients	(T2) Off Road Erosion $\hat{\mu}$	(T2) Off Road Erosion $\hat{\sigma}$	(T3) Road Damage $\hat{\mu}$	(T3) Road Damage $\hat{\sigma}$	(T4) Road Failure $\hat{\mu}$	(T4) Road Failure $\hat{\sigma}$
b	68.5		58.0		50.7	
		17.7		16.9		21.0
a	31.5		42.0		49.3	
Σ	100.0		100.0		100.0	

Slope Erosion Events

Coefficients	(D2) Rockslide $\hat{\mu}$	(D2) Rockslide $\hat{\sigma}$	(D3) Debris Avalanche/flow $\hat{\mu}$	(D3) Debris Avalanche/flow $\hat{\sigma}$	(D4) Slump Earthflow $\hat{\mu}$	(D4) Slump Earthflow $\hat{\sigma}$	(D5) Creep Acceleration $\hat{\mu}$	(D5) Creep Acceleration $\hat{\sigma}$
b	54.4		59.7		34.8		34.7	
		28.4		25.0		18.8		20.0
a	45.6		40.3		65.2		65.3	
Σ	100.0		100.0		100.0		100.0	

and four slope erosion events. A complete data listing of each respondent's replies and a sample questionnaire are on file in the Forest Engineering Department at OSU.

These seven coefficient pairs were to be used in the functional relationship (to be called the ZETA Function):

$$z_i = \left[b \left(\frac{P_i}{P_{am}} \right) + a \left(\Theta_{\nu i} \right) \right] .$$

where: z_i, i = 1, 12 = the erosion index, ZETA, or z,

b, a = coefficients,

P_i, i = 1, 12 = Harvey Creek Drainage precipitation value for month i,

P_{am} = Harvey Creek Drainage maximum monthly average precipitation value,

$\Theta_{\nu i}$ i = 1, 12 = Harvey Creek Drainage monthly volumetric water content for month i.

Notice the consistently high standard deviations for each b/a pair in Table 12. Subsequent contact with several survey respondents revealed the probable reasons for this type of variation. Most respondents expressed a general lack of confidence in their "specific" responses, and they were somewhat confused during the questioning due to the novelty and hypothetical nature of the ZETA Function presented. They did indicate however, confidence in "trend" differences for 'b' and 'a' for use in the ZETA Function. For these reasons, the values in Table 12 were not employed. Three general b/a pairs were utilized: 35/65, 50/50, and 65/35. These pairs cover the range for each b/a pair in Table 12, and Table 13 presents the respectively assigned b/a pairs for each event type.

Utilizing the ZETA Function, 150 years of monthly precipitation and soil water content simulated from the hydrologic model, and

Table 13. General Pair Assignments for Hydrologic Coefficients for Road and Slope Erosion.

Road Erosion Events

Coefficients	(T2) Off Road Erosion	(T3) Road Damage	(T4) Road Failure
b	65	65	50
a	35	35	50

Slope Erosion Events

Coefficients	(D2) Rockslide	(D3) Debris Avalanche/flow	(D4) Slump Earthflow	(D5) Creep Acceleration
b	50	65	35	35
a	50	35	65	65

coefficients from Table 13, three 1800 member (12 months for 150 years) ZETA populations were calculated. For this step the $\Theta_{\nu i}$ component was determined by: $\Theta_{\nu i} = S_i/48.0$ For discussion purposes, the erosion index populations for each b/a pair shall be referred to as:

1) b/a of 65/35 ---- ZETA 1, for indexing erosion potentials for events T2, T3, and D3,
2) b/a of 50/50 ---- ZETA 2, for indexing erosion potentials for events T4 and D2,
3) b/a of 35/65 ---- ZETA 3, for indexing erosion potentials for events D4 and D5.

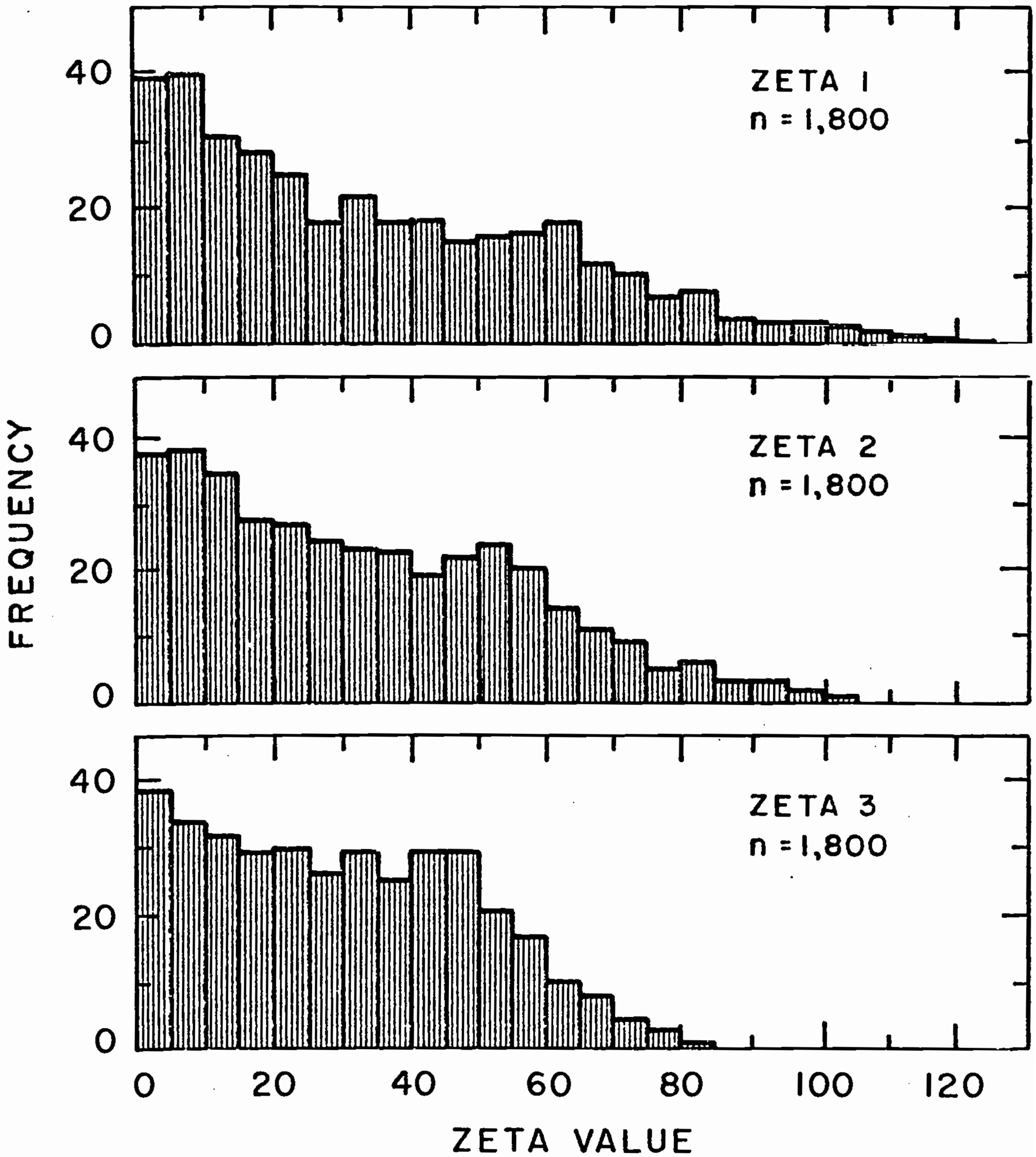
Histograms of these three index populations are illustrated in Figure 4. Histogram and population statistics analysis indicated each ZETA k distribution was probably a joint distribution of at least two separate functions. Monthly ZETA k groupings were examined to determine if there was a logical breakdown of the parent distributions.

It was found that ZETA k population components for the four summer months, Jun - Sep, behaved in a nearly exponential manner (Figure 5). Monthly observations for Oct - May had a more uniform bell shaped response (Figure 6). Table 14 reports important population statistics for parent populations and their wet and dry components.

The logical breakdown into two distributions for each ZETA k population demonstrates that two very different hydrological patterns exist in the study area. Intuitive knowledge of this climate and geological type does not conflict with this result. Because of this and the fact that almost no significant erosion activity is expected from June through September, the wet month ZETA k populations were assumed to represent the complete erosion potential index for the appropriate erosion events.

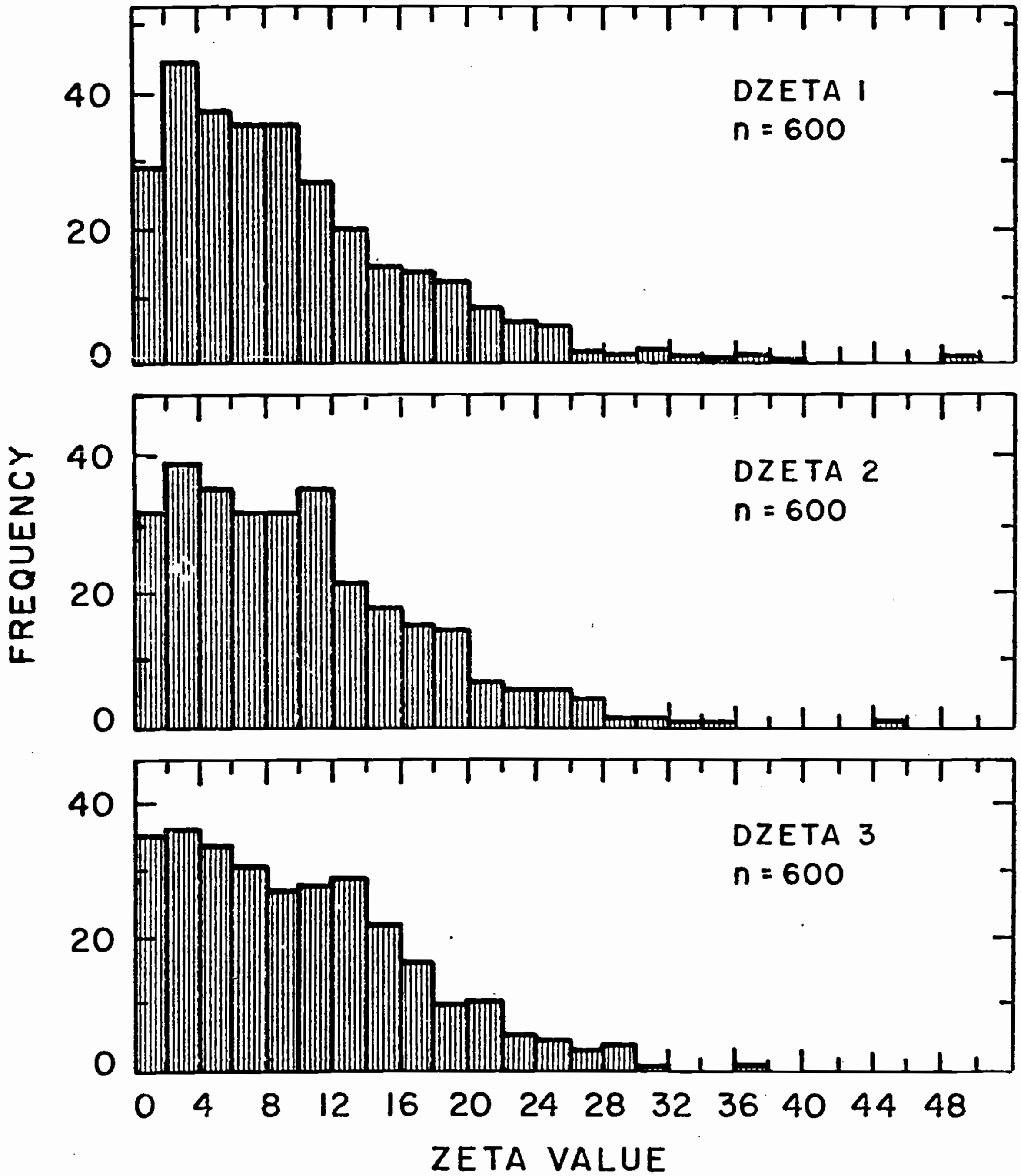
Each distribution was fit to a functional form to allow for more thorough analysis of distribution relationships. The Weibull and Normal functions were used for fitting; Table 15 reports results. Fits and tests

FIGURE 4. Three ZETA k Population Histograms.[a]



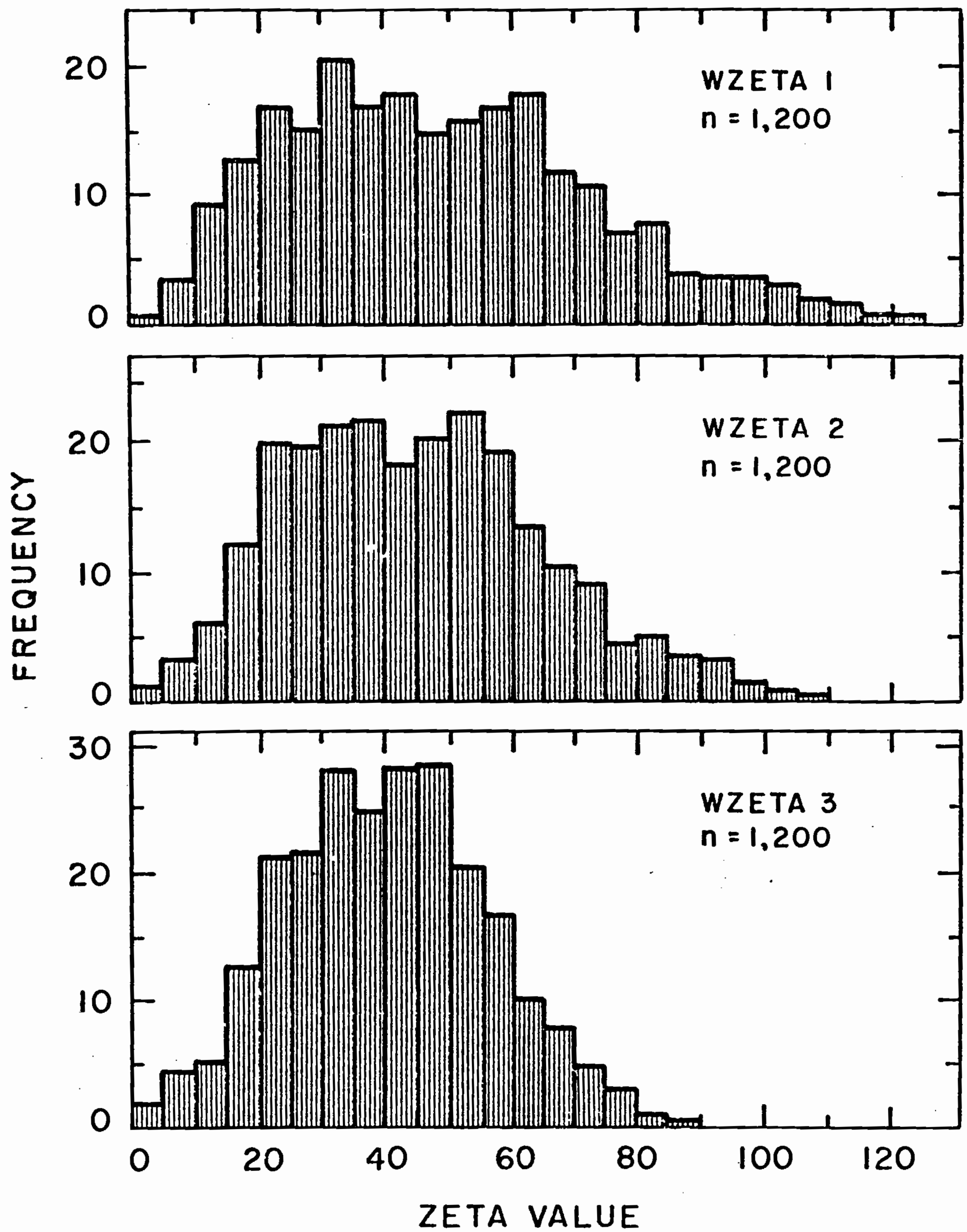
[a]Actual frequencies are obtained by multiplying the interval width times the indicated frequency level.

FIGURE 5. Three DZETA k Population Histograms.[a]



[a]Actual frequencies are obtained by multiplying the interval width times the indicated frequency level.

FIGURE 6. Three WZETA k Population Histograms.[a]



[a]Actual frequencies are obtained by multiplying the interval width times the indicated frequency level.

Table 14. Descriptive Statistics for Nine ZETA k Type Populations.

STATISTICS	DISTRIBUTIONS								
	ZETA 1	WZETA 1	DZETA1	ZETA 2	WZETA 2	DZETA 2	ZETA 3	WZETA 3	DZETA 3
Sample Size	1800	1200	600	1800	1200	600	1800	1200	600
Mean	36.17	49.38	9.74	33.16	44.81	9.86	30.14	40.23	9.98
Median	30.55	46.50	8.00	29.40	43.10	8.70	28.90	40.05	8.80
Maximum	126.70	126.70	55.40	107.60	107.60	46.40	89.30	89.30	37.40
Minimum	0.10	2.60	0.10	0.10	2.00	0.10	0.10	1.40	0.10
Range	126.60	124.10	55.30	107.50	105.60	46.30	89.20	87.90	37.30
Standard deviation	27.81	24.66	7.45	23.65	20.18	7.00	19.78	16.02	7.07
Skewness	0.727	0.545	1.370	0.571	0.414	0.976	0.345	0.170	0.717
Kurtosis	2.766	2.815	5.947	2.509	2.728	4.165	2.218	2.685	3.023

Table 15. Erosion Index Distribution Fitting Parameters and Statistics.

Distribution	Weibull Parameters $\hat{\alpha}$, $\hat{\beta}$	Normal Parameters $\hat{\mu}$, $\hat{\sigma}$	χ^2_ν Weibull Test	χ^2_ν Normal Test
WZETA 1	$\hat{\alpha} = 2.122$ $\hat{\beta} = 55.85$	$\hat{\mu} = 49.38$ $\hat{\sigma} = 24.66$	$\chi^2 = 9.173$ $\nu = 10$	$\chi^2 = 40.800$ $\nu = 10$
WZETA 2	$\hat{\alpha} = 2.369$ $= 50.58$	$\hat{\mu} = 44.81$ $\hat{\sigma} = 20.18$	$\chi^2 = 5.149$ $\nu = 10$	$\chi^2 = 38.791$ $\nu = 10$
WZETA 3	$\hat{\alpha} = 2.704$ $\hat{\beta} = 45.17$	$\hat{\mu} = 40.23$ $\hat{\sigma} = 16.02$	$\chi^2 = 6.393$ $\nu = 10$	$\chi^2 = 13.068$ $\nu = 10$

Table 16. Tests of H_0 for the Three WZETA k Distributions.

Distribution	E(X)	V(X)	$\hat{\alpha}$	$\hat{\beta}$	Hypotheses at $\gamma = 0.001$ EQUAL E(X)'s	EQUAL V(X)'s	EQUAL $\hat{\alpha}$'s	EQUAL $\hat{\beta}$'s
WZETA 1	49.46	598.1	2.122	55.85				
					R	R	R	R
WZETA 2	44.94	337.4	2.369	50.58				
					R	R	R	R
WZETA 3	40.17	259.8	2.704	45.17				
					R	R	R	R
WZETA 1	49.46	598.1	2.122	55.85				

n = 1200 (sample size)
R -- Hypothesis rejected

were conducted in the manner outlined in the Precipitation section of this chapter. All fits were non-significant and best for the Weibull function. Figure 7 illustrates the three Weibull distributions superimposed on the appropriate population histograms.

Similarity among Weibull parameters, α and β, for the three functions required tests be conducted to determine if the distributions were significantly different. A strict rule was established to test the null hypothesis, H_o, that there was no significant difference. It entailed rejection of:

1) Equal expected values --- $E(x_o) = E(x_1)$,
2) Equal variances --- $V(x_o) = V(x_1)$,
3) Equal shape parameters --- $\alpha_o = \alpha_1$,

and 4) Equal scale parameters --- $\beta_o = \beta_1$.

Equations for $E(x)$ and $V(x)$ for the Weibull distribution are:

1) $E(x) = \beta \left[\Gamma\ (1 + 1/\alpha) \right]$,

and 2) $V(x) = \beta^2 \left(\Gamma\ (1 + 2/\alpha) - \left[\Gamma (1 + 1/\alpha) \right]^2 \right)$.

Tests utilized were (Wetherill, 1972 and Thoman, et al, 1969):

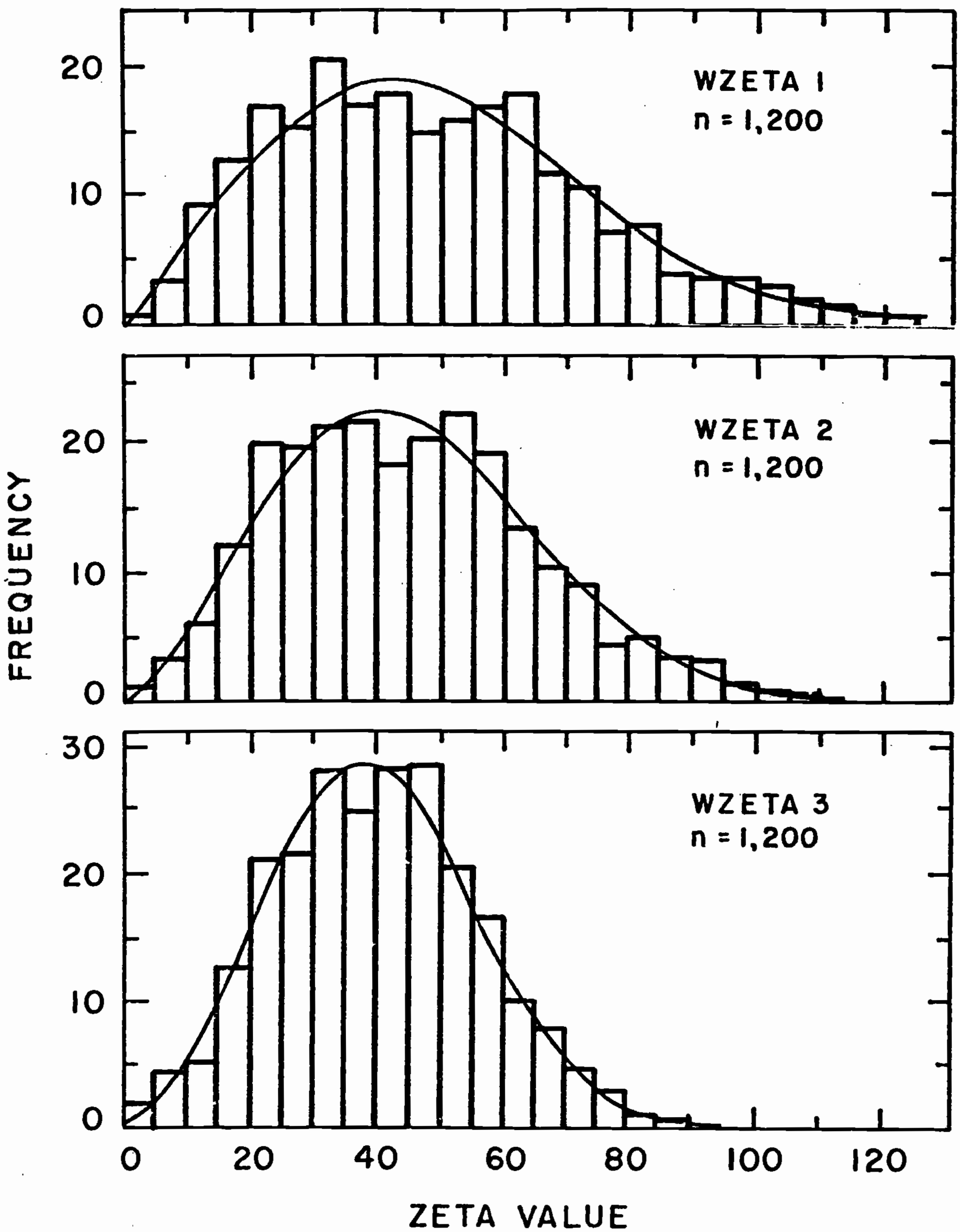
1) $E(x_o) = E(x_1)$ --- $\dfrac{\left[E(x_i) - E(x_j) \right]}{\hat{\sigma}\ \sqrt{n}} \sim N(0,1),\ \gamma = .001,$

2) $V(x_o) = V(x_1)$ --- $\left[\dfrac{V(x_i)}{V(\ _j)} \right] \sim F_{\nu_i,\ \nu_j},\ \gamma = .001,$

3) $\alpha_o = \alpha_1$ --- $\dfrac{\ln(\hat{\alpha}_i) - \ln(\hat{\alpha}_j)}{\sqrt{2(.608)/n}} \sim N(0,1), \gamma = .001,$

and 4) $\beta_o = \beta_1$ --- $\dfrac{\left[\hat{2}_i \ln \dfrac{(\hat{\beta}_i)}{\hat{\beta} i} \right]}{\sqrt{1.109/n}} \sim N(0,1),\ \gamma = .001.$

FIGURE 7. Three WZETA k Population Histograms Overlain with Appropriate Weibull pdf Curves.[a]



[a]Actual frequencies are obtained by multiplying the interval width times the indicated frequency level.

Here, $\hat{\sigma}^2$ is the pooled variance estimate of $V(x_i)$ and $V(x_j)$:

$$\hat{\sigma}^2 = \left[(n-1)\,V(x_i) + (m-1)V(x_j)\right] \Big/ \left[\, m + n - 2 \,\right].$$

The ν_i and ν_j represent degrees of freedom, γ the level of significance tested for, i and j respective population indicators, and m and n appropriate sample sizes. Table 16 reports the null hypothesis, H_o, test results. In all three cases the H_o was rejected. This demonstrates that the emphasis on importance of précipitation and soil water content levels results in different erosion potential index distributions. Hence, knowing both variables, P_i and S_i, provides more erosion potential information than knowing only one or the other.

Therefore, both variables should play an important role in any realistic erosion modeling. Development of the ZETA Function and specification of the Weibull forms illustrates two possible approaches for integrating P_i and S_i into an erosion model. The first involves stochastic simulation of P_i and S_i with subsequent calculation of monthly z_i values from the ZETA Function:

$$z_i = \left[b(P_i/P_{am}) + a\ (\Theta_{\nu i}) \right] .$$

The second approach centers on direct random simulation of the monthly z_i values from the three Weibull distributions:

$$\text{WZETA 1} \sim F(z_i) = 1-e^{-(z_i/55.85)^{2.122}} ,$$

$$\text{WZETA 2} \sim F(z_i) = 1-e^{-(z_i/50.58)^{2.369}} ,$$

$$\text{WZETA 3} \sim F(z_i) = 1-e^{-(z_i/45.17)^{2.704}} .$$

(Note: for the remainder of this paper, all WZETA.k populations shall be referred to simply as ZETA.k populations.)

In each case, the monthly z_i values serve as the stochastic mechanism which would drive an erosion model by specifying the random monthly erosion potential for each independent erosion event. Both approaches are discussed throughout the remainder of this report. However, only the first approach was employed for completing all final erosion model runs for this study. Once the theory for this type of erosion analysis is more thoroughly understood, a more sophisticated modeling procedure, which employs the second approach, is recommended. The erosion model structure to be presented herein allows for employment of either approach.

VI. CONSTRUCTING EROSION PROBABILITY FUNCTIONS TAILORED TO HARVEY CREEK CLIMATOLOGICAL AND HYDROLOGICAL CONDITIONS

This study has defined seven erosion events and three erosion potential index (ZETA k, k = 1,3) populations:

1) off road erosion T2,
2) road damage T3,
3) road failure T4,
4) rockslide D2,
5) debris avalanche/flow D3,
6) slump/earthflow D4,
7) creep (slow mass flow) acceleration D5;

and

1) ZETA 1 - for indexing erosion potentials for events T2, T3, and D3,

2) ZETA 2 - for indexing erosion potentials for events T4 and D2,

3) ZETA 3 - for indexing erosion potentials for events D4 and D5.

Furthermore, there exists a family of functions on each ZETA k (k = 1,3) which expresses the probability for occurrence of each T_j (j = 2,4) and D_j (j = 2,5) over the range of the appropriate z_i values in each ZETA k population. Allow that:

$$G_j(z_i) = Pr(T_j | z_i) \qquad \begin{cases} 0 \le G_j(z_i) \le 1.0 \\ 0 \le z_i \le \infty \end{cases}$$

and

$$H_j(z_i) = Pr(D_j | z_i) \qquad \begin{cases} 0 \le H_j(z_i) \le 1.0 \\ 0 \le z_i \le \infty \end{cases}$$

These two functions express the probabilities for T_j and D_j "given the condition of z_i": e.g., conditional probabilities of T_j and D_j.

The reader will recall that Table 7 reported three conditional probabilities for each T_j and D_j obtained from the empirical probability survey.[2] The three climatic conditions were qualitative descriptors: dry, normal wet, and very wet. Quantitative values in z_i can be determined for these three conditions for each T_j and D_j by applying: 1) definitions of dry, normal wet, and very wet; and 2) the appropriate ZETA k function (k = 1,3). Let n=climatic condition:

1) z_{i1} - be z_{in} value for the average October, (dry, n=1)

2) z_{i2} - be z_{in} value for the average December, (normal wet, n=2),

3) z_{i3} - be z_{in} value for the once in 50 year climatic condition, (very wet, n=3).

Recall the defining ZETA Function:

$$z_i = \left[b(P_i/P_{am}) + a\,(\Theta_{\nu i}) \right] \quad i = 1,8$$ [3]

Here:

z_i, i = 1,8, on b/a pair 65/35 defines z_i values for ZETA 1,

z_i, i = 1,8, on b/a pair 50/50 defines z_i values for ZETA 2,

and z_i, i = 1,8, on b/a pair 35/65 defines z_i values for ZETA 3.

Table 17 reports three pairs of (probabilities | z_i values) for each erosion event. The probabilities are taken from Table 7 and the z_i values were calculated by inserting precipitation and soil water content values for the average October and December and the once in 50 year extreme into the appropriate ZETA Function.

---

[2] Two events in Table 7, T1 and D1, are 'nothing' events and have deterministic probabilities based on calculation of the other T_j and D_j probabilities and an initial assumption of mutually exclusive, exhaustive event sets. These two 'non-events' are referred to further only where computationally necessary.

[3] The i =1,8, defines the period October through May, the period of consequential erosion occurrence for the subject study area.

Table 17. Pairings for z_{in} Values and Event Probabilities.

EVENT CLASS	Dry	Normal Wet	Very Wet
Road Erosion	$(g_{ij} \mid z_{i1})$	$(g_{ij} \mid z_{i2})$	$(g_{ij} \mid z_{i3})$
T2 - ZETA 1	(.02 | 31.0)	(.22 | 72.0)*	(.32 | 125.0)
T3 - ZETA 1	(.02 | 31.0)	(.13 | 72.0)	(.22 | 125.0)
T4 - ZETA 2	(.01 | 27.0)	(.07 | 63.0)	(.14 | 105.0)
Slope Erosion	$(h_{ij} \mid z_{i1})$	$(h_{ij} \mid z_{i2})$	$(h_{ij} \mid z_{i3})$
D2 - ZETA 2	(.02 | 27.0)	(.07 | 63.0)	(.07 | 105.0)
D3 - ZETA 1	(.01 | 31.0)	(.11 | 72.0)	(.19 | 125.0)
D4 - ZETA 3	(.01 | 23.0)	(.10 | 55.0)	(.15 | 85.0)
D5 - ZETA 3	(.03 | 23.0)	(.19 | 55.0)	(.23 | 85.0)

*NOTE: e.g., when $z_i = 72.0$, probability of T2 = 0.22

The temporal and space relationships established for the probabilities from Table 7 were on a per month per mile and per month per acre basis:[4]

1) probabilities/month - mile for all T_j,

2) probabilities/month - acre for all D_j.

The intention was to use Table 17 and an assumption about a general form of the $G_j(z_i)$ and $H_j(z_i)$ to estimate crude mathematical function forms. However, due to limitations of the questionnaire approach used to acquire Table 7 data, the inability of respondents to frame their knowledge in the temporal and space constraints given, and a general lack of perception of the temporal and space aspect of the

[4] See discussion on the empirical probability survey, Page 18.

erosion problem, Table(s) 7 (and 17) probabilities are "gross" over estimates of what one would expect, as can be seen in the following discussion based on empirical evidence.

A thorough review of available research underlines this point. Tables 18, 19, and 20 summarize frequency estimates in time and space for three road (T_j) and four slope (D_j) erosion events. This information was compiled from 10 separate studies which examined nearly 600 square miles of mountaineous terrain and some 200 miles of road:

1) Study (1), Fiksdal (1974a),
2) Study (2), Fiksdal (1974b),
3) Study (3), Morrison (1975),
4) Study (4), Swanson and Dyrness (1975),
5) Study (5), O'Loughlin (1972),
6) Study (6) Colman (1973),
7) Study (7) Dyrness (1967),
8) Study (8) Rice, Corbett, and Bailey (1969),
9) Study (9) Bishop and Stevens (1964),
10) Study (10), Paine (1971).

Information in Tables 18-20 is not exact; some subjective interpretation was employed during compilation because of differing methods of data reporting for the 10 studies. Additionally, survey limitations, study constraints, and the dynamic nature of the forest eco-system most certainly have led to underestimates of event frequencies over-time for each study. However, data reflected in Table 20 sets at least a minimum level and establishes a relative temporal and space trend for these event types.

To demonstrate how far apart Table 17 and Table 20 results are, consider:

> The probability for just one month, December (z_{i2}), for event D3 is .11/month-acre from Table 7. If we apply just this single monthly probability to the land area of study (1) for 80 years we have: (.11)(10,000) (80) = 88,000 debris avalanche events expected in just 80 Decembers. The actual number of such events recorded in study (1) is 99 for an 80 year period.

Table 18. Summary Table for Road Erosion Event Periodicity.

Event Types: Number[a] T2	Number[b] T3	Number T4	Area (acres)	Area (km^2)	Period Studied (years)	Study Location	Study (Number)
275	136	9	200	0.8	7	Northwestern Washington	(1)
187	124	26	150	0.6	15	Western Oregon	(3)
242	128	19	520	2.1	25	Western Oregon	(4)
88	28	2	790	3.2	25	Coast British Columbia	(5)
110	28	17	150[d]	0.6	40	Northern California	(6)
121	56	11	275	1.1	>1[c]	Western Oregon	(7)

Note: All events reported in referenced studies were greater than 100 yds^3 in size.

[a] Study (5) reports suggested adjustment of factor of "10" to include events smaller than 100 yds^3, e.g. 275 = 11 X 25 where study (1) reported 25 T2.

[b] Study (5) reports suggested adjustment of factor of "3" to include events smaller than 100 yds^3, e.g. 136 = 4 X 34 where study (1) reported 34 T3.

[c] One major storm period, 1964-1965.

[d] Rough estimate.

Table 19. Summary Table for Slope Erosion Event Periodicity

EVENT TYPES								
Number D2	Number D3	Number D4	Number D5	Area (acres)	Area (km^2)	Period Studied (years)	Study Location	Study (Number)
19	99[a]	60[a]	4	10,000	40.5	80	Northwestern Washington	(1)
X	80[a]	49[a]	X	10,300	41.6	80	Northwestern Washington	(2)
X	157[a]	94[a]	X	11,000	46.1	80	Northwestern Washington	(2)
X	50[b]	26[b]	X	4,300	17.4	90	Western Oregon	(3)
1	32	14	22	15,300	62.1	25	Western Oregon	(4)
X	60	X	X	150,000	600.0	25	Coast British Columbia	(5)
59	61	92	30	160,000	647.0	40	Northern California	(6)
X	2	10	X	15,500	62.1	>1[c]	Western Oregon	(7)
X	83	0	X	270	1.1	10	Southern California	(8)
X	129	0	X	10,000	40.5	100	Southeastern Alaska	(9)
X	74	30	X	9,900	40.0	2[d]	New Zealand	(10)

X - Not measured

[a] Adjusted by author's suggested factor of "seven" for all small streamside events which are dissipated every 10-20 years.

[b] Adjusted by author's suggested factor of "two" under assumption 50% events recorded.

[c] One major storm period 1964-1965.

[d] Two major storms

Table 20. Historical Temporal and Space Relationships for Road and Slope Erosion Events.

Event Type	# Events (n)	Σ(Period)(Acres) (PA)	Σ(Period)(km^2) (PK)	n/PA (Per year - acre)	n/PK (Per year - km^2)
T2	1023	42,675	172.2	0.02400	5.9408
T3	500	42,675	172.2	0.01172	2.9036
T4	84	42,675	172.2	0.00197	0.4878
Σ	607	X	X	0.03390	9.3322
D2	77	7.663×10^6	3.112×10^4	0.00001/0.00002[a]	0.00247/0.00534[a]
D3	827	1.446×10^7	5.846×10^4	0.000057/.00016[b]	0.01416/0.04016[b]
D4	375	1.107×10^7	4.346×10^4	0.000035/.00008[c]	0.00863/0.0210[c]
D5	56	7.663×10^6	3.112×10^4	0.000007/.00006[d]	0.00180/0.01421[d]
Σ	1320	X	X	0.000109	0.027060

[a] Only Study (1).
[b] Only Studies (1), (2), (3), (4), (7), (8), (9), and (10).
[c] Only Studies (1), (2), (3), (4), (7), (10).
[d] Only Study (4).

Such wide differences in expected event numbers demonstrate the difficulties in utilizing Tables 7 and 17 data to construct probability functions. For this reason the original approach was discarded and a more general one adopted.

Examination of qualitative descriptions for event frequencies in the 10 studies and crude time and space frequency graphs (not shown here) indicate some strong points. Most erosion events occur at very low monthly frequencies, even through the normally wet winter months. However, the frequencies jump considerably for storms of the 5 to 20 year recurrence interval. The overall relationship seems to be of exponential form for all events studied herein.[5] Therefore, the following functional form (CDF) was assumed for all events: [6]

$$Q_j(z_i) = a\left[1 - e^{(-\lambda z_i)}\right]^b - c.$$

When a = 1, b = 1, and c = 0 this distribution is the exponential CDF. Manipulation of the four parameters a, b, c, and λ allow for shaping and scaling the function appropriately for each event. Initially this involved setting b = 1 for all seven event functions. Then simultaneous equation methods and the assumption: $(1-e^{-\lambda z}) \approx \left[\lambda z - (\lambda^2 z^2)/2\right]$

were used on the general form:

$$q = a(1-e^{-\lambda z})^{b=1} - c,$$

$$q \simeq a(\lambda z - \lambda^2 z^2/2) - c,$$

$$q \simeq A(z) - B(z^2) - C^7$$

---

5 See Megahan, 1974 for a discussion of exponential erosion relationships.

6 To specify the forms for $G_j(z_I)$ and $H_j(z_i)$.

7 With several $(q|z)$ data points, ordinary least squares methods could be utilized here.

to determine values of A, B, and C for each event function.

Note that:

$\hat{\lambda} = 2B/A$, $\hat{a} = A^2/2B$, and $\hat{c} = C$.

Initially $\hat{a}$ was set equal to 1.0 and two (q|z) points were estimated for the seven erosion events from Table 20 data and intuitive analysis of time and space relationships. Two equations of $q \simeq A(z)-(A^2/2)z^2-C$ were formed from each (q|z) pair and solved for A and C simultaneously employing the quadratic equation. Knowing A, C, and $\hat{a}$ allowed calculation of $\hat{\lambda}$ and $\hat{c}$. The $\hat{\lambda}$ and $\hat{c}$ were then plugged into the function $(1-e^{-\hat{\lambda}z}) - \hat{c}$ and evaluated. If the original assumed data point pairs of (q|z) were not violated, the function for that event was specified by $\hat{\lambda}$ and $\hat{c}$, with $\hat{a}$=1 and $\hat{b}$=1. If further scaling or shaping was required, a trial and error process was employed varying $\hat{a}$ and $\hat{b}$ until a set was determined which satisfied the assigned (q |z) pairs. The following seven (CDF's) functions were specified in this manner:

1) $G_2(z_i) = (1-e^{-.01z_i})^2 - 0.22$
   for (0.0 | 65) and (0.30 | 125) for T2,
2) $G_3(z_i) = (1-e^{-.01z_i}) - 0.51$ for
   (0.0 | 72) and (0.20 | 125) for T3,
3) $G_4(z_i) = (1-e^{-.0017z_i}) - 0.10$ for
   (0.0 | 63) and (0.05 | 105) for T4,
4) $H_2(z_i) = (1-e^{-.00001z_i})$ for
   (0.0| 0) and (0.001 | 105) for D2,
5) $H_3(z_i) = (1-e^{-.012z_i})^2 - 0.33$ for
   (0.0| 72) and (0.25 | 125) for D3,
6) $H_4(z_i) = (1-e^{-.01z_i}) - 0.42$
   for (0.0 | 55) and (0.15 | 85) for D4,
7) $H_5(z_i) = (1-e^{-.001z_i}) - 0.05$
   for (0.0 | 55) and (0.10 | 85) for D5.

Because there is a relatively high number of events per km^2 for all T_j[8], calculations were handled more conveniently in units of events/month-acre. (e.g., actual acres of land cleared for road right-of-way). Conversely, because the frequency rate for D_j[8] is extremely low on a per acre basis, calculations were handled on a unit basis of events/month - km^2. These new temporal and space units can be adjusted by multiplying or dividing by a constant. For computational convenience, these new units were utilized for this study. Each function has a z_i value at which it equals zero; each is defined over the z_i range:

1) $G_2(z_i)$ defined: $63.31 \leq z_i \leq \infty$
   0 elsewhere,

2) $G_3(z_i)$ defined: $71.33 \leq z_i \leq \infty$
   0 elsewhere,

3) $G_4(z_i)$ defined: $61.98 \leq z_i \leq \infty$
   0 elsewhere,

4) $H_2(z_i)$ defined: $0.0 \leq z_i \leq \infty$
   0 elsewhere

5) $H_3(z_i)$ defined: $71.20 \leq z_i \leq \infty$
   0 elsewhere

6) $H_4(z_i)$ defined: $54.47 \leq z_i \leq \infty$
   0 elsewhere,

and 7) $H_5(z_i)$ defined: $51.29 \leq z_i \leq \infty$
   0 elsewhere.

These CDF forms, used in conjunction with the appropriate z_i values[9], specify the conditional probability relationships for seven erosion events as tailored to the Harvey Creek Drainage climatological

---

[8] See Table 20.

[9] The z_i values are calculated either directly from simulated S_i and P_i and the appropriate ZETA Functions or simulated from the three Weibull distributions on z_i (e.g. from the $F(z_i)$ functions).

and hydrologic variables. Exact on-site probabilities are determined by applying Bayesian analysis to the z_i values, the event conditional probability functions ($Q_j(z_i)$), and the appropriate set of on-site, variable state, conditional probabilities.[10]

---

[10] To be derived from Tables 3-6.

VII. EMPLOYING BAYESIAN ANALYSIS TO DETERMINE ON-SITE EVENT PROBABILITIES IN TIME AND SPACE

Data summarized in Tables 3-6 was utilized to structure conditional probability Tables 21 and 22. The final step in the journey from the general to the particular involves application of Bayesian analysis to all previously specified assumptions, distributions, functions, and these two tables. Recall that calculation of on-site event probabilities employs the Bayesian formula:

$$P(EV_j|SS) = \frac{P(EV_j)\ P(SS|EV_j)}{P(EV_1)P(SS|EV_1) + \ldots + P(EV_n)P(SS|EV_n)}$$

where:

EV_j ---------------erosion event j,

SS ---------------site (variable) state,

$P(EV_j|SS)$---------posterior probability of event j, occurring on sites with variable state SS,

$P(EV_j)$------------prior probability of event j occurring <u>anywhere</u>,

$P(SS|EV_j)$---------likelihood of site with variable state SS being associated with all historical events j: called conditional probability of SS given EV_j has <u>already</u> occurred.

Tables 21 and 22 allow for calculating respectively some 25,000 and 90,000 possible conditional probability and variable combinations. Obviously, any one watershed will not have that many different "cells", therefore, a simplified approach is required to calculate the posterior probability of event j for striking any cell (e.g., $P(EV_j|SS)$). For now, ignore the need for $P(EV_j)$, the "prior" event probabilities.[11]

---

11 These probabilities are the products of either the ZETA Function or the $F(z_i)$ and $Q_j(z_i)$ CDF's.

Table 21. Conditional Probability Table for Cause of Road Erosion and Eight On-Site Variables, Given that the Specified Event has Occurred.

Road Age

Event	R1	R2	R3	R4
T1	.08	.18	.34	.40
T2	.58	.24	.10	.08
T3	.49	.25	.14	.12
T4	.48	.25	.14	.13

Road Standard

Event	S1	S2
T1	.62	.38
T2	.36	.64
T3	.38	.62
T4	.40	.60

Road Width

Event	M1	M2
T1	.59	.41
T2	.44	.56
T3	.45	.55
T4	.43	.57

Slope Class

Event	U1	U2	U3	U4
T1	.56	.24	.13	.07
T2	.06	.13	.26	.55
T3	.07	.16	.28	.49
T4	.06	.16	.28	.50

Soil Type

Event	V1	V2	V3	V4
T1	.23	.28	.35	.14
T2	.35	.24	.20	.21
T3	.30	.24	.20	.26
T4	.24	.28	.19	.29

Landform

Event	W1	W2	W3	W4
T1	.45	.21	.21	.13
T2	.11	.24	.21	.44
T3	.11	.25	.25	.39
T4	.12	.23	.26	.39

Bedding Plane Dip

Event	X1	X2	X3	X4	X5
T1	.07	.16	.19	.27	.31
T2	.40	.20	.17	.12	.11
T3	.40	.21	.17	.12	.10
T4	.46	.19	.15	.11	.09

Fracture Angle

Event	Y1	Y2	Y3	Y4	Y5
T1	.07	.15	.24	.27	.27
T2	.41	.21	.14	.13	.11
T3	.44	.20	.13	.11	.12
T4	.43	.22	.13	.11	.12

Table 22. Conditional Probability Table for Cause of Slope Erosion and Eight On-Site Variables, Given that the Specified Event has Occurred.

Main Timber Age

Event	E1	E2	E3	E4	E5
D1	.10	.12	.19	.27	.32
D2	.29	.26	.18	.15	.12
D3	.36	.33	.15	.09	.07
D4	.28	.28	.20	.13	.11
D5	.35	.25	.17	.12	.11

Harvest Method

Event	H1	H2	H3	H4
D1	.20	.25	.12	.43
D2	.23	.19	.45	.13
D3	.25	.20	.46	.09
D4	.27	.20	.41	.12
D5	.26	.21	.39	.14

Silvicultural Method

Event	C1	C2	C3
D1	.15	.32	.53
D2	.50	.28	.22
D3	.67	.23	.10
D4	.56	.28	.16
D5	.57	.27	.16

Slope Class

Event	U1	U2	U3	U4
D1	.62	.22	.11	.05
D2	.02	.09	.25	.64
D3	.03	.10	.25	.62
D4	.11	.20	.32	.37
D5	.05	.14	.26	.55

Soil Type

Event	V1	V2	V3	V4
D1	.17	.29	.30	.24
D2	.52	.18	.19	.11
D3	.47	.21	.21	.11
D4	.10	.18	.17	.55
D5	.33	.24	.21	.22

Land Form

Event	W1	W2	W3	W4
D1	.40	.23	.24	.13
D2	.12	.21	.07	.60
D3	.11	.23	.09	.57
D4	.14	.20	.51	.15
D5	.16	.28	.24	.32

Bedding Plane Dip

Event	X1	X2	X3	X4	X5
D1	.07	.15	.20	.28	.30
D2	.53	.17	.13	.09	.08
D3	.45	.20	.15	.10	.10
D4	.42	.20	.16	.12	.10
D5	.41	.21	.16	.11	.11

Fracture Angle

Event	Y1	Y2	Y3	Y4	Y5
D1	.08	.15	.23	.26	.28
D2	.46	.21	.12	.11	.10
D3	.42	.20	.13	.13	.12
D4	.37	.22	.15	.12	.14
D5	.39	.22	.15	.13	.11

The conditional probability for all events for any cell type (combination of more than one on-site variable) can be calculated in the following manner.

(1) Select a category of erosion events, either T_j or D_j. For illustration purposes D_j is used.

(2) Describe the on-site variables which define a cell's characteristics. For sake of discussion, a cell (CL1) with V1 (shallow noncohesive soil), W1 (normal slope-landform), U3 (slope class of 51-70 percent) and E2 (timber of age 6-10 years) will be compared to a cell (CL2) with V1, W1, U2 (slope class 21-50 percent) and E5 (timber of age 80 years or greater).

(3) Extract the appropriate columns under each variable state (V1, W1, U2, U3, E2, and E5) from Table 22 and set up a matrix form.

Cell CL1

Event	E2	U3	V1	W1
D1	.12	.11	.17	.40
D2	.26	.25	.52	.12
D3	.33	.25	.47	.11
D4	.28	.32	.10	.14
D5	.25	.26	.33	.16

Cell CL2

Event	E5	U2	V1	W1
D1	.32	.22	.17	.40
D2	.12	.09	.52	.12
D3	.07	.10	.47	.11
D4	.11	.20	.10	.14
D5	.11	.14	.33	.16

4) For each matrix accomplish the simple iterative procedure:

for each Row D_j, j=1,5: $(E2_j)(U3_j)(V1_j)(W1_j) = C1_j$

$$(E5_j)(U2_j)(V1_j)(W1_j) = C2_j$$

5) Then, the conditional probability for each set of particular on-site conditions, given that D_j has occurred, is:

$$P(E2,U3,V1,W1|D_j) = (C1_j)/\sum_{j=1}^{5} C1_j ,$$

$$P(E5,U2,V1,W1|D_j) = (C2_j)/\sum_{j=1}^{5} C2_j .$$

Completion of these steps for cells CL1 and CL2 resulted in the following conditional probabilities:

Event	for CL1 $P(CL1 \mid D_j)$	for CL2 $P(CL2 \mid D_j)$
D1	.061	.690
D2	.287	.098
D3	.311	.053
D4	.091	.045
D5	.250	.114

To calculate the actual probability of event T_j or D_j affecting a specified road segment or cell in any given month, accomplish the following.

1) Calculate three values of z_i from the appropriate ZETA Function and existing climatic and hydrologic conditions, <u>or</u> simulate such from the appropriate $F(z_i)$ CDF.

2) Solve all $G_j(z_i)$ and $H_j(z_i)$ for the posterior probabilities for all T_j and D_j (the $P(EV_j)$). For example, assume the 50 year storm event (i.e. the very wet situation) has occurred, then:

   FOR: ZETA 1 ZETA 2 ZETA 3

   $z_i = 125$, $z_i = 105$, $z_i = 85$,

   and from the $G_j(z_i)$ and $H_j(z_i)$:

   units of: events/month-acre

   $$\begin{cases} P(T2) = .289 \\ P(T3) = .203 \\ P(T4) = .063 \\ P(T1) = 1.0 - P(T2) - P(T3) - P(T4) = .445, \end{cases}$$

   and:

   units of: events/month-km²

   $$\begin{cases} P(D2) = .001 \\ P(D3) = .274 \\ P(D4) = .153 \\ P(D5) = .031 \\ P(D1) = 1.0 - P(D2) - P(D3) - P(D4) - P(D5) = .541 \end{cases}$$

3) To illustrate use of these probabilities employ the $P(D_j)$ with the conditional probabilities calculated for CL1 and CL2.

Event	$P(CL1 \mid D_j)$	x	$P(D_j)$	=	$a_1/\Sigma a_1$	=	$P(D_j \mid CL1)$	
D1	.061	x	.541	=	$.033/\Sigma a_1$	=	.286	temporal/space units are per km^2 per month
D2	.287	x	.031	=	$.009/\Sigma a_1$	=	.078	
D3	.311	x	.153	=	$.048/\Sigma a_1$	=	.416	
D4	.091	x	.274	=	$.025/\Sigma a_1$	=	.217	
D5	.250	x	.001	=	$.0003/\Sigma a_1$	=	.003	
			Σa_1	=	.1153	Σ =	1.000	

Event	$P(CL2 \mid D_j)$	x	$P(D_j)$	=	$a_2/\Sigma a_2$	=	$P(D_j \mid CL2)$	
D1	.690	x	.541	=	$.373/\Sigma a_2$	=	.941	temporal/space units are per km^2 per month
D2	.098	x	.031	=	$.003/\Sigma a_2$	=	.008	
D3	.053	x	.153	=	$.008/\Sigma a_2$	=	.020	
D4	.045	x	.274	=	$.012/\Sigma a_2$	=	.030	
D5	.114	x	.001	=	$.0001/\Sigma a_2$	=	.001	
			Σa_2	=	.3961	Σ =	1.000	

For a hypothetical watershed which has 15 km^2 of CL1 type land and 50 km^2 of CL2, the expected event frequencies (EF) for D_j for the 50 year storm are:

Event	$P(D_j \mid CL1)$	x	Area = EF_1	$P(D_j \mid CL2)$	x	Area	= EF_2
D2	.078	x	15 = 1.2	.008	x	50	= 0.4
D3	.416	x	15 = 6.2	.020	x	50	= 1.0
D4	.217	x	15 = 3.3	.030	x	50	= 1.5
D5	.003	x	15 = 0.1	.001	x	50	= 0.1

$EF_1 + EF_2$ =	Expected Frequency	for Event D_j
1.2 + 0.4 =	1.6	rockslides
6.2 + 1.0 =	7.2	debris avalanches
3.3 + 1.5 =	4.8	slumps
0.1 + 0.1 =	0.2	creep events accelerated

Remember, that CL1 and CL2 differ in two ways. First, CL1 has much younger timber (6-10 years) than CL2 (greater than 80 years) and CL1 has steeper terrain (21-50 percent vs. 51-70 percent). Changing these two factors had a substantial impact on the expected frequency outcomes. In this way, the method outlined so far provides one quantitative measure of how differing variable states affect the expected erosion frequencies. A second such measure was also derived.

Data compiled from the 10 studies referenced for Tables 18-20 in Chapter VI was used to develop this second quantitative measure. Different "event size" distributions in terms of "cubic yards per event" were built to estimate predicted event sizes. Table 23 presents the appropriate fit tests and distribution parameter estimates.

For off road erosion (T2) two distributions were developed. First a Weibull distribution was fit to nearly 90 T2 events greater than 100 cubic yards in size. Secondly, assuming that events over 100 cubic yards represent only one out of every ten such events a second right skewed Weibull distribution was constructed empirically to represent this population of event sizes (O'Loughlin, 1972). The parameters for this second distribution are arbitrary, hence no fit test was conducted.

Similarly, road damage (T3) event size was broken into two categories: those events measured greater than 200 cubic yards, and those smaller. Weibull distributions were used for both classes. The small class again had arbitrary Weibull parameters, hence no fit test, and the larger class was fit against some 80 actual event sizes. For this study, four out of five T3 events were assumed to be from the smaller size class (O'Loughlin, 1972 and Swanston, 1975).

One size class was assumed for road failure events (T4) due to their naturally larger size by definition. A Weibull distribution was fit to 75 individual road failure events and the appropriate χ^2 goodness of fit test was conducted.

Table 23. Summary Table for Erosion Event Size Distributions.

Event Type	Weibull $\hat{\alpha}$	Parameters $\hat{\beta}$	χ^2	ν
Road Erosion				
T2 (Small)	1.2500	75.00	N	N
T3 (Large	1.0102	724.60	12.53	5
T3 (Small)	1.2500	125.00	N	N
T3 (Large)	1.1300	780.14	7.56	4
T4	0.8760	6274.77	6.28	5
Slope Erosion				
D2	0.9180	1041.22	4.86	5
D3 (Small)	1.6602	540.57	10.23	6
D3 (Large)	1.4066	4831.28	12.19	5
D4 (Small)	1.6526	491.82	3.03	6
D4 (Large)	1.1463	8736.68	8.98	5
D5	0.7861	4428.78	X	X

N - not fit, empirical estimates, therefore, no X^2_ν statistics reported.

X - no χ^2_ν statistic reported due to small uncertain parent population.

Limited information was available on rockslides (D2), however, 66 recorded events could be identified to be directly associated with rockslide activities. Therefore, one size class distribution was fit to these 66 event sizes. Again the functional form was Weibull.

Two size classes were assumed for debris avalanche/flows. The smaller class involved young timber, recently cut-over sites, and immediate streambank areas. The larger class covered what has been referred to as the natural events, occurring on virtually undisturbed sites. Careful analysis of data from the 10 studies referenced earlier demonstrated the validity of this approach. There are two distinct size populations for D3 events which correspond to the assumed classifications. Both were fit with a Weibull function and a goodness of fit test performed. The small class contained 100 sample points and the larger class 130.

A similar approach was taken with slump/earthflow (D4) event sizes. A small size class which involves occurrences on young stands, recently cut areas, immediate stream banks, and shallow transitional (cohesive to non-cohesive) soils was fit with a Weibull distribution based on 63 sample points. The larger class, for less disturbed, more classical, deep cohesive soiled areas, was fit with a Weibull distribution based on some 65 size samples. Appropriate tests were conducted.

Very little information was available for estimating the monthly contribution of an accelerated creep (slow mass flow) event (D5). Several events have been measured which are related to such activity but no actual creep acceleration data was available in cubic yards/event month. Therefore, a very crude estimate of this erosion contribution was made by fitting a Weibull distribution to the small number (nearly 30) of the "related" events. Because reasonable fit testing requires at least 40 sample points and because of the unsure relationship between the event sizes used and creep acceleration, no χ^2 test for this fit is reported. Reporting such a test would add false credibility to the function being employed.

A most important point is that just as with the $G_j(z_i)$ and $H_j(z_i)$ CDF's, these event size distributions are estimates and only as accurate as the available raw data on erosion events and the simplifying assumptions employed.

To this point combined methods for estimating frequencies and sizes of seven erosion events have been established which provide quantitative measures of the erosion process. Examination of a changing watershed over time will provide a dynamic view of this activity. The remaining portion of this study is directed at outlining various alternatives and developing the simulation techniques required to accomplish a dynamic system view of each alternative in a changing Harvey Creek Drainage.

VIII. SPECIFICATION OF HARVEST AND ROAD ALTERNATIVES FOR THE HARVEY CREEK DRAINAGE

Development of harvest and road alternatives required organizing and mapping all on-site physical variables relative to this study.[12] Through close cooperation with USDA FS personnel at the Siuslaw National Forest Headquarters in Corvallis, up-to-date resource inventory materials were made available for all relevant variable types and states (Lindner, et al, 1975). Figures 8 - 11 are resource maps of study site conditions for soil, slope, and timber types, and landform classes. Timber age classes correspond roughly with timber types and a detailed age class map is not included herein. Also not illustrated here, are maps for bedding plane angle and fracture angle classes. According to the US Geological Survey (1961), study area bedding planes are virtually horizontal ($\pm 3^{o}$). Additionally, steep sloped areas in the Harvey Creek Drainage result from highly steepened fracture angles (Burroughs et al, 1971, and Swanston, 1975). Therefore, all slopes exceeding 50 percent were assumed to be underlain by horizontal bedding planes fractured "steeply with" the slope. Slopes less than 50 percent were assumed to have horizontal beds fractured "gently with" the slope.

Computer processing of this resource material required adaptation of a systematic mapping method for the entire study area. A simple uniform grid approach was employed; Harvey Creek Drainage was divided into a set of uniform cells and blocks. Figure 12 is a map of the 88 blocks established for the study area. Each block was subdivided into a series of smaller, uniform cells measuring sixteen

[12] See Chapter III.

FIGURE 8. Harvey Creek Drainage Soil Type Map.

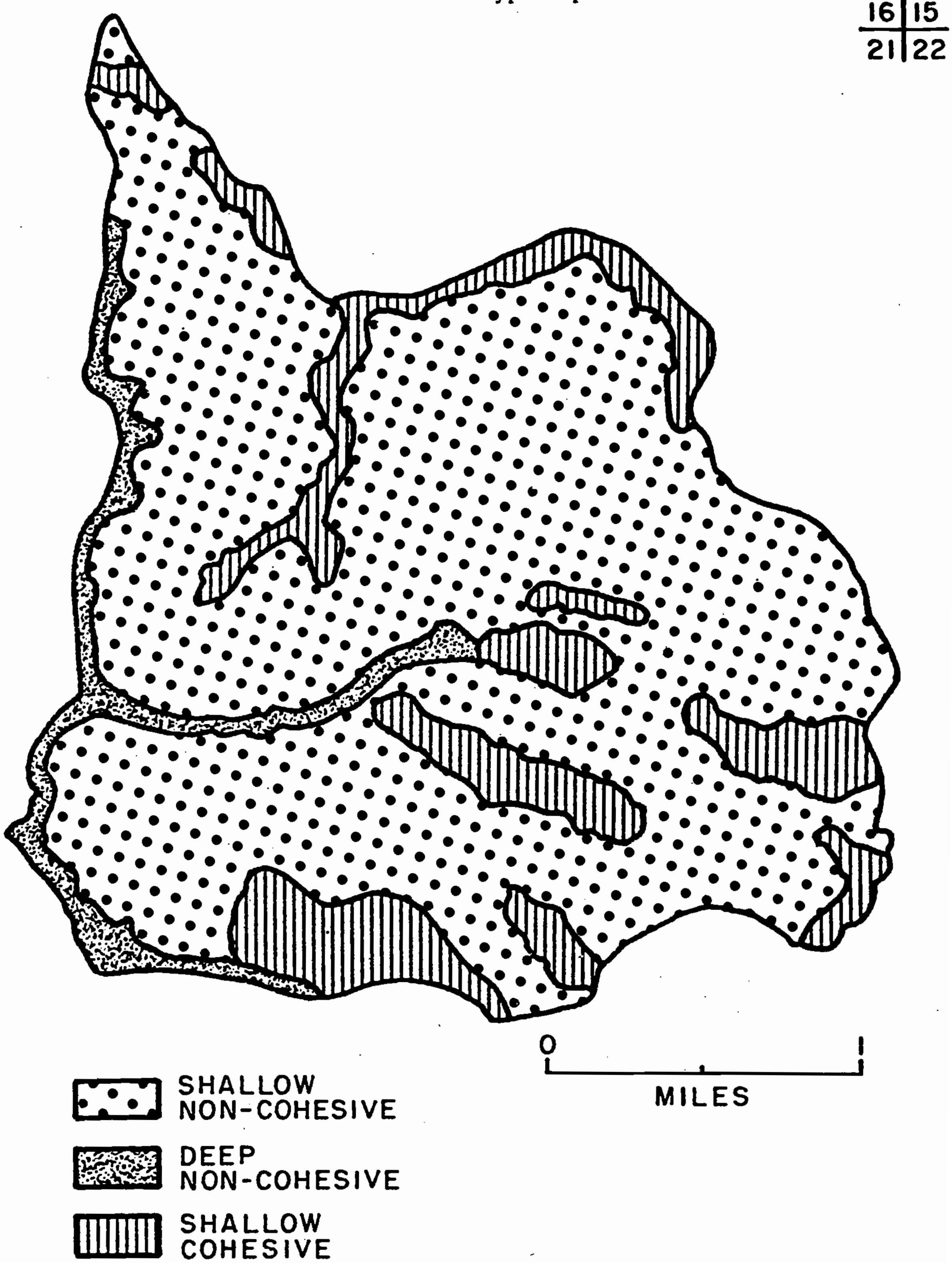


Figure 9. Harvey Creek Drainage
Slope Type Map.

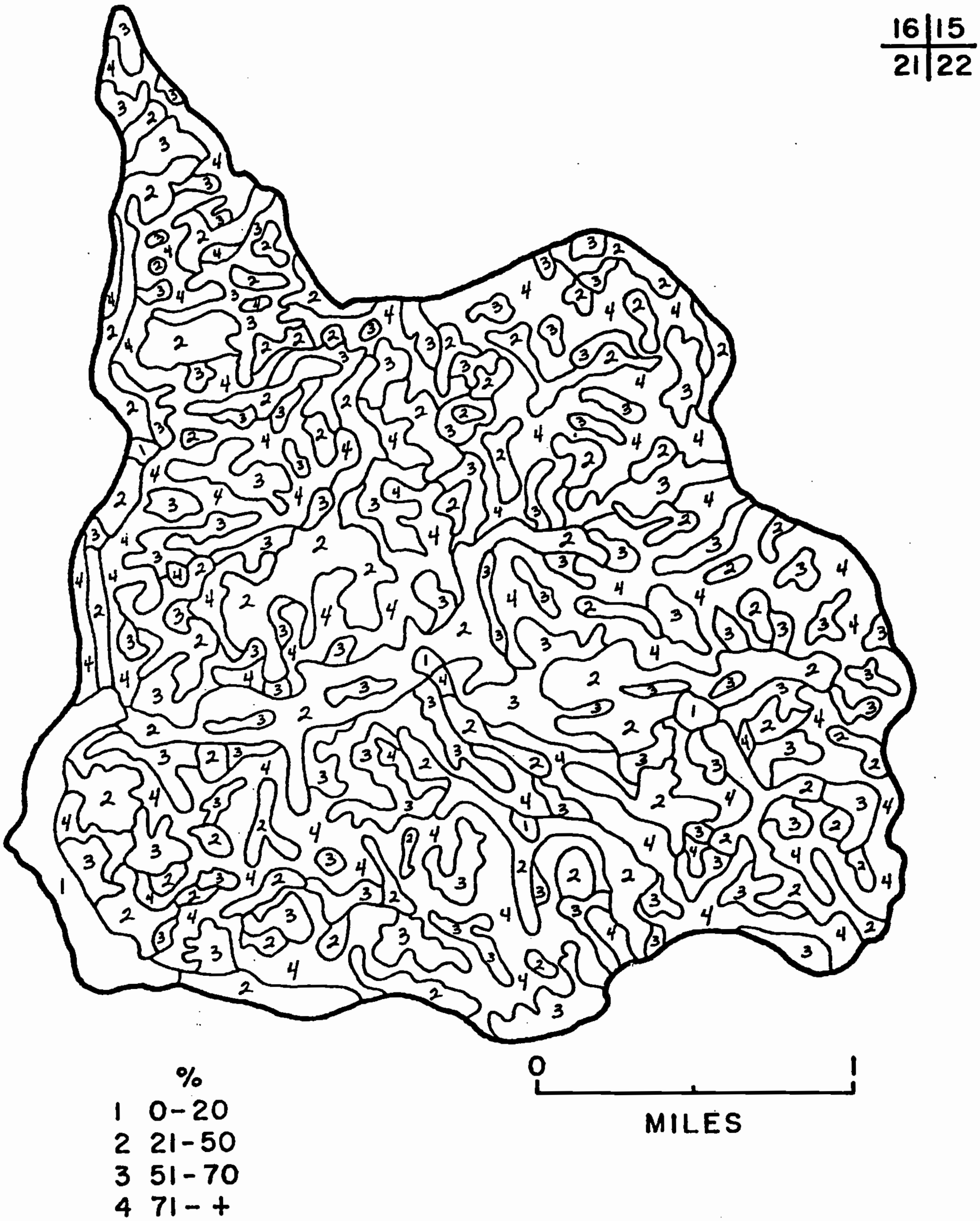
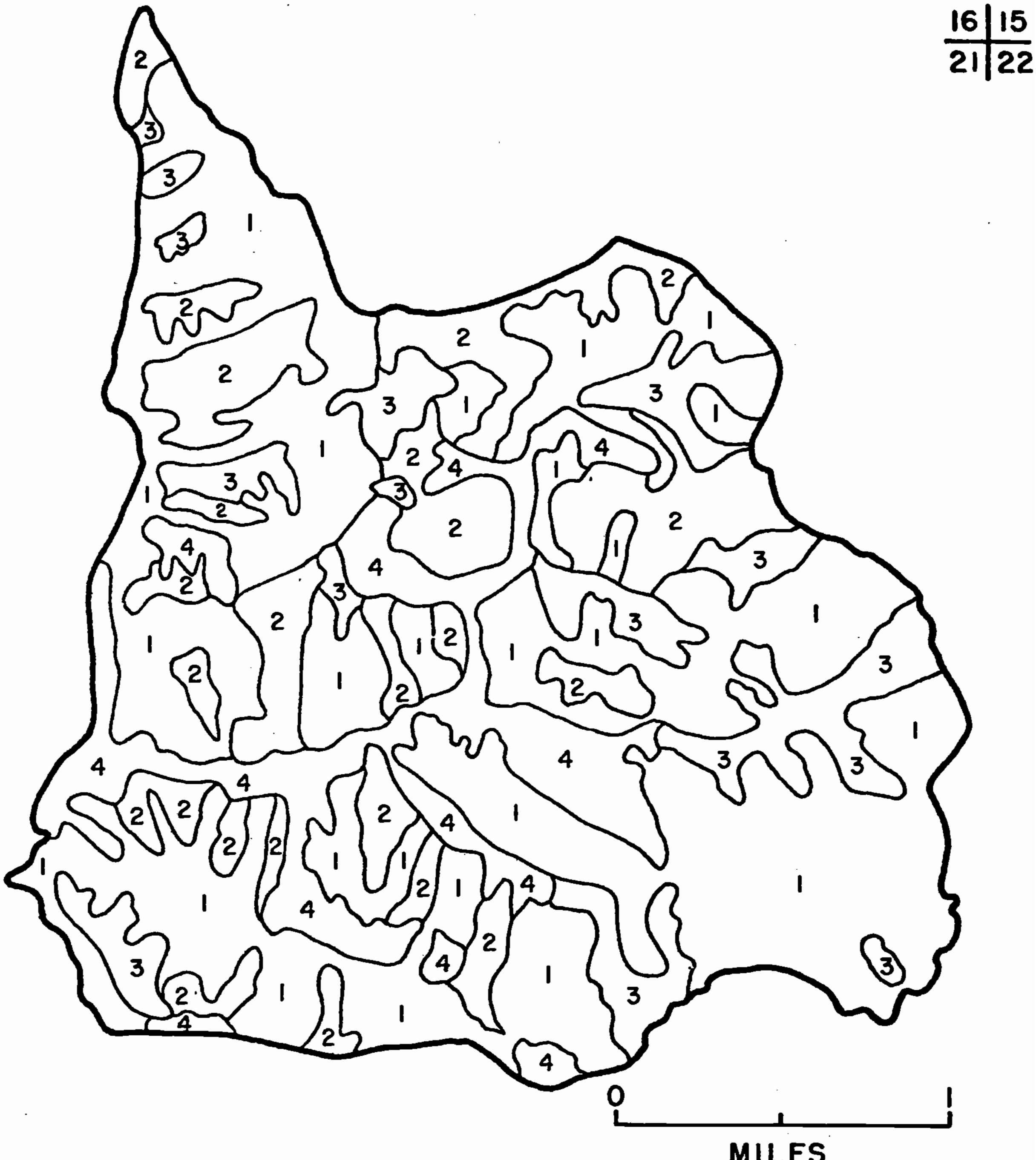


FIGURE 10. Harvey Creek Drainage
Timber Type Map.



1 DOUGLAS-FIR HIGH SITE
2 DOUGLAS-FIR LOW SITE
3 DOUGLAS-FIR MIX (60%) HIGH SITE
4 DOUGLAS-FIR MIX (60%) LOW SITE

FIGURE 11. Harvey Creek Drainage
Landform Type Map.

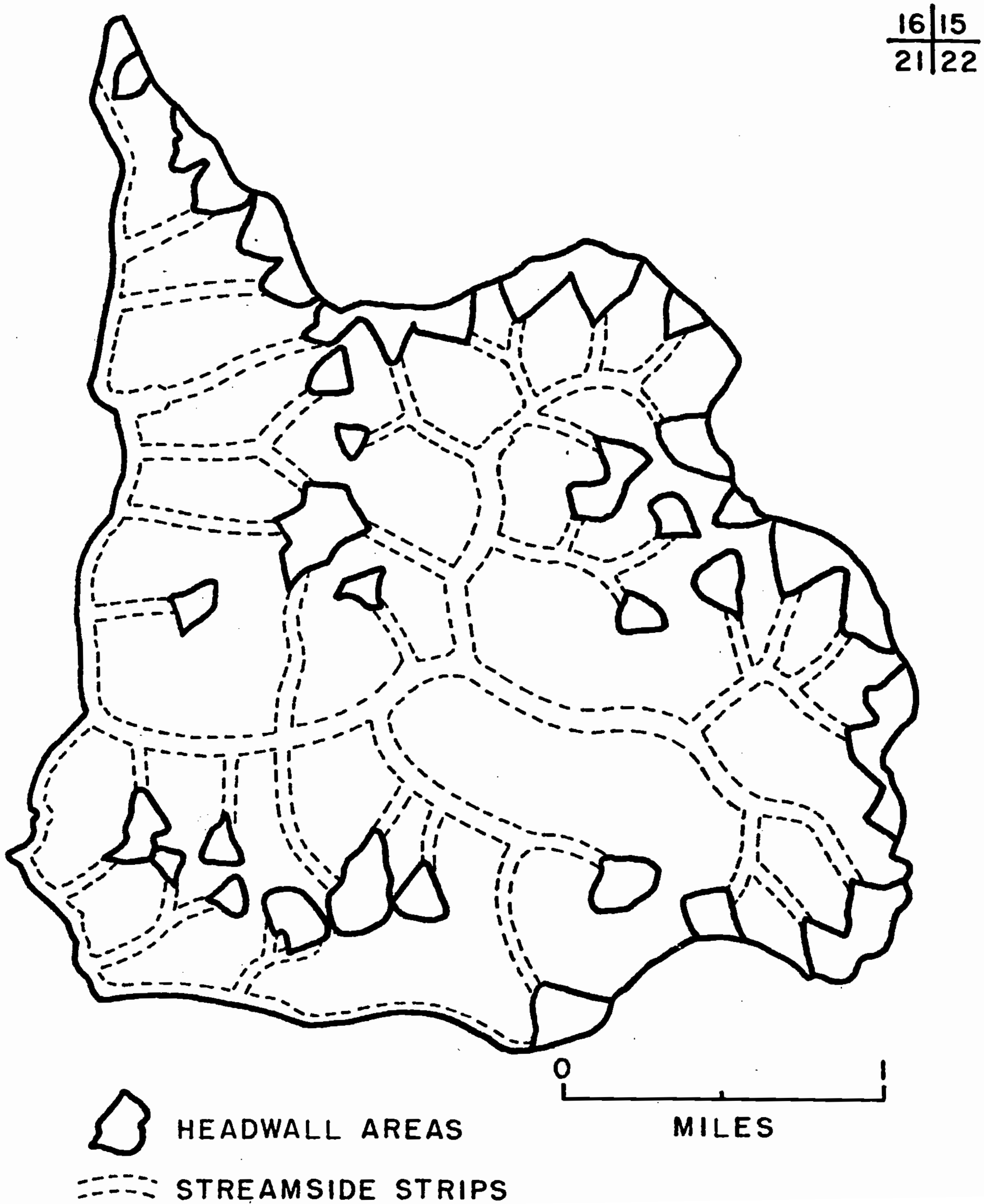
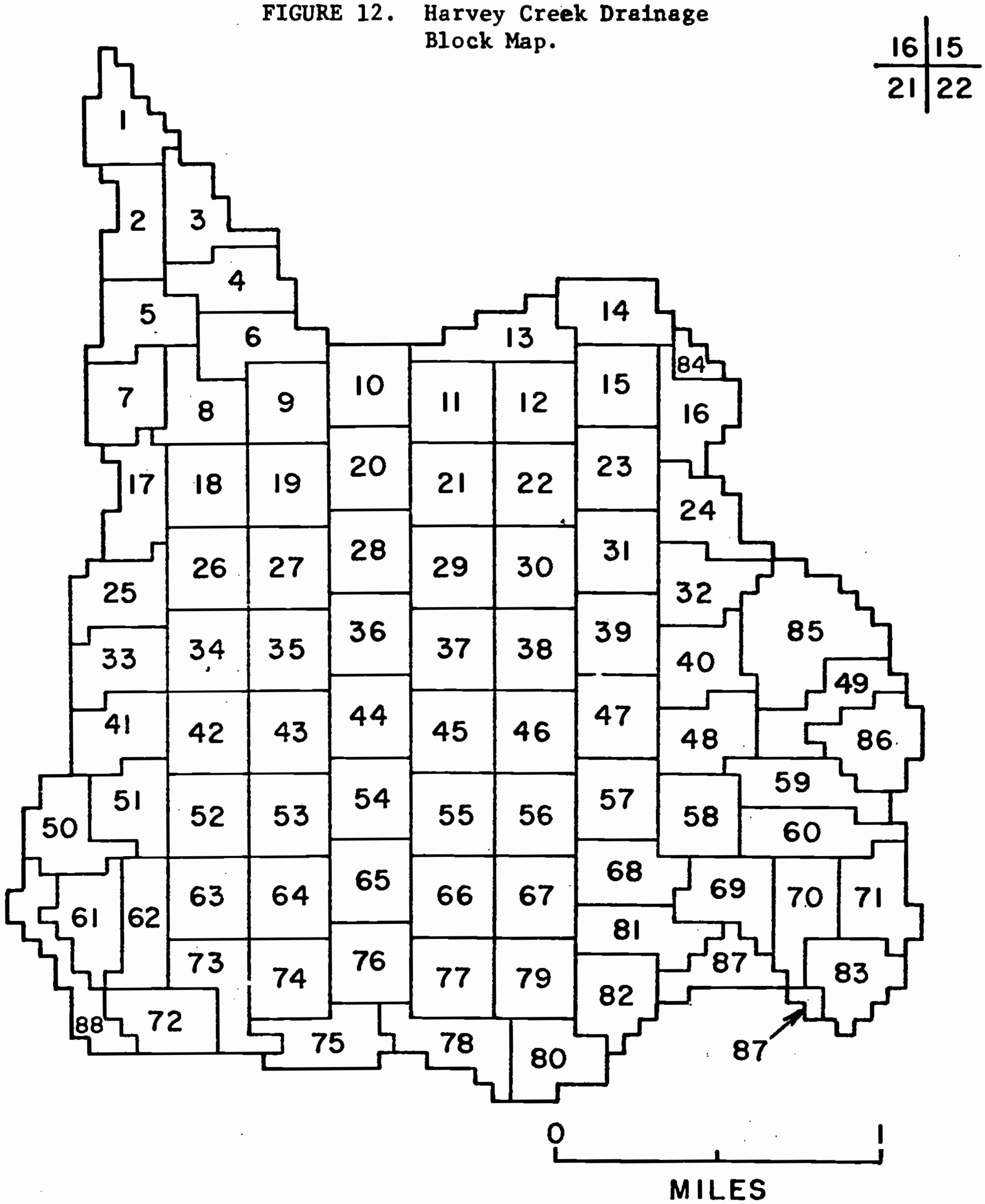


FIGURE 12. Harvey Creek Drainage Block Map.



square chains (1.60 acres) in size. Blocks 1-83 contain 25 cells, hence are 40 acres each. These blocks cover all acreage never harvested. The remaining five blocks (84-88) involve land harvested within the past 20 years. No attempt was made to modify these block arrangements to correspond to a common 40 acre size. These five blocks contain respectively (84-88), six, 52, 27, 22, and 25 cells. The entire drainage contains 2207 1.6 acre cells, or covers an area of 3531.20 acres.

A cell map was laid over each resource map and all cells were assigned a code for the variable state occupying the majority of each cell. This included codes for timber age (Ei), harvest method (Hi), silvicultural method (Ci), slope (Ui), soil type (Vi), land-form (Wi), bedding plane angle (Xi), and fracture angle (Yi) (See page 19 for key to these variables). Two variances from actual existing on-site conditions were employed for reasons explained below.[13] First, timber age for cells in blocks 84-88 was not placed in age classes E1 and E2 (0-5 and 6-10 years old for newly regenerated areas). Headwall and streambank cells were assigned an E5 age class class (41 + years). All other cells were assigned an E4 class (21-40 years). Second, cells in blocks 84-88 were assigned a harvest class of H4 (no harvesting) and a silvicultural class of C3 (natural forest). This compromise with reality was adopted in order to have a homogeneous data base for initial conditions. Such homogeneous initial conditions help to simplify ordinal alternative comparisons by reducing the potential sources of variation in each outcome set for the harvest and

---

13 Actual codes for all cells in blocks 84-88 would have been E1 (0-5 years), H3 (highlead), and C1 (clearcut).

road alternatives specified. All cells in blocks 1 - 83 were assigned harvest and silvicultural codes of H4 and C3.

The basis for all harvest alternatives specified is an 88 year cutting period with an identical timing schedule for each block's harvest year employed in every alternative. For example, this reduces any variation introduced due to different cutting periods and harvest schedules being utilized from alternative to alternative. A single block was scheduled for harvest each year with priority on time of harvest being dictated by most accessible first to least accessible last. This allows for building and maintaing an access system on a systematic, as-needed basis and reduced road building and maintenance investment costs. No attempt was made to determine the optimal block harvest scheduled which minimized such costs; a simple empirical assignment process was employed. Table 24 presents the block cutting schedule. Table 25 is the assumed volume table utilized for this study and the four timber types annotated in Figure 10. This table was adapted from Siuslaw National Forest yield tables presented by Johnson (1973) and interpretations of Bulletin 201 (McArdle, et al, 1961).

Data pertaining to the existing road system was also provided by Siuslaw National Forest personnel (Saurbier, 1975). Approximately six miles of primary gravel surfaced road (S2, M1) has been constructed in the past 15 years. Appropriate variable states for road standard (Si), road surface (Mi), slope class (Ui), road age (Ri), landform class (Wi), soil type (Vi), bedding plane angle (Xi), and fracture angle (Yi) were assigned these road segments (See page 19 for key to these variables). This existing forest road served as the basic

Table 24. Block Cutting Schedule.

Year	Block Cut	Year	Block Cut	Year	Block Cut	Year	Block Cut
1	1	23	65	45	34	67	76
2	60	24	19	46	33	68	74
3	2	25	54	47	73	69	27
4	3	26	11	48	72	70	26
5	59	27	10	49	21	71	24
6	4	28	9	50	48	72	46
7	58	29	64	51	49	73	43
8	57	30	68	52	79	74	41
9	5	31	67	53	80	75	39
10	6	32	20	54	81	76	40
11	15	33	53	55	35	77	38
12	61	34	12	56	32	78	37
13	16	35	13	57	31	79	75
14	17	36	14	58	30	80	36
15	62	37	83	59	22	81	29
16	18	38	70	60	23	82	28
17	56	39	69	61	47	83	25
18	55	40	71	62	45	84	84
19	7	41	50	63	44	85	85
20	8	42	51	64	42	86	86
21	63	43	52	65	78	87	87
22	66	44	82	66	77	88	88

Table 25. Yield Tables for Unthinned Stands of Four Timber Types (Actual Volume in Scribner Board Feet per acre).

Stand Age	Type I	Type II	Type III	Type IV
20	7998	1342	4796	805
30	17154	2878	10421	1748
40	25809	5329	15311	5000
50	33955	8722	19467	8357
60	41591	15185	22888	11045
70	48717	21040	25575	13058
80	55332	26247	27527	14559
90	61438	31118	28745	14559
100	67034	35516	29229	15487
110	72120	39430	28978	15843
120	76695	42951	27992	15304
130	80762	46236	26000	14885
140	84317	48977	25000	14521
150	87363	51201	24000	14061

access component for all alternatives considered.

Ten different harvest and associated road alternatives were specified for this study. Table 26 presents the harvest and road specifications for each Harvey Creek alternative. Headwalls and streamside areas were treated in various ways. In some alternatives they were left in their natural state (1-5 and 7); in others they were both clearcut and partial cut.[14] The mixed alternatives (6 and 10) allowed for construction of some primary, gravel surfaced roads. No midslope roads were scheduled. For alternative six, all timber accessible by running skyline from the non-midslope roadways was partial cut by that system. All other timber was clearcut by the helicopter skycrane. This provided minimal new road construction, no midslope roads, partial cutting of the steepest slopes (closest to ridgetop roads) by a relatively cheap system, and clearcutting of the less steep slopes (more removed from the ridge top areas) by a long reach system. Alternative 10 differed from six only in the silvicultural system assigned each block. An attempt was made to assign partial cuts to all blocks dominated by headwall and streamside cells. All other blocks were assigned the clearcut option. This alternative employed more of a prescription approach designed to consider the special problems of the steep slopes, headwalls, streambank areas, and limited good locations for road placement.

14
All partial cuts are assumed to have 40 percent removal for this study.

Table 26. Harvest and Road Alternatives for the Harvey Creek Drainage

Alternative Number	Harvest Method	Silvicultural Method	Headwall Treatment	Streamside Treatment	Harvest System	Road Segments Utilized
1	H2	C1	H4-C3	H4-C3	Sikorsky S64E Skycrane	1-70
2	H1	C1	H4-C3	H4-C3	Running Skyline Smith-Berger Marc I	1-125
3	H3	C1	H4-C3	H4-C3	West Coast Falcon	1-162
4	H2	C2	H4-C3	H4-C3	Skycrane	1-70
5	H1	C2	H4-C3	H4-C3	Running Skyline	1-125
6	-Mix- H1 & H2	-Mix- C2 & C1	-Mix- H1-C1 H2-C2	-Mix- H1-C1 H2-C2	Skycrane & Running Skyline	1-70
7	H4	C3	H4-C3	H4-C3	None	1-30 (existing)
8	H2	C2	H2-C2	H2-C2	Skycrane	1-70
9	H1	C2	H1-C2	H1-C2	Running Skyline	1-125
10	-Mix- H1 & H2	-Mix- C2 & C1	-Mix- H1 & H2 C1 & C2	-Mix- H1 & H2 C1 & C2	Skycrane & Running Skyline	1-70

An infinite number of such alternatives could be devised, but monetary constraints dictated this somewhat limited approach. These ten alternatives provide for a wide range of reasonable alternative comparisons.

Figure 13 illustrates the existing and planned road segments referenced in Table 26. All road segments were assigned the appropriate set of on-site variable states and measured for length in feet. The primary road segments were assigned an average right-of-way width of 50 feet and the secondary one of 35 feet. State-of-the-art construction methodology was assumed for all road construction which includes where physically possible:

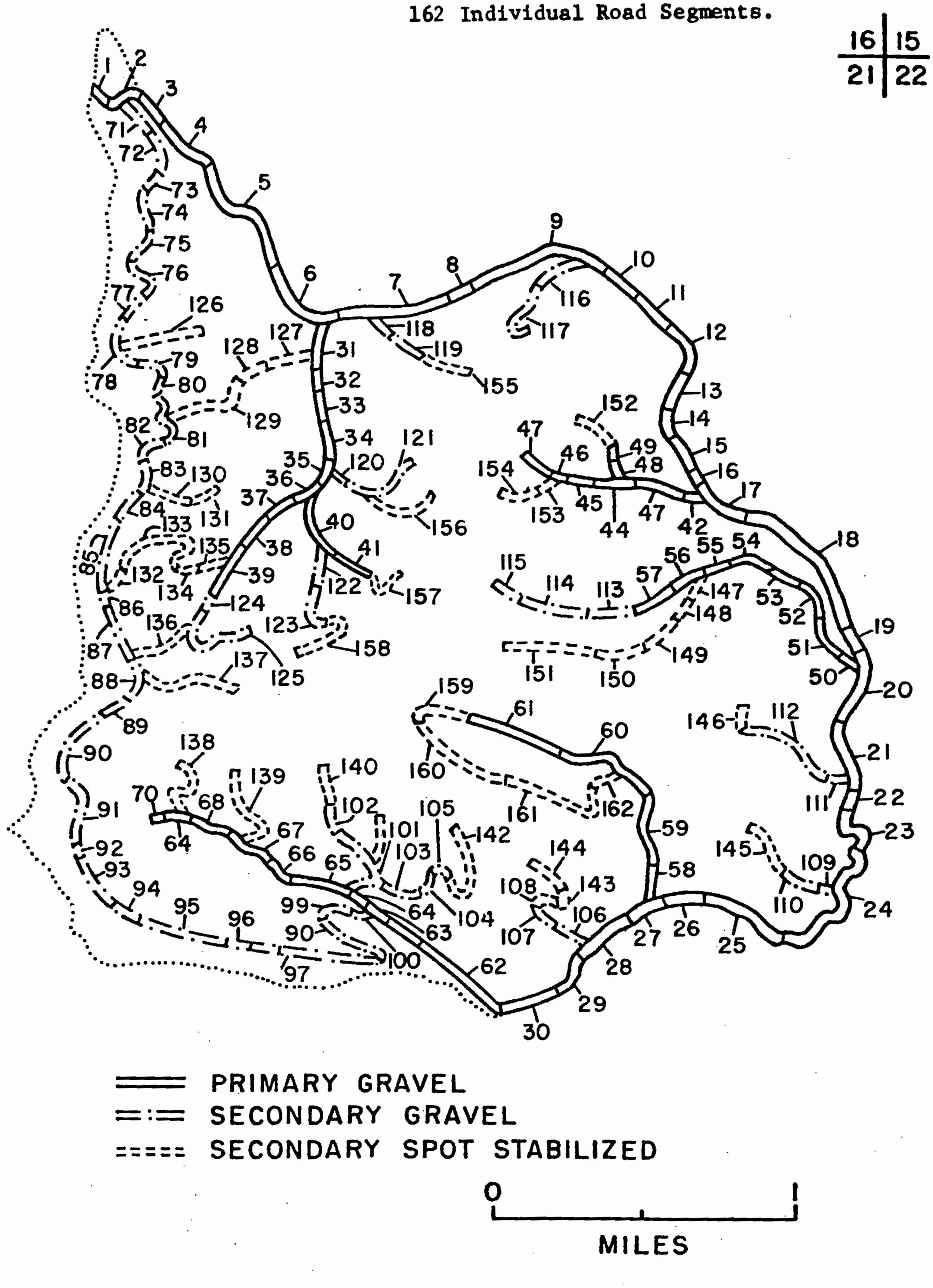
1) right-of-way cleanup,
2) trimming cut banks,
3) end-hauling,
4) twenty-five year flood design for culverts, drainage ways, and stream crossings,
5) stabilizing all cut banks and fill slopes,
6) outsloping all midslope roads with burms,
7) clearing drainage ways of all debris during construction,
8) constructing only during dry periods.

Road segments 1-30 on Figure 13 represent the existing six miles of roadway. Layout of the other 132 planned segments was accomplished by employing technical assistance from Siuslaw National Forest engineering personnel and application of an automated road layout program designed and written for the desk top Hewlett Packard 9830 calculator,[15] (Saurbier, 1975 and Burke, 1974). Actual road placements

---

15 Use of trade names or equipment designations in this report does not imply endorsement by either Oregon State University or the project researcher.

FIGURE 13. Harvey Creek Drainage Road Alternative Map for 162 Individual Road Segments.



would be governed by specific on-site conditions encountered during construction activities, however, this study assumed the planned location was the actual placement location. As with harvest blocks, each road segment was assigned a year of construction. New segments were built on a time schedule to provide access to scheduled concurrent timber harvest. Either a subset or all of the 162 segments are constructed over the 88 year period depending on access requirements for the particular harvest system employed for a specific alternative. Road segments 1-70 were primary gravel (S2, M1), 71-125 secondary gravel (S1, M1), and 126-162 secondary spot stabilized (S1, M2).

Density of forest access requirements are dictated by the yarding capabilities of particular harvest systems employed. Recall that the harvest systems assumed for each alternative in this study are delineated in Table 26. Figures 14-16 and Table 27 present general system specifications for the systems selected. Haulback line capacities for the West Coast Falcon and Smith Berger Marc I systems dictated limits on maximum yarding distance allowed when these systems are used. For this study a maximum yarding distance of 1200 feet was assumed for the West Coast Falcon system (all highlead settings) and one of 2100 feet was assumed for the Smith Berger Marc I (all skyline settings). Maximum yarding distance for the skycrane was assumed to be 8000 feet. These capacities dictated how much road need be constructed in order to reach all timber in one block. Further assumptions were that all yarding would be uphill and that only one landing need be established on an access road each year to harvest the scheduled block.

This process of collecting resource data, designing a grid mapping

FIGURE 14. Highlead Yarding System Schematic (Dykstra, 1974).

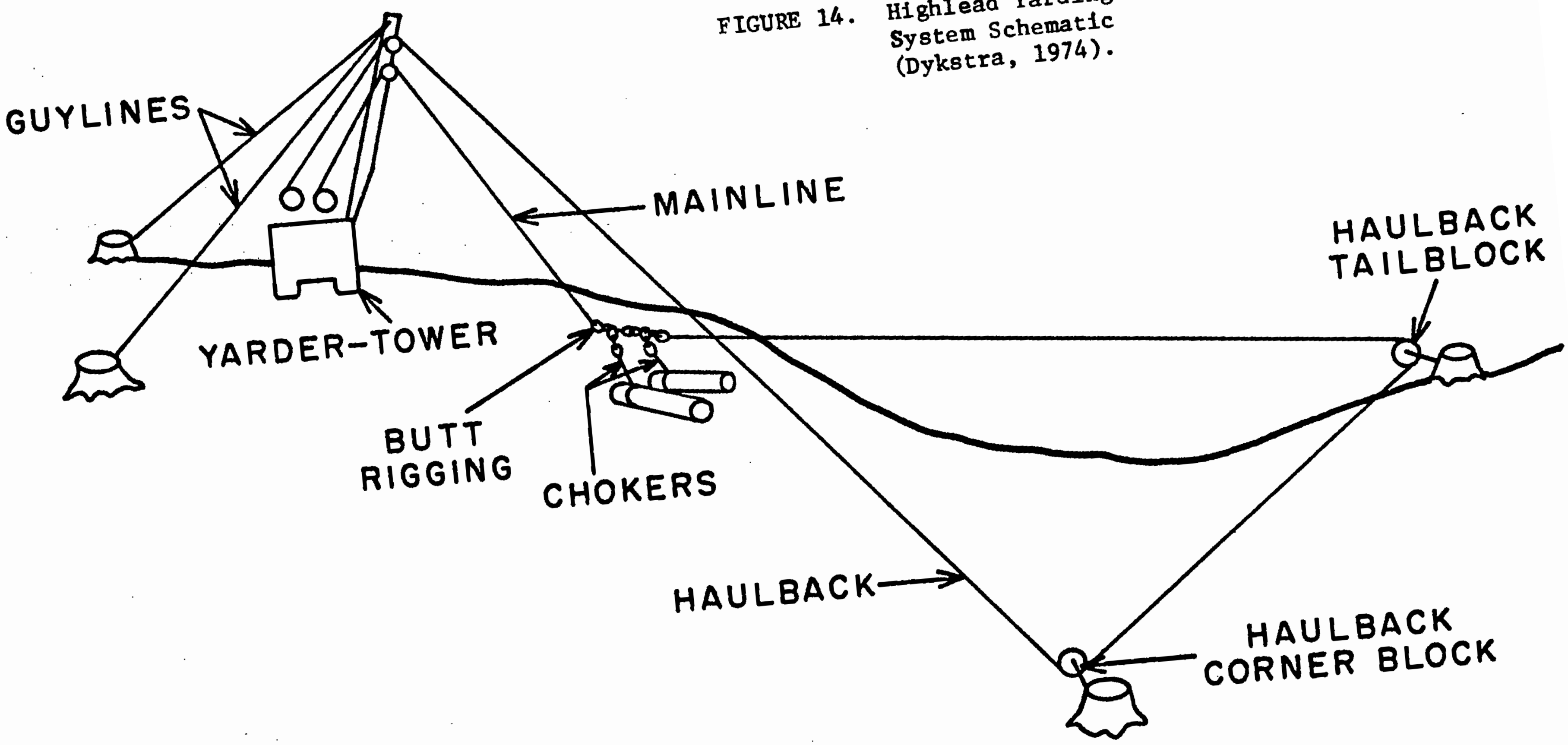


FIGURE 15. Skyline Yarding System Schematic (Dykstra, 1975).

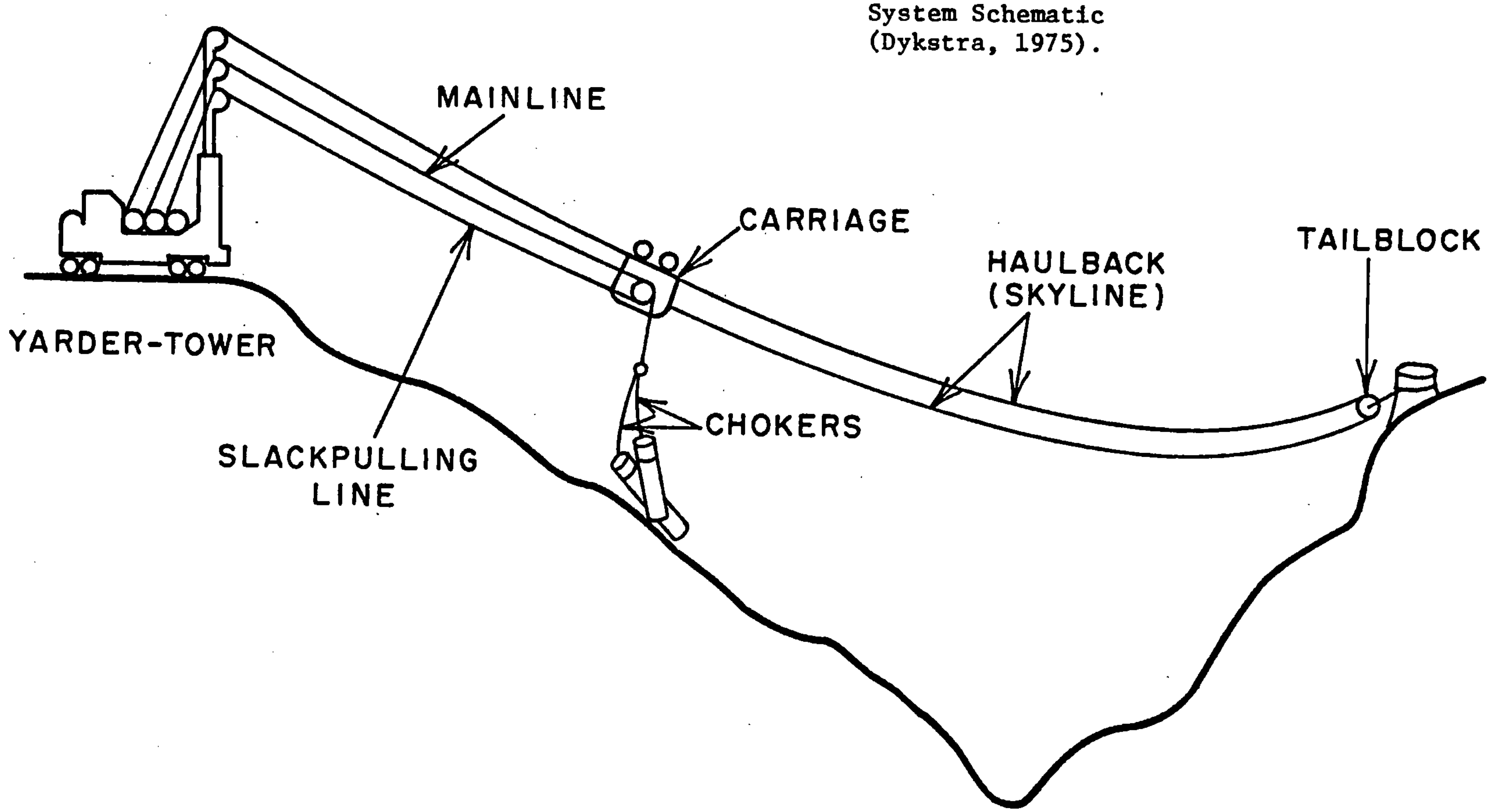


FIGURE 16. Helicopter Yarding System Schematic (Dykstra, 1975).

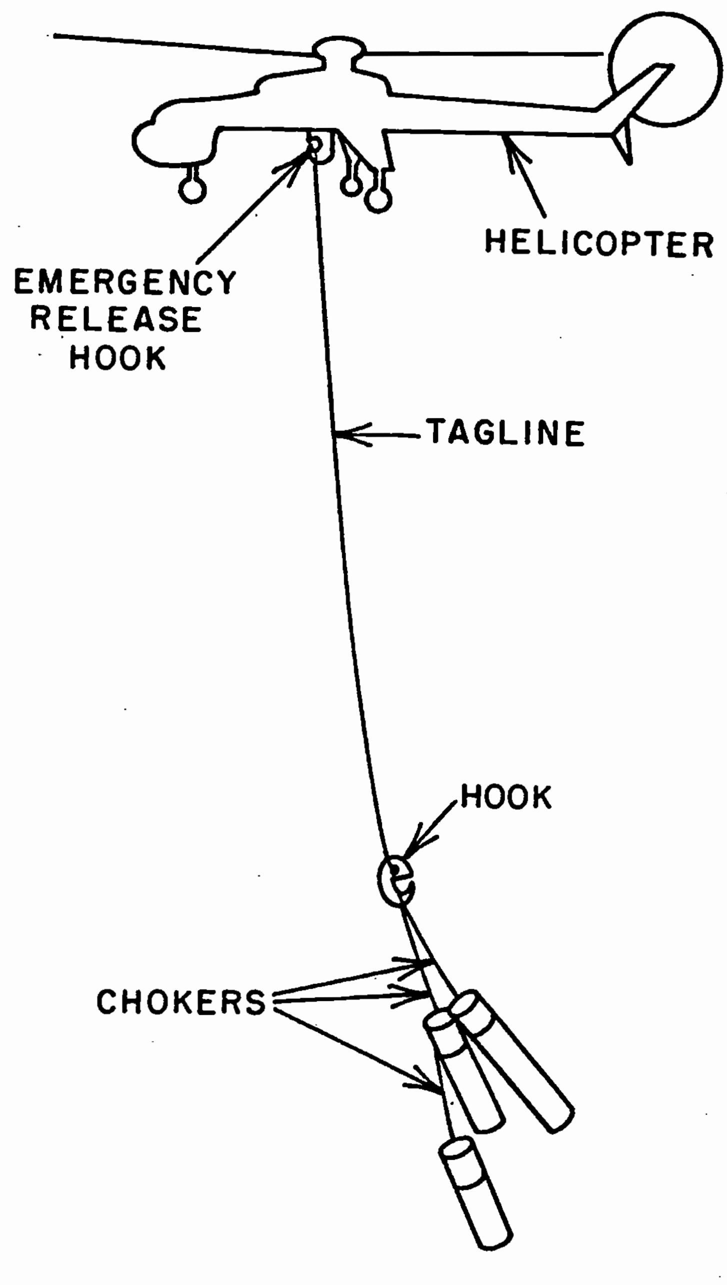


Table 27. Harvest System Specifications (Dykstra 1974 and 1975).

West Coast Falcon	Smith Berger Marc I	Sikorsky S64E Skycrane
Weight ... 72,780 pounds	Weight 99,500 pounds	Average operating weight ... 22,000 pounds
Drum Capacities Skyline ... 2,000 feet 1" line Mainline ... 1,200 feet 3/4" line Haulback ... 2,700 feet 1/2" line Strawline ... 2,500 feet 3/8" line	Drum Capacities Mainline ... 2,200 feet 7/8" line Slackpulling ... 2,300 feet 5/8" line Haulback ... 4,400 feet 7/8" line Strawline ... 4,500 feet 7/8" line	Max gross life capacity... 42,000 pounds[a] Average loaded cruise speed ... 95 knots[a]
Line speed ... 2,120 feet/minute	Line speeds Mainline ... 425 feet/minute Haulback ... 1,800 feet/minute	Vertical rate of climb ... 1330 feet/minute[a]
Line pull ... 67,000 pounds	Line pull: Mainline ... 62,000 pounds Haulback ... 29,000 pounds	Normal external load lifting capacity ...20,000 pounds[a]

[a] At mean sea level with atmospheric temperature of $59^{o}F$, barometric pressure of 29.92 inches and no wind.

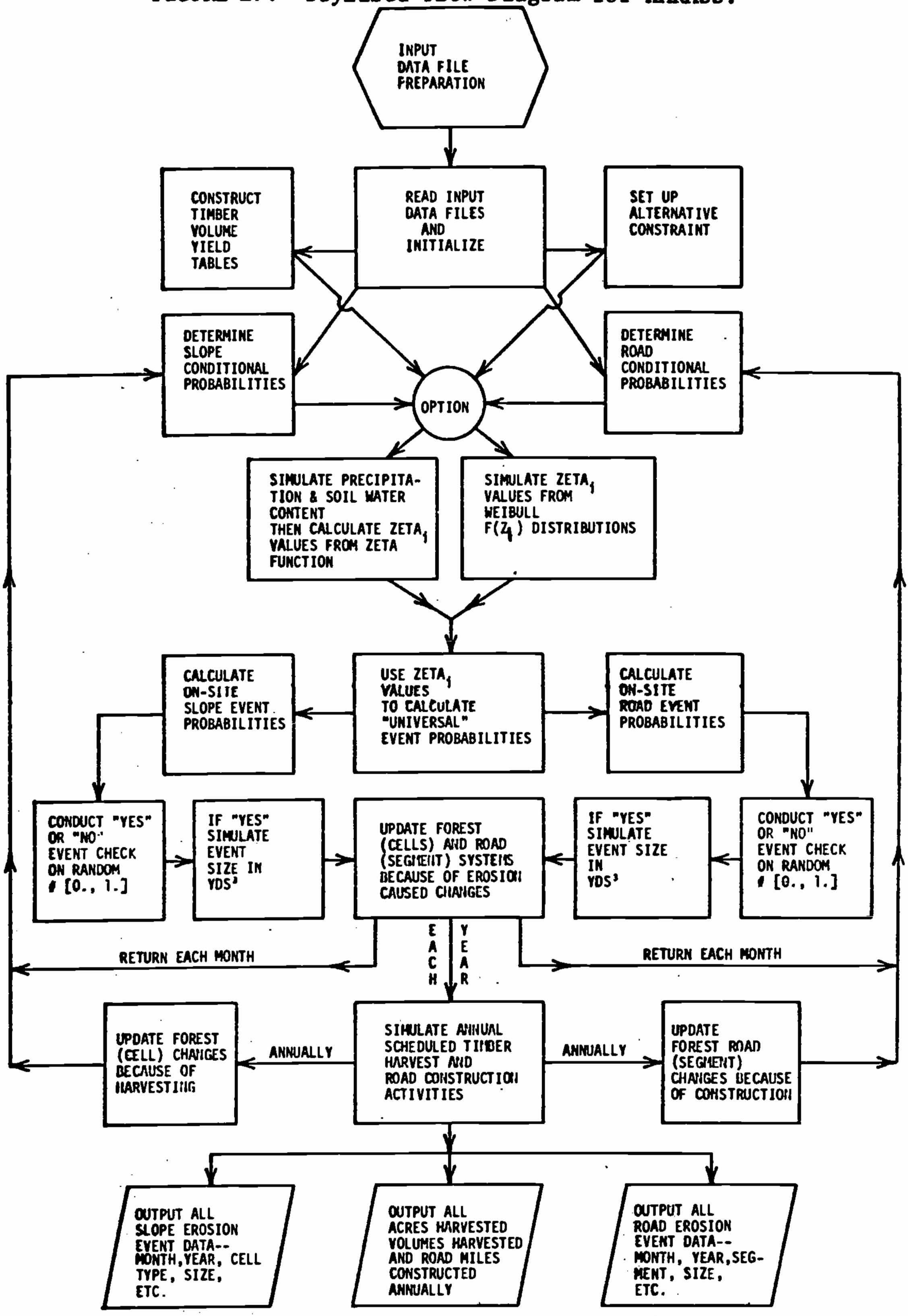
system, assigning variable states for all relevant variables to each cell, selecting harvest systems, specifying harvest alternatives, and outlining required road plans for each harvest alternative set the stage for construction of a harvesting, road building, and erosion simulation model for the Harvey Creek Drainage.

IX. THE HARVEY CREEK EROSION SIMULATION MODEL -- HARASS

The Harvest And Road Associated Soil Slips Model (HARASS) is a FORTRAN IV simulation model which simulates over time the harvesting, road construction, timber growth, climatic conditions, slope erosion, and road erosion associated with a set of proposed harvest alternatives. Appendix D contains a program listing and samples of all relevant data files utilized in operational runs. A complete program deck and all documentation are on file in the Forest Engineering Department at OSU. Figure 17 is a stylized flow diagram of major model operations.

The basic premise of HARASS is that the stochastic nature of climatic and hydrologic parameters control the stochastic properties of erosion phenomena as conditioned by specific on-site variable states. Therefore, stochastic simulation of climatic and hydrologic parameters can be used to drive the probabilistic mechanism for simulation of erosion processes. The key that provides the linkage between climatic and hydrologic parameters and erosion processes is the application of Bayesian probability analysis through "Bayes Theorem." This link provides the mechanism for conditioning all erosion event probabilities on both the climatic and hydrologic parameters and the on-site variable states. Once the climatic and hydrologic conditions are established and the set of on-site variable states is defined, the event probabilities can be determined. HARASS was constructed to reproduce this simple process. Numerous modeling assumptions, constrains, and model embellishments were included in order to facilitate the goal of using this process to simulate erosion phenomena as related to

FIGURE 17. Stylized Flow Diagram for HARASS.



various harvest and road alternatives. Table 28 presents a listing of significant model assumptions, constraints, and special features.

The model structure has general applicability. However, the specific HARASS form presented here must be modified somewhat. HARASS utilization requires simulation of monthly precipitation (P_i)[16] and soil water content levels (S_i) to use for determination of monthly z_i values. Each new area of application requires development of a new watershed model which simulates montly P_i and S_i.

The new watershed model can be incorporated into HARASS by its replacement (in synonomous form) of subroutine WTRSHED. Or, the new watershed model can be used external to HARASS to build three new ZETA k populations which in turn are fit for new Weibull shape and scale parameters by using the Weibull Fit program in Appendix B. These new parameters can be employed in subroutine ZCALCI in lieu of using subroutines WTRSHED and ZCALCII to calculate monthly z_i values.

One other modification must be adopted. Because the ZETA k distributions used in this study were the basis for construction of the universal probability, $Q_j(z_i)$, functions for each event type in T_j and D_j, any new ZETA k populations must be scaled to these initial populations. If this scaling was not accomplished, new $Q_j(z_i)$ would have to be developed for each model use. The scaling factor recommended

---

[16] This study area has no significant snowfall, therefore P_i is monthly precipitation delivered to the watershed. In areas which experience snowfall accumulation, P_i represents the monthly water amount in inches delivered to the soil surface layer, e.g. January snowfall melting in March provides P_i for March and none for Janaury. This requires inclusion of a snowmelt component in the appropriate areas.

Table 28. Key HARASS Assumptions, Constraints, and Special Features.

ASSUMPTIONS	CONSTRAINTS	SPECIAL FEATURES
Road segments and forest cells are mutually exclusive.	Model limited to 2200 cells and 160 segments (arbitrary).	Harvest constraints can be read in by either cells or blocks.
Road and slope erosion events are mutually exclusive, and all sets are exhaustive.	Model limited to five timber types and ten year increment volume tables.	A linear algorithm calculates annual timber yields by type from the 10 year tables.
All on-site variables are mutually exclusive and all sets are exhaustive.	All model function simulation is constrained by random number generator employed.	A matrix column multiplication approach is used to calculate Bayesian conditional probabilities.
The subjective probability schedules (Tables 3-6) do represent reality.	Model has no built in regeneration lag.	A random number function simulates up to 40 streams of random number integers {1,8388608}.
Monthly measures of precipitation and ground H_2O content provide an index of erosion potentials.	All road repairs are accomplished prior to summer cutting period.	The z_i values can be calculated through either a watershed model or simulated from 3 continuous Weibull distributions.
The ZETA Function, as hypotehsized, determines the level of the erosion potential index.	All partial cuts are 40 %.	Numerous harvest alternatives can be specified by keying several internal program options.
The watershed model does represent reality.	Any cell with a road has a 20% area reduction.	Once timber regenerated and over 40 years old model transfer H_i and C_i states to H4 and C3.
Event probability functions have the $Q_j(z_i)$ form presented.	Any road failure larger than 3000 yds^3 sets road age back to zero.	Model tabulates and reports annual road construction by type and annual harvest by areas and type.
"Bayes Theorem" is applicable.	Any D3 or D4 event larger than 5000 yds^3 sets cell timber age back to zero.	
Event size distributions represent reality as presented.	Road right-of-way widths are 50 and 35 feet respectively for S2 and S1.	Model tabulates and reports event sizes, locations, times of occurrence, P_i, S_i, all on-site variable states and totals, means and standard deviations.

is:

$$\text{FACTOR}_k = \left[\frac{\hat{\mu}_{nk}}{\hat{\sigma}_{nk}}\right] \Big/ \left[\frac{\hat{\mu}_{hk}}{\hat{\sigma}_{hk}}\right]$$

Here:

$\hat{\mu}_{hk}$ .... mean of ZETA k population for Harvey Creek Drainage.

$\hat{\sigma}_{hk}$ .... standard deviation of ZETA k population for Harvey Creek Drainage,

$\hat{\mu}_{nk}$ .... mean of ZETA k population for new drainage basin,

$\hat{\sigma}_{nk}$ .... standard deviation of ZETA k population for new drainage basin.

When the user has replaced WTRSHED with a new watershed model, FACTOR_k is read in for use in subroutine ZCALCI. All new z_i values are multiplied by the appropriate FACTOR_k in this subprogram. For this study, FACTOR_k (k =1, 3) was set equal to one. If the option to employ Weibull distributions for simulating new z_i values is selected, FACTOR_k should be multiplied times all z_i values in each ZETA k population prior to fitting the new $\hat{\alpha}_k$ and $\hat{\beta}_k$ parameters. Then, simulation of z_i values in HARASS from subroutine ZCALCII requires no further internal modification. A word of caution; this scaling process has not been thoroughly tested and it may produce inaccurate responses. If a user is not satisfied with utilizing the $Q_j(z_i)$ probability functions developed herein basied on this study's ZETA k populations, he may fit new $Q_j(z_i)$ functions to the new ZETA k populations just as was done in Chapter VI. Regardless of the approach taken, any application should be examined carefully before actual implementation proceeds.

HARASS is a relatively simple simulation model which is unique only in the way in which it combines basic theoretical components of watershed modeling, Bayesian analysis, and elementary activity scheduling, processing, monitoring, and updating. The key to its structure is found in my reliance on the Aristotlean philosophy: producing deductions on the particular from hypotheses about the general. The scope of its application has broad potential because of this philosophical perspective. Utilized in conjunction with an economic analysis model, to be discussed in Chapter X, HARASS can provide insightful information for the decision making process on a variety of horizons. Evaluation of model outcome in Chapter XI for the 10 harvest and road alternatives specified for this study will demonstrate this clearly.

X. THE HARVEST AND ROAD PRESENT NET VALUE MODEL -- HARP.

The Harvest And Road Present net value model (HARP) is a FORTRAN IV analytical model which determines over time the following:

1) annual construction costs,
2) annual maintenance costs,
3) annual road repair costs,
4) annual total road costs,
5) annual harvesting energy requirements,
6) annual regeneration costs,
7) annual harvest equipment costs,
8) annual harvest labor costs,
9) annual harvest setup costs,
10) annual total harvest costs,
11) annual total timber sale returns,
12) alternative discounted returns,
13) alternative discounted costs,
14) alternative present net value.

Appendix E contains a program listing and samples of all relevant data files used in operational runs. A complete program deck and all documentation are on file in the Forest Engineering Department at OSU. Figure 18 is a stylized flow diagram of major model processes.

HARP was designed and built to be used in conjunction with HARASS. Key output from HARASS serves as input for HARP:

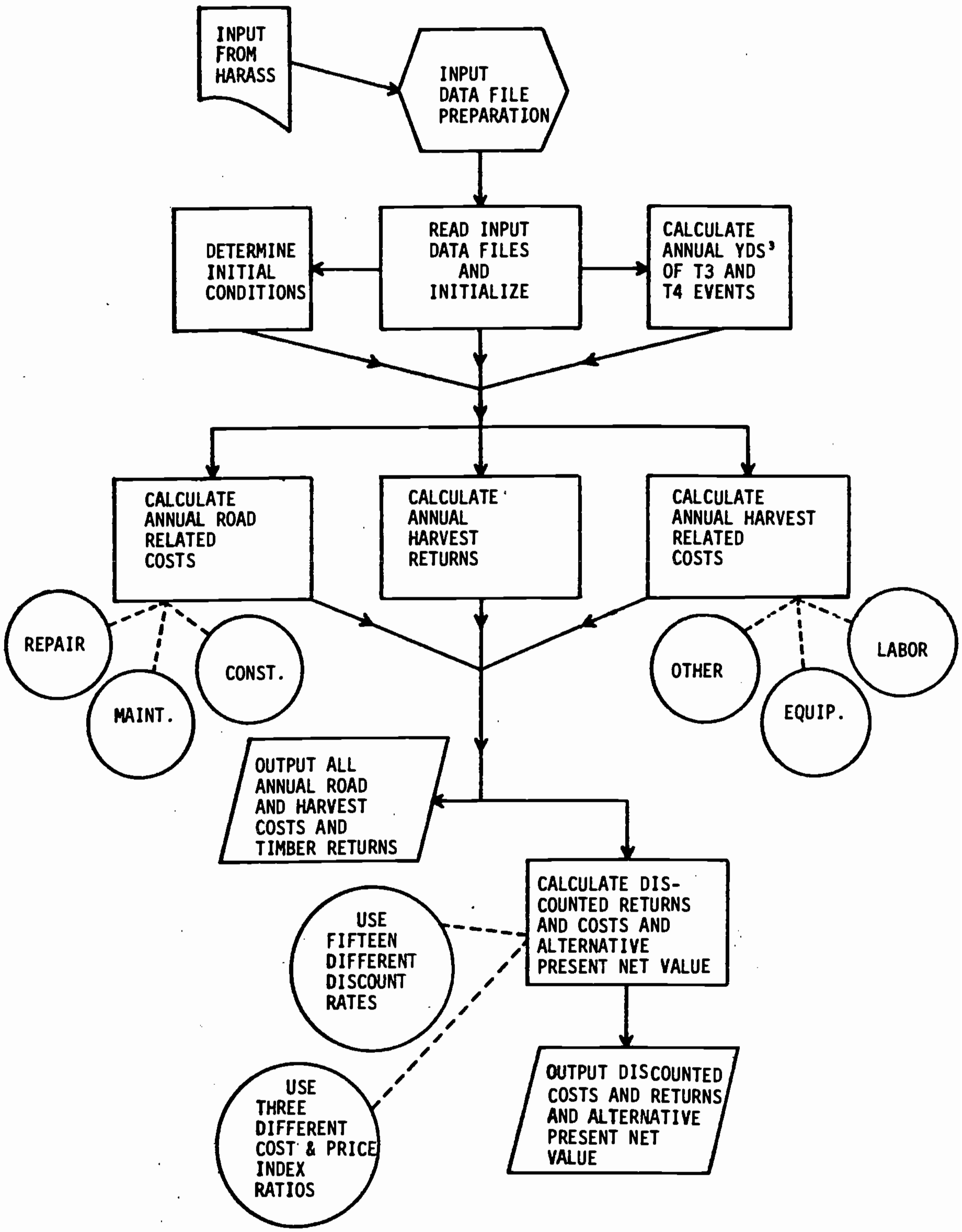
1) table of road damage (T3) and road failure (T4) events by month, year, location, and size in cubic yards,

2) table of annual road construction by type (Si,Mi) and annual acres and timber volume harvested by type.

Additionally, review of Appendices D and E will illustrate that some input files for HARASS also serve in identical form as input files for HARP. This joint design simplifies the work involved in setting up model runs and reduces overall cost of operation.

Calculation of annual road costs involves utilization of construction and erosion data from HARASS and numerous model cost equations and assumptions. All cost data incorporated into HARP runs for this study were provided by the Siuslaw National Forest and

FIGURE 18. Stylized Flow Diagram for HARP.



tailored to specific site conditions and engineering problems for the Harvey Creek Drainage (Saurbier, 1975). Road construction, rocking, maintenance, and repair costs (1975 dollars) utilized are illustrated in Table 29. Notice the relatively high construction costs for ridgetop roads versus midslope roads. This may appear counterintuitive, but because ridgetop roads can be fully contained in the road right-of-way (i.e. all construction material permanently kept in the road right-of-way) when extra construction care, such as end-hauling, is applied, their costs are higher. It is not physically possible to contain a midslope road on the steep slopes of the study area, hence it makes no sense to plan a costly construction procedure which will prove futile.

A point of interest is that the Siuslaw National Forest engineering staff "does not" recommend midslope roads for the Harvey Creek Drainage. However, midslope roads are included as a viable option for this study in order to determine what might be expected to occur if they were constructed, both from an erosional perspective and from a "total" cost perspective. Another important point is that the relatively high construction costs for the secondary roads (very nearly equal that for primary roads) is due to their normal location in rougher terrain than primary roads. All costs included in Table 29 include a basic 20 percent overhead cost component.

Calculation of annual harvest costs depends on output from HARASS on type, volume, and location of timber harvest as well as acres harvested. All costs relationships are based primarily on work reported by Dykstra (1974 and 1975) dealing with production and cost equations for a variety of harvest systems and conditions. Part of the rationale for selecting the particular harvest systems

Table 29. Basic Road Related Costs (Saurbier, 1975).

Road Segment Type	Construction (1975 Dollars) Per Mile	Rocking (1975 Dollars) Per Mile	Maintenance (1975 Dollars) Per Mile	Erosion Repairs[a] Road Damage (1975 Dollars) Per yd^3.	Erosion Repairs[a] Road Failure (1975 Dollars) Per yd^3.
Primary-Gravel (S2, M1)-Ridgetop	200,000	24,000	500	1.75	2.50
Primary-Gravel (S2, M1)-Midslope	100,000	24,000	500	1.75	2.50
Primary-Spot Stabilized (S2, M2)-Ridgetop	200,000	0	500	1.75	2.50
Primary-Spot Stabilized (S2, M2)-Midslope	100,000	0	500	1.75	2.50
Secondary-Gravel (S1, M1)-Ridgetop	180,000	12,000	200	1.75	2.50
Secondary-Gravel (S1, M1)-Midslope	80,000	12,000	200	1.75	2.50
Secondary-Spot Stabilized (S1, M2)-Ridgetop	180,000	0	200	1.75	2.50
Secondary-Spot Stabilized (S1, M2)-Midslope	80,000	0	200	1.75	2.50

[a]Only events larger than 10 cubic yards are repaired.

specified in Chapter VIII was that Dykstra included all of these systems in his production rate and cost analyses. The basic approach for calculating harvest costs is as follows:

1) determine single turn time in minutes for a particular system under specific site conditions,

2) calculate total number of turns required to harvest a unit,

3) determine number of yarding road changes and number of landings per unit,

4) calculate total harvest time in hours from --

$$\text{Harvest Time} = \Big[(\text{Turn Time})(\text{Number of Turns})(\text{Delay Coefficient}) + (\text{Road Change Time})(\text{Number of Yarding Roads} - 1)\Big] / 60.0,$$

5) then: $$\text{Harvest Costs} = \Big[(\text{Harvest Time})(\text{Labor cost/hour} + \text{Equipment cost/hour})\Big] + \Big[(\text{Setup Cost})(\text{Number Landings})\Big]$$

Single turn time in minutes is calculated from regression equations taken from Dykstra's work. The basic form is:

$$\text{Turn Time} = a + b(X_1) + c(X_2) + d(X_3) + e(X_4) \; f(X_5) + g(X_6) + h\,(X_7) + i\,(X_8) \;,$$

where:

a ... regression constant,
b ... $b - i$ are regression coefficients,
X_1 ... board feet volume per turn,
X_2 ... volume per turn/number logs per turn,
X_3 ... number logs per turn,
X_4 ... slope yarding distance in feet,
X_5 ... chord slope in percent,
X_6 ... lateral yarding distance in feet,
X_7 ... tagline length in feet,
X_8 ... number of riggers.

Table 30 contains all constants, coefficients and assumed levels of each variable X_1 - X_8 for the harvest systems identified in Tables 26 and 27. All variables are self-explanatory except chordslope. This is the slope of a line drawn from the skyline fairlead on the yarder tower

Table 30. Turn Time Variable and Regression Coefficient Values (Dykstra 1974 and 1975).

	HIGHLEAD CLEARCUT West Coast Falcon	SKYLINE CLEARCUT Smith-Berger Marc I	SKYLINE PARTIAL CUT Smith-Berger Marc I	HELICOPTER CLEARCUT Sikorsky S64E Skycrane	HELICOPTER PARTIAL CUT Sikorsky S64E Skycrane
Variables					
X_1	250	500	350	1700	1700
X_2	125	250	175	425	425
X_3	2	2	2	4	4
X_4	760	1200	1200	5500	5500
X_5	-60	-60	-60	-30	-30
X_6	0	0	75	0	0
X_7	0	0	0	250	250
X_8	2	2	2	2	2
Regression Coefficients					
a	3.69500	3.08900	1.9400	1.85900	1.37200
b	0.00288	0.00091	0.00086	-0.00005	0.00006
c	-0.00403	-0.00106	-0.00039	0.00006	-0.00005
d	0.00000	0.00000	0.03046	0.04773	0.03120
e	0.00170	0.00184	0.00212	0.00036	0.00025
f	0.00000	0.00000	0.00194	-0.00539	0.01269
g	0.00000	0.00000	0.01186	0.00000	0.00000
h	0.00000	0.00000	0.00000	-0.00100	0.00000
i	0.00000	0.00000	-0.11478	0.00000	0.00000

to the tailhold. For helicopters, this is the slope of a line connecting the landing and hook point. For uphill yarding, chord-slope values are negative. All variable values assumed for this study are gross averages for the drainage "as a whole" and were arrived at after consultation with Dykstra; HARP allows for a more refined approach if a user desires such an option. He may input a set of variable values for each block harvested instead of one overall drainage set. Remaining elements required to complete the harvest cost equation are presented in Table 31. Also included in Table 31 is an estimate of energy consumption for each system in gallons of fuel per thousand board feet (M fbm) harvested.

Regeneration costs are calculated based on an expression presented by Lembersky and Johnson (1974) and similar to one used by Buongiorno and Teeguarden (1973):

Cost = 15.0 + 0.10 (number trees planted per acre). Because site preparation costs are not included for this study, this cost is assumed to represent the relative cost for regeneration. Based on information provided by Lindner, et al (1975), the number of trees planted per acre was assumed to be 375. For this study, this forces regeneration costs to be a constant $52.50 per acre. Any model user can modify the basic equation by changing the values of 15, .10, and 375 which are included as input data.

Annual harvest returns are based on the value of each timber type and the volume harvested annually by HARASS. HARASS allows for five timber types; four were used for this study. Table 32 presents these four types[17] and the assumed values at the mill

---

17 See also, Chapter VIII, Figure 10.

Table 31. Harvest Cost Equation Components (Dykstra, 1974 and 1975).

	HIGHLEAD CLEARCUT West Coast Falcon	SKYLINE CLEARCUT Smith-Berger Marc I	SKYLINE PARTIAL CUT Smith Berger Marc I	HELICOPTER CLEARCUT Sikorsky S64E Skycrane	HELICOPTER PARTIAL CUT Sikorsky S64E Skycrane
Delay Coefficient	1.15	1.10	1.25	1.30	1.30
No. of Landings per Block	1	1	1	1	1
No. of Roads per Block	15	10	10	1[a]	1[a]
Road Change Time (minutes)	15	30	40	0	0
Setup Cost (dollars)	725	750	750	1000	1000
Labor Cost (dollars/hour)	31.90	31.90	31.90	149.80	149.80
Equipment Cost (dollars/hour)	12.30	18.70	18.70	1363.60	1363.60
Energy Used (gallons/M fbm)	3.50	1.90	2.30	19.30	19.30

[a] Actually equal to zero, but set at 1 for computational purposes.

in 1975 dollars. HARP allows the user to input up to five different values.

Table 32. Timber Values at the Mill for Four Harvey Creek Timber Types (Rowley, 1975)[18]

Timber Type	Type Description	Value at the Mill (1975 Dollars)
Type I	Douglas-fir High Site	175.00
Type II	Douglas-fir Low Site	150.00
Type III	Douglas-fir Mix (60%) High Site	150.00
Type IV	Douglas-fir Mix (60%) Low Site	125.00

Discounted returns and costs and present net values (PNV) are calculated for each alternative for nominal interest rates from one to fifteen percent. Also included in HARP is an option to introduce three different pairs of annual cost and price indices. For this study a constant annual price index of 2.7 percent is assumed (USDA FS, 1973). In order to examine the impact of costs rising faster than returns, returns rising faster than costs, and no difference in the rates of increase, three different annual cost indices were employed: 3.5, 2.0, and 2.7 percent. A user can modify an input file to alter the cost and price indicies employed. The discounted costs, discounted returns , and PNV are calculated from:

$$DC = \sum_{i=1}^{n} \left[(TC_i)\ (1+CI)^n \ /\ (1+R)^n \right],$$

$$DR = \sum_{i=1}^{n} \left[(TR_i)(1+RI)^n / (1+R)^n \right], \text{ and } PNV = DR - DC.$$

18 These are "optimistic" mill values.

Here:

- DC .... discounted costs,
- DR .... discounted returns,
- TC_i.... total annual costs for year i,
- TR_i.... total annual returns for year i,
- R .... annual nominal discount rate in decimals,
- CI .... annual cost index in decimals,
- RI .... annual returns index in decimals,
- n .... number years in alternative,
- PNV.... present net value for alternative at the specified set of cost and return indicies and the selected annual nominal discount rate.

The products of HARP are two output tables which list all annual cost components and all discounted costs and returns and present net values for each alternative. This output, combined with that from HARASS, provides a set of analytical information which can be introduced into the decision making process to aid in identification, quantification, and integration of harvest and road alternative constraints. Review and analysis of output from both HARASS and HARP for the ten specified harvest and road alternatives illustrates this point in the following chapter.

XI. EVALUATION OF TEN HARVEST AND ROAD ALTERNATIVES FOR THE HARVEY CREEK DRAINAGE

The purpose of this chapter is to demonstrate how HARASS and HARP may be employed simultaneously to evaluate various harvest and road alternatives. These two models do not provide "decisions", they provide "information" which may be integrated into the decision making process. Both HARASS and HARP are "models" and as such are "abstractions" from reality. Therefore, all model output must be viewed in a relative, rather than absolute, perspective.

Table 33 illustrates examples of output obtained from HARASS for each alternative. Table 34 demonstrates examples of model products from HARP. These two models were analyzed in 30 trial runs of varying size and complexity. No significant model inconsistencies were observed. All model subroutines and analytical components were examined with great care and no apparent analytical errors were uncovered for each of the final model forms. Once HARASS and HARP models functioned as planned and without any observed instabilities, the ten alternatives specified in Chapter VIII were submitted to model evaluation.

Each alternative was submitted to one 88 year run for HARASS and HARP. A more appropriate approach would have been to submit each alternative to numerous runs under different, independent random number sets. This would have allowed for a more thorough evaluation of the impact natural variation in the stochastic process might have on each alternative. This limited approach was dictated primarily by financial

TABLE 33. Examples of Model Output from HARASS.

ROAD EROSION STATISTICS
FOR ALTERNATIVE NO. 1

OFF ROAD EROSION

YEAR	MONTH	SEG-MENT	SIZE IN CUBIC YD.
1	2	15	19.2
1	2	18	549.7
1	2	24	5.9
1	3	9	105.1
1	3	11	83.3
1	3	17	169.2
1	3	19	39.0
1	3	26	25.1
4	2	9	192.1
4	2	18	126.5
4	2	22	5.6
6	3	9	67.4
6	3	31	46.1
6	3	32	131.0
7	4	31	30.0
9	3	31	1291.6
10	4	2	3.1
10	4	5	370.1
10	4	6	78.2
10	4	9	92.1
10	4	32	12.5
10	4	34	86.0
10	4	40	41.0

ROAD DAMAGE

YEAR	MONTH	SEG-MENT	SIZE IN CUBIC YD.
1	2	7	228.3
1	3	5	132.9
1	3	9	243.9
1	3	17	69.7
1	3	21	314.7
1	3	29	176.9
1	3	30	10.7
4	2	4	173.9
4	2	7	189.3
4	2	21	711.4
4	2	24	142.2
4	2	26	261.2
6	3	9	397.8
6	3	18	42.2
6	3	31	79.9
6	3	32	137.7
10	4	4	259.1
10	4	5	169.3
10	4	9	72.3
10	4	17	32.7
10	4	20	349.1
10	4	26	442.6

ROAD FAILURE

YEAR	MONTH	SEG-MENT	SIZE IN CUBIC YD.
1	2	18	6049.5
4	2	9	1114.7
6	3	25	7468.1
10	4	5	1725.3
10	4	17	12907.0
10	4	19	22539.6

SUMMARY DATA

	OFF ROAD EROSION	ROAD DAMAGE	ROAD FAILURE
TOTAL EVENTS	23	22	6
TOTAL SIZE	3570.0	4637.7	51804.1
MEAN SIZE	155.2	210.8	8634.0
STD. SIZE	276.3	162.2	8049.0

Table 33. Continued.

ROAD EROSION STATISTICS
FOR ALTERNATIVE NO. 1

SEGMENT NUMBER	SEGMENT LENGTH (FEET)	EVENT TYPE T(K)	EVENT SIZE CUBIC YARDS	ROAD AGE R(K)	ROAD STAND-DARD CLASS S(K)	ROAD WIDTH CLASS M(K)	SLOPE CLASS U(K)	SOIL TYPE V(K)	LANDFORM W(K)	BEDDING PLANE DIP X(K)	BEDDING PLANE FRACTURE ANGLE Y(K)	PRECIP-ITATION P(J)	SOIL WATER CONTENT G(J)	YEAR	MONTH
7	1900.0	3	228.3	2	2	1	1	3	4	3	2	22.73	17.43	1	2
15	640.0	2	19.2	2	2	1	1	1	4	3	2	22.73	17.43	1	2
18	2610.0	2	549.7	3	2	1	2	1	4	3	2	22.73	17.43	1	2
18	2610.0	4	6049.5	3	2	1	2	1	4	3	2	22.73	17.43	1	2
24	2660.0	2	5.9	3	2	1	2	3	4	3	2	22.73	17.43	1	2
5	1849.0	3	132.9	3	2	1	2	3	4	3	2	22.91	10.36	1	3
9	2600.0	2	105.1	2	2	1	2	3	4	3	2	22.91	10.36	1	3
9	2600.0	3	243.9	2	2	1	2	3	4	3	2	22.91	10.36	1	3
11	823.0	2	83.3	2	2	1	2	3	4	3	2	22.91	10.36	1	3
17	950.0	2	169.2	2	2	1	1	1	4	3	2	22.91	10.36	1	3
17	950.0	3	69.7	2	2	1	1	1	4	3	2	22.91	10.36	1	3
18	2610.0	2	39.0	3	2	1	2	1	4	3	2	22.91	10.36	1	3
21	1188.0	3	314.7	3	2	1	2	3	4	3	2	22.91	10.36	1	3
26	700.0	2	25.1	3	2	1	2	1	4	3	2	22.91	10.36	1	3
29	760.0	3	176.9	3	2	1	2	3	4	3	2	22.91	10.36	1	3
30	1045.0	3	10.7	3	2	1	2	1	4	3	2	22.91	10.36	1	3
4	1056.0	3	173.9	3	2	1	2	1	4	3	2	24.25	19.41	4	2
7	1900.0	3	159.3	3	2	1	1	3	4	3	2	24.25	19.41	4	2
9	2600.0	2	192.1	3	2	1	2	3	4	3	2	24.25	19.41	4	2
9	2600.0	4	1114.7	3	2	1	2	3	4	3	2	24.25	19.41	4	2
18	2610.0	2	126.5	3	2	1	2	1	4	3	2	24.25	19.41	4	2
21	1188.0	3	711.4	3	2	1	2	3	4	3	2	24.25	19.41	4	2
22	315.0	2	5.6	3	2	1	2	1	4	3	2	24.25	19.41	4	2
24	2650.0	3	142.2	3	2	1	2	3	4	3	2	24.25	19.41	4	2
26	700.0	3	261.2	3	2	1	2	1	4	3	2	24.25	19.41	4	2
9	2600.0	2	67.4	3	2	1	2	3	4	3	2	23.66	14.08	6	3
9	2600.0	3	397.8	3	2	1	2	3	4	3	2	23.66	14.08	6	3
18	2610.0	3	42.2	3	2	1	2	1	4	3	2	23.66	14.08	6	3
25	1490.0	4	7468.1	3	2	1	2	1	1	3	2	23.66	14.08	6	3
31	855.0	2	46.1	1	2	1	2	1	4	3	2	23.66	14.09	6	3
31	855.0	3	79.9	1	2	1	2	1	4	3	2	23.66	14.08	6	3
32	412.0	2	131.0	1	2	1	2	3	4	3	2	23.66	14.09	6	3
32	412.0	3	137.7	1	2	1	2	3	4	3	2	23.66	14.09	6	3
31	855.0	2	30.0	1	2	1	2	1	4	3	2	17.75	12.07	7	4
31	855.0	2	1291.6	1	2	1	2	1	4	3	2	15.53	15.98	8	3
2	974.0	2	3.1	4	2	1	2	3	4	3	2	35.47	12.74	10	4
4	1056.0	3	259.1	4	2	1	2	1	4	3	2	35.47	12.74	10	4
5	1849.0	2	370.1	4	2	1	2	3	4	3	2	35.47	12.74	10	4
5	1849.0	3	169.3	4	2	1	2	3	4	3	2	35.47	12.74	10	4
5	1849.0	4	1725.3	4	2	1	2	3	4	3	2	35.47	12.74	10	4
6	1400.0	2	78.2	4	2	1	2	1	4	3	2	35.47	12.74	10	4
9	2600.0	2	92.1	3	2	1	2	3	4	3	2	35.47	12.74	10	4
9	2600.0	3	72.3	3	2	1	2	3	4	3	2	35.47	12.74	10	4
17	950.0	3	32.7	3	2	1	1	1	4	3	2	35.47	12.74	10	4
17	950.0	4	12907.0	3	2	1	1	1	4	3	2	35.47	12.74	10	4
18	2610.0	4	22539.6	4	2	1	2	1	4	3	2	35.47	12.74	10	4
20	1457.0	3	349.1	4	2	1	1	1	4	3	2	35.47	12.74	10	4
26	700.0	3	442.6	4	2	1	2	1	4	3	2	35.47	12.74	10	4
32	412.0	2	12.5	1	2	1	2	3	4	3	2	35.47	12.74	10	4
34	523.0	2	86.0	1	2	1	2	3	4	3	2	35.47	12.74	10	4
40	1294.0	2	41.0	1	2	1	2	3	4	3	2	35.47	12.74	10	4

Table 33. Continued.

SLOPE EROSION STATISTICS
FOR ALTERNATIVE NO. 1

ROCKSLIDES

YR.	MON.	BLK.	CELL	SIZE IN CUBIC YARDS

SUMMARY DATA	
TOTAL EVENTS 0	TOTAL SIZE 0
MEAN SIZE 0	STD. SIZE .

DEBRIS AVALANCHE/FLOWS

YR.	MON.	BLK.	CELL	SIZE IN CUBIC YARDS
1	2	14	341	10116.4
4	2	4	76	1083.4
4	2	4	97	152.3
4	2	8	189	9103.4
4	2	14	341	2941.5
6	3	3	66	1111.6
10	4	1	4	762.5
10	4	3	73	501.6
10	4	5	104	348.9
10	4	6	132	375.7
10	4	6	135	384.2
10	4	6	145	156.8
10	4	6	146	684.1
10	4	9	214	81.5
10	4	9	217	1169.5

SUMMARY DATA	
TOTAL EVENTS 15	TOTAL SIZE 28872.3
MEAN SIZE 1924.8	STD. SIZE 3198.8

SLUMP EARTHFLOWS

YR.	MON.	BLK.	CELL	SIZE IN CUBIC YARDS

SUMMARY DATA	
TOTAL EVENTS 0	TOTAL SIZE 0
MEAN SIZE 0	STD. SIZE .

CREEP ACCELERATIONS

YR.	MON.	BLK.	CELL	SIZE IN CUBIC YARDS
4	2	1	4	8602.1
4	2	1	14	175.3
4	2	10	250	370.0
10	4	3	66	4129.9

SUMMARY DATA	
TOTAL EVENTS 4	TOTAL SIZE 13277.2
MEAN SIZE 3319.3	STD. SIZE 3964.4

Table 33. Continued.

SLOPE EROSION STATISTICS
FOR ALTERNATIVE NO. 1

CELL NUMBER	CELL SIZE (ACRES)	EVENT TYPE D(K)	EVENT SIZE CUBIC YARDS	TIMBER AGE E(K)	HARVEST TYPE H(K)	SILVICULTURE CLASS C(K)	SLOPE CLASS U(K)	SOIL TYPE V(K)	LANDFORM W(K)	BEDDING PLANE DIP Y(K)	BEDDING PLANE FRACTURE ANGLE Y(K)	PRECIPITATION P(J)	SOIL WATER CONTENT G(J)	YEAR	MONTH
341	1.6	3	10116	5	4	3	4	1	4	3	1	22.73	17.43	1	2
4	1.6	5	8602	1	2	1	4	3	1	3	1	24.25	19.41	4	2
14	1.3	5	175	1	2	1	3	3	1	3	1	24.25	19.41	4	2
76	1.6	3	1083	1	2	1	3	1	1	3	1	24.25	19.41	4	2
97	1.6	3	152	1	2	1	3	1	1	3	1	24.25	19.41	4	2
189	1.6	3	9103	5	4	3	3	1	2	3	1	24.25	19.41	4	2
250	1.6	5	370	5	4	3	3	1	2	3	1	24.25	19.41	4	2
341	1.6	3	2842	1	4	3	4	1	4	3	1	24.25	19.41	4	2
66	1.6	3	1112	1	2	1	4	1	1	3	1	23.66	14.08	6	3
4	1.6	3	762	2	2	1	4	1	1	3	1	35.47	12.74	10	4
65	1.6	5	4130	1	2	1	4	1	1	3	1	35.47	12.74	10	4
73	1.6	3	502	2	2	1	4	1	1	3	1	35.47	12.74	10	4
104	1.6	3	349	1	2	1	4	1	1	3	1	35.47	12.74	10	4
132	1.6	3	376	1	2	1	4	1	1	3	1	35.47	12.74	10	4
135	1.6	3	384	1	2	1	4	1	1	3	1	35.47	12.74	10	4
145	1.6	3	157	1	2	1	4	1	1	3	1	35.47	12.74	10	4
146	1.6	3	684	1	2	1	4	1	1	3	1	35.47	12.74	10	4
214	1.6	3	81	1	2	1	3	1	1	3	1	35.47	12.74	10	4
217	1.6	3	1169	1	2	1	3	1	1	3	1	35.47	12.74	10	4

ANNUAL ROAD CONSTRUCTION AND TIMBER
HARVEST SUMMARY STATISTICS
FOR ALTERNATIVE NO. 2

YEAR	ROAD CONSTRUCTION DATA: SECONDARY GRAVEL (FEET)	SECONDARY SPOT STABILIZED (FEET)	PRIMARY GRAVEL (FEET)	PRIMARY SPOT STABILIZED (FEET)	TIMBER HARVEST DATA: TIMBER TYPE 1 ACRES	TIMBER TYPE 1 VOLUME (BOARD) (FEET)	TIMBER TYPE 2 ACRES	TIMBER TYPE 2 VOLUME (BOARD) (FEET)	TIMBER TYPE 3 ACRES	TIMBER TYPE 3 VOLUME (BOARD) (FEET)	TIMBER TYPE 4 ACRES	TIMBER TYPE 4 VOLUME (BOARD) (FEET)	TIMBER TYPE 5 ACRES	TIMBER TYPE 5 VOLUME (BOARD) (FEET)	YEAR
1	0.00	0.00	0.00	0.00	39.1	427212.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
2	0.00	0.00	0.00	0.00	37.1	385090.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2
3	0.00	0.00	0.00	0.00	39.7	135002.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3
4	0.00	0.00	0.00	0.00	38.7	714747.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4
5	0.00	0.00	1267.00	0.00	40.0	233591.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5
6	0.00	0.00	0.00	0.00	0.0	0.0	38.4	117312.9	0.0	0.0	0.0	0.0	0.0	0.0	6
7	0.00	0.00	1030.00	0.00	40.0	266600.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7
8	0.00	0.00	0.00	0.00	0.0	0.0	40.0	407157.9	0.0	0.0	0.0	0.0	0.0	0.0	8
9	1855.00	0.00	2320.00	0.00	0.0	0.0	40.0	51432.9	0.0	0.0	0.0	0.0	0.0	0.0	9
10	0.00	0.00	1315.00	0.00	40.0	92543.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10

Table 34. Examples of Model Output from HARP.

SUMMARY TABLE FOR
COSTS AND RETURNS FOR
HARVEST AND ROAD ALTERNATIVE 5

YEAR	ROAD COSTS: CONSTRUC-TION	ROAD COSTS: MAINTE-NANCE	ROAD COSTS: REPAIRS	ROAD COSTS: TOTAL ROAD COSTS	HARVEST COSTS: ENERGY IN GALLONS	HARVEST COSTS: REGENER-ATION	HARVEST COSTS: EQUIP-MENT	HARVEST COSTS: LABOR	HARVEST COSTS: SETUP	HARVEST COSTS: TOTAL HARVEST COSTS	TOTAL RETURNS
1	0.00	3045.00	19951.70	22996.70	2166.26	2089.25	6710.43	10595.26	750.00	19554.96	180941.56
2	0.00	3045.00	0.00	3045.00	19581.19	1947.75	47732.49	7449.96	1000.00	70121.00	176924.24
3	0.00	3045.00	0.00	3045.00	2442.26	2031.75	6476.30	10929.40	750.00	20115.46	155924.49
4	0.00	3045.00	0.00	3045.00	2460.19	2031.75	6451.00	11999.05	750.00	20242.80	197203.03
5	53751.52	3245.35	19.73	57016.19	21495.34	2100.00	74624.08	9197.92	1000.00	95322.01	194915.50
6	0.00	3245.35	20550.40	23795.75	1337.67	2015.00	3559.50	6772.25	750.00	12337.05	87237.59
7	43695.37	3331.39	241.45	47137.32	50479.97	2107.00	176712.24	19417.95	1000.00	193225.20	451127.69
8	0.00	3331.50	0.00	3331.50	11555.24	2100.00	40137.70	4479.39	1000.00	47647.09	99915.32
9	99763.64	3754.64	37734.00	140256.27	1075.52	2100.00	2994.24	4923.17	750.00	10654.49	79148.91
10	55757.03	3949.17	213.60	59301.72	2495.40	2107.00	6517.60	11114.39	750.00	20495.06	193112.35
11	41703.03	4011.26	0.00	45714.29	2709.42	2107.00	7313.92	13329.47	750.00	23391.29	194936.73
12	0.00	4031.26	61060.25	65091.51	21161.65	2100.00	73497.70	8074.40	1000.00	84674.10	191990.26
13	0.00	4031.26	0.00	4031.26	7734.62	2107.00	7392.19	12091.39	750.00	22013.57	205773.00
14	30243.49	4101.79	0.00	34341.26	2121.22	2100.00	5594.07	9525.77	750.00	17959.04	161549.19
15	0.00	4100.79	715.40	4815.16	22977.03	2100.00	79304.39	8787.09	1000.00	91672.06	209341.00
16	0.00	4100.79	14392.43	18491.29	1419.70	1947.75	3769.41	6429.44	750.00	12894.61	97523.69
17	0.00	4101.79	42327.90	46421.69	12109.11	1961.50	42057.96	4529.33	1000.00	47641.79	94112.29
18	0.00	4101.79	0.00	4101.79	8244.19	2080.25	24732.90	3151.97	1000.00	34945.02	64496.59
19	0.00	4100.79	16761.03	20402.55	1201.77	2016.00	2451.41	4702.95	750.00	9432.72	94975.29
20	26351.00	4230.79	29017.95	59739.55	1021.46	2084.25	2745.71	4651.05	750.00	10263.91	66443.15
21	27007.09	4363.76	10520.53	41497.03	23429.00	2069.50	81371.51	4417.17	1000.00	93379.10	212430.61
22	0.00	4159.34	562.63	4711.50	5796.39	2069.50	11561.77	19721.02	750.00	34103.29	533977.90
23	0.00	4369.76	97049.65	101417.61	7110.94	2094.25	10437.99	11453.02	750.00	92725.24	541947.40
24	0.00	4154.35	0.00	4164.76	2497.70	1961.50	7064.01	12951.73	750.00	21930.03	205255.79
25	0.00	4161.46	63641.00	69093.46	23339.91	2016.00	81041.65	8935.15	1000.00	92903.31	211622.22
26	0.00	4169.46	3021.19	7310.11	5914.72	2107.00	11339.07	19794.94	750.00	34213.00	515566.19
27	0.00	4734.96	380.70	4927.66	7317.95	2100.00	10171.49	12361.11	750.00	54194.54	555733.10
28	75934.13	4597.29	1.00	80531.38	7061.06	2016.00	10107.69	31214.15	750.00	52109.03	537254.53
29	0.00	4595.29	51961.03	56516.11	22231.09	1361.50	77221.09	8091.22	1000.00	98667.06	201595.19
30	42437.12	4756.49	1151.30	48553.90	6137.71	2109.00	12739.03	20876.64	750.00	35994.60	563114.99
31	0.00	4755.40	11139.40	15901.40	3452.60	2109.00	9010.11	15170.14	750.00	27230.30	225149.99
32	40910.01	4911.16	925.70	46669.47	1266.41	2100.00	3175.94	5759.95	750.00	11994.59	69126.69
33	0.00	4911.16	0.00	4911.16	1195.65	2103.00	38195.57	4217.43	1000.00	45711.57	71597.30
34	0.00	4911.16	24651.49	29562.46	1266.40	2109.00	3417.61	5995.62	750.00	12110.23	70021.50
35	0.00	4911.16	141774.21	146651.53	7169.94	2100.00	19103.40	32599.15	750.00	54541.55	560599.10
36	0.00	4911.16	25965.79	30793.14	2774.73	2163.00	7144.59	12197.99	750.00	22192.38	207620.49
37	42289.19	5133.10	0.00	47891.10	6094.12	2109.00	12072.52	20591.23	750.00	35516.91	557634.30
38	49004.05	5214.57	2920.05	57214.16	69409.01	2100.00	211479.27	23232.12	1000.00	237011.99	552033.36
39	0.00	5214.57	18530.00	23743.57	64919.29	2100.00	150112.20	16498.77	1000.00	169792.96	547730.30
40	14127.77	5243.00	17107.00	16479.30	913.41	2160.00	1435.96	2449.41	750.00	6735.20	27913.76
41	65927.27	5491.21	1005.53	72504.01	13250.16	2100.00	46021.73	5055.77	1000.00	54177.50	102991.39
42	0.00	5491.21	0.00	5491.21	11107.36	2100.00	38956.50	4260.63	1000.00	46225.13	72457.00
43	100994.45	6151.26	413.20	107531.29	25119.27	2100.00	91413.40	10042.33	1000.00	104555.74	230646.24
44	0.00	6153.24	26957.10	33110.34	7580.22	2100.00	5050.75	8615.93	750.00	16516.75	231020.02
45	0.00	6153.24	4303.27	10453.51	2609.54	2100.00	5251.30	8950.23	750.00	17059.61	240352.03

Table 34. Continued.

46	0.00	6151.24	494.45	6551.43	1211.04	2100.00	3972.22	6605.55	750.00	13327.77	151029.45
47	0.00	6151.24	5586.20	11737.44	14793.60	2100.00	65155.79	7157.49	1000.00	75414.65	145993.33
48	0.00	6153.24	0.00	6153.24	11130.29	2100.00	30699.40	4753.27	1000.00	46039.57	72145.40
49	0.00	6151.24	4213.13	10365.36	526.46	2100.00	1469.96	2515.49	750.00	6924.94	29611.75
50	0.00	6151.24	3311.30	9461.54	61933.72	2100.00	212306.21	23739.21	1000.00	239396.42	551963.09
51	0.00	6151.24	15496.63	21647.11	67444.24	2100.00	150191.54	17129.95	1000.00	176452.49	611541.13
52	0.00	6153.24	93.99	6247.21	67444.24	2100.00	234250.69	25711.99	1000.00	263094.50	611541.03
53	0.00	6151.24	0.00	6151.24	62201.19	2100.00	216947.17	23734.14	1000.00	242091.31	564019.46
54	0.00	6153.24	47910.20	54061.44	1392.42	2100.00	2247.29	3511.60	750.00	9910.00	71959.35
55	0.00	6151.24	39191.93	45337.16	1131.91	2100.00	2253.99	3951.93	750.00	8975.92	72421.40
56	0.00	6153.24	0.00	6151.24	6727.96	2101.00	12415.34	21190.91	750.00	36447.15	573527.79
57	0.00	6151.24	42251.69	49434.91	6519.59	2100.00	13231.42	22571.24	750.00	34652.66	611541.90
58	0.00	6151.24	76772.00	82926.24	6451.94	2101.09	12941.05	21903.61	750.00	37593.66	591116.52
59	0.00	6153.24	1.93	6155.16	6439.59	2100.00	13231.42	22571.24	750.00	39652.66	611541.30
60	0.00	6151.24	79715.12	85967.36	1924.00	2101.00	3609.91	6304.77	750.00	12950.71	144900.30
61	0.00	6151.24	0.00	6153.24	67444.24	2100.00	234250.60	25711.90	1000.00	263094.59	611541.03
62	0.00	6151.24	0.00	6153.24	2209.00	2100.00	5902.57	9139.50	750.00	19551.96	144399.73
63	49106.92	5697.31	6453.09	62553.22	1344.39	2100.00	3576.99	6191.73	750.00	12520.61	71954.34
64	0.00	6557.31	57340.70	64049.03	1102.01	2100.00	2265.29	3955.01	750.00	8992.29	72590.76
65	14517.64	6741.94	0.00	21295.47	7563.35	2100.00	17747.51	1943.69	1000.00	22797.10	59553.75
66	0.00	6791.94	0.00	6791.94	11412.03	2100.00	26429.05	2391.40	1000.00	32432.44	71712.13
67	0.00	6791.94	91309.20	99091.04	25977.59	2100.00	93709.27	10233.56	1000.00	107093.03	244616.43
68	94573.49	9116.53	18949.75	121639.92	5559.16	2100.00	13133.54	22404.27	750.00	38397.91	605290.15
69	0.00	9116.59	60181.09	76297.59	2655.94	2100.00	5343.06	9114.63	750.00	17307.60	244616.40
70	0.00	9115.59	37247.65	45364.34	6539.59	2100.00	13231.42	22571.24	750.00	39652.66	611541.08
71	0.00	8116.59	4754.40	12971.09	3159.05	2100.00	8293.55	14079.61	750.00	25193.17	240382.13
72	0.00	9114.59	0.00	9116.59	67444.24	2100.00	234259.69	25731.90	1000.00	263094.50	611541.00
73	0.00	9115.59	134174.40	142391.16	7935.31	2109.00	20552.75	35077.64	750.00	50470.39	603773.52
74	0.00	9116.59	97515.55	135632.24	9082.73	2194.09	20991.15	35637.04	750.00	59462.90	613460.50
75	0.00	8115.59	2279.20	10395.99	6639.59	2100.00	13231.42	22571.24	750.00	38652.66	611541.00
76	0.00	9115.49	22334.33	30451.01	2179.49	2016.00	5795.91	9713.61	750.00	10205.52	141553.97
77	0.00	9115.69	72744.72	80951.41	765.10	2100.00	1501.13	2731.33	750.00	7192.46	60491.40
78	0.00	9116.59	0.00	9115.59	2427.57	2100.00	5297.20	9019.47	750.00	17156.75	242021.92
79	0.00	9115.59	0.00	8116.69	64352.24	2100.00	223511.39	24554.13	1000.00	251165.92	593504.74
80	0.00	9114.59	0.00	8115.69	1375.95	2100.00	3659.24	6240.52	750.00	12749.76	74775.90
81	0.00	8116.59	0.00	8114.49	4477.29	2100.00	11450.97	19975.01	750.00	34375.09	291996.72
82	0.00	9116.69	619.45	9735.14	3758.95	2100.00	7606.57	12975.91	750.00	23432.40	299916.72
83	0.00	8115.59	376.00	8492.75	4469.99	2100.90	11631.92	19942.52	750.00	34324.34	291514.69
84	0.00	9116.69	0.00	8116.69	5465.82	451.50	12657.00	1393.54	1000.00	15499.04	49559.76
85	0.00	9116.49	33356.30	41472.99	45647.09	4269.25	105715.63	11613.52	1000.00	122597.41	413985.75
86	0.00	9115.69	0.00	8116.69	25109.33	2169.25	50150.52	6389.20	1000.00	67706.96	227675.25
87	0.00	8116.69	4434.50	12551.19	19393.96	1695.75	44121.40	4923.92	1000.00	52441.15	175400.41
88	0.00	8116.69	45524.20	53644.99	9453.24	2100.00	10592.30	10563.92	750.00	32296.22	502272.45

THE AMOUNT OF FOREST CLEARED FOR FOREST ROAD RIGHT-OF-WAY WAS= 70.43 ACRES

THE TOTAL ENERGY CONSUMED PER HARVEST ALTERNATIVE WAS 1258639.96 GALLONS

Table 34. Continued.

SUMMARY TABLE FOR
THE PRESENT NET VALUE
CALCULATIONS AT VARIOUS INTEREST
RATES AND PRICE AND COST INDICIES
FOR HARVEST AND ROAD ALTERNATIVE 6

ANNUAL PRICE INDEX	ANNUAL COST INDEX	ANNUAL DISCOUNT RATE	DISCOUNTED RETURNS	DISCOUNTED COSTS	PRESENT NET VALUE
2.7	2.7	1.0	61424393.47	19581183.59	41843215.95
2.7	2.7	2.0	35742105.56	11690944.21	24061161.34
2.7	2.7	3.0	22017995.22	7395548.63	14632446.59
2.7	2.7	4.0	14376865.95	4951275.55	9425590.41
2.7	2.7	5.0	9932365.35	3509917.45	6422447.90
2.7	2.7	6.0	7227551.73	2617374.60	4613477.73
2.7	2.7	7.0	5505291.17	2039507.11	3456791.06
2.7	2.7	8.0	4359752.53	1646857.84	2712964.59
2.7	2.7	9.0	3566129.15	1370749.71	2195379.44
2.7	2.7	10.0	2995628.49	1168644.19	1826982.36
2.7	2.7	11.0	2571056.12	1015725.89	1555330.23
2.7	2.7	12.0	2247925.39	996609.34	1251317.03
2.7	2.7	13.0	1994073.39	801455.59	1192617.80
2.7	2.7	14.0	1790802.95	723786.39	1057016.48
2.7	2.7	15.0	1624957.69	659206.11	965751.58
2.7	2.0	1.0	61424393.47	13604492.50	47819916.97
2.7	2.0	2.0	35742105.56	8622137.07	27119968.48
2.7	2.0	3.0	22017995.22	5533953.51	16484041.71
2.7	2.0	4.0	14376863.95	3952236.36	10424629.60
2.7	2.0	5.0	9932365.35	2827425.89	7104939.46
2.7	2.0	6.0	7227551.73	2173617.73	5053934.00
2.7	2.0	7.0	5505291.17	1737413.50	3767894.67
2.7	2.0	9.0	4359752.53	1433818.90	2925933.63
2.7	2.0	9.0	3566129.15	1214157.33	2351970.92
2.7	2.0	10.0	2995628.49	1049603.49	1945223.00
2.7	2.0	11.0	2571956.12	922510.94	1648345.19
2.7	2.0	12.0	2247925.39	821720.79	1426204.60
2.7	2.0	13.0	1994073.39	739953.43	1254119.95
2.7	2.0	14.0	1790992.94	672318.19	1118494.58
2.7	2.0	15.0	1624957.69	615437.67	1009520.02
2.7	3.5	1.0	61424393.47	30457624.60	30966770.87
2.7	3.5	2.0	35742105.56	17473734.32	18271367.73
2.7	3.5	3.0	22017995.22	10599062.67	11418932.55
2.7	3.5	4.0	14376865.95	6797271.89	7579594.16
2.7	3.5	5.0	9932365.35	4521347.45	5411017.90
2.7	3.5	6.0	7227551.73	3316412.34	3910739.39
2.7	3.5	7.0	5505291.17	2459035.74	3046212.43
2.7	3.5	8.0	4359752.53	1963332.13	2396420.40
2.7	3.5	9.0	3566129.15	1597063.76	1969064.39
2.7	3.5	10.0	2995626.49	1336519.07	1659109.42
2.7	3.5	11.0	2571050.12	1144364.03	1427492.09
2.7	3.5	12.0	2247925.30	998024.44	1249900.94
2.7	3.5	13.0	1994073.39	883400.74	1110672.64
2.7	3.5	14.0	1790802.06	791411.24	999191.62
2.7	3.5	15.0	1624957.69	716029.06	908927.93

considerations.[19] Because of relatively consistent results obtained in trial runs, this reduced approach did not appear to be a serious problem for this level of analysis.

A summary of data obtained from the two models for the ten operational runs is presented in Tables 35-38. The extensive alternative analysis which follows is based on this data and is intended only to demonstrate the type of analysis possible.[20]

Analysis of the Alternatives

Recall that ten harvest and road alternatives were specified in Chapter VIII. A brief description of each alternative is summarized here to facilitate analysis discussion:

1) Helicopter clearcutting on all cells except headwalls and streamside strips, which were not harvested at all. Access system included existing six miles of primary gravel road and new construction of 10 miles of similar road way during the 88 year cutting cycle.

2) Skyline clearcutting on all cells except headwalls and streamside strips, which were not harvested at all. Access system included existing six miles of primary gravel road and 16 miles of secondary gravel road during the 88 year cutting cycle.

---

19 Complete model development and testing expenses and operational run costs totaled nearly 7,000 dollars. Final model run costs for each alternative averaged approximately 100 dollars. The combined computer processing unit (cpu) time required for HARASS and HARP was about 1000 cpu seconds per alternative at the OSU CDC 6400 computer system. Wall-clock time on this time-sharing system varied between 5 and 7 hours for each set of model runs.

20 Much additional model data is produced, but it is too voluminous to be included. This information would be available for any intensive alternative analysis.

Table 35. Erosion Information and Associated Primary Data Components for Ten Harvest and Road Alternatives for the Harvey Creek Drainage.

ALTER-NATIVE	ENERGY USED (MILLION GALLONS)	CLEARED RIGHT-OF-WAY (ACRES)	SECONDARY GRAVEL (MILES)	SECONDARY SPOT-STABILIZED (MILES)	PRIMARY GRAVEL (MILES)	FOREST AREA (ACRES)	FOREST AREA (km^2)	TOTAL EROSION RATE[a] (PER YEAR PER ACRE)	Σ(ROAD EROSION) / Σ(SLOPE EROSION)
1	2.460	70.43	0	0	16.23	3460.8	14.01	6.88	0.661
2	0.242	106.02	15.77	0	16.23	3425.2	13.86	9.25	0.774
3	0.446	137.38	15.77	10.87	16.23	3393.8	13.73	15.16	0.525
4	0.985	70.43	0	0	16.23	3460.8	14.01	3.70	2.918
5	0.117	106.02	15.77	0	16.23	3425.2	13.86	4.89	4.176
6	1.242	70.43	0	0	16.23	3460.8	14.01	6.41	0.755
7	0.000	36.88	0	0	6.09	3494.3	14.14	2.17	1.290
8	1.588	70.43	0	0	16.23	3460.8	14.01	4.04	2.143
9	0.189	106.02	15.77	0	16.23	3425.2	13.86	5.23	3.066
10	1.251	70.43	0	0	16.23	3460.8	14.01	8.43	0.486

ALTERNATIVE	OFF ROAD EROSION[b]					ROAD DAMAGE[b]					ROAD FAILURES[b]					TOTAL[c] EROSION
	N	$\hat{\mu}$	$\hat{\sigma}$	Σ	N / ACRE-YEAR	N	$\hat{\mu}$	$\hat{\sigma}$	Σ	N / ACRE-YEAR	N	$\hat{\mu}$	$\hat{\sigma}$	Σ	N / ACRE-YEAR	
1	1063	126.5	274.0	134.5	0.172	386	266.0	412.6	102.7	0.062	81	7581.2	7760.8	614.1	0.013	851.3
2	1564	127.1	266.5	198.8	0.167	618	258.5	415.2	159.8	0.066	108	7960.2	9169.4	859.7	0.012	1218.2
3	2316	131.3	267.9	304.1	0.192	860	260.8	418.9	224.3	0.071	148	7319.5	8592.9	1083.3	0.012	1611.6
4	1063	126.5	274.0	134.5	0.172	386	266.0	412.6	102.7	0.062	81	7581.2	7760.8	614.1	0.013	851.3
5	1564	127.1	266.5	198.8	0.167	618	258.5	415.2	159.8	0.066	108	7960.2	9169.4	859.7	0.012	1218.2
6	1063	126.5	274.0	134.5	0.172	386	266.0	412.6	102.7	0.062	81	7581.2	7760.8	614.1	0.013	851.3
7	439	118.9	255.7	52.2	0.135	206	223.5	351.3	46.0	0.063	34	8205.8	9089.7	279.0	0.010	377.3
8	1063	126.5	274.0	134.5	0.172	386	266.0	412.6	102.7	0.062	81	7581.2	7760.8	614.1	0.013	851.3
9	1564	127.1	266.5	198.8	0.167	618	258.5	415.2	159.8	0.066	108	7960.2	9169.4	859.7	0.012	1218.3
10	1063	126.5	274.0	134.5	0.172	386	266.0	412.6	102.7	0.062	81	7581.2	7760.8	614.1	0.013	851.3

See Footnotes on next page.

Table 35. Continued.

ALTERNATIVE	ROCKSLIDES[b] N	$\hat{\mu}$	$\hat{\sigma}$	Σ	N/km²-YEAR	DEBRIS AVALANCHE FLOWS[b] N	$\hat{\mu}$	$\hat{\sigma}$	Σ	N/km²-YEAR	SLUMP/EARTHFLOWS[b] N	$\hat{\mu}$	$\hat{\sigma}$	Σ	N/km²-YEAR
1	9	794.7	602.4	7.2	0.007	1250	763.5	1370.7	954.4	1.014	48	458.1	385.8	22.0	0.039
2	14	791.7	553.6	11.1	0.011	1758	670.4	1166.3	1178.6	1.441	70	468.3	364.4	32.8	0.057
3	33	711.1	493.3	23.5	0.027	3724	574.4	836.5	2137.9	3.082	153	455.5	295.2	69.7	0.127
4	3	874.3	82.5	2.6	0.002	54	4932.2	3038.3	266.3	0.044	1	2083.5	d	2.1	0.001
5	3	874.3	82.5	2.6	0.002	54	4932.2	3038.3	266.3	0.044	1	2083.5	d	2.1	0.001
6	10	815.7	571.9	8.2	0.008	1125	806.4	1463.3	907.2	0.912	29	486.6	450.3	14.1	0.024
7	3	874.3	82.5	2.6	0.002	54	4932.2	3038.3	266.3	0.043	1	2083.5	d	2.1	0.001
8	4	880.0	68.3	3.5	0.003	83	4330.2	3399.3	359.4	0.067	1	2083.5	d	2.1	0.001
9	4	880.0	68.3	3.5	0.003	84	4280.4	3409.3	359.6	0.069	1	2083.5	d	2.1	0.001
10	14	791.7	553.6	11.1	0.011	1703	777.7	1397.3	1324.4	1.381	66	1207.0	4087.9	79.7	0.054

ALTERNATIVE	CREEP ACCELERATION[b] N	$\hat{\mu}$	$\hat{\sigma}$	Σ	N/km²-YEAR	TOTAL EROSION[c]
1	67	4544.5	5548.1	304.5	0.054	1288.0
2	96	4317.4	5361.8	414.5	0.079	1636.9
3	167	5011.8	6320.6	837.0	0.138	3068.0
4	12	1724.8	1902.3	20.7	0.010	291.7
5	12	1724.8	1902.3	20.7	0.010	291.7
6	45	4410.5	6064.6	198.5	0.036	1128.0
7	12	1724.8	1902.3	20.7	0.010	291.7
8	13	2472.8	3254.7	32.1	0.011	397.2
9	13	2472.8	3254.7	32.1	0.011	397.3
10	79	4264.6	5356.4	336.9	0.064	1752.0

FOOTNOTES -

[a] In cubic yards per year per acre.

[b] All figures for $\hat{\mu}$ and $\hat{\sigma}$ are in cubic yards.
Those for all Σ's are in 1000's of cubic yards.
All N/Acre-Year are in number of events per acre of cleared right-of-way per year, and N/km² -year are in number number of events per square kilometer of forest per year.
Number of years calculations based on is 88.

[c] Data in 1000's of cubic yards.

[d] Not calculated.

Table 36. Present Net Values (PNV) of Ten Harvest and Road Alternatives for Fifteen Nominal Discount Rates and Three Cost and Price Index Ratios.[a]

ALTERNATIVE	INTEREST RATES (%) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	COST INDEX/ PRICE INDEX
1	19.96	12.39	7.82	5.27	3.71	2.84	2.24	1.84	1.54	1.32	1.17	1.04	0.94	0.85	0.78	2.7/2.7 (%)
2	34.55	20.66	13.18	8.97	6.49	4.94	3.92	3.23	2.72	2.36	2.08	1.86	1.67	1.53	1.40	
3	28.73	17.24	11.10	7.64	5.59	4.31	3.46	2.88	2.45	2.12	1.88	1.69	1.53	1.39	1.28	
4	6.59	3.85	2.40	1.65	1.12	0.84	0.66	0.55	0.47	0.40	0.35	0.32	0.29	0.26	0.25	
5	5.36	3.30	2.19	1.56	1.19	0.95	0.79	0.67	0.59	0.52	0.47	0.43	0.39	0.37	0.34	
6	35.33	19.36	11.18	6.85	4.48	3.12	2.31	1.81	1.47	1.25	1.09	0.97	0.87	0.80	0.74	
7	(2.13)	(1.38)	(0.93)	(0.66)	(0.49)	(0.37)	(0.29)	(0.24)	(0.20)	(0.17)	(0.14)	(0.12)	(0.11)	(0.10)	(0.09)	
8	15.32	8.97	5.63	3.80	2.73	2.08	1.66	1.39	1.18	1.03	0.92	0.83	0.76	0.70	0.65	
9	16.59	9.88	6.35	4.39	3.25	2.54	2.08	1.75	1.52	1.34	1.20	1.09	1.00	0.93	0.87	
10	41.84	24.06	14.63	9.43	6.42	4.61	3.47	2.71	2.20	1.83	1.56	1.35	1.19	1.07	0.97	
1	29.96	17.29	10.58	6.91	4.83	3.50	2.69	2.16	1.78	1.52	1.31	1.16	1.06	0.93	0.85	2.0/2.7 (%)
2	39.35	23.24	14.62	9.82	7.00	5.26	4.14	3.38	2.83	2.42	2.13	1.90	1.71	1.55	1.43	
3	35.50	20.96	13.18	8.87	6.34	4.79	3.78	3.09	2.60	2.24	1.97	1.76	1.58	1.44	1.32	
4	10.74	6.10	3.66	2.35	1.60	1.16	0.88	0.69	0.58	0.49	0.42	0.37	0.33	0.30	0.28	
5	10.00	5.80	3.60	2.39	1.70	1.28	1.01	0.83	0.70	0.61	0.54	0.48	0.44	0.40	0.37	
6	42.59	23.15	13.24	8.03	5.18	3.56	2.60	2.01	1.62	1.36	1.17	1.03	0.93	0.84	0.78	
7	(1.57)	(1.04)	(0.73)	(0.53)	(0.40)	(0.31)	(0.25)	(0.21)	(0.17)	(0.15)	(0.13)	(0.11)	(0.10)	(0.09)	(0.08)	
8	20.69	11.85	7.25	4.76	3.33	2.48	1.93	1.57	1.33	1.15	1.01	0.90	0.82	0.75	0.70	
9	21.64	12.60	7.88	5.29	3.80	2.90	2.32	1.92	1.64	1.43	1.28	1.15	1.05	0.97	0.90	
10	47.82	27.32	16.48	10.52	7.10	5.05	3.77	2.93	2.35	1.95	1.65	1.43	1.25	1.12	1.01	
1	4.55	3.70	3.03	2.51	2.11	1.79	1.54	1.35	1.19	1.07	0.96	0.88	0.81	0.75	0.69	3.5/2.7 (%)
2	25.04	15.62	10.40	7.38	5.53	4.33	3.52	2.95	2.54	2.21	1.96	1.77	1.60	1.47	1.35	
3	16.38	10.67	7.47	5.56	4.36	3.54	2.96	2.54	2.21	1.95	1.75	1.59	1.45	1.33	1.23	
4	(0.92)	(0.14)	0.20	0.33	0.37	0.36	0.34	0.32	0.29	0.27	0.25	0.24	0.22	0.21	0.20	
5	(3.12)	(1.18)	(0.27)	0.16	0.35	0.43	0.45	0.44	0.43	0.40	0.38	0.36	0.34	0.32	0.30	
6	21.69	12.40	7.49	4.82	3.30	2.41	1.86	1.50	1.26	1.09	0.97	0.87	0.80	0.74	0.69	
7	(3.10)	(1.93)	(1.27)	(0.87)	(0.62)	(0.46)	(0.36)	(0.28)	(0.23)	(0.19)	(0.16	(0.14)	(0.12)	(0.11)	(0.10)	
8	5.55	3.83	2.37	1.95	1.64	1.40	1.22	1.07	0.96	0.87	0.80	0.74	0.68	0.64	0.60	
9	7.31	4.99	3.67	2.87	2.34	1.97	1.71	1.50	1.34	1.21	1.10	1.02	0.94	0.88	0.82	
10	30.97	18.27	11.43	7.58	5.31	3.91	3.01	2.40	1.97	1.66	1.43	1.25	1.11	1.00	0.91	

[a]Data in millions of dollars, and data in brackets, (—), represents negative values.

Table 37. Present Net Value (PNV) Rankings of Ten Harvest and Road Alternatives for Fifteen Nominal Discount Rates and Three Cost and Price Index Ratios[a]

ALTERNATIVE	INTEREST RATES (%)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1[b]	5	5	5	5	5	5	5	4	4	5	5	5	5	5	5
2	3	2	2	2	1	1	1	1	1	1	1	1	1	1	1
3	4	4	4	3	3	3	3	2	2	2	2	2	2	2	2
4	8	8	8	8	9	9	9	9	9	9	9	9	9	9	9
5	9	9	9	9	8	8	8	8	8	8	8	8	8	8	8
6	2	3	3	4	4	4	4	5	6	6	6	6	6	6	6
7	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)
8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
9	6	6	6	6	6	6	6	6	5	4	4	4	4	4	4
10	1	1	1	1	2	2	2	3	3	3	3	3	3	3	3
1[c]	5	5	5	5	5	5	4	4	4	4	4	4	4	5	5
2	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1
3	4	4	4	3	3	3	2	2	2	2	2	2	2	2	2
4	8	8	8	9	9	9	9	9	9	9	9	9	9	9	9
5	9	9	9	8	8	8	8	8	8	8	8	8	8	8	8
6	2	3	3	4	4	4	5	5	6	6	6	6	6	6	6
7	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)
8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
9	6	6	6	6	6	6	6	6	5	5	5	5	5	4	4
10	1	1	1	1	1	2	3	3	3	3	3	3	3	3	3
1[d]	7	7	6	6	6	6	6	6	6	6	6	5	5	5	5
2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1
3	4	4	4	3	3	3	3	2	2	2	2	2	2	2	2
4	(8)	(8)	8	8	8	9	9	9	9	9	9	9	9	9	9
5	(9)	(9)	(9)	9	9	8	8	8	8	8	8	8	8	8	8
6	3	3	3	4	4	4	4	4	5	5	5	6	6	6	6
7	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)
8	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7
9	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4
10	1	1	1	1	2	2	2	3	3	3	3	3	3	3	3

[a]Data in brackets, (--), represents ranking based on negative values.

[b]Cost Index/Price Index ratio = 2.7/2.7.

[c]Cost Index/Price Index ratio = 2.0/2.7.

[d]Cost Index/Price Index ratio = 3.5/2.7.

Table 38. Summary Table for Key Road and Harvest Cost Components at a Nominal Interest Rate of Five Percent and Three Cost and Price Index Ratios.[a]

ALTERNATIVE	CONSTRUCTION COSTS	MAINTENANCE COSTS	REPAIR COSTS	TOTAL ROAD COSTS	REGENERATION COSTS	EQUIPMENT COSTS	LABOR COSTS	SETUP COSTS	TOTAL HARVEST COSTS	TOTAL COSTS	TOTAL TIMBER RETURNS
1[b]	530.7	188.3	658.4	1377.4	48.7	3590.7	389.1	38.3	4066.8	5444.2	9154.1
2	972.7	223.3	844.0	2040.0	48.7	206.1	351.6	28.7	635.1	2675.1	9154.1
3	1145.2	249.0	1082.5	2476.7	48.7	281.4	729.6	27.7	1087.4	3564.1	9154.1
4	530.7	188.3	658.4	1377.4	48.7	964.0	105.9	38.3	1156.9	2534.3	3664.6
5	972.7	223.3	844.0	2040.0	48.7	132.1	225.4	28.7	434.9	2474.9	3664.6
6	530.7	188.3	658.4	1377.4	79.4	1457.4	418.5	32.4	1987.9	3365.1	7843.1
7	0	116.6	370.0	486.6	0	0	0	0	0	486.6	0
8	530.7	188.3	658.4	1377.4	79.4	1572.8	172.8	38.3	1863.3	3240.7	5974.2
9	972.7	223.3	844.0	2040.0	79.4	212.9	363.1	28.7	684.1	2724.1	5974.2
10	530.7	188.3	658.4	1377.4	79.4	1553.9	466.9	32.4	2132.6	3510.0	9932.4
1[c]	455.4	147.3	517.3	1120.0	39.5	2834.3	307.1	31.3	3212.5	4332.2	9154.1
2	796.7	171.7	642.5	1610.9	39.5	167.1	285.1	23.5	515.2	2126.1	9154.1
3	916.4	191.5	824.1	1932.3	39.5	223.8	580.2	22.7	866.1	2798.4	9154.1
4	455.4	147.3	517.3	1120.0	39.5	781.7	85.9	31.3	938.4	2058.4	3664.6
5	796.7	171.7	642.5	1610.9	39.5	107.2	182.8	23.5	353.0	1963.9	3664.6
6	455.4	147.3	517.3	1120.0	64.9	1125.6	325.7	26.5	1542.7	2662.7	7843.1
7	0	95.5	303.8	399.3	0	0	0	0	0	399.3	0
8	455.4	147.3	517.3	1120.0	64.9	1284.1	141.1	31.3	1521.4	2641.4	5974.2
9	796.7	171.7	642.5	1610.9	64.9	173.8	296.5	23.5	558.7	2169.6	5974.2
10	455.4	147.3	517.3	1120.0	64.9	1242.1	373.9	26.5	1707.4	2827.4	9932.4
1[d]	642.2	257.3	892.2	1791.7	63.5	4571.2	495.1	49.5	5179.3	6971.0	9154.1
2	1248.2	311.5	1185.4	2745.1	63.5	269.5	459.7	37.2	829.9	3575.0	9154.1
3	1510.7	347.4	1520.4	3378.5	63.5	365.8	949.2	36.0	1414.5	4793.0	9154.1
4	642.2	257.3	892.2	1791.7	63.5	1260.9	138.5	49.5	1512.4	3304.1	3664.6
5	1248.2	311.5	1185.4	2745.1	63.5	172.8	294.7	37.2	568.2	3313.3	3664.6
6	642.2	257.3	892.2	1791.7	102.9	2029.2	577.0	41.8	2750.9	4542.6	7843.1
7	0	150.9	470.0	620.9	0	0	0	0	0	620.9	0
8	642.2	257.3	892.2	1791.7	102.9	2044.4	224.6	49.5	2421.4	4213.1	5974.2
9	1248.2	311.5	1185.4	2745.1	102.9	276.7	472.0	37.2	888.8	3633.9	5974.2
10	642.2	257.3	892.2	1791.7	102.9	2065.6	619.3	41.8	2829.6	4621.3	9932.4

[a] Figures are all in thousands of dollars.

[b] Cost Index/Price Index ratio = 2.7/2.7.

[c] Cost Index/Price Index ratio = 2.0/2.7.

[d] Cost Index/Price Index ratio = 3.5/2.7.

3) Highlead clearcutting on all cells except headwalls and streamside strips, which were not harvested at all. Access system included existing six miles of primary gravel road, 16 miles of secondary gravel road, and 11 miles of secondary spot-stabilized road.

4) Helicopter partial cutting on all cells except headwalls and streamside strips, which were not harvested at all. Access system requirements were identical to those for Alternative One.

5) Skyline partial cutting on all cells except headwalls and streamside strips, which were not harvested at all. Access system requirements were identical to those for Alternative Two.

6) Mixture of helicopter clearcutting and skyline partial cutting. Access system requirements were identical to those for Alternative One. All blocks within reach of a running skyline system from this road network were partial cut by that system. All other blocks were helicopter clearcut. No special cutting restrictions were applied on headwalls and streamside strips.

7) No harvesting or new road construction planned. This represents the "status quo" alternative.

8) Helicopter partial cutting on all cells. No special cutting restrictions were applied on headwalls and streamside strips. Access system requirements were identical to those for Alternative One.

9) Skyline partial cutting on all cells. No special cutting restrictions were applied on headwalls and streamside strips. Access system requirements were identical to those for Alternative Two.

10) Mixture of helicopter and skyline clearcutting and partial cutting. Access system requirements were identical to those for Alternative One. Prescription alternative where all blocks with substantial headwalls and streamside strips were partial cut, all others were clearcut. Blocks accessible by a running skyline from this road system were harvested by that system, all other blocks were helicopter harvested. No other special cutting restrictions were applied on headwalls and streamside strips.

These ten harvest and road alternatives can be evaluated in terms of numerous decision maker criteria. The criteria set employed depends directly on the goals of the management agency and the primary decision maker. The decision maker criteria set considered for this analysis is:

1) minimize total road related costs,
2) minimize road construction costs,
3) minimize road maintenance costs,
4) minimize road repair costs,
5) minimize total harvest costs,
6) minimize harvest labor costs,
7) minimize harvest equipment costs,
8) minimize total road and harvest costs,
9) maximize total gross returns,
10) maximize total net returns,
11) minimize annual road erosion rates,
12) minimize annual slope erosion rates,

and 13) minimize annual total erosion rates.

Table 39 presents data for each harvest and road alternative for these 13 managerial criteria. All economic information is for a nominal discount rate of five percent, a cost index of 2.7 percent and a price index of 2.7 percent. This choice is arbitrary, and any analyst could examine other sets of discount rates and cost/price index ratios.

Table 39. Decision Maker Criteria and Ordinal Comparisons for Ten Harvest and Road Alternatives.[a]

MANAGERIAL CRITERIA	ALTERNATIVES									
	1	2	3	4	5	6	7	8	9	10
Total Road Costs	1377 2	2040 3	2477 4	1377 2	2040 3	1377 2	487 1	1377 2	2040 3	1377 2
Road Construction Costs	531 2	973 3	1145 4	531 2	973 3	531 2	0 1	531 2	973 3	531 2
Road Maintenance Costs	188 2	223 3	249 4	188 2	223 3	188 2	117 1	188 2	223 3	188 2
Road Repair Costs	658 2	844 3	1083 4	658 2	844 3	658 2	370 1	658 2	844 3	658 2
Total Harvest Costs	4067 10	635 3	1087 5	1157 6	435 2	1988 8	0 1	1863 7	684 3	2133 9
Harvest Labor Costs	389 7	352 5	730 10	106 2	225 4	419 8	0 1	173 3	363 6	467 9
Harvest Equipment Costs	3591 10	206 3	281 5	964 6	132 2	1457 7	0 1	1573 9	213 4	1554 8
Total Costs	5444 10	2675 4	3564 9	2534 3	2475 2	3365 7	487 1	3241 6	2724 5	3510 8
Total Gross Returns	9154 2	9154 2	9154 2	3665 5	3665 5	7843 3	0 6	5974 4	5974 4	9932 1
Total Net Return	3710 5	6479 1	5590 3	1131 9	1190 8	4478 4	(487) 10	2733 7	3250 6	6422 2
Annual Road Erosion Rate	2.74 2	3.93 3	5.19 4	2.74 2	3.93 3	2.74 2	1.21 1	2.74 2	3.93 3	2.74 2
Annual Slope Erosion Rate	4.14 4	5.32 5	9.97 7	0.96 1	0.96 1	3.67 3	0.96 1	1.30 2	1.30 2	5.69 6
Annual Total Erosion Rate	6.88 7	9.25 9	15.16 10	3.70 2	4.89 4	6.41 6	2.17 1	4.04 3	5.23 5	8.43 8

[a] Ordinal values appear below each managerial criteria value, all economic data is in thousands of dollars, discount rate used is five percent, cost index is 2.7 percent, price index is 2.7 percent, all erosion rates are in cubic yards per year per watershed acre, and data in brackets, (--) refers to negative value.

Road Cost Criteria

Table 39 shows that Alternative Three is the worst single alternative in terms of all road cost criteria. Road costs for this alternative dominated all cost components with nearly 70 percent of the total. Road erosion damage accounted for nearly 45 percent of all road related outlays, and by itself equaled the timber harvest expenses for this alternative. Note that these extra costs were more than four times the normal maintenance costs. The "status quo" option, Alternative Seven, was at the opposite end of the spectrum as the minimum cost alternative for all road cost criteria. Under the assumption that the existing roadway will be maintained and repaired to keep it operational, the only expected costs for this alternative are for maintenance and repairs. This cost actually represents a type of fixed overhead cost required to keep this resource system component as a part of the active business enterprise.

Close analysis of Table 39 reveals additional interesting road cost criteria information. Total road costs as a percentage of all costs, and road repair costs as a percentage of all road costs for each alternative are:

Alternative	$\frac{\text{Total Road Costs}}{\text{Total Costs}} \times 100\%$	$\frac{\text{Repair Costs}}{\text{Total Road Costs}} \times 100\%$
ONE	25.0	48.0
TWO	76.0	41.0
THREE	70.0	45.0
FOUR	54.0	48.0
FIVE	82.0	41.0
SIX	41.0	48.0
SEVEN	100.0	76.0
EIGHT	43.0	48.0
NINE	75.0	41.0
TEN	39.0	48.0

Three important observations can be quickly noted. Repair expenses comprise a significant amount of all road related costs regardless of the alternative. Road related expenses are the most limiting cost component for all skyline and highlead dominated alternatives. And, the repairs cost component was always 3-4 times higher than normal maintenance expenses for all alternatives.[21]

Harvest Cost Criteria

Analysis of harvest cost criteria is somewhat more complex due to the greater variations across all alternatives and across all harvest cost criteria. The minimum cost alternative for all such criteria is again the "status quo" option, Alternative Seven. This is an obvious result due to the absence of any harvesting for this alternative. The worst alternative in terms of total harvest cost and harvest equipment cost criteria is Alternative One. For this alternative equipment expenses are very significant, comprising 88 percent of all harvest costs and nearly 66 percent of total outlays. The most costly alternative in terms of harvest labor cost criteria was the highlead option, Alternative Three. This cost component was from 2-7 times greater than similar outlays for all other alternatives where timber was harvested. The most efficient options for all harvest cost criteria, when timber is cut, were the three alternatives dominated by the skyline system; Alternatives Two, Five, and Nine. The partial use of helicopter harvesting (and the concomitant high equipment costs) for Alternatives Six and Ten caused these two options to be placed eight and ninth respectively in terms of total harvest cost criteria.

---

[21] Road related costs are the only costs for Alternative Seven.

Manipulation of data in Table 39 reveals additional helpful information on harvest related cost criteria. The percentages of harvest and labor costs to all harvest costs, and total harvest costs to all expenses for each alternative are as follows:

Alternative	Labor Costs / Total Harvest Cost	Equipment Costs / Total Harvest Cost	Total Harvest Costs / Total Costs
	(Note: all times 100%)		
ONE	10.0	88.0	75.0
TWO	55.0	32.0	24.0
THREE	67.0	26.0	30.0
FOUR	9.0	83.0	46.0
FIVE	52.0	30.0	18.0
SIX	21.0	73.0	59.0
SEVEN	N/A	N/A	0.0
EIGHT	9.0	84.0	57.0
NINE	53.0	31.0	25.0
TEN	22.0	73.0	61.0

Note that all alternatives which employ any helicopter harvesting, except the limited partial cut option for Alternative Four, have harvest costs as the majority expense. This less desirable ordinal placement is not at all unexpected, but the magnitude of the dominance, especially for clearcutting, is quite significant. Also important is that all alternatives not employing the helicopter system are dominated by the labor cost criteria when all harvest costs criteria are compared.

Total Cost Criteria

The most expensive alternative in terms of the total cost criteria is Alternative One, the helicopter clearcut option. Outlays here are 150 percent higher than those for the next most expensive option, Alternative Three. Note also that Alternative Three, the highlead clearcut alternative, carried a substantially higher total cost than might be normally expected. Harvey Creek Drainage is quite steep and highly dissected. Selection of a highlead system for such an area is questionable on efficiency grounds, and application of Dykstra's (1974) highlead cost equation bears this out by yielding both higher harvest costs and total costs than those noted for the skyline system in Alternative Two.

Once again, the least cost option is the "status quo" alternative, number Seven. The least cost alternative, when timber is harvested, is the partial cut skyline option of Alternative Five. The percentage of total costs to total gross returns for the ten alternatives is as follows:

Alternative	Total Costs / Total Gross Returns x 100%	Alternative	Total Costs / Total Gross Returns x 100%
ONE	59.0	SIX	43.0
TWO	29.0	SEVEN	N/A
THREE	39.0	EIGHT	54.0
FOUR	69.0	NINE	46.0
FIVE	68.0	TEN	35.0

The (Total Costs)/(Total Gross Returns) x 100% for Alternative Seven (N/A) is relative. The only returns component for this study is that for timber harvest. Other returns, such as recreational fees, reduction in forest fire fighting expenses, etc., could easily alter the interpretation of the costs related to this alternative. Observe that the skyline clearcut option, Alternative Two is by far the most efficient alternative presented, and the helicopter partial cutting option, Alternative Four, the least efficient in terms of total cost criteria.

Timber Returns Criteria

Review of Tables 38 and 39 illustrates that the highest level of gross returns does not necessarily maximize net returns. Higher costs associated with Alternatives One, Three, and Ten caused a lower ordinal value for net returns than recorded for gross returns. The alternative which maximizes gross returns is Alternative Ten. Other alternatives could be designed with fewer or no cutting restrictions on headwalls and streamside strips which would provide an even greater maximum gross return. The best option for maximizing net returns under all modeling constraints employed for this study is Alternative Two, the skyline clearcut option.

The least rewarding alternative in terms of timber returns criteria is obviously Alternative Seven, the "status quo." One might even conclude that another criteria, cost of forgone timber harvesting , should be included in net returns comparisons. Such a cost for this study is the sum of the total costs for Alternative Seven and the best net returns alternative total, for Alternative Two (i.e., \$487,000 + \$6,479.000 = \$6,966,000). Choice between maximization of gross or net returns actually reduces to a preference for productivity maximization or net profit maximization.

Erosion Criteria

Recall that Alternative Seven is the "status quo" option against which all others can be compared for erosion yields. Existing drainage right-of-way occupies one per cent of the area. The road erosion rate is 1.21 cubic yards per year per acre. The slope erosion rate is 0.96

cubic yards per year per acre, and this rate is the expected natural background annual erosion level. The overall expected base erosion rate is 2.17 cubic yards per year per acre. All rates are based on an 88 year period and 3531 acres. The ratios of each alternative's expected annual road slope, and total erosion rates to the "status quo" or existing background levels of Alternative Seven are as follows:

Alternative	Annual Road Erosion Rate $1.21/yds^3$- acre	Annual Slope Erosion Rate $0.96/yds^3$ - acre	Annual Total Erosion Rate $2.17/yds^3$ -acre
ONE	2.3	4.3	3.2
TWO	3.2	5.5	4.3
THREE	4.3	10.4	7.0
FOUR	2.3	1.0	1.7
FIVE	3.2	1.0	2.3
SIX	2.3	3.8	3.0
SEVEN	1.0	1.0	1.0
EIGHT	2.3	1.4	1.9
NINE	3.2	1.4	2.4
TEN	2.3	5.9	3.9

By far, the most serious erosion impacts were produced by the highlead clearcut option, Alternative Three. The ten-fold increase of natural slope erosion and seven-fold extension of existing total road and slope erosion represent an extremely substantial slope stability impact. The least erosive alternative when timber was removed was Alternative Four. This partial cut helicopter option precluded harvesting on headwalls and streamside strips. Based on a joint criteria of allowing harvest access, but requiring minimal erosion, this alternative would be selected. Enforcement of the single criteria to minimize total erosion would result in maintenance of the "status quo" through adoption of Alternative Seven.

Recall that there are only four basic road systems employed for all ten harvest and road alternatives: the existing, helicopter, skyline, and highlead access road networks. The right-of-way for these four systems occupy one, two, three, and four percent of the study area acreage respectively. Review of data from complete HARASS output (not included here, but similar to Table 33) and Table 35 provides more information related to the criteria for minimizing annual road erosion rates. For the existing road system, over 95 percent of road events were associated with headwalls. This was not unexpected because a substantial portion of the inplace road system was constructed across ridge tops just above headwall areas. This illustrates the problem of locating roads in such areas and that even though future options may avoid such road placement, future decisions will be impacted by already existing conditions.

For the helicopter access system over 70 percent of all road related erosion events occurred associated with headwalls. Almost all remaining events were associated with either midslope roads (slopes greater than 50 percent) or roads on moderate slopes with shallow non-cohesive soils. Roads required for skyline harvest yielded erosion events which were associated with headwalls more than 50 percent of the time and midslope roads greater than 40 percent of the time. Almost all remaining events occurred on road segments located in streamside strips with shallow, non-cohesive soils.

Headwall association occurred in 50 percent of all road related events for the highlead road system option. Midslope roads accounted for 45 percent of these events and streamside strips with shallow non-cohesive soil were associated with the remaining five percent.

In all alternatives, all road related events were dominated by the younger (1-10 years old) age groups. The most unstable road type observed was the primary gravel roadway constructed on a headwall as a midslope road. The few such segments included in each alternative plus those segments simply associated with headwalls yielded a tremendously high proportion of all road events and total sediment volumes moved.

Reference to HARASS output for each alternative (not included here, but similar to Table 33) and Tables 35 and 39 provides additional information related to the decision maker criteria of minimizing slope erosion. The single most serious form of slope erosion for all alternatives was the debris avalanche/flow category. The percent of total slope events and total slope erosion volume moved for debris avalanche/flows for the ten harvest and road alternatives is as follows:

Alternative	Debris Avalanche/flows as Percent of Total Slope Events	Debris Avalanche/Flows as Percent of Total Slope Erosion Volume
ONE	91.0	75.0
TWO	91.0	72.0
THREE	91.0	70.0
FOUR	77.0	91.0
FIVE	77.0	91.0
SIX	93.0	80.0
SEVEN	77.0	91.0
EIGHT	82.0	90.0
NINE	82.0	91.0
TEN	91.0	76.0

Slope erosion events were dominated by cells with young timber (0-20 years old) in Alternatives One-Three, Six, and Ten. For example, 95 percent of all slope erosion events occurred on clearcut slopes with timber age less than 20 years old with an almost equal split between the 0-5 year and 6-20 year groupings for Alternative Three. For Alternative Six, over 94 percent of all slope events were initiated on harvested cells with over 90 percent being associated with age classes 0-20 years old and slopes in excess of 50 percent with shallow non-cohesive soils. Of these events, three percent were associated with partial cut headwalls, 20 percent with clearcut headwalls, 36 percent with clearcut streamside strips, and 40 percent on steep normal slopes. Significantly, blocks clearcut had less than 10 percent headwall occupancy and less than 25 percent streamside strips, yet over 50 percent of all events occurred in these cells.

For Alternative Ten, helicopter clearcutting was applied to 25 blocks, helicopter partial cutting to eight, skyline clearcutting to 24, and skyline partial cutting to 31 blocks. Partial cut blocks contained nearly 40 percent headwalls and less than 10 percent streamside strips. Most of the remainder was normal slopes of over 50 percent slope. Clearcut areas had less than one percent headwalls and nearly 20 percent streamside strips. All other cells in the clearcut blocks were on normal slopes with the majortiy having slopes greater than 50 percent. Clearcut areas accounted for 93 percent of all slope events and partial cut slopes about one percent. The remaining erosion from slopes was from normally expected natural events. Also, even though almost all headwalls were partial cut only 12 events resulted. On the other hand, a small percentage of all clearcut areas contained headwalls, yet over 100 slope events were recorded for this small proportion of sensitive cells. Approximately 55 percent of all clearcut related erosion was associated with skyline harvesting. Additionally, even though a small percentage of skyline clearcut blocks contained streamside strips, a very high rate of failure occurred for such cells. Over 300 events were recorded, and this is directly related to the steep slopes associated with these particular streamside strips. The overall slope expected annual erosion rate of 5.69 cubic yards per acre was the second highest level for all ten alternatives. This level resulted even though care was exercised to limit most clearcutting in sensitive cells. The reason for this reality was that greater than 50 percent of all slope events occurred on normal, shallow non-cohesive soiled cells with a slope greater than 50 percent which were clearcut.

Also noticeable was the absence of significant impact of partial cutting on the slope erosion problem. This is emphasized by examining the slope erosion rates for Alternatives Four, Five, Eight, and Nine. This is primarily due to the fact that partial cutting was limited to 40 percent removal and the average age of the main timber type seldom dipped below 40 years. Therefore, high levels of slope erosion noted under clearcutting operations for stands younger than 20 years never appeared.

All of this information taken collectively can have an impact on how the analyst may design an alternative to meet a decision maker criteria of minimizing erosion levels. Some key points are:

1) midslope roads on oversteepened slopes, and headwall associated roads can lead to substantially accelerated erosion,

2) road erosion rates are directly proportional to acres of right-of-way cleared, regardless of the terrain type,

3) there are only minor differences in slope erosion rates associated with skyline and helicopter harvest systems,

4) partial cutting of streamside strips and headwalls had little impact on the total erosion level,

5) clearcutting of oversteepened slopes with shallow non-cohesive soils accelerates erosion substantially,

6) clearcutting headwall areas and streamside strips with steep slopes results in extremely high probability of accelerated erosion.

Alternative Analysis Synopsis

The model output and alternative analysis still have not provided the decision maker with a set of answers as to how this drainage should be managed. The final management scheme will depend on the decision maker's constraints, orders of value, and long range management goals as they are tempered by his selected set of managerial criteria. If his main goal is to maximize profits regardless of other impacts he would clearcut the entire drainage with a skyline system. If he wished to minimize all erosion he would maintain the "status quo" or possibly partial cut all stands accessible from the six miles of existing roadway. Between these two extremes reside a wide variety of other options. The results of this modeling application and analysis help to explain the relative consequences for each of these options.

XII. METHODOLOGY PERSPECTIVE AND APPLICATIONS

This study has presented a new methodology for analyzing selected cost and return components and erosion potentials for a wide variety of harvest and road alternatives. The interested reader may ask at this juncture: what does this methodology do for him? Could a competent analyst have guessed the relevent model outcomes correctly prior to analysis and precluded a substantial investment of time and money? Does this methodology provide a means for evaluating indirect or direct impacts of timber harvests and forest roads? If the methodology has desirable utility, how might it be employed by research analysts and field specialists? What types of problems lend themselves to this type of analytical procedure? These questions are appropriate and require discussion.

Perspective

Much recent research has been accomplished for evaluating timber returns, road costs, and accelerated mass erosion. Most advancements have been on an individual, rather than an integrated, topical basis. This research output, combined with decades of practical forestry experience, has helped build specific areas of expertise wherein specialists can address quite competently one topical area at a time. For example, a logging engineer would not be surprised that helicopter harvesting was dominated by equipment expenses. Or, any erosion expert could explain before hand that highlead clearcutting should lead to the highest erosion rates in steep unstable terrain.

If such knowledge exists before hand, then why apply a seemingly redundant and expensive analytical methodology? The answer is straight forward: the methodology presented herein provides a capability to evaluate "multiple alternative outcome comparisons" in addition to individual outcome analysis. For example, could the logging engineer explain before hand how higher rates of erosion might impact highlead cost structures? Or, would the erosion expert understand at the outset the harvest tradeoffs which may yield a better balance among the competing decision maker criteria for road costs, harvest costs, timber returns, and expected erosion rates? Under existing catalogs of expertise, the answer to these rhetorical questions is: most probably not. However, following application of this study's methodology, the logging engineer and erosion expert would be much more able to understand how their areas of concern are related. This in turn would help lead to joint development of alternatives which include logical tradeoffs that tend to balance the often conflicting sets of decision maker criteria.

Direct or Indirect Impacts

Impacts measured by the methodology in this study are all direct. For example, no attempt was made to calculate local economic impacts such as public in-lieu payments, economic multiplier effects, or primary and secondary employment changes. Such evaluations are important, but they are indirect and beyond the scope of this study. Additionally, all erosion impacts considered are directly tied to the harvest operations or road placement. Indirect impacts, such as how much sediment enters the streams, how many spawning beds may be destroyed, or how sediment can affect downstream water treatment costs are also beyond this study's scope.

Applications and Problem Types

The methodology presented herein is intended to be general in nature. Hypothetically speaking, it could be applied anywhere for analysis of numerous types of problems. How well the methodology functions will be evaluated in long term performance for a wide variety of applications. The purpose of this section is to explain how a researcher can apply the entire methodology, how a field expert can employ portions of the theory, and what major types of problems can be evaluated under the analytical structure presented.

Research Applications and Problem Types

This discussion assumes that the conditional probability matricies in Tables 21 and 22 and the form of event probability functions (Q_j (z_i)) are acceptable. Where there is disagreement with this assumption, the matricies and functions can be modified to produce agreement. Once this assumption is accepted, application of the study methodology reduces primarily to a problem of data gathering, alternative specifications, data coding for electronic data processing (edp) and watershed modeling.

Complete application requires acquisition of certain resource information in terms of definitions on pages 9-11 for:

1) existing road system, to include location, standard, surface, and age;
2) existing vegetative cover, to include type, location, site, and age of major timber types;
3) slope classes;
4) soil types;
5) landform classes;
6) bedding plane angles;
7) fracture angles;

8) historical harvest methods;

9) historical silvicultural methods.

This information should be gathered at map scales of no less than two inches to the mile and preferably at four inches to the mile.

Other major steps entail adaptation of a uniform grid map (blocks and cells) to all resource data, specification of alternatives (see Chapter VIII), and coding of all required data input files for edp. Also, use of HARP may require alterations in production function variable values and coefficients (See Table 30 and Dykstra 1974,1975), road cost data (see Table 29), and timber returns data (see Table 32).

The only remaining step is to utilize watershed modeling to develop erosion index distributions for the selected area of application. This is a most critical step and requires information on monthly records for: 1) precipitation; 2) runoff; and 3) evapotranspiration. Watershed modeling can proceed as was presented in Chapter V. The main products will be soil water content (S_i), precipitation (P_i), and monthly ZETA values (z_i) for the ZETA k (k = 1, 3) populations. Procedures on how to adapt and employ this information into HARASS model runs are explained in Chapter IX. Note, if an analyst is not satisfied with using the procedures for scaling new ZETA k populations to those used in this study for calculation of event probabilities from the $Q_j(z_i)$ CDF's, one other step can be taken. New $Q_j(z_i)$ CDF's can be fit which are tailored specifically to the new ZETA k populations. Procedures in Chapter VI outline the steps necessary to accomplish this task.

Completion of the above steps will allow an analyst to begin evaluation of harvest and road alternatives under the HARASS and HARP structures. A most important point is: potential methodology users do not have to "recreate the wheel" in order to apply the theory presented. Most efforts will be centered around rather simple data acquisition and management tasks.

A major research application involves refutation testing for this entire theory. This is very important and should be an early area of concern.

Several different drainages should be studied with this methodology in order to determine if expected model erosion products conform or conflict with what is actually observed. This research application can lead to model modifications which will help generate more realistic deductions.

Research analysts could study also the roles each of the individual variables and variable states play in erosion processes. Regression analysis applied to HARASS output tables may provide very insightful information in this regard. Research efforts can also be directed at uncovering least troublesome and most troublesome variable state combinations. This would lead to subsequent development of field guides which could help streamline field analysis for certain problem types. Similar work could be accomplished regarding cost and return components and PNV calculations.

A major research problem involves analyses similar to this study's alternative evaluation. This can proceed for whole drainages (as done herein), or by applying a sample process. The sample process would entail construction of artificial drainages which contain variable state combinations that are proportionate to actual area distributions of like combinations for the drainages under study. Results from this sample approach could then be extrapolated to cover whole drainages. Such an approach would be more efficient than model analyses of complete drainage resource data bases. These research applications and problem types do not cover all possible cases. Actual methodology employment is only really limited by the goals of the using agency, monetary constraints, and the imagination of the research analyst.

Field Applications and Problem Types

Use of the theory presented here does not necessarily require employment of sophisticated simulation modeling and edp techniques and equipment. Field specialists can utilize portions of the theory to develop "crude" comparative measures for various potential road placement locations and harvest and silvicultural methods for a cutting unit(s).

Resource data required for each potential road location and cutting unit is:

1) road standard and surface, planned,
2) road segment length(s),
3) harvest method planned,
4) silvicultural method planned,
5) cutting unit(s) area,
6) slope class(es),
7) soil type(s),
8) landform(s),
9) bedding plane angle(s),
10) fracture angle(s) of the bedding planes

This data should be gathered for the variable states defined on pages 9-11. Some information for climatic and hydrologic conditions may also be required. How much of this type of data is needed depends on how complex and complete the analysis must be.

At the simplest level, a user can ignore climatic and hydrological conditions completely. Matricies in Tables 21 and 22, which correspond to resource data components 1, 3, 4, and 6-10 above, are used exactly as explained on page 74 and top of page 75 to calculate the conditional probabilities for each road event and slope event for all specified variable state combinations. These conditional probabilities can be used alone for a crude marginal analysis. For example, assume the following was calculated:

Pr (Road Segment (1)/T4) = 0.35,

and Pr (Road Segment (2)/T4) = 0.07.

Then a marginal comparison could be made:

> When a road failure (T4) does occur, it has a 35 percent chance of affecting road segment (1) and a seven percent chance of affecting road segment (2). Road segment (1) is five times more susceptible (35/7) to road failures than segment (2).

Remember, this tells you nothing about expected levels of activity, only relative comparisons of susceptibility. A wide variety of road standards, surfaces, and locations can be compared in this manner.

The next level of complexity would be to calculate "expected values" of activity level for a few specific climatic and hydrologic conditions. The easiest approach is to use the functions on page 69 and evaluate each one at a low, medium, and high value of z_i (within the range specified for each function). These three values for each function would approximate the probabilities under dry, normally wet, and very wet climatic and hydrologic conditions for three road and four slope erosion events. Then the user would proceed for each event exactly as described on pages 75-76. Remember that in the final step, where expected values are calculated (bottom of page 76), the "area" units required for road erosion are "acres of right-of-way" and for slope erosion "squre kilometers." Right-of-way acres are calculated most easily by: (road length)X(right-of-way width) / 43,560. Recall that the right- of-way widths used for the two road standards in this study were 50 feet for primary roads and 35 feet for secondary roads.

The products of this calculation set would be expected values of all road and slope events for each different road segment and set of conditions in every cutting unit at three different climatic and hydrologic conditions. Numerous adaptations on this approach can be made. Some include estimating total events by multiplying each expected value by the estimate of the number of times each of the climatic and hydrologic conditions will occur in, say, a 50 year period. Then, the mean size of the event distributions on page 78 can be calculated and multiplied times the total number of 50 year expected events to give a crude idea of expected volume of sediment produced for each event category.

Even more complex approaches are possible, such as estimating average monthly precipitation (P_i) and soil water content (S_i) and calculating 12 z_i values for each ZETA k function. These values can then be utilized exactly as the three z_i values were above to calculate annual expected averages for numbers of events and sediment volumes (see also pages 102-104). Regardless of how simple or complex the field specialist wishes to be, he can use his imagination to develop several different crude measures for marginal erosion impacts.

Cost and returns analyses may be conducted by applying appropriate production functions and cost/return components (see Dykstra 1974 and 1975) to timber harvesting. Also, use of a simple road cost matrix (see Table 29) can be used to calculate estimated road expenses. Determination of a complete PNV analysis, such as done by HARP, is not recommended for field applications unless some type of automated calculation support is available. If this is the case, the PNV equations on pages 114-115 can be applied to annual cost and return components without having to employ the HARP computer program. If a complete PNV analysis is required, the field specialist should work with a trained analyst or researcher to set up an entire HARASS, HARP run set, just as explained in the previous section. Once again, these few field applications do not exhaust all possibilities. A wide variety of applications exist, and the limiting constraints for what is done are: agency goals, available funding and manpower, computational facilities, and the imagination of each potential user.

XIII. SUMMARY AND CONCLUSIONS

This study has attempted to develop and demonstrate a methodology which will help integrate potential erosion consequences into the bundle of costs and benefits associated with a projected forest use. Integral to the study was the intent to provide information which may help determine what the limiting constraints are: road construction costs, maintenance costs, repair costs, forgone access cost, silvicultural system(s) employed, harvest expenses, or expected erosion potentials. Hopefully, the methodology presented herein will provide some of the critical inputs necessary to help incorporate these often conflicting criteria into the decision making process.

The guiding philosophy for the study was Aristotlean: hypotheses about the general were used to produce deductions on the particular. The forest ecosystem was viewed as a conglomerate of an infinite number of variables and variable state combinations. Examination of an infinite set is beyond anyone's comprehension, therefore, an attempt was made to reduce the problem to a finite set of controlling variables and general interrelating principles. Three key assumptions were made:

1) the finite variable states <u>define</u> adequately individual <u>and</u> collective erosive characteristics of <u>any</u> forest site,

2) the general principles presented represent the "a priori" first principle set,

3) the rule that all members of a class have like characteristics is applicable for this study.

The finite variables for the two separate erosion classes defined were:

1) Road erosion ---
   a. road age,
   b. road standard,
   c. road surface,
   d. slope type,
   e. soil type,
   f. landform type,
   g. bedding plane angle,
   h. fracture angle.

2) Slope erosion ---
   a. timber age,
   b. harvest method,
   c. silvicultural method,
   d. slope type,
   e. soil type,
   f. landform type,
   g. bedding plane angle,
   h. fracture angle.

All "apriori" first principles were couched in probabilistic terms, and are directly interpreted from probability Tables 4-6 and 21-23 and the mathematical forms of the ZETA Function and the $Q_j(z_i)$ function families. Because no single body of thought existed from which to derive these probabilistic relationships, a special survey technique was employed. The intent of the survey was to translate the existing collective, qualitative , expert opinions of these relationships into a single set of quantitative expressions. These expressions represent what is known; when what is known changes, they and the consequent first principles must change accordingly. The rule relating class and characteristics was employed along with "Bayes' Theorem" to produce logical deductions based on the definitions and "a priori," first principles. The theory, in essence, is that slopes (roads) with similar variable states under similar hydrologic and climatologic conditions have as a logical consequence similar selected erosion event probabilities.

Application of this theory results in testable hypotheses about forest site erosion events. A significant portion of this study was devoted to constructing the analytical framework necessary for obtaining such testable hypotheses. This entailed gathering, mapping, interpreting, and coding substantial amounts of hydrologic, climatologic, geomorphologic, and resource state data. Subsequently, a hydrologic model was constructed for the subject study area, and a measure of local erosion potentials for each of seven mutually exclusive erosion events was established in terms of the ZETA Function. The watershed model and erosion potential products were then integrated into an erosion simulation model along with all other definitions, "a priori" first principles and rules. This FORTRAN IV model, HARASS, produces the testable hypotheses on on-site erosion consequences. Neither a goal nor a product of this study was to "test" these hypotheses. An intensive investment of time and money will be required to conduct meaningful refutation tests, and this is seen as a product of future years of research.

Because one of the goals of this research project was to integrate erosion consequences and all other major costs and return components into the decision making process, a companion financial model was developed. This FORTRAN IV model, HARP, is an analytical model which is used in tandem with HARASS and evaluates a wide variety cost and benefit components for any harvest and road alternative. The development of the theory and structuring of HARASS and HARP composes the "methodology" sought as a primary research goal for this study.

The final goal of this study was to demonstrate "how" this methodology can be applied. The formating and subsequent HARASS and HARP evaluation of ten different harvest and road alternatives accomplished this goal. A methodology which will help integrate erosion data and certain related capital investments into the decision-making process was developed and demonstrated.

Evaluation of the Methodology Preffered

Development of any model requires abstraction from reality through the inclusion of assumptions and constraints. Some of these model restrictions are trivial and some can be extremely critical. The methodology proffered by this study is typical in this regard.

The most critical restrictions are the three key assumptions discussed in the previous section of this chapter. These define the world within which the methodology operates and set the stage for rules of operation. If this study has excluded a key variable(s) from the defining set, utilized improper conditional probabilities (which are the basis for the first principles), or the rule on like characteristics does not hold, then the theory will produce refutable deductions. Improvement in knowledge may cause a change in the first two assumptions and a modification of interpretation of the third, but the basic methodology, still will be applicable. Therefore, even though these key assumptions are critical to the final form of hypotheses developed, they are not critical to the methodology structure presented.

Several important restrictions were built into the model structure for HARASS. The most important is the "mutually exclusive" restriction assumed for all event types and all on-site (defining) variables and variable states. The importance of this restriction arises when on-site event probabilities are calculated. Under the mutually exclusive restriction the co-variance matrix for each set of variable states is ignored. If this matrix is synergistic the calculated probability will be less than the actual, and if it is antagonistic the reverse occurs. Crude estimates can be made for these matricies, but determination of the synergistic, antagonistic aspect is not within the scope of current knowledge. How critical the mutually exclusive restriction really is may be known only through future hypotheses testing.

A second important HARASS restriction involves the utilization of three ZETA k populations to serve as erosion indices for the seven road and slope erosion events studied. There is no precedence for this approach. The ZETA Function presented is empirical and highly hypothetical.. The function form employed is additive, however, actual structure may be multiplicative, exponential, or many other more complex possibilities. The additive form was selected due to the ease with which it can be used and interpreted. There is no current evidence which can cause rejection of the ZETA Function use in this form. A source of evidence will be available when adequate hypotheses testing for HARASS can be completed. A possible interim approach would be to test internal hypotheses that high z_i values correspond to past high erosion rates and low values with low rates for several independent watersheds.[22] This was not a formal goal nor product of this study. If the ZETA Function form is refutable, the methodology for the study will not be altered. The current form can be replaced without impacting on the methodology structure.

The next critical HARASS restriction encompassed the assumed form for the event probability functions: $Q_j (z_i)$. Little evidence was available from which to specify the seven event probabilities of

---

22

This was done in a very crude manner for several locations over a range of climatic conditions and no evidence was observed which would lead to rejection of the current ZETA Function form.

this form. This lead to an empirical approach for finalizing each function equation. Once again, the complete impact of the assumptions regarding these function forms cannot be known without thorough internal and final model hypotheses testing. However, once again, refutation of these internal function assumptions will not lead to alteration of the developed methodology, but only a replacement or modification of the seven functions used.

The fourth major model restriction was that "Bayes' Theorem" could be applied to determine on-site, conditioned, erosion event probabilities. Little need be said about this restriction except that how accurately hypotheses can be developed from this theorem depends only on the non-refutability of the three key methodology assumptions and the three HARASS restrictions just discussed.

Assumptions regarding erosion size distributions were also important. For the most part these size distributions were based on existing data and represent the composite current knowledge. More indepth future research on event sizes may indicate that the functions employed should be altered or replaced. Such a change will not impact the methodology; it only will lead to minor internal model modifications.

Numerous other restrictions were employed throughout the structuring of HARASS and HARP, however, those of major interest have been discussed. Because of the hypothetical nature of the completed methodology presented and lack of any rigorous hypotheses testing, one might logically ask: just how reliable and realistic is this entire approach? Some evidence, though not rigorous, does exist which helps shed light on such a question.

Expected annual slope erosion rates from HARASS varied from a natural level of 0.96 cubic yards per acre to nearly 10 cubic yards per acre for a specified harvest regime. Most rates were between 1.0 and 6.0 cubic yards per acre per year. The expected annual road erosion rate per acre of road right-of-way was 130 to 140 cubic yards per acre for all alternatives. Total alternative erosion rates ranged from a low of about two to over 15 cubic yards per acre per year. In all three cases these rates are higher than those reported for several other studies.

Swanson and Dyrness (1975) found annual rates of 0.21 and 0.91 cubic yards per acre for a natural forest site and a clearcut site. Additionally, their data reveals a rate of 10.1 cubic yards per acre for road-right-of ways each year and a total annual rate of 0.65 cubic yards per acre for the H.J. Andrews Experimental Forest in Western Oregon.

Fiksdal (1974a) reported slope erosion for a Northwestern Washington drainage with nearly 20 percent in recent clearcuts to have an annual erosion rate of 0.30 cubic yards per acre. Road event rates were nearly 50 cubic yards per acre of cleared right-of-way, and total erosion was occurring at an annual rate of 1.71 cubic yards per acre. O'Loughlin (1972) recorded data which yields total erosion rates of from 0.01 to approximately 2.5 cubic yards per year per acre for eleven watersheds in Southwestern British Columbia, Canada. In a study of a Western Oregon drainage, Morrison (1975) reported an annual rate of 0.24 cubic yards per acre for a natural forest and 0.62 for a clearcut area. The rate for road erosion was 82.4 cubic yards per acre per year, and total annual road and slope erosion was 3.21

cubic yards per acre.

The expected annual frequencies reported by HARASS for slope erosion varied from 0.0002 per acre to 0.0131 per acre. These two frequencies were for a natural condition and a highlead clearcut regime respectively. For most harvest alternatives the frequency range was 0.0003 to 0.0062. The frequencies for road erosion on a per acre of right-of-way cleared basis ranged from .2 to .3 per year. The annual frequency level for all road and slope events ranged from 0.0024 to .0238 per acre. The range for all harvest alternatives except the highlead alternative was 0.0051 to 0.0136. Again, these frequencies were higher than recorded for other studies.

Frequencies reported by Morrison (1975) were 0.0001 and 0.011 per year per acre for natural and clearcut conditions respectively. The road rate per year per acre of cleared right-of-way was 0.033. Total road and slope frequency per year was 0.0015 per acre. O'Loughlin (1972) reports data for natural rates as low as 0.00001 per acre per year and clearcut frequencies as high as 0.00034. Road and slope frequencies combined ranged from 0.00004 to 0.00084 events per acre per year. Swanson and Dyrness (1975) recorded a frequency of 0.00008 events per year per acre for natural conditions for slope erosion and one of 0.00194 for clearcut areas. Road erosion frequencies were 0.00563 events per acre per year, and total road and slope erosion annual frequency was 0.00036 events per acre.

The higher levels for annual erosion rates and frequencies were not unexpected for one very important reason. This study attempted to account for numerous events not included in past studies These included smaller road and slope erosion events and an expected proportion never measured for most studies due to measurement technique limitations. This will cause an increase in both total events and total volume of material moved over that reported in existing studies. This higher level is only critical in two areas. First, HARP charges off road repairs based on volume of material moved and HARASS reduces site productivity by dropping the age class of a cell when a large event occurs. More frequent larger events will carry a higher cost to the system, and may distort PNV calculations and site productivity loss if the estimates are much too high. Secondly, attempts to calculate actual expected erosion rates may be a logical extension of this methodology. Estimates on the high-side may lead to critical errors for such an application. Care must be exercised in future model testing to determine if the difference between model results and past study data is apparent or real.

One important area where absolute levels are not important is in determining comparative impacts of different forest activities. For example, this study resulted in increases over the natural erosion level of four to fifteen times for the ten alternatives. Most increases were from four to nine times the natural level. Swanson and Dyrness (1975) reported a five-fold increase and Morrison (1975) more than a ten-fold increase for total erosion volume on a per year per acre basis. For road related erosion levels this study reported increases ranging from 24 to 125 times natural levels. Swanson and Dyrness reported an increase of 30 times and Morrison as high as 300 times natural erosion levels based on a per year per acre-of right-of-way cleared. The main point here is that ratios are often very important in determining the type of impact expected. Even though this methodology yields higher frequencies and volumes than historically noted, this increase is carried proportionately by all forest components. This results in comparative analyses statistics which do not appear to be out of the range of what is currently known, and this result is of significance in lending credibility to the methodology proffered.

Remarks

On numerous occasions in this report I have pointedly stated that the methodology developed and demonstrated is an abstraction from reality and as such only yields "relative," not "absolute" information. The importance of this comment cannot be overstated, and any attempt by myself or any potential user of this methodology to ignore this fact would be a serious error. Additionally, the method presented herein offers an analytical tool which can be employed under "office conditions" in order to evaluate forest site impacts. Use of the methodology without well integrated on-site activities can also result in serious error through misinterpretations of forested conditions and alternative specification requirements. The purpose of this study has not been to discover a panacea for erosion problems currently troubling forest managers; it has been to develop a process by which the systems contributing to these problems can be more formally structured and evaluated. Hopefully, this has been achieved.

Conclusions

The following conclusions have been derived from a study designed to develop and demonstrate a methodology for integrating specified erosion problems and capital components into the decision making process:

1) enough expertise exists to allow use of the Aristotlean method for developing deductions on the particular from hypotheses about the general for the analysis of forest erosion processes,

2) an erosion index function family does exist, and for this study was represented by a functional form which integrates the combined relationship of precipitation and soil moisture content levels,

3) frequencies of slope and road erosion are quite small in time and space, but can be represented functionally by an exponential type function based on a specific erosion index family for each mutually exclusive erosion event,

4) erosion event size distributions can be represented by continuous function forms,

5) the Weibull distribution has a "wide" range of applicability for analysis of many forest eco-system variables which have numeric values greater than or equal to zero,

6) development of an erosion simulation model which is a logical consequence of the above five conclusions is within current state-of-the-art techniques,

7) road construction on steep normal slopes, across headwalls, or steep streamside slopes can lead to substantially accelerated erosion rates, which impact on both the forest eco-system and the forest operations cost structure,

8) clearcut harvesting of steep,shallow non-cohesive soiled slopes, headwall slopes, or steep streamside slopes can lead to substantially accelerated erosion rates, which impact on both the forest eco-system and the forest operations cost structure,

9) the first 10 years after road construction appear to be most critical for road erosion events simulated herein,

10) the first 20 years after initial cutting appear to be most critical for slope erosion events simulated herein,

11) together, slope erosion and road erosion can create significant economic impact on the forest investment capital structure,

12) the methodology developed in this study can be applied to a wide range of research and field oriented problems which deal with analyses of managerial criteria and tradeoffs associated with timber harvests and forest roads.

BIBLIOGRAPHY

Bailey, Robert G. 1971. Landslide hazards related to land use planning in Teton National Forest, Northwest Wyoming. Ogden. 131 p. (Forest Service, U.S. D. A., Intermountain Region).

Bishop, Daniel M. and Mervin E. Stevens. 1964, Landslides on logged areas in Southeast Alaska. Fairbanks. 18 p. (Northern Forest and Range Experiment Station, U.S. D. A. Forest Service Research Paper NOR-1).

Brownlee, K. A. 1965. Statistical Theory and Methodology in Science and Engineering. New York, John Wiley and Sons, Incorporated. 590 p.

Buongiorno, Joseph and Dennis E. Teeguarden. 1973. An economic model for selecting Douglas-fir reforestation projects. Hilgardia, Vol. 42 No. 3.

Burke, Doyle. 1974. Automated analysis of timber access road alternatives. 40 p. (Pacific Northwest Forest and Range Experiment Station, U. S. D. A. Forest Service General Technical Report PNW-27).

Burroughs, Edward R. Jr., George R. Chalfant, and Martin A. Townsend. 1973. Guide to reduce road failures in Western Oregon. Portland 111 p. (Bureau of Land Management, U. S. D. I., Oregon State Office).

Colman, Steven M. 1973. The history of mass movement processes in the Redwood Creek basin, Humboldt County, California. Masters Thesis. University Park, Penn State University. 151 p.

Draper, N. R. and H. Smith. 1968. Applied Regression Analysis. New York, John Wiley and Sons, Incorporated. 407 p.

Dykstra, Dennis P. 1974. A comparative analysis of production rates and costs for cable, balloon, and helicopter yarding systems in old-growth Douglas-fir. (A report to the Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S.D.A.). Corvallis, Oregon State University. Forest Research Laboratory. 98 p.

________________ 1975. Production rates and costs for cable, balloon, and helicopter yarding systems in old-growth Douglas-fir, Part II. (A report to the Pacific Northwest Forest and Range Experment Station, Forest Service, U.S.D.A.). Corvallis, Oregon State University. Forest Research Laboratory. 100 p.

Dyrness, C.T. 1967. Mass soil movements on the H.J. Andrews Experimental Forest. Portland. 12 p. (Pacific Northwest Forest and Range Experiment Station, U.S.D.A. Forest Service Research Paper PNW-42).

Fiksdal, Allen J. 1974a. A landslide survey of the Stequaleho Creek Watershed and Upper Clearwater River Area. Olympia. 19pp. (Department of Natural Resources, Washington State, unpublished report).

________________ 1974b. A landslide survey of the Upper Clearwater and Solleks River Areas, Jefferson County. Olympia. 6p. (Department of Natural Resources, Washington State, unpublished report).

Fishman, George S. 1973. Concepts and Methods in Discrete Event Digital Simulation. New York, John Wiley and Sons, Incorporated. 385 p.

Halter, Albert N., and Gerald W. Dean. 1971. Decisions Under Uncertainty with Research Applications. California, Southwestern Publishing Company. 265 p.

Johnson, Kenneth N. 1973. Evaluation of management alternatives for an undeveloped, forested area in Oregon's Coast Range. Doctoral Dissertation. Corvallis, Oregon State University. 187 p.

Kmenta, Jan. 1971. Elements of Econometrics. New York, The Macmillan Company. 655 p.

Larrabee, Harold A. 1964. Reliable Knowledge. Boston. Houghton Mifflin Company. 409 p.

Lemberskey, Mark R. and K. Norman Johnson. 1974. An infinite horizon Markov decision process approach to optimal management policies for young growth stands. Corvallis, Oregon State University. Technical Report No. 41. 44 p.

Lindner, Jack G., Stuart D. Gresswell, James R. Maxwell, George S. Bush, and Norman S. Adams. 1975. Personal communications and conference consultations regarding collection, analysis, and interpretation of Siuslaw National Forest land resource information. Corvallis. Siuslaw National Forest Headquarters, United States Forest Service U.S.D.A.

McArdle, Richard E., Walter H. Meyer, and Donald Bruce. 1961. The yield of Douglas-fir in the Pacific Northwest. Washington D. C. 74 p. (U.S.D.A., Technical Bulletin No. 201).

McNutt, James A. 1974. An analysis of erosion impacts associated with forest roads: a stochastic evaluation of interrelationships. Unpublished report. Corvallis, Oregon State University. Forest Research Laboratory. 32 p.

Megahan, Walter F. 1974. Erosion over time on severely disturbed granitic soils: a model. Ogden. 14 p. (Intermountain Forest and Range Experiment Station, U.S.D.A. Forest Service Research Paper INT-156).

Morrison, Peter H. 1975. Ecological and geomorphological consequences of mass movements in the Alder Creek watershed and implications for forest land management. Bachelor of Arts (Honor College) Thesis. Eugene, University of Oregon. 102 p.

Mustonen, Seppo E. 1968. Estimating evapotranspiration in a humid region. Washington, D.C. 123 p. (U.S.D.A. in Cooperation with Ohio Agricultural Research and Development Center, Technical Bulletin No. 1389).

O'Loughlin, Colin L. 1972. An investigation of the stability of the Steepland Forest soils in the Coast Mountains, Southwest British Columbia. Doctoral Dissertation. Vancouver, The University of British Columbia. 147 p.

Orwig, Charles E. 1973. Prediction of monthly stream flows for Oregon Coastal Basins using physiographic and meteorological parameters. Masters Thesis. Corvallis, Oregon State University. 116 p.

Pain, C.F. 1971. Rapid mass movement under forest and grass in the Hunua Ranges, New Zealand. Australian Geographical Studies, 9: 77-84 (1971).

Payne, Stanley L. 1951. The Art of Asking Questions. Princeton, Princeton University Press. 249 p.

Popper, Karl R. 1957. Philosophy of Science: A personal report, in British Philosophy in the Mid-Century. London. C. A. Mace (ed.). Allen and Unwin. pp. 155-94.

Rice, R. M., E.S. Corbett, and R.G. Bailey. 1969. Soil slips related to vegetation, topography, and soil in Southern California. Water Resources Research, Vol. 5, No. 3.

Rowley, Marvin L. 1975. Personal communications regarding current mill Douglas-fir timber values for four timber types in Western Oregon. Corvallis. Oregon State University, School of Forestry.

Saurbier, James A. 1975. Personal communications regarding forest road placement, standards, and construction methodology and road cost data for construction, maintenance, rocking, and damage repairs. Corvallis. Siuslaw National Forest Headquarters, United States Forest Service U.S.D.A.

Scheurman, H. Lynn.1974. Personnal communications regarding stochastic variate generation, statistical distribution fitting, and distribution uniformity testing. Corvallis, Department of Statistics, Oregon State University.

Swanson, Fred J. and C.T. Dyrness. 1975. Impact of clearcutting and road construction on soil erosion by landslides in the Western Cascade Range, Oregon. Geology, July 1975.

Swanston, Douglas N. 1975. Personal communications regarding geomorphic and physiographic characteristics of Oregon Coast Range land forms. Corvallis, Forest Science Laboratory, United States Forest Service U.S.D.A.

Thoman, Darrel R., Lee J. Bain, and Charles E. Antle. 1969. Inferences on the parameters of the Weibull distribution. Technometrics, Vol. 11, No. 3.

United States Forest Service. 1973. The outlook for timber in the United States. Washington D.C. Forest Resource Report 20. 367 p.

United States Forest Service. 1974. Process and action plan for stratifying Siuslaw National Forest commercial forest lands according to suitability for timber production. Siuslaw National Forest, Corvallis. 4 p.

United States Department of Agriculture and United States Weather Bureau, U.S.D.C. 1964. Map of normal annual precipitation, state of Oregon.

______________________ 1971. Precipitation intensity maps for Oregon.

United States Department of the Interior, Geological Survey. 1961. Geological map of the lower Umpqua River Area Oregon. Oil and gas investigations map OM-204.

United States Department of the Interior, Geological Survey. 1970. Map of Pacific Slope basins in Oregon and Lower Columbia River Basin showing average annual runoff in inches.

Warner, Rex. 1958. The Greek Philosophers. New York. The New American Library Incorporated. 238 p.

Wetherill, Barrie G. 1972. Elementary Statistical Methods. London, Chapman and Hall Ltd. 346 p.

Yee, Carlton S. 1975. Soil and hydrologic factors affecting the stability of natural slopes in the Oregon Coast Range. Doctoral Dissertation. Corvallis, Oregon State University. 203 p.

APPENDICES

Appendix A. SELECTED RUNOFF AND PRECIPITATION DATA

The three data files in this appendix are:

1) Monthly runoff in inches of water as recorded at Tidewater, Oregon on the Alsea River from 1955-1974.

2) Simulated monthly precipitation and actual precipitation in inches of water for Alsea Fish Hatchery, Oregon. Simulated data covers 1933-1951 and actual data 1952-1974.

3) Actual monthly precipitation in inches of water for Honeyman State Park, Oregon from 1933-1974.

This information was used to develop a watershed model for the Harvey Creek Drainage near Reedsport, Oregon.

1) Runoff data for Tidewater, Oregon.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1955	9.06	6.71	10.51	10.64	3.01	1.08	0.74	0.37	0.47	3.36	13.22	22.74
1956	22.62	10.84	14.67	4.98	1.48	0.83	0.46	0.30	0.31	1.31	2.18	7.39
1957	5.00	10.28	13.33	5.20	2.34	1.23	0.64	0.45	0.31	0.64	1.79	13.44
1958	12.43	16.35	5.94	7.62	2.32	1.09	0.50	0.28	0.31	0.46	7.77	6.25
1959	18.37	11.98	5.96	4.14	2.39	1.27	0.63	0.35	1.18	1.75	2.28	3.81
1960	5.42	15.34	9.67	8.02	5.62	2.05	0.76	0.46	0.35	0.66	11.19	5.70
1961	8.27	19.76	17.76	4.56	4.04	1.32	0.65	0.37	0.36	1.01	3.85	11.16
1962	[illegible]	8.03	[illegible]	4.77	3.47	1.25	0.65	0.45	0.42	2.21	7.52	6.56
1963	2.93	10.61	7.97	10.78	6.38	1.37	0.81	0.45	0.47	1.01	8.22	5.26
1964	21.29	5.66	9.11	2.73	1.74	0.97	0.61	0.44	0.32	0.36	4.20	25.61
1965	20.71	6.82	3.31	2.61	1.85	0.87	0.46	0.32	0.20	0.40	4.09	9.04
1966	19.09	6.07	14.65	2.96	1.14	0.60	0.40	0.23	0.23	0.48	3.65	11.76
1967	15.29	7.67	8.14	4.87	1.87	0.85	0.41	0.25	0.21	1.90	2.34	10.20
1968	8.30	15.10	7.03	2.94	1.99	2.22	0.71	0.81	0.74	2.72	9.45	19.88
1969	13.71	12.65	7.07	3.19	2.03	1.14	0.71	0.38	0.51	1.29	2.64	10.54
1970	23.70	10.52	4.51	3.40	2.53	0.94	0.49	0.29	0.31	0.81	5.70	15.50
1971	19.80	5.88	14.66	8.82	2.25	1.39	0.79	0.43	0.89	1.08	8.86	19.18
1972	19.86	9.50	13.53	7.60	2.69	1.25	0.56	0.33	0.34	0.31	1.60	10.04
1973	10.69	3.08	5.21	3.04	1.57	0.78	0.41	0.25	0.62	0.71	20.24	21.51

2)a. Simulated Precipitation Data for Alsea Fish Hatchery on the Alsea River

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1933	22.70	12.19	11.94	3.35	8.70	2.45	0.03	0.95	6.48	4.99	6.62	22.14
1934	13.94	3.53	7.71	3.86	3.51	0.60	0.41	0.56	2.18	9.66	18.78	20.64
1935	11.78	7.46	14.31	4.65	1.52	1.50	0.43	0.26	3.84	5.00	8.45	9.97
1936	18.35	10.98	7.29	3.43	5.40	1.33	0.68	0.20	0.75	0.49	10.14	15.22
1937	16.13	19.72	8.35	12.69	3.64	4.64	0.13	1.63	2.77	6.27	21.68	18.87
1938	13.34	15.86	21.44	3.88	2.17	0.69	0.31	0.08	2.71	6.79	13.72	8.19
1939	12.58	12.44	8.73	2.59	2.14	2.86	1.16	0.90	0.17	7.51	6.24	20.03
1940	11.33	22.47	12.79	4.23	3.46	0.15	0.75	0.19	3.81	9.49	13.37	15.75
1941	16.33	5.49	4.25	4.65	13.13	2.33	0.07	0.77	8.67	3.48	14.56	23.68
1942	11.88	14.14	6.72	6.71	5.65	2.85	1.63	0.12	0.11	3.25	22.26	24.21
1943	13.56	8.55	11.51	5.82	3.26	2.15	0.72	1.63	0.11	14.00	9.07	7.13
1944	8.08	11.44	8.02	8.45	3.01	1.24	0.08	0.17	2.22	3.17	12.86	7.64
1945	13.15	15.21	16.20	8.48	5.79	0.22	1.14	0.38	4.32	1.74	23.08	12.14
1946	14.72	11.50	10.14	5.48	1.82	2.94	0.80	0.18	3.53	11.73	18.42	18.25
1947	11.82	6.69	11.83	6.44	1.33	5.10	1.46	0.90	2.61	20.69	12.40	11.22
1948	14.27	16.82	11.70	11.22	5.64	1.24	1.25	1.58	6.72	4.07	15.18	13.38
1949	4.73	20.15	8.33	2.54	5.22	0.91	0.63	0.50	3.31	4.45	13.30	13.17
1950	27.77	15.03	13.81	5.52	2.94	1.26	0.54	1.33	2.71	15.08	17.88	13.44
1951	18.97	12.02	13.59	3.60	3.86	0.53	0.86	0.28	2.71	10.58	14.45	15.93

2)b. Actual Precipitation Data from Alsea Fish Hatchery on the Alsea River.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1952	26.29	11.00	11.62	2.22	2.29	3.17	0.05	0.24	1.08	0.45	4.15	15.52
1953	34.45	15.48	14.19	7.67	8.86	1.52	0.19	3.53	1.10	7.79	20.12	23.72
1954	23.38	12.51	9.36	6.99	2.43	2.94	0.81	2.89	2.18	6.51	10.46	17.34
1955	8.94	11.93	15.02	13.17	1.99	1.49	2.43	0.01	3.91	13.86	16.58	23.68
1956	25.96	17.59	15.38	1.63	1.47	1.90	0.07	0.60	2.31	10.17	4.15	17.56
1957	7.27	12.97	15.66	5.48	4.26	2.05	0.91	1.20	0.77	5.55	7.65	23.59
1958	15.35	16.10	7.59	9.72	1.74	2.05	0.01	0.21	3.35	4.24	20.62	11.94
1959	23.75	11.71	10.55	2.27	5.61	3.22	0.70	0.37	11.48	9.52	8.44	7.52
1960	9.11	16.60	13.25	7.76	9.01	0.57	0.01	2.62	0.51	7.62	23.13	6.64
1961	11.63	25.10	20.22	5.58	5.24	0.65	0.33	1.82	2.30	8.69	13.84	16.02
1962	6.15	12.87	14.53	8.09	3.31	1.07	0.17	1.80	4.25	9.12	17.66	6.95
1963	5.70	13.23	12.90	10.74	6.00	2.80	1.33	0.13	3.92	6.87	15.64	9.47
1964	26.62	5.07	12.18	5.13	1.73	1.60	1.67	1.53	1.75	2.29	17.11	32.30
1965	25.72	7.14	1.93	5.15	3.93	1.01	0.28	0.73	0.09	4.22	15.05	16.18
1966	18.37	8.68	16.99	2.44	1.55	1.13	0.61	0.37	1.49	6.49	13.20	17.89
1967	21.81	7.49	13.91	6.92	2.01	0.61	9.01	0.01	1.51	12.35	7.28	13.90
1968	14.15	14.49	11.14	4.14	5.03	2.93	0.36	5.81	3.15	10.46	15.81	23.91
1969	20.00	8.87	6.81	5.93	3.92	3.18	0.11	0.01	5.13	6.72	6.44	17.73
1970	26.77	7.53	5.28	9.29	2.85	2.03	0.02	0.01	3.67	6.76	17.42	21.57
1971	19.53	11.45	15.98	8.89	5.35	3.12	0.29	0.94	7.73	5.71	18.11	23.86
1972	23.53	13.20	14.92	11.93	2.58	2.29	0.07	0.55	3.58	1.86	10.48	17.40
1973	12.64	3.79	9.69	3.73	2.65	2.71	0.01	0.84	6.61	5.69	34.18	23.33
1974	23.50	18.88	17.55	7.99	4.15	3.02	2.16	0.01	2.12	0.96	11.56	21.04

(3) Precipitation Data for Honeyman State Park, Oregon

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1933	18.11	9.78	10.02	2.73	10.15	3.10	0.04	1.13	5.35	5.05	2.75	17.76
1934	11.03	2.69	6.27	3.20	3.28	0.50	0.55	0.64	1.98	9.34	16.97	16.53
1935	9.30	5.87	12.16	3.93	0.65	1.64	0.58	0.27	3.28	5.06	4.89	7.87
1936	14.59	8.77	5.90	2.81	5.78	1.40	0.91	0.19	0.85	0.58	6.87	12.12
1937	12.80	16.15	6.83	11.98	3.45	7.11	0.17	1.98	2.44	6.25	20.36	15.09
1938	10.55	12.87	18.76	3.21	1.51	0.60	0.41	0.04	2.40	6.73	11.05	6.44
1939	9.94	9.99	7.16	2.05	1.47	3.79	1.55	1.06	2.41	7.39	2.30	16.03
1940	8.94	18.50	10.78	3.54	3.22	0.08	1.01	0.18	3.26	9.18	10.64	12.55
1941	12.96	4.26	3.31	3.93	6.02	2.91	0.09	0.90	7.06	3.61	12.03	19.18
1942	9.38	11.42	5.41	5.90	6.11	3.78	2.19	0.09	0.36	3.39	21.04	19.45
1943	10.73	6.76	9.63	5.04	2.95	2.62	0.96	1.98	0.36	13.19	5.61	5.59
1944	6.34	9.16	6.54	7.63	2.62	1.28	0.10	0.15	2.01	3.31	10.04	6.00
1945	10.40	12.32	13.89	7.66	6.30	0.14	1.53	0.41	3.66	1.90	22.00	9.62
1946	11.66	9.21	8.41	4.72	1.04	3.94	1.07	0.16	3.04	11.19	16.55	14.58
1947	9.33	5.24	9.92	5.64	0.39	8.03	1.96	1.07	2.32	18.86	9.51	8.88
1948	11.30	13.68	9.80	10.45	6.10	1.29	1.68	1.92	5.54	4.18	12.76	16.63
1949	3.68	16.51	6.81	2.01	5.55	0.86	0.85	0.56	2.87	4.54	10.56	10.46
1950	22.23	12.17	11.71	4.75	2.52	1.31	0.72	1.60	2.40	14.13	15.92	10.68
1951	15.09	9.64	11.51	2.96	3.75	0.43	1.15	0.29	2.40	10.16	11.90	12.69
1952	14.33	9.74	12.78	2.55	1.99	3.16	0.16	0.39	1.20	1.65	4.01	13.60
1953	20.85	12.64	12.47	7.87	8.45	2.55	0.40	3.64	2.61	5.02	15.69	19.02
1954	18.80	8.68	7.73	6.07	1.81	4.38	0.72	2.99	2.62	6.98	10.39	16.66
1955	7.77	8.38	11.54	11.16	2.03	1.58	2.88	0.01	2.90	12.92	14.11	19.64
1956	21.59	14.29	8.65	1.40	2.93	3.73	0.07	0.55	2.04	11.77	2.15	12.53
1957	7.78	10.35	16.66	4.68	3.38	2.25	0.75	1.51	1.97	7.62	4.00	20.21
1958	12.76	15.03	8.04	8.13	1.27	1.70	0.01	0.81	3.07	4.80	15.18	10.12
1959	24.86	11.40	8.71	2.36	4.34	3.06	0.87	0.81	7.56	6.24	4.57	5.97
1960	12.51	14.51	11.20	7.76	10.11	0.59	0.09	2.07	0.91	7.32	18.77	5.09
1961	7.73	17.06	15.51	5.77	7.61	1.23	0.30	[illegible]	1.38	[illegible]	[illegible]	9.02
1962	4.96	10.69	12.07	6.00	4.33	1.10	0.15	2.44	2.90	8.21	12.66	6.47
1963	5.05	10.65	9.49	12.16	5.54	2.87	1.36	0.06	3.73	6.24	14.61	7.96
1964	17.67	3.61	10.66	4.17	1.69	3.54	2.61	1.49	1.29	2.48	14.01	20.51
1965	20.57	4.43	2.03	5.06	2.57	1.26	0.54	0.74	0.58	3.69	13.61	15.04
1966	15.26	8.06	14.68	1.94	1.10	1.83	1.01	0.32	2.92	5.14	13.88	12.38
1967	19.06	7.10	9.52	7.74	2.06	0.95	0.01	0.01	2.06	7.20	6.70	12.18
1968	9.83	10.77	8.78	3.53	3.99	3.46	0.72	7.21	2.72	11.28	14.92	21.26
1969	22.15	7.48	4.06	3.95	3.66	4.87	0.29	0.14	5.47	8.07	6.37	15.80
1970	21.27	8.59	3.98	7.88	5.99	1.32	0.02	0.21	5.08	11.45	18.99	16.60
1971	16.61	8.41	13.41	9.61	2.35	2.98	0.38	3.24	3.46	4.30	12.35	17.32
1972	12.38	9.23	10.77	8.25	1.65	1.02	0.33	0.57	2.23	1.13	6.58	13.59
1973	8.61	3.28	10.39	2.24	2.84	3.21	0.03	0.79	5.12	4.93	19.73	18.99
1974	14.07	11.08	18.41	3.89	3.37	2.16	3.16	0.11	0.43	1.37	10.05	15.18

Appendix B. COMPUTER PROGRAM FOR ESTIMATING WEIBULL SHAPE AND SCALE PARAMETERS

This program was written by Dennis Dykstra of the OSU School of Forestry, Department of Forest Engineering in Corvallis and collaborated on by this project researcher.

```
      PROGRAM WEIBULL
C
C          THIS PROGRAM COMPUTES ESTIMATES FOR THE WEIBULL
C     DISTRIBUTION PARAMETERS BETA AND GAMMA, ASSUMING THAT
C     THE LOCATION PARAMETER, ALPHA, IS EQUAL TO ZERO.
C     THE METHODOLOGY USED IS THAT OF MAXIMUM LIKELIHOOD
C     ESTIMATION AS DESCRIBED BY G. S. FISHMAN IN "CONCEPTS
C     AND METHODS IN DISCRETE EVENT DIGITAL SIMULATION", JOHN
C     WILEY & SONS, 1973, P. 246.  GAMMA, THE SHAPE PARAMETER,
C     CORRESPONDS TO FISHMAN≠S ALPHA; AND BETA, THE SCALE
C     PARAMETER (OR CHARACTERISTIC LIFE) IS ALSO FISHMAN≠S
C     BETA.
C
C          REQUIRES DATA INPUT (OBSERVATIONS) FROM LOGICAL
C     UNIT NUMBER 5.
C
      DIMENSION X(1500)
      N=0
  100 N=N+1
      X(N)=FFIN(5)
      IF (X(N).LE.0.0) X(N)=0.00001
      IF (EOF(5)) GO TO 110
      GO TO 100
  110 N=N-1
C
C          COMPUTE FISHMAN≠S A (THE ARITHMETIC MEAN), B (THE
C     RAW SUM OF SQUARES), AND C (THE LOGARITHMIC MEAN).
C
      A=B=C=0
      DO 120 I=1,N
      A=A+X(I)
      B=B+(X(I)**2)
      C=C+(LOGF(X(I)))
  120 CONTINUE
      A=A/FLOAT(N)
      C=C/FLOAT(N)
C
C          ITERATIVELY FIND GAMMA, THE SHAPE PARAMETER.
C
      GAMMA0=SQRT(((B-FLOAT(N)*(A**2))/(FLOAT(N-1)))/A)
C
C          FUNCTION G IS FISHMAN≠S FUNCTION F; FUNCTION H
C     IS HIS FUNCTION F≠.
C
      ITER=0
      STEP=1.
      XLAST=1.
      DT=G(GAMMA0,N,X,C)/H(GAMMA0,N,X,C)
      IF (DT .LT. 0.) XLAST=-1.
      GAMMA=GAMMA0-(STEP*XLAST)
  130 DT=G(GAMMA0,N,X,C)/H(GAMMA0,N,X,C)
      IF (DT .LT. 0. .AND. XLAST .GT. 0.) GO TO 135
      IF (DT .GT. 0. .AND. XLAST .LT. 0.) GO TO 135
  134 GAMMA=GAMMA0-(STEP*XLAST)
      ITER=ITER+1
      GAMMA0=GAMMA
      GO TO 130
  135 STEP=STEP/2.
      IF (STEP .LT. .001) GO TO 136
      XLAST=XLAST*(-1.)
      GO TO 134
  136 GAMMA=GAMMA0-(G(GAMMA0,N,X,C)/H(GAMMA0,N,X,C))
      ITER=ITER+1
      T=ABS(GAMMA-GAMMA0)
      IF (T .LT. .00001) GO TO 140
      GAMMA0=GAMMA
      GO TO 130
```

```
C
C           COMPUTE BETA, THE SCALE PARAMETER.
C
  140 BETA=0
      DO 150 I=1,N
      BETA=BETA+(X(I)**GAMMA)
  150 CONTINUE
      BETA=(BETA/FLOAT(N))**(1./GAMMA)
C
C           PRINT RESULTS.
C
      WRITE (61,160) BETA,GAMMA,ITER
  160 FORMAT (≠1WEIBULL PARAMETER ESTIMATES≠/≠0 BETA HAT = ≠,
     1  E16.8/≠ GAMMA HAT = ≠,E16.8/≠0THE ESTIMATION OF GAMMA ≠,
     2  ≠WAS REQUIRED ≠,I5,≠ ITERATIONS.≠)
      CALL EXIT
      END
      FUNCTION G(GAMMAD,N,X,C)
C
C           THIS FUNCTION CORRESPONDS TO FISHMAN≠S FUNCTION F.
C
      DIMENSION X(1)
      X1=X2=0
      DO 100 I=1,N
      X1=X1+((X(I)**GAMMAD)*LOGF(X(I)))
      X2=X2+(X(I)**GAMMAD)
  100 CONTINUE
      G=(FLOAT(N)/GAMMAD)+(FLOAT(N)*C)-((FLOAT(N)*X1)/X2)
      RETURN
      END
      FUNCTION H(GAMMAD,N,X,C)
C
C           THIS FUNCTION CORRESPONDS TO FISHMAN≠S FUNCTION F≠.
C
      DIMENSION X(1)
      X1=X2=X3=0
      DO 100 I=1,N
      X1=X1+((X(I)**GAMMAD)*((LOGF(X(I)))**2))
      X2=X2+(X(I)**GAMMAD)
      X3=X3+((X(I)**GAMMAD)*(LOGF(X(I))))
  100 CONTINUE
      H=-(FLOAT(N)/(GAMMAD**2))-((FLOAT(N)*X1)/X2)-((FLOAT(N)*
     1      (X3**2))/(X2**2))
      RETURN
      END
```

Appendix C. COMPUTER PROGRAM FOR THE HARVEY CREEK WATERSHED AND EROSION INDEX MODEL

```
      PROGRAM HARVEYWS
C
C  THIS PROGRAM IS A SIMULATION ROUTINE FOR SIMULATING
C  THE PRECIPITATION, RUNOFF, EVAPOTRANSPIRATION, AND
C  GROUND WATER CONTENT FOR THE HARVEY CREEK WATER-
C  SHED IN THE SMITH-UMPQUA BLOCK FOR ANALYSIS OF THE
C  FREQUENCY OF VARIOUS CONCENTRATIONS OF HIGH GROUND
C  WATER CONTENT AND PRECIPITATION LEVELS.
C
      DIMENSION ET(12),G(12),P(12),R(12),AL(12),ALE(12)
      DIMENSION PP(12),TP(12),TR(12),TET(12),TG(12)
      DIMENSION IA(12),IC(12),IR(12),ALPHA(12)
      DIMENSION BETA(12),ZETA(12,7),B(7),A(7)
      DIMENSION U(12),W(12),X(12),RR(12)
      DIMENSION RAP(12),PA(12)
      READ(4,100) (IA(K),IC(K),IR(K),K=1,12)
  100 FORMAT(3(3X,I7))
      READ(5,101) (ALE(I),AL(I),I=1,12)
  101 FORMAT(2F10.2)
      READ(6,102) (ALPHA(J),BETA(J),J=1,12)
  102 FORMAT(2F10.3)
      READ(7,103) (B(KL),A(KL),KL=1,3)
  103 FORMAT(2F10.3)
      READ(8,104) (PP(K),RR(K),K=1,12)
  104 FORMAT(2F10.2)
      READ(10,105) (RAP(KL),PA(KL),KL=1,12)
  105 FORMAT(2F10.3)
      AP=AR=AET=0.0
C
C  PRINT THE MAIN TABLE HEADINGS
C
      WRITE(31,200) (IK,IK=1,3)
  200 FORMAT(1H1,4X,*MONTHLY*,3X,*WATER*,4X,*RUNOFF*,6X
     5,*ET*,6X,*G-LOSS*,3(5X,*ZETA*,I1)/
     2        1H ,5X,*RAIN*,4X,*CONTENT*///)
      WRITE(33,400)
  400 FORMAT(1H1,3X,*YEARLY*,4X,*WATER*,5X,*ANNUAL*,4X
     2,*ANNUAL*/
     3        1H ,3X,*PRECIP*,3X,*CONTENT*,4X,*RUNOFF*,5X,*ET*/
     4        1H ,11X,*AT YEAR END*///)
C
C  NOW THE LIMITING CONSTANTS AND LENGTH CONSTANTS ARE
C  TO BE READ IN.  IP ESTABLISHES HOW FAR ONE WISHES TO
C  RUN THE RANDOM NUMBER GENERATORS TO START A NEW RUN.
C  THE JP SETS THE NUMBER OF YEARS THE MODEL IS TO BE RUN.
C  THE SOILDP AND PAVG SCALE THE ZETA CALCULATION, AND
C  WILL BE ALTERED AFTER THE FIRST FEW RUNS TO REFLECT THE
C  VALUES BEING RECORDED IN THOSE RUNS.
C
      GSEED=FFIN(9)
      ALT=FFIN(9)
      GMIN=FFIN(9)
      GMAX=FFIN(9)
      SOILDP=FFIN(9)
      PAVG=FFIN(9)
      IP=FFIN(9)
      JP=FFIN(9)
      G0=GSEED
C
C  NOW WE WILL RUN THE RANDOM NUMBER GENERATOR UP FOR A
C  FEW POINTS TO START IT AT A NEW PLACE EACH RUN.
C
      DO 10 IPP=1,IP
      DO 10 J=1,12
      IR(J)=AND(AND(IR(J)*IA(J),8388607)+IC(J),8388607)
   10 CONTINUE
C
C  THE PRECIPITATION LEVELS FOR EACH MONTH ARE NOW
C  CALCULATED FROM TWELVE DISTINCT WEIBULL DISTRIBUTIONS.
C
C  ADDITIONALLY, FOLLOWING THAT THE LEVELS OF RUNOFF,
C  ET, AND GROUND WATER CONTENT WILL BE CALCULATED AS
C  THIS IS THE HEART OF THE MODEL.
C
      DO 350 N=1,JP
      DO 300 J=1,12
      IR(J)=AND(AND(IR(J)*IA(J),8388607)+IC(J),8388607)
      U(J)=IR(J)/8388608.
      W(J)=(-ALOG(1.-U(J)))
      P(J)=BETA(J)*(W(J)**(1.0/ALPHA(J)))


      IF(P(J).LE.0.0) P(J)=0.00001
  300 CONTINUE
C
C  CALCULATE ET FOR EACH MONTH.
C
      DO 301 I=1,6
      ET(I)=ALE(I)
  301 CONTINUE
      DO 302 I=7,12
      ET(I)=0.90*ALE(I)*((P(I)+0.40)**0.20)
  302 CONTINUE
C
C  CALCULATE GROUNDWATER LOSS FOR EACH MONTH.
C
      DO 349 I=1,12
      AL(I)=RAP(I)*ALT*(P(I)/PA(I))
  349 CONTINUE
```

```
C
C   CALCULATE THE RUNOFF FOR EACH MONTH
C
       R(1)=-1.253+.207*P(1)+.063*PP(12)+.184*PP(10)
      2+1.090*RR(11)
       R(2)=-7.864+.692*P(2)+.539*P(1)
       R(3)=-7.953+.429*P(3)+.255*P(2)+1.921*R(1)
       R(4)=.367*(P(4)**1..75)*(P(3)**.199)
       R(5)=-.541+.804*P(5)+1.045*P(4)-1.033*R(4)-.351*P(2)
       R(6)=-4.082+.442*P(6)+.164*P(3)
       R(7)=.245+.57.*P(7)+.356*P(5)-.286*P(5)
       R(8)=.389*(P(8)**.385)*(P(7)**.367)*(P(5)**.305)
       R(9)=.494*(P(9)**.484)*(P(6)**.127)
       R(10)=.449*(P(1 )**.141)*(P(9)**.51.)*(R(7)**.119)
       R(11)=.029+.073*P(11)+.474*R(10)+.019*P(9)-.011*P(8)
       R(12)=..46+.089*P(12)+.369*P(11)+.043*P(10)
       RR(11)=R(11)
       PP(10)=P(10)
       PP(12)=P(12)
       DO 349 KL=1,12
       IF(R(KL).LT.0.0)  R(KL)=0.0
   349 CONTINUE
C
C   CALCULATE THE LEVEL OF GROND WATER CONTENT USING A BASIC
C   WATER BALANCE EQUATION.
C
       DO 305 I=1,12
       G(I)=G0+P(I)-R(I)-ET(I)-AL(I)
       IF(G(I).LT.GMIN) G(I)=GMIN
       IF(G(I).GT.GMAX)   G(I)=GMAX
C
C   CALCULATE THE THREE GENERAL  ZETA VALUES.
C
       DO 303 K=1,7
       ZETA(I,K)=((B(K)*P(I))/PAVG)+((A(K)*G(I))/SOILDP)
   303 CONTINUE
       G0=G(I)
   305 CONTINUE
       DO 304 I=1,12
       WRITE(31,201) P(I),G(I),R(I),ET(I),AL(I),(ZETA(I,LI),LI=1,3)
   201 FORMAT(1H ,3F10.3)
       WRITE(34,221) (ZETA(I,JK),JK=1,3)
   221 FORMAT(1H ,3F10.3)
       WRITE(35,231) P(I),G(I),R(I),ET(I),AL(I)
   231 FORMAT(1H ,5F10.3)
   304 CONTINUE
       DO 307 I=1,8
       WRITE(36,232) P(I),G(I),R(I),ET(I),AL(I)
   232 FORMAT(1H ,5F10.3)
       WRITE(37,233) (ZETA(I,JK),JK=1,3)
   233 FORMAT(1H ,3F10.3)
   307 CONTINUE
       DO 308 I=9,12
       WRITE(38,232) P(I),G(I),R(I),ET(I),AL(I)
       WRITE(39,233) (ZETA(I,JK),JK=1,3)
   308 CONTINUE
       DO 306 KP=1,12
       AP=AP+P(KP)
       AR=AR+R(KP)
       AET=AET+ET(KP)
       TP(KP)=TP(KP)+P(KP)
       TR(KP)=TP(KP)+R(KP)
       TET(KP)=TET(KP)+ET(KP)

       TG(KP)=TG(KP)+G(KP)
   306 CONTINUE
       WRITE(31,202)
   202 FORMAT(1H ,/////)
C
C   WRITE OUT THE SUMMARY DATA FOR THE ANNUAL TABLE
C
       WRITE(33,401) AP,G(12),AR,AET
   401 FORMAT(1H ,4F10.3)
       AP=AET=AR=0.0
   350 CONTINUE
C
C   WRITE OUT THE SUMMARY AVERAGES TABLE
C
       DO 351 K=1,12
       TP(K)=TP(K)/(FLOAT(JP))
       TR(K)=TR(K)/(FLOAT(JP))
       TG(K)=TG(K)/(FLOAT(JP))
       TET(K)=TET(K)/(FLOAT(JP))
   351 CONTINUE
       WRITE(32,500)
   500 FORMAT(1H1,10X,4(3X,*AVERAGE*)/
      2         1H ,13X,*PRECIP-*,3X,*RUNOFF*,4X,*EVAPO-*
      6,4X,*GROUND*/
      3         1H ,13X,*TATION*,14X,*TRANSPI-*,2X,*WATER*/
      4         1H ,33X,*RATION*,4X,*CONTENT*///)
       DO 352 KKL=1,12
       WRITE(32,501) TP(KKL),TR(KKL),TET(KKL),TG(KKL)
   501 FORMAT(1H ,10X,4F10.3)
   352 CONTINUE
       END
```

Appendix D. COMPUTER PROGRAM AND DATA FILES FOR HARASS

```
      PROGRAM HARASS(INPUT, OUTPUT, TAPE1=72/80, TAPE2=TAPE1,
     2   TAPE26=OUTPUT, TAPE30=72/80, TAPE31=TAPE30, TAPE32=TAPE30,
     3   TAPE33=TAPE30, TAPE34=72/80, TAPE35=72/80, TAPE36=72/80,
     4   TAPE37=72/80, TAPE38=TAPE30, TAPE39=INPUT, TAPE45, TAPE46
     5   , TAPE47, TAPE48, TAPE49 )
C
C  THIS PROGRAM IS A FORTRAN IV SIMULATION MODEL WHICH SIMULATES OVER
C  TIME THE HARVESTING, ROAD CONSTRUCTION, TIMBER GROWTH, SLOPE EROSION,
C  AND ROAD EROSION ASSOCIATED WITH ANY SET OF PROPOSED HARVEST ALTER-
C  NATIVES.
C
      COMMON/ZERO/IR(40),IA(40),IC(40),IRRN(40)
      COMMON/ONE/ZETA(3,8),MONTHS,I1,I2,I3,P(12),G(12),
     2           PZ(8),GZ(8)
      COMMON/TWO/GPZ(4,8),HPZ(5,8),GLAMDA(4),HLAMDA(5),
     2           GA(4),HA(5),GB(4),HB(5),GC(4),HC(5),I4,
     3           ALPHAD(7),ALPHAT(6),BETAD(7),BETAT(6),
     4           UXD(5),UXT(4),WDD(5),WT(4),SDE(5),STE(4)
      COMMON/THREE/NBLK,NCEL,ME,MH,MC,MU,MV,MW,MX,MY,MCYR,MCH,MCC,MTAGE,
     2           DG(5),DMH(5),DSIZE(5),NDSLIP(5),ICELL,IECS,CELLS,
     3           MROAD,MTYPE
      COMMON/FOUR/TSIZE(4,162),NTSLIP(4,162),NSEGS,NBLKS,NCELS,NYR,
     2           NYEARS,J,NR(162),NM(162),NS(162),NU(162),
     3           NV(162),NW(162),NX(162),NY(162),FLG(162),
     4           WD(162),NBK(162),NA(162),NCL(162,10),I6,NALT,
     5           IEVENT(2207),KSKIP
      COMMON/FIVE/D(5),DE(5,5),DM(5,4),DC(5,3),DU(5,4),DV(5,4),DW(5,4),
     2            DX(5,5),DY(5,5),SUMD
      COMMON/SIX/TR(4,4),TM(4,2),TS(4,2),TU(4,4),TV(4,4),TW(4,4),
     2           TY(4,5),T(4),TG(4,162),SUMT,KR,KM,KS,KU,KV,KW,KX,KY
     3          ,TX(4,5),TTM(4)
      COMMON/SEVEN/CONST(2,2),ACRES(5),VOLTIM(5),I8
C
C
C  ACCOMPLISH APPROPRIATE INITIALIZATION STEPS.
C
      DIMENSION VOLT(150,5),NRR(162),IRCAD(2207),MTYP(8A)
      DIMENSION MCUTSEQ(55),MHALT(58,7),MCALT(58,7),NAGE(7)
      DIMENSION UD(5),UT(4),CM(5),TMG(4,162),IRR(40),PHPZ(5,8)
      DIMENSION FGPZ(4,8)
      SUMT=SLMC=TSLMT=DSUMD=0.0
      I1=I2=I3=I4=I5=I6=I7=I8=I9=KSKIP=0
      CONST(1,1)=CONST(1,2)=CONST(2,1)=CONST(2,2)=0.0
      VOLTIM(1)=VOLTIM(2)=VOLTIM(3)=VOLTIM(4)=VOLTIM(5)=0.0
C
C  READ IN ALL BASIC MODEL DATA, TO INCLUDE PROBABILITY MATRICIES,
C  SITE STATE DATA, ALTERNATIVE DATA, AND GENERAL CONTROL INFORMATION.
C
      DO 350 K=1,4
C
C  THESE VALUES ARE THE CONDITIONAL PROBABILITIES FOR EVENTS T1,T2,T3.T4
C  AND T5: NOTHING, OFF ROAD EROSION, ROAD DAMAGE, AND ROAD FAILURE
C  FOR VARIABLES: TS--ROAD STANDARD, TM--ROAD SURFACE, TU--SLOPECLASS.
C  TV--SOIL TYPE, TW--LANDFORM, TX--BEDDING PLANE ANGLE, AND
C  TY--FRACTURE ANGLE OF THE BEDDING PLANES.
C
      READ(30,300) (TS(K,I),I=1,2)
      READ(30,300) (TM(K,I),I=1,2)
      READ(30,302) (TU(K,I),I=1,4)
      READ(30,302) (TV(K,I),I=1,4)
      READ(30,302) (TW(K,I),I=1,4)
      READ(30,302) (TR(K,I),I=1,4)
      READ(30,303) (TX(K,I),I=1,5)
      READ(30,303) (TY(K,I),I=1,5)
  350 CONTINUE
  300 FORMAT(2F5.3)
  301 FORMAT(3F5.3)
  302 FORMAT(4F5.3)
  303 FORMAT(5F5.3)
      DO 351 K=1,5
```

```
C
C  THESE VALUES ARE THE CONDITIONAL PROBABILITIES FOR EVENTS 01,02,
C  03, 04, AND 05(  NOTHING, ROCKSLIDES, DEBRIS AVALANCHES, SLUMPS,
C  AND CREEP ACCELERATION FOR VARIABLES(  DC--SILVICULTURAL METHOD,
C  DU--SLOPE CLASS,  DV--SOIL TYPE,  DW--LANDFORM,  DX--BEDDING PLANE
C  ANGLE,  DH--HARVEST METHOD,  DY--BEDDING PLANE ANGLE,  DY--FRACTURE
C  ANGLE OF THE BEDDING PLANES,  AND DE--TIMBER AGE CLASS.
C
      READ(31,301)  (DC(K,I),I=1,3)
      READ(31,302)  (DU(K,I),I=1,4)
      READ(31,302)  (DV(K,I),I=1,4)
      READ(31,302)  (DW(K,I),I=1,4)
      READ(31,302)  (DH(K,I),I=1,4)
      READ(31,303)  (DX(K,I),I=1,5)
      READ(31,303)  (DY(K,I),I=1,5)
      READ(31,303)  (DE(K,I),I=1,5)
  351 CONTINUE
C
C  HERE, THE GLAMDA AND HLAMDA SETS ARE THE PARAMETERS EMPLOYED IN THE
C  SUBROUTINE PROCALC TO CALCULATE THE UNIVERSAL PROBABILITIES FOR
C  THE EXPONENTIAL FORMS ON ROAD AND SLOPE EROSION EVENTS.  THESE PARA-
C  METERS MAY BE MODIFIED IF RESEARCH INDICATES SUCH IS NECESSARY.
C  THE ALPHAT, ALPHAD, BETAT, AND BETAD SETS ARE THE WEIBULL SHAPE
C  AND SCALE PARAMETERS USED IN FUNCTIONS SIZET AND SIZED TO SIMULATE
C  EVENT SIZES IN CUBIC YARDS.  NCELS ESTABLISHES THE NUMBER OF CELLS,
C  NBLKS THE NUMBER OF BLOCKS,  NYEARS, THE NUMBER OF YEARS TO BE SIMULATI
C  IECS THE WORD LENGTH FOR THE EXTERNAL CORE STORAGE MECHANISM EMPLOYED,
C  NTYPES THE NUMBER OF TIMBER TYPES EMPLOYED BY THE USER, MONTHS THE
C  NUMBER OF MONTHS OUT OF EACH YEAR WHEN SIGNIFICANT EROSION IS A
C  REALISTIC POSSIBILITY, NALT THE ALTERNATIVE NUMBER,  IOPTION THE OPTIO
C  TO EITHER USE ESTABLISHED (WEIBULL) FUNCTIONS OR A BASIC WATERSHED
C  MODEL TO SIMULATE THE EROSION PARAMETERS ZETA 1, ZETA 2, AND ZETA 3,
C  MHPLAN THE OPTION (1 OR 0) TO READ HARVEST ALTERNATIVE DATA IN BY
C  BLOCKS OR CELLS,  MLIMIT (1 OR 0) IF THE USER WISHES TO LIMIT
C  HARVESTING ON STREAMSIDE AND HEADWALL CELLS WHEN THE BLOCK READ IN
C  APPROACH IS USED (MHPLAN=1).  MCHLIM AND MCCLIM THE HARVEST AND
C  SILVICULTURAL LIMITS TO BE PLACED ON THE CELLS WHEN MLIMIT=1,
C  ROADPCT THE DECIMAL VALUE FOR THE PERCENT OF ANY CELL A ROAD RIGHT-
C  OF-WAY WILL OCCUPY.  ACRESKM THE SCALING PARAMETER FOR SCALING SLOPE
C  EROSION EVENT PROBABILITIES (=247.1) IF CELLS MEASURED IN ACRES)
C  SOFEET THE SCALING FACTOR FOR ALL ROAD EROSION PROBABILITIES SET
C  =63360 WHEN ROAD LENGTHS AND WIDTHS ARE MEASURED IN FEET, CSIZE
C  IS THE BASIC CELL SIZE WHEN CONSTANT SIZED CELLS ARE USED.
C

      READ(32,305)  (GLAMDA(K),GA(K),GB(K),GC(K),K=2,4)
      READ(32,305)  (HLAMDA(K),HA(K),HB(K),HC(K),K=2,5)
      READ(32,120)  (ALPHAT(K),BETAT(K),K=2,6)
      READ(32,120)  (ALPHAD(K),BETAD(K),K=2,7)
      READ(39,307)  NCELS,NBLKS,NYEARS,NSEGS,IECS,NTYPES,MONTHS
      READ(39,307)  NALT,IOPTION,MHPLAN,MLIMIT,MAGE,MCHLIM,MCCLIM
      READ(39,306)  ROADPCT,ACRESKM,SOFEET,CSIZE
  305 FORMAT(F10.5,F10.2,F10.2,F10.2)
  120 FORMAT(F10.5,F10.3)
  307 FORMAT(7I10)
  306 FORMAT(4F10.3)
C
C  THESE THREE VARIABLES ARE SEEDS FOR THE 40 RANDOM NUMBER GENERATORS
C  USED IN THE FUNCTION RANDOM.
C
      READ(33,309)  (IR(K),IA(K),IC(K),K=1,40)
  309 FORMAT(3I10)
C
C  THESE STEPS READ IN THE BASIC 10 YEAR INCREMENT YIELD TABLE
C  APPROACH EMPLOYED FOR THIS MODEL.  FIVE TIMBER CLASSES ARE
C  ALLOWED FOR A 150 YEAR TABLE BEGINNING AT YEAR 20 AND
C  MOVING IN TENS TO YEAR 150.  THIS CAN BE REPLACED BY YIELD
C  FUNCTIONS IF SUCH BECOME AVAILABLE TO ANY USER.
C
      JUS=20
  400 READ(38,315)  (VOLT(JUS,N),N=1,5)
  315 FORMAT(5X,5F10.1)
      JUS=JUS+10
      IF(JUS.LE.150) GO TO 400
```

```
      C
      C  NOW THIS SETS UP ANNUAL YIELD TABLES FOR ALL TIMBER TYPES FROM THE
      C  TEN YEAR INCREMENT YIELD TABLES JUST READ IN ABOVE.
      C
            DO 399 MTIM=20,150
              DO 401 MTY=1,NTYPES
              MTIM1=MTIM/10
              MTIM2=10*MTIM1
              MTIM3=MTIM-MTIM2
              MTIM4=MTIM2+10
              V1=VOLT(MTIM4,MTY)-VOLT(MTIM2,MTY)
              V1=V1/10.0
              TIM3=FLOAT(MTIM3)
              V1=TIM3*V1
              VOLT(MTIM,MTY)=V1+VOLT(MTIM2,MTY)
        401   CONTINUE
        399 CONTINUE
            DO 403 MJ=1,19
              DO 402 MK=1,NTYPES
              VOLT(MJ,MK)=0.0
        402   CONTINUE
        403 CONTINUE
      C
      C  THIS SECTION CALCULATES THE INITIAL ROAD SEGMENT EVENT CONDITIONAL
      C  PROBABILITIES AFTER THE INITIAL CONDITIONS ARE READ IN.EACH ALT-
      C  ERNATIVE WILL HAVE A DIFFERENT SET OF INITIAL CONDITIONS AND HENCE A
      C  DIFFERENT SET OF EVENT CONDITIONAL PROBABILITIES.
      C

            DO 357 I=1,NSEGS
      C
      C  THESE VARIABLES ARE THE BASIC CODING FOR EACH SET OF SITE VARIABLES
      C  FOR ALL ROAD SEGMENTS: NR--ROAD AGE, NS--ROAD STANDARD, NM--ROAD
      C  SURFACE, NU--SLOPE CLASS, NV--SOIL TYPE, NW--LANDFORM, NX--ANGLE
      C  OF THE BEDDING PLANES, AND NY--FRACTURE ANGLE OF THE BEDDING PLANES.
      C  RLG IS THE PLANED FOR OR EXISTING ROAD SEGMENT LENGTH IN FEET.
      C  WD IS THE ROAD WIDTH, NBK THE BLOCK NUMBER THE ROAD SEGMENT BEGINS
      C  IN, AND THE TEN NCL VALUES ARE FOR UP TO TEN DIFFERENT CELLS THE ROAD
      C  SEGMENT OCCUPIES.
      C
            READ(34,312) NR(I),NS(I),NM(I),NU(I),NV(I),NW(I),NX(I),
           2NY(I),RLG(I),WD(I),NBK(I),(NCL(I,JK),JK=1,10)
        312 FORMAT(5X,8I1,F6.1,F4.0,I4,10I5)
            KR=NR(I)
            KS=NS(I)
            KM=NM(I)
            KU=NU(I)
            KV=NV(I)
            KW=NW(I)
            KX=NX(I)
            KY=NY(I)
            CALL ROADEVT
              DO 355 K=1,4
              TG(K,I)=T(K)
        355   CONTINUE
            READ(35,319) (NAGE(K),K=1,7)
        319 FORMAT(10X,7I10)
            NA(I)=NAGE(NALT)
            IF(NA(I).LT.0) GO TO 357
              DO 320 KKK=1,10
            ICRD=NCL(I,KKK)
              IF(ICRD.NE.0) IROAD(ICRD)=1
        320   CONTINUE
        357 CONTINUE
      C
      C  WHEN THE VARIABLE MHPLAN IS EQUAL TO 1, THE DATA DRIVING EACH HARVEST
      C  ALTERNATIVE IS READ IN IN A BLOCK RESOULTION AND EACH CELL IS LATER
      C  ASSIGNED THAT SET OF HARVEST CONSTRAINTS AND DATA SETS.  WHEN THE
      C  VALUE OF MHPLAN IS EQUAL TO 0, THIS DATA IS TO BE FORMATED AND READ
      C  IN BY CELL.  THIS SECOND ALTERNATIVE ALLOWS FOR MORE FLEXIBILITY AND
      C  FINER RESOULTION, HOWEVER THE PREPROGRAMMING DATA ACCUMULATION,FOR-
      C  MATTING, AND DATA FILE ESTABLISHMENT ARE MUCH MORE INVOLVED.  HENCE
      C  MHPLAN EQUAL TO 1 IS A TRADEOFF IN ECONOMICS AND TIME WITH A SACRI-
      C  FICE IN RESOLUTION.
```

```
C
C  NOW THE DATA FOR THE CELLS IS READ IN AND THE INITIAL PROBABILITIES FOR
C  THE EVENTS AND ON-SITE CONDITIONS ARE CALCULATED AND STORED IN AN
C  EXTERNAL CORE STORAGE DEVICE.
C
      IF(MHPLAN.EQ.0) GO TO 318
        DO 317 J=1,NBLKS
C
C  WHEN THE MHPLAN IS =1 AND ALTERNATIVE DATA IS READ IN BY BLOCKS,
C  MCUTSEQ IS THE YEAR IN WHICH THAT BLOCK IS TO BE HARVESTED, MTYP
C  IS THE TIMBER TYPE IN THE BLOCK,  MHALT AND MCALT (SEVEN OF THEM)
C  ARE THE SEVEN DIFFERENT HARVESTING AND SILVICULTURAL ALTERNATIVES FOR

C  EACH BLOCK.  WHEN MHPLAN=0, THIS DATA IS READ DIRECTLY INTO EACH CELL
C  COMPONENT AND MORE FLEXIBILITY IS AFFORDED.
C
      READ(37,316) MCUTSEQ(J),MTYP(J),(MHALT(J,K),MCALT(J,K),K=1,7)
  316   FORMAT(I3,5X,I2,14I5)
  317   CONTINUE
  318   DO 354 ICELL=1,NCELS
        READ(36,310) NBLK,NCEL,ME,MH,MC,MU,MV,MW,MX,MY
  310   FORMAT(I3,1X,I5,1X,8I1)
        DMH(1)=OSIZE(1)=1.0
        OSIZE(2)=OSIZE(3)=OSIZE(4)=OSIZE(5)=0.0
        DMH(2)=DMH(3)=DMH(4)=DMH(5)=0.0
        NOSLIP(1)=1
        NOSLIP(2)=NOSLIP(3)=NOSLIP(4)=NOSLIP(5)=0
        IEVENT(ICELL)=0
        IF(MHPLAN.EQ.0) GO TO 322
        MCH=MHALT(NBLK,NALT)
        MCC=MCALT(NBLK,NALT)
        MTYPE=MTYP(NBLK)
        MCYR=-MCUTSEQ(NBLK)
        CELLS=CSIZE
        IF(ME.EQ.1) MTAGE=5
        IF(ME.EQ.2) MTAGE=10
        IF(ME.EQ.3) MTAGE=20
        IF(ME.EQ.4) MTAGE=40
        IF(ME.EQ.5) MTAGE=MAGE
        MROAD=IROAD(ICELL)
        IF(IROAD(ICELL).EQ.1) CELLS=(1.0-RCADPCT)*CSIZE
        IROAD(ICELL)=0
        IF(MLIMIT.EQ.0) GO TO 95
          DO 96 KAS=2,4
          IF(MW.EQ.KAS) MCH=MCHLIM
          IF(MW.EQ.KAS) MCC=MCCLIM
   96     CONTINUE
        GO TO 95
  322   READ(37,311) MCYR,MCH,MCC,MTAGE,CELLS,MTYPE,MROAD
  311   FORMAT(10X,I3,1X,I1,1X,I1,1X,I3,1X,F4.0,1X,I3,1X,I1)
   95   CALL SLOPEVT
        CALL WRITECS(NBLK,IECS*(ICELL-1),IECS)
  354   CONTINUE
C
C  NOW BEGINS THE MAIN PROGRAM ACTIVITY. WE START WITH A WATERSHED IN A
C  CONDITION SPECIFIED BY INITIAL SITE AND ROAD VARIABLE STATES.THESE
C  STATES ARE ALTERED EACH YEAR AS DEFINED BY THE SUBJECT ALTERNATIVE
C  LAYOUT. EACH MONTH, PRECIPITATION AND SOIL WATER CONTENT ARE CHECKED,
C  VARIABLE STATES UPDATED, MONTHLY EVENT PROBABILITIES CALCULATED, AND
C  EVENT OCCURRENCE CHECKED. THIS IS REPEATED FOR THE NUMBER OF YEARS
C  COVERED BY THE SUBJECT ALTERNATIVE.
C
      DO 399 NYR=1,NYEARS
      IF(IOPTION.EQ.1) CALL ZCALCI
      IF(IOPTION.EQ.2) CALL WTRSHED
      IF(IOPTION.EQ.2) CALL ZCALCII
C
C  CALCULATE THE NINE UNIVERSAL MONTHLY PROBABILITIES.
C
        DO 358 J=1,MONTHS
```

```
               GPZ(2,J)=GPZ(3,J)=GPZ(4,J)=1.0
               HPZ(2,J)=HPZ(3,J)=HPZ(4,J)=HPZ(5,J)=1.0
               IF(ZETA(1,J).LE.63.0) GPZ(2,J)=0.0
               IF(ZETA(1,J).LE.71.0) GPZ(3,J)=0.0
               IF(ZETA(2,J).LE.61.0) GPZ(4,J)=0.0
               IF(ZETA(1,J).LE.71.0) HPZ(3,J)=0.0
               IF(ZETA(3,J).LE.54.0) HPZ(4,J)=0.0
               IF(ZETA(3,J).LE.51.0) HPZ(5,J)=0.0
               IF(HPZ(3,J).EQ.0.0.AND.HPZ(4,J).EQ.0.0.AND.HPZ(5,J).EQ.0.0)
            2  HPZ(2,J)=0.0
  358 CONTINUE
C
C  NOTICE THAT WITH THE LIMITS PLACED ABOVE ON THE ZETA VALUES REQUIRED
C  BEFORE ANY OF THE UNIVERSAL PROBABILITIES IS MORE THAN ZERO ESTABLISHES
C  THE FACT THAT MOST EROSION ACTIVITY OCCURS UNDER MORE UNUSUAL CIR-
C  CUMSTANCES THAN ONE NORMALLY OBSERVES.  THIS IS A REFLECTION OF NOTED
C  RESEARCH AND SUBSEQUENT EVALUATION OF SUCH IN THIS PROJECT.
C
         CALL PRCALC
C
C  CALCULATE EVENT PROBABILITIES FOR,DETERMINE POINTS OF OCCURRENCE,
C  AND OUTPUT SUMMARY DATA FOR EACH EVENT OCCURRENCE OVER THE EIGHT
C  WET MONTHS THAT MAKE UP THE YEAR. BEGIN WITH ROAD EROSION.
C
               DO 387 J=1,MONTHS
               KS=((IRAN(IRRN,14)/8388608.)*NSEGS+1.0)
               KSE=NSEGS
  359            DO 365 N=KS,KSE
                 IF(GPZ(2,J).EQ.0.0.AND.GPZ(3,J).EQ.0.0.AND.GPZ(4,J).EQ.0.0)
            2    GO TO 364
                 IF(NA(N).LT.0) GO TO 364
                   DO 340 K=2,4
                   PGPZ(K,J)=GPZ(K,J)*(RLG(N)*WO(N)/SCFEET)
  340              CONTINUE
                   PGPZ(1,J)=1.0-PGPZ(2,J)-PGPZ(3,J)-PGPZ(4,J)
                   DO 360 K=1,4
                   TTM(K)=TG(K,N)*PGPZ(K,J)
                   TSUMT=TSUMT+TTM(K)
  360              CONTINUE
                   DO 361 K=1,4
                   TMG(K,N)=TTM(K)/TSUMT
  361              CONTINUE
                 UT(2)=(IRAN(IRRN,15)/8388608.)
                 UT(3)=(IRAN(IRRN,16)/8388608.)
                 UT(4)=(IRAN(IRRN,17)/8388608.)
                 TSUMT=0.0
                   DO 363 K=2,4
                   IF(TMG(K,N).LT.UT(K)) GO TO 362
C
C  TSIZE IS THE EVENT SIZE FOR EVENTS T2, T3, AND T4 AS CALCULATED
C  IN THE FUNCTION SIZET.
C
                   TSIZE(K,N)=SIZET(STE,K)
                   NTSLIP(K,N)=1
                   GO TO 363
  362              NTSLIP(K,N)=0
  363              CONTINUE


                 GO TO 365
  364            TMG(1,N)=1.0
                 TMG(2,N)=TMG(3,N)=TMG(4,N)=0.0
                 NTSLIP(2,N)=NTSLIP(3,N)=NTSLIP(4,N)=0
  365            CONTINUE
               IF(N.LT.NSEGS) GO TO 368
               KSE=KS-1
               KS=1
               GO TO 359
C
C  NOW CALCULATE SIMILAR COMPONENTS FOR SLOPE EROSION ACTIVITIES.
C
```

```
  368 IF(HPZ(2,J).EQ.0.0) KSKIP=1
      IF(KSKIP.EQ.1) GO TO 376
      KSD=((IRAN(IRRN,13)/8388608.)*NCELS+1.0)
      KSDE=NCELS
  367   DO 375 ICELL=KSD,KSDE
        CALL READECS(NBLK,IECS*(ICELL-1),IECS)
          DO 341 K=2,5
          PHPZ(K,J)=HPZ(K,J)*(CELLS/ACRESKM)
  341     CONTINUE
        PHPZ(1,J)=1.0-PHPZ(2,J)-PHPZ(3,J)-PHPZ(4,J)-PHPZ(5,J)
          DO 342 K=1,5
          OM(K)=OG(K)*PHPZ(K,J)
          OSUMD=OSUMD+OM(K)
  342     CONTINUE
          DO 369 K=1,5
          DMH(K)=OM(K)/OSUMD
  369     CONTINUE
        UD(2)=(IRAN(IRRN,19)/8388608.)
        UD(3)=(IRAN(IRRN,20)/8388608.)
        UD(4)=(IRAN(IRRN,21)/8388608.)
        UD(5)=(IRAN(IRRN,22)/8388608.)
        OSUMD=0.0
          DO 371 K=2,5
          IF(DMH(K).LT.UD(K)) GO TO 370
C
C  DSIZE IS THE EVENT SIZE FOR EVENTS D2, D3, D4, AND D5 AS CALCULATED
C  IN THE FUNCTION SIZED.
C
          DSIZE(K)=SIZED(SDE,K,MW,MH,MV)
          IEVENT(ICELL)=1
          NDSLIP(K)=1
          GO TO 371
  370     NDSLIP(K)=0
  371     CONTINUE
       IF(NDSLIP(2).EQ.0.AND.NDSLIP(3).EQ.0.AND.NDSLIP(4).EQ.0
     2.AND.NDSLIP(5).EQ.0) GO TO 375
        CALL WRITECS(NBLK,IECS*(ICELL-1),IECS)
  375   CONTINUE
      IF(KSDE.NE.NCELS)  GO TO 376
      KSDE=KSD-1
      KSD=1
C
C  HERE ARE SOME COMMENTS ABOUT IMPORTANT VARIABLES USED IN THE SECTION
C  ABOVE.  KS,KSE,KSD,AND KSDE ARE ALL INTEGER VALUES USED TO DETERMINE
C  RANDOMLY WHERE THE TABLE OF ROAD SEGMENTS AND CELLS ARE ENTERED EACH
C  TIME.  THIS INSURES THAT THERE IS A NEW ENTRY POINT EACH MONTH, AND
C  REDUCES THE POSSIBILITIES OF SOME PATTERN EMERGEING SIMPLY DUE TO
C  THE ORDER OF SEGMENTS AND CELLS IN THE ORIGINAL DATA FILES.
C  THE NTSLIP AND NDSLIP VARIABLES  INDICATE WHETHER OR NOT A
C  ROAD OR SLOPE EROSION EVENT HAS OCCURED(=1) OR HAS NOT OCCURED (=0).
C  THE UT AND UD VARIABLES ARE SIMPLY RANDOM NUMBERS BETWEEN ZERO AND
C  ONE USED TO CHECK AGAINST FOR EVENT OCCURRENCE.  WHEN THE PROBABILITY
C  FOR AN EVENT IS EQUAL TO OR GREATER THAN THE VALUE OF THIS RANDOM
C  NUMBER THEN THE EVENT IS SAID TO HAVE OCCURRED.  THE TMG AND DMH VARI-
C  ABLES ARE THE EVENT PROBABILITIES FOR THIS MONTH FOR THE APPROPRIATE
C  ROAD SEGMENT OR CELL.  THE RLG AND WD VARIABLE IN THHE ROAD
C  SEGMENT PORTION  SCALE THE PROBABILITIES TO A PER MONTH PER
C  ACRE BASIS.  THE CELLS AND ACRESKM DIVISION HELPS SCALE THE
C  VALUES FOR SLOPE EROSION PROBABILITIES TO A PER MONTH PER SQUARE KM.
C  ONCE THESE VALUES HAVE BEEN CALCULATED AND CHECKED AGAINST THE RANDOM
C  NUMBERS TO SEE IF AN EVENT OCCURED THE MODEL MOVES ON.
C
      GO TO 367
C
C  NOW WRITE OUT ANY EROSION DATA FOR SLOPES AND ROADS RECORDED FOR
C  MONTH J
C
  376 CALL WRITE1
```

```
C
C  THIS  COMPONENT UPDATES CELL AND SEGMENT VARIABLE STATES BASED ON
C  MONTHLY AND YEARLY CHANGES. EACH MONTH, AFTER SOME ROAD EVENTS, THE RO
C  AGE FOR THAT SEGMENT IS SET BACK TO ZERO FOR SOME T3 AND T4 EVENTS.
C  FOR SLOPE EVENTS THE TIMBER AGE IS SET BACK TO ZERO FOR ANY AFFECTED
C  CELLS FOR SOME D3 AND D4 EVENTS. AT YEAR END, THE MODEL SIMULATES THE
C  ALTERNATIVE ROAD CONSTRUCTION AND TIMBER HARVEST. THIS REQUIRES RE-
C  SETTING TIMBER AGE TO ZERO FOR CELLS CUT AND BEGINNING A ROAD SEG-
C  MENT AT AGE ZERO. FOR EACH CELL INVOLVED WITH A NEW ROAD THERE IS
C  A 20 PERCENT REDUCTION IN AREA FOR THE 1.6 ACRE CELLS. THIS PROGRAM WI
C  ALLOW A USER TO ALTER THE PERCENT IF THE USER HAS A BASIC CELL SIZE
C  LARGER OR SMALLER THAN 1.6 ACRES, OR FOUR SQUARE CHAINS.  ONCE A CELL
C  IS HARVESTED, IT SHALL REMAIN IN THE HARVEST METHOD CLASS FOR 20
C  YEARS AFTER WHICH IT SHALL BE MOVED TO H4, NO HARVESTING. THE CELL
C  SHALL BE MOVED FROM C3, NEVER CUT,TO EITHER C1 OR C2, CLEARCUT AND
C  PARTIAL CUT, AND KEPT THERE INDEFINITELY. ALL OF THESE CHANGES WILL
C  REQUIRE UPDATING THE CELL AND SEGMENT CONDITIONAL PROBABILITIES TO
C  REFLECT THE DIFFERENT ON-SITE CONDITIONS AS ALTERED.
C
      DO 381 N=1,NSEGS
      IF(NTSLIP(3,N).EQ.1.OR.NTSLIP(4,N).EQ.1.) GO TO 378
      GO TO 381
  378 IF(TSIZE(4,N).LE.3000.0) GO TO 381
      NA(N)=0
      IF(NR(N).EQ.1) GO TO 381
      NR(N)=1
      KR=NR(N)
      KS=NS(N)
      KM=NM(N)
      KU=NU(N)
      KV=NV(N)
      KW=NW(N)
      KX=NX(N)
      KY=NY(N)


      CALL ROADEVT
        DO 377 K=1,4
        TG(K,N)=T(K)
  377   CONTINUE
  381 CONTINUE
     IF(KSKIP.EQ.1) GO TO 10
      DO 386 KIK=1,NCELS
      IF(IEVENT(KIK).EQ.0) GO TO 386
      ICELL=KIK
      CALL READECS(NBLK,IECS*(ICELL-1),IECS)
      IF(DSIZE(2).LE.5000.0.AND.DSIZE(3).LE.5000.0.AND.DSIZE(4)
     2 .LE.5000.0.AND.DSIZE(5).LE.5000.0) GO TO 385
      MTAGE=0
      IF(ME.EQ.1) GO TO 385
      ME=1
      CALL SLOPEVT
  385 NDSLIP(2)=NDSLIP(3)=NDSLIP(4)=NDSLIP(5)=0
      DSIZE(2)=DSIZE(3)=DSIZE(4)=DSIZE(5)=0.0
      CALL WRITECS(NBLK,IECS*(ICELL-1),IECS)
      IEVENT(KIK)=0
  386 CONTINUE
C
C  THE ABOVE STEPS UPDATE THE SYSTEM STATE AND CONDITIONAL PROBABILITIES
C  DUE TO CHANGES BROUGHT ABOUT BY MONTHLY EROSION EVENTS. NOW WE BEGIN
C  UPDATING THE SYSTEM FOR ANNUAL CHANGES DUE TO ROAD BEING BUILT AND
C  TIMBER BEING HARVESTED.
C
   10 KSKIP=0
  387 CONTINUE
C
C  THIS SECTION DETERMINES WHICH ROAD SEGMENTS ARE TO BE BUILT EACH
C  YEAR AND THE LENGTH AND TYPE OF SUCH ROAD CONSTRUCTION IS RECORDED.
C
        DO 392 N=1,NSEGS
        NA(N)=NA(N)+1
        IF(NA(N).LT.0) GO TO 392
        IF(NA(N).GT.0) GO TO 389
```

```
              DO 388 JK=1,9
              ICRD=NCL(N,JK)
              IF(ICRD.NE.0) IROAD(ICRD)=1
  388         CONTINUE
            NSS=NS(N)
            NMM=NM(N)
            CONST(NSS,NMM)=CONST(NSS,NMM)+RLG(N)
  389       IF(NA(N).GE.0.AND.NA(N).LE.5) NRR(N)=1
            IF(NA(N).GT.5.AND.NA(N).LE.10) NRR(N)=2
            IF(NA(N).GT.10.AND.NA(N).LE.20) NRR(N)=3
            IF(NA(N).GT.20) NRR(N)=4
            IF(NR(N).EQ.NRR(N)) GO TO 392
            NR(N)=NRR(N)
            KR=NR(N)
            KS=NS(N)
            KM=NM(N)
            KU=NU(N)
            KV=NV(N)
            KX=NX(N)
            KW=NW(N)
            KY=NY(N)
C
C  WHEN ROAD SEGMENTS ARE BUILT THEY MUST HAVE A PROBABILITY CALCULATED--
C  THAT IS A CONDITIONAL PROBABILITY BASIED ON ALL ON-SITE VARIABLES.
C
            CALL ROADEVT
              DO 391 K=1,4
              TG(K,N)=T(K)
  391         CONTINUE
  392       CONTINUE
C
C  THIS SECTION DETERMINES WHICH ACRES ARE TO BE HARVESTED AND
C  RECORDS THE ACRES AND TYPE AS WELL AS VOLUMES OF TIMBER REMOVED ON
C  AN ANNUAL BASIS.  ALSO THE SECTION UPDATES CONDITIONAL PROBABILITIES
C  FOR ALL HARVESTED ACRES BECAUSE CHANGES IN THE STATE OF ON-SITE
C  VARIABLES FOR HARVEST TYPE, SILVICULTURAL TYPE AND TIMBER AGE
C  (MH,MC,AND MF) REQUIRE CHANGES IN THESE PROBABILITIES.
C
            DO 394 ICELL=1,NCELS
            CALL READECS(NBLK,IECS*(ICELL-1),IECS)
            MTAGE=MTAGE+1
            IF(MTAGE.GT.150) MTAGE =150
            MCYR=MCYR+1
            IF(MCYR.LT.0) GO TO 393
            IF(MCYR.NE.0) GO TO 393
            MC=MCC
            MH=MCH
            IF(MH.EQ.4.AND.MC.EQ.3) GO TO 393
            IF(MC.EQ.2)  PCTCUT=0.40
            VOLTIM(MTYPE)=VOLTIM(MTYPE)+(VOLT(MTAGE,MTYPE)*CELLS)
            IF(MC.EQ.2)  VOLTIM(MTYPE)=PCTCUT*VOLTIM(MTYPE)
            ACRES(MTYPE)=ACRES(MTYPE)+CELLS
            IF(MC.EQ.2)  MTAGE=MTAGE/2
            IF(MC.EQ.2)  GO TO 393
            MTAGE=0
            ME=1
            CALL SLOPEVT
            MROAD=IROAD(N)
            IF(IROAD(N).EQ.1)CELLS=(1.0-ROADPCT)*CSIZE
            IROAD(N)=0
            CALL WRITECS(NBLK,IECS*(ICELL-1),IECS)
            GO TO 394
  393       IF(MTAGE.GE.0.AND.MTAGE.LE.5) MME=1
            IF(MTAGE.GT.5.AND.MTAGE.LE.10) MME=2
            IF(MTAGE.GT.10.AND.MTAGE.LE.20) MME=3
            IF(MTAGE.GT.20.AND.MTAGE.LE.40) MME=4
            IF(MTAGE.GT.40) MME=5
            IF(MTAGE.GT.20) MH=4
            IF(MTAGE.GT.40) MC=3
            IF(ME.EQ.MME) GO TO 493
            ME=MME
```

```
      CALL SLOPEVT
      WROAD=IROAD(N)
      IF(IROAD(N).EQ.1)CELLS=(1.0-ROADPCT)*CSIZE
      IROAD(N)=0
  493 CALL WRITECS(NBLK,IECS*(ICELL-1),IECS)
  394 CONTINUE
C
C  WRITE OUT THE ANNUAL HARVEST AND ROAD CONSTRUCTION DATA AND RETURN
C  TO CALCULATE ANOTHER YEAR'S DATA.
C
      CALL WRITE2
      DO 395 K=1,5
      WDLTIM(K)=0.0
      ACRES(K)=0.0
  395 CONTINUE
      DO 397 K=1,2
        DO 396 J=1,2
        CONST(K,J)=0.0
  396   CONTINUE
  397 CONTINUE
  399 CONTINUE
      STOP
      END

C
C
      SUBROUTINE ROADEVT
C
C
C  THIS SUBPROGRAM CALCULATES THE CONDITIONAL PROBABILITIES FOR THE
C  FOUR ROAD EROSION EVENTS
C
      COMMON/SIX/TR(4,4),TM(4,2),TS(4,2),TU(4,4),TV(4,4),TW(4,4),
     2          TY(4,5),T(4),TG(4,162),SUMT,KR,KM,KS,KU,KV,KW,KX,KY,
     3          TX(4,5),TTM(4)
      DO 355 K=1,4
      T(K)=TR(K,KR)*TS(K,KS)*TM(K,KM)*TU(K,KU)*TV(K,KV)*TW(K,KW)
     2*TX(K,KX)*TY(K,KY)
      SUMT=SUMT+T(K)
  355 CONTINUE
      DO 356 K=1,4
      T(K)=T(K)/SUMT
  356 CONTINUE
      SUMT=0.0
      RETURN
      END

C
C
      SUBROUTINE SLOPEVT
C
C
C  THIS SUBPROGRAM CALCULATES THE CONDITIONAL PROBABILITIES FOR THE
C  FIVE SLOPE EROSION EVENTS.
C
      COMMON/THREE/NBLK,NCEL,ME,MH,MC,MU,MV,MW,MX,MY,MCYR,MCH,MCC,MTAGE,
     2          DG(5),DMH(5),DSIZE(5),NDSLIP(5),ICELL,IECS,CELLS,
     3          WROAD,MTYPE
      COMMON/FIVE/D(5),DE(5,5),DH(5,4),DC(5,3),DU(5,4),DV(5,4),DW(5,4),
     2          DX(5,5),DY(5,5),SUMD
      DO 352 K=1,5
      D(K)=DE(K,ME)*DH(K,MH)*DC(K,MC)*DU(K,MU)*DV(K,MV)*DW(K,MW)
     2*DX(K,MX)*DY(K,MY)
      SUMD=SUMD+D(K)
  352 CONTINUE
      DO 353 K=1,5
      DG(K)=D(K)/SUMD
  353 CONTINUE
      SUMD=0.0
      RETURN
      END
```

```
C
C
      SUBROUTINE ZCALCI
C
C
C  THIS SUBPROGRAM DETERMINES VALUES OF ZETA1, ZETA2, AND ZETA3 UNDER
C  OPTION I. THIS OPTION EMPLOYS INVERSE TRANSFORMATION ON THE WEIBULL
C  FUNCTION FOR ZETA2 WITH ZETA1 AND ZETA3 CALCULATED FROM REGRESSIONS
C  ON THE DETERMINED VALUE OF ZETA2. FOR THIS MODEL EIGHT ZETA VALUES
C  FOR EACH ZETA (1,2, AND 3) ARE SIMULATED PER YEAR. THIS IS BECAUSE
C  THE ZETA DISTRIBUTIONS USED COVER ONLY THE EIGHT WET MONTHS,OCTOBER
C  THROUGH MAY. IF A USER DEVELOPS A ZETA FUNCTION FOR USE THAT COVERS
C  MORE OR LESS THAN 8 MONTHS HE ONLY NEED INSERT THE FUNCTION PARA-
C  METERS AND SET MONTHS=NUMBER OF MONTHS COVERED BY THE FUNCTION.
C
      COMMON/ZERO/IR(40),IA(40),IC(40),IRRN(40)
      COMMON/ONE/ZETA(3,8),MONTHS,I1,I2,I3,P(12),G(12),PZ(8),GZ(8)
      DIMENSION ALPHA(3),BETA(3)
      IF(I1.NE.0) GO TO 300
      READ(1,100) (ALPHA(I),BETA(I),I=1,3)
      I1=I1+1
  100 FORMAT(2F10.3)
  300 DO 20 N=1,MONTHS
      U=IRAN(IRRN,13)/8399609.
      W=(-ALOG(1.0-U))
      ZETA(2,N)=BETA(2)*(W**(1.0/ALPHA(2)))
      ZETA(1,N)=1.2159*ZETA(2,N)-5.0995
      ZETA(3,N)=0.7841*ZETA(2,N)+5.0950
   20 CONTINUE
      P(1)=P(2)=P(3)=P(4)=P(5)=P(6)=P(7)=P(8)=P(9)=P(10)=P(11)=P(12)=99.
      G(1)=G(2)=G(3)=G(4)=G(5)=G(6)=G(7)=G(8)=G(9)=G(10)=G(11)=G(12)=0.
      RETURN
      END
```

```
C
C
      SUBROUTINE ZCALCII
C
C
C  THIS SUBPROGRAM DETERMINES VALUES OF ZETA 1, ZETA 2, AND ZETA 3 UNDER
C  OPTION II. THIS OPTION EMPLOYS THE SIMULATED VALUES OF MONTHLY PRE-
C  CIPITATION AND SOIL WATER CONTENT FROM THE WATERSHED MODEL (SUBROU-
C  TINE WTRSHED) AND THE BASIC ZETA FUNCTION. EIGHT VALUES FOR ZETA 1,
C  ZETA 2, AND ZETA 3 ARE CALCULATED ANNUALY FOR THE MONTHS OCTOBER
C  THROUGH MAY. THESE ARE THE MONTHS OF SIGNIFICANT EROSION POTENTIAL
C  FOR HARVEY CREEK DRAINAGE. IF A USER DETERMINES THAT MORE,OR FEWER
C  MONTHS SHOULD BE INCLUDED HE SHALL CHANGE THE VALUE OF MONTHS TO
C  REFLECT THIS DIFFERENCE. THIS OPTION IS THE ONE FOR *GENERAL* USE
C  UNTIL A WEIBULL FUNCTION IS FIT FOR THE AREA UNDER STUDY FOR THE
C  THREE ZETA DISTRIBUTIONS.
C
      COMMON/ONE/ZETA(3,8),MONTHS,I1,I2,I3,P(12),G(12),PZ(8),GZ(8)
      DIMENSION A(3),B(3),WFACTOR(3)
      IF(I3.NE.0) GO TO 300
      READ(1,100) (A(I),B(I),WFACTOR(I),I=1,3)
  100 FORMAT(3F10.3)
      READ(1,101) PAVG,SOILOP
  101 FORMAT(2F10.3)
      I3=I3+1
  300 DO 21 I=1,MONTHS
        DO 20 K=1,3
        ZETA(K,I)=((B(K)*PZ(I))/PAVG)+((A(K)*GZ(I))/SOILOP)
        ZETA(K,I)=WFACTOR(K)*ZETA(K,I)
   20   CONTINUE
      WRITE(26,899) (ZETA(K,I),K=1,3)
  899 FORMAT(1H ,3F10.3)
   21 CONTINUE
      RETURN
      END
```

```
C
C
      SUBROUTINE WTRSHED
C
C
C  THIS SUBPROGRAM IS A WATERSHED SIMULATION MODEL FOR THE HARVEY CREEK
C  DRAINAGE. ANY USER CAN ADAPT THIS TO FIT ANY SUBJECT AREA. THE PRO-
C  DUCTS OF THE MODEL ARE RUNOFF, EVAPOTRANSPIRATION, PRECIPITATION,
C  AND GROUND WATER CONTENT PER MONTH IN INCHES OF WATER. THE LATTER TWO
C  PRODUCTS ARE INPUTS FOR SUBROUTINE ZCALCII FOR CALCULATION OF THE
C  THREE MONTHLY ZETA VALUES.
C
      DIMENSION ET(12),R(12),AL(12),ALF(12),AAL(12),RR(12),PA(12)
      DIMENSION PP(12),BETA(12),ALPHA(12),U(12),W(12),RAP(12)
      DIMENSION IRR(12)
      COMMON/ZERO/IP(40),IA(40),IC(40),IRRN(40)
      COMMON/ONE/ZETA(3,8),MONTHS,I1,I2,I3,P(12),G(12),PZ(8),GZ(8)
      IF(I2.NE.0) GO TO 300
      AP=AR=AET=0.0
      I2=I2+1
C
C  READ IN THE BASIC DATA
C
      READ(2,120)  (ALF(I),AL(I),I=1,12)
      READ(2,120)  (ALPHA(I),BETA(I),I=1,12)
      READ(2,120)  (PP(I),RR(I),I=1,12)
      READ(2,120)  (RAP(I),PA(I),I=1,12)
      READ(2,121)  GSEED,ALT,GMIN,GMAX,SOILBP,PAVG
      READ(2,122)  IP,JP
  120 FORMAT(F10.3,F10.3)
  121 FORMAT(F10.3)
  122 FORMAT(I8)
C
C  VARIABLES ALF AND AL ARE HARVEY CREEK LAKE EVAPOTRANSPIRATION
C   AND GROUND WATER LOSS MONTHLY AVERAGE ESTIMATES. ALPHA
C   AND BETA ARE THE SHAPE AND SCALE PARAMETERS FOR THE 12
C   PRECIPITATION WEIBULL DISTRIBUTIONS.PP AND RR ARE PRECIP
C   AND RUNOFF MEASURES FOR THE LAST WATER YEAR ON RECORD.
C   RAP AND PA ARE MONTHLY AVERAGES FOR PERCENT RUNOFF (OF
C   THE TOTAL) AND INCHES OF PRECIPITATION. GSEED SEEDS WATER
C   CONTENT FOR MODEL INITIALIZATION. ALT IS THE AVERAGE AN-
C   NUAL SUB-SURFACE GROUND WATER LOSS. GMIN AND GMAX ARE
C   LOWER AND UPPER LIMITS FOR GROUND WATER CONTENT. SCILD
C   IS THE AVERAGE WATERSHED SOIL DEPTH. PAVG IS THE AVERAGE
C   PRECIPITATION FOR THE MONTH WITH THE HIGHEST AVERAGE.
C
C   ALSO, MODEL VARIABLES ARE: ET, EVAPOTRANSPIRATION; G,
C   GROUND WATER CONTENT; P, PRECIPITATION; R, RUNOFF; AAL,
C   MONTHLY SUBSURFACE GROUND WATER LOSS. PZ AND GZ ARE THE
C   PRECIP AND SOIL WATER CONTENTS FOR OCTOBER-MAY TO BE USED
C   IN ZETA CALCULATIONS.  VARIABLE US IS A MONTHLY RANDOM NUMBER AND W
C   IS USED TO HELP SIMULATE THE MONTHLY PRECIPITATION VALUES FROM THE
C   WEIBUL DISTRIBUTIONS.
C
C  RUN THE RANDOM NUMBER GENERATORS TO A NEW STARTING POINT EACH TIME.
C
      DO 21 IPP=1,IP

        DO 20 K=1,12
        IRR(K)=IRAN(IRRN,K)
   20   CONTINUE
   21 CONTINUE
C
C  SIMULATE 12 MONTHLY PRECIPITATION VALUES FOR TWELVE MONTHS BEGINNING
C  WITH OCTOBER AND ENDING WITH SEPTEMBER.
C
  300 DO 22 K=1,12
      U(K)=IRAN(IRRN,K)/8388608.
      W(K)=(-ALOG(1.0-U(K)))
      P(K)=BETA(K)*(W(K)**(1.0/ALPHA(K)))
      IF(P(K).LE.0.0) P(K)=0.00001
   22 CONTINUE
```

```
C
C  CALCULATE MONTHLY EVAPOTRANSPIRATION.
C
      DO 23 I=1,6
      ET(I)=ALE(I)
   23 CONTINUE
      DO 24 I=7,12
      ET(I)=0.90*ALE(I)*((P(I)+0.40)**0.20)
   24 CONTINUE
C
C  CALCULATE MONTHLY GROUND WATER LOSS (SUBSURFACE LOSSES).
C
      DO 28 I=1,12
      AAL(I)=RAP(I)*ALT*(P(I)/PA(I))
   28 CONTINUE
C
C  CALCULATE MONTHLY RUNOFF
C
      R(1)=-1.263+.207*P(1)+.063*PP(12)+.184*PP(10)+1.690*RR(11)
      R(2)=-7.664+.637*P(2)+.539*P(1)
      R(3)=-7.853+.823*P(3)+.255*P(2)+1.921*R(1)
      R(4)=.367*(P(4)**1.075)*(P(3)**.193)
      R(5)=-.691+.804*P(5)+1.045*P(4)-1.033*R(4)-.351*R(2)
      R(6)=-4.092+.949*P(5)+.164*P(3)
      R(7)=.245+.570*P(7)+.356*P(5)-.296*R(5)
      R(8)=.395*(P(8)**.385)*(P(7)**.367)*(P(5)**.305)
      R(9)=.454*(P(8)**.434)*(P(6)**.127)
      R(10)=.497*(P(10)**.051)*(R(9)**.510)*(R(7)**.119)
      R(11)=.025+.073*P(11)+.474*R(10)+.018*P(9)-.011*P(8)
      R(12)=.346+.089*P(12)+.069*P(11)+.043*P(10)
      RR(11)=R(11)
      PP(10)=P(10)
      PP(12)=P(12)
      DO 25 KL=1,12
      IF(R(KL).LT.0.0) R(KL)=0.0
   25 CONTINUE
C
C  CALCULATE MONTHLY GROUND WATER CONTENT FROM A SIMPLE WATER BALANCE
C  EQUATION.
C
      DO 26 I=1,12
      G(I)=GSEED+P(I)-R(I)-ET(I)-AAL(I)
      IF(G(I).LT.GMIN) G(I)=GMIN

      IF(G(I).GT.GMAX) G(I)=GMAX
   26 CONTINUE
C
C  TRANSFER BACK TO MAIN PROGRAM MONTHLY VALUES FOR OCT.--MAY.
C
      DO 27 J=1,MONTHS
      PZ(J)=P(J)
      GZ(J)=G(J)
   27 CONTINUE
      WRITE(26,890) (PZ(K),K=1,8)
      WRITE(26,890) (GZ(K),K=1,8)
  890 FORMAT(1H ,8F8.3)
      RETURN
      END
```

```
C
C
      FUNCTION IRAN(IRPPN,K)
C
C
C  THIS FUNCTION CALCULATES AND RETURNS A RANDOM NUMBER EACH TIME
C  SUMMONED FOR 40 DIFFERENT STREAMS OF RANDOM NUMBERS.
C
      DIMENSION IRPPN(40)
      COMMON/ZERO/IR(40),IA(40),IC(40),IRRN(40)
      IR(K)=AND(AND(IA(K)*IR(K),8388607)+IC(K),8388607)
      IRPPN(K)=IR(K)
      IRAN=IRPPN(K)
      RETURN
      END
```

```
C
C
      SUBROUTINE PRCALC
C
C
C  THIS SUBPROGRAM CALCULATES MONTHLY UNIVERSAL PROBABILITIES FOR THE
C  FOUR ROAD AND FIVE SLOPE EROSION EVENTS WHEN THEY ARE NOT EQUAL ZERO.
C
      COMMON/ONE/ZETA(3,8),MONTHS,I1,I2,I3,P(12),G(12),PZ(8),GZ(8)
      COMMON/TWO/GPZ(4,8),HPZ(5,8),GLAMDA(4),HLAMDA(5),GA(4),
     2          HA(5),GB(4),HB(5),GC(4),HC(5),I4,ALPHAD(7),
     3          ALPHAT(6),BETAD(7),BETAT(6),UXD(5),UXT(4),WDD(5),
     4          WT(4),SDE(5),STE(4)
      DO 11 J=1,MONTHS
      IF(GPZ(2,J).EQ.0.0) GO TO 1
      GPZ(2,J)=(GA(2)*(1.0-EXP(-GLAMDA(2)*ZETA(1,J)))**GB(2))-GC(2)
    1 IF(GPZ(3,J).EQ.0.0) GO TO 2
      GPZ(3,J)=(GA(3)*(1.0-EXP(-GLAMDA(3)*ZETA(1,J)))**GB(3))-GC(3)
    2 IF(GPZ(4,J).EQ.0.0) GO TO 3
      GPZ(4,J)=(GA(4)*(1.0-EXP(-GLAMDA(4)*ZETA(2,J)))**GB(4))-GC(4)
    3 IF(HPZ(2,J).EQ.0.0) GO TO 4
      HPZ(2,J)=(HA(2)*(1.0-EXP(-HLAMDA(2)*ZETA(2,J)))**HB(2))-HC(2)
    4 IF(HPZ(3,J).EQ.0.0) GO TO 5
      HPZ(3,J)=(HA(3)*(1.0-EXP(-HLAMDA(3)*ZETA(1,J)))**HB(3))-HC(3)
    5 IF(HPZ(4,J).EQ.0.0) GO TO 6
      HPZ(4,J)=(HA(4)*(1.0-EXP(-HLAMDA(4)*ZETA(3,J)))**HB(4))-HC(4)
    6 IF(HPZ(5,J).EQ.0.0) GO TO 7
      HPZ(5,J)=(HA(5)*(1.0-EXP(-HLAMDA(5)*ZETA(3,J)))**HB(5))-HC(5)
    7 DO 9 K=2,4
      IF(GPZ(K,J).LT.0.000)  GPZ(K,J)=0.000
    9 CONTINUE
      DO 10 K=2,5
      IF(HPZ(K,J).LT.0.000)  HPZ(K,J)=0.000
   10 CONTINUE
   11  CONTINUE
      DO 8 I=1,MONTHS
      WRITE(26,891)  (GPZ(K,I),K=2,4)
      WRITE(26,892)  (HPZ(K,I),K=2,5)
  891 FORMAT(1H ,3F10.5)
  892 FORMAT(1H ,4F10.5)
    8 CONTINUE
      RETURN
      END
```

```
C
C
C  THIS SET OF SUBROUTINES ESTABLISH THE CABILITY TO ACCESS A
C  PSEUDO EXTERNAL CORE STORAGE FACILITY FOR THE CDC 6400.  THIS
C  IS ACCOMPLISHED DUE TO THE VERY LARGE CORE REQUIREMENTS FOR
C  THIS SIMULATION PROGRAM.
C
C
      SUBROUTINE WRITEC( CFW, EFW, NWD )
      DIMENSION FECS(35)
      INTEGER EFW
      DATA ( IFST = 1 )
      ENTRY WRITECS
      IF (IFST.NE.1) GO TO 100
      IFST = 0
      CALL FILEWA( FECS, 3LLFN, 4LFECS, 3LMRL, 81920, 2LRT, 1LU )
      CALL OPENM( FECS, 3LI-O )
  100 CALL PUT( FECS, CFW, 10 * NWD, EFW + 1 )
      RETURN
      ENTRY READEC
      ENTRY READECS
      IF (IFST.EQ.1) CALL STOPR( 6HREADEC, 101 )
      CALL GET( FECS, CFW, EFW + 1, 0, 0, 10 * NWD )
      RETURN
      END
```

```
      SUBROUTINE STOPR( RTNAME, ISTOP )
      DIMENSION MESBFL(4)
      ENCODE ( 40, 1, MESBFL ) ISTOP, RTNAME
    1 FORMAT ( 1H , 9H*** STOP , I3, 12H IN ROUTINE , A7, 4H *** )
      CALL SYSTEM( 52, MESBFL )
      STOP 7777
      END

C
C
      FUNCTION SIZET(STEE,K)
C
C
C  THIS FUNCTION RETURNS VALUES FOR EVENT SIZES FOR THREE ROAD EROSION
C  EVENTS:  OFF ROAD EROSION, ROAD DAMAGE, AND ROAD FAILURE.
C
C
C  TWO BASIC SIZES FOR OFF ROAD EROSION AND ROAD DAMAGE ARE EMPLOYED.
C  SMALL OFF ROAD EVENTS OCCUR APPROXIMATELY 9 OUT OF 10 TIMES AND
C  ROAD DAMAGE EVENTS ARE SMALL ABOUT 4 OUT OF 5 TIMES.  SMALL MEANS
C  APPROXIMATELY LESS THAN 150 CUBIC YARDS.  THIS FUNCTION IS SET UP TO
C  HANDLE THIS DISCRIMINATION AND MULTIPLE SIZE SIMULATION.
C
      DIMENSION STEE(4)
      COMMON/ZERO/IR(40),IA(40),IC(40),IRRN(40)
      COMMON/TWO/GPZ(4,5),HPZ(5,8),GLAMDA(4),HLAMDA(5),GA(4),
     2           HA(5),GB(4),HB(5),GC(4),HC(5),I4,ALPHAD(7),
     3           ALPHAT(6),BETAD(7),BETAT(6),UXD(5),UXT(4),WDD(5),
     4           WT(4),SDE(5),STE(4)
      IF(K.NE.2) GO TO 10
      KEV2=((IRAN(IRRN,32)/8388608.)*10+1.0)
      GO TO 20
   10 IF(K.NE.3) GO TO 20
      KEV3=((IRAN(IRRN,33)/8388608.)*5+1.0)
   20 IF(K.EQ.2.AND.KEV2.EQ.1) GO TO 30
      IF(K.EQ.3.AND.KEV3.EQ.1) GO TO 40
      IF(K.EQ.2) UXT(K)=IRAN(IRRN,26)/8388608.
      IF(K.EQ.3) UXT(3)=IRAN(IRRN,27)/8388608.
      IF(K.EQ.4) UXT(4)=IRAN(IRRN,28)/8388608.
      WT(K)=(-ALOG(1.-UXT(K)))
      STEE(K)=BETAT(K)*(WT(K)**(1.0/ALPHAT(K)))
      GO TO 50
   30 UXT(2)=IRAN(IRRN,34)/8388608.
      WT(2)=(-ALOG(1.-UXT(2)))
      STEE(2)=BETAT(5)*(WT(2)**(1.0/ALPHAT(5)))
      GO T O 50
   40 UXT(3)=IRAN(IRRN,35)/8388608.
      WT(3)=(-ALOG(1.-UXT(3)))
      STEE(3)=BETAT(6)*(WT(3)**(1.0/ALPHAT(6)))
   50 SIZET=STEE(K)
      RETURN
      END

C
C
      FUNCTION SIZED(SDEE,K,MMW,MMH,MMV)
C
C
C  THIS FUNCTION RETURNS VALUES FOR EVENT SIZES FOR FOUR SLOPE EROSION
C  EVENTS.  THEY ARE ROCKSLIDES,DEBRIS AVALANCHES, SLUMPS, AND CREEP.
C  EXPECTED SIZES OF CREEP EVENTS ARE ONLY VERY ROUGH ESTIMATES BECAUSE
C  LIMITED DATA AVAILABLE TO USE FOR SIZE ESTIMATION.  WHEN SUCH DATA
C  IS AVAILABLE THE PROGRAM IS EASILY MODIFIED TO REFLECT MORE ACCURATE
C  SIZES OF THE CREEP EVENTS.
C
      DIMENSION SDEE(5)
      COMMON/ZERO/IR(40),IA(40),IC(40),IRRN(40)
```

```
      COMMON/TWO/GPZ(4,9),HPZ(5,8),GLAMDA(4),HLAMDA(5),GA(4),
     2          HA(5),GB(4),HB(5),GC(4),HC(5),I4,ALPHAD(7),
     3          ALPHAT(6),BETAD(7),BETAT(6),UXD(5),UXT(4),WDD(5),
     4          WT(4),SDE(5),STE(4)
      COMMON/THREE/NBLK,NCEL,ME,MH,MC,MU,MV,MW,MX,MY,MCYR,MCH,MCC,MTAGE,
     2          DG(5),DMH(5),DSIZE(5),NDSLIF(5),ICELL,IECS,CELLS,
     3          MROAD,MTYPE
C
C  SMALL SLUMPS AND DEBRIS AVALANCHES OCCUR ON SLOPES HARVESTED AND
C  ON STREAMBANKS.  SMALL SLUMPS ALSO OCCUR IN THE NON-COHESIVE SOILS.
C  THIS FUNCTION IS WRITTEN TO HANDLE SUCH DIFFERENTIATION
C  IN CALCULATING EVENT SIZES.
C
      IF(K.EQ.2.OR.K.EQ.5) GO TO 10
      IF(K.EQ.3.AND.MMH.EQ.3) GO TO 20
      IF(K.EQ.3.AND.MMH.NE.4) GO TO 20
      IF(K.EQ.4.AND.MMH.EQ.3) GO TO 30
      IF(K.EQ.4.AND.MMH.NE.4) GO TO 30
      IF(K.EQ.4.AND.MMV.EQ.1) GO TO 30
      IF(K.EQ.4.AND.MMV.EQ.2) GO TO 30
   10 IF(K.EQ.2) UXD(2)=IRAN(IRRN,23)/8399609.
      IF(K.EQ.3) UXD(3)=IRAN(IRRN,24)/8399609.
      IF(K.EQ.4) UXD(4)=IRAN(IRRN,25)/8399608.
      IF(K.EQ.5) UXD(5)=IRAN(IRRN,29)/8389608.
      WDD(K)=(-ALOG(1.0-UXD(K)))
      SDEE(K)=BETAD(K)*(WDD(K)**(1.0/ALPHAD(K)))
      GO TO 40
   20 UXD(3)=IRAN(IRRN,39)/5399609.
      WDD(3)=(-ALOG(1.-UXD(3)))
      SDEE(3)=BETAD(6)*(WDD(3)**(1.0/ALPHAD(6)))
      GO TO 40
   30 UXD(4)=IRAN(IRRN,31)/5399609.
      WDD(4)=(-ALOG(1.-UXD(4)))
      SDEE(4)=BETAD(7)*(WDD(4)**(1.0/ALPHAD(7)))
   40 SIZED=SDEE(K)
      RETURN
      END
```

```
C
C
      SUBROUTINE WRITE2
C
C
C  THIS SUBPROGRAM WRITES OUT ALL HARVEST AND ROAD BUILDING DATA FOR EACH
C  YEAR.  THE INFORMATION IS TO BE USED IN A COST ANALYSIS PROGRAM.
C
      COMMON/FOUR/TSIZE(4,162),NTSLIP(4,162),NSEGS,NBLKS,NCELS,NYR,
     2          NYEARS,J,NR(162),NM(162),NS(162),NU(162), NV(162),
     3          NW(162),NX(162),NY(162),RLC(162),WD(162),NBK(162),
     4          WA(162),NCL(162,10),I6,NALT,IEVENT(2207),KSKIP
      COMMON/SEVEN/CONST(2,2),ACRES(5),VOLTIM(5),I8
      IF(I9.NE.0)GO TO 300
      WRITE(49,490) NALT
  490 FORMAT(1H1,49X,*ANNUAL ROAD CONSTRUCTION AND TIMBER*/
     2        1H ,53X,*/HARVEST SUMMARY STATISTICS*/
     3        1H ,55X,*FOR ALTERNATIVE NO.*,1X,I3//
     4        1H ,44X,41(*=*)//
     5        1H ,14X,*ROAD CONSTRUCTION DATA*,44X,*TIMBER HARVEST DATA*/
     6        1H ,10X,30(*-*),34X,27(*-*))
      WRITE(49,491)
  491 FORMAT(1H ,3X,*YEAR   SECONDARY  SECONDARY  PRIMARY   PRIMARY*,2X
     2,*TIMBER TYPE 1  TIMBER TYPE 2  TIMBER TYPE 3  TIMBER TYPE 4*,1X
     3,*TIMBER TYPE 5  YEAR*/
     4        1H ,12X,*GRAVEL*,5X,*SPOT*,5X,*GRAVEL*,5X,*SPOT*/
     5        1H ,20X,*STABILIZED*,10X,*STABILIZED*,
     $5(2X,*ACRES VOLUME *)/
     6        1H ,48X,5(9X,*(BOARD)*)/
     7        1H ,8X,4(4X,*(FEET)*),1X,5(9X,*(FEET)*)//
     8        1H ,1X,5(*---------*,2X),5(*-------------*,2X),*----*//)
```

```
      I9=I8+1
  300 WRITE(49,492)NYR,(CONST(K,1),CONST(K,2),K=1,2),(ACRES(M),
     2VOLTIM(M),M=1,5)
     2,NYR
  492 FORMAT(1H ,3X,I3,4X,4F10.2,5(F5.1,F10.1),1X,I3)
      RETURN
      END

C
C
      SUBROUTINE WRITE1
C
C
C  THIS SUBPROGRAM WRITES OUT ALL EROSION ACTIVITY RECORDED EACH MONTH
C  AND MAINTAINS A FILE OF INTERNAL SUMMARY STATISTICS FOR FINAL OUTPUT
C  AT END OF TIME PERIOD COVERING THIS HARVEST ALTERNATIVE.
C
      DIMENSION TN(4),TNT(4),DNN(5),DNND(5)
      DIMENSION NUMD(5),SUMTTT(4),SUMD(5),VART(4),VARD(5),TMEAN(4)
      DIMENSION NUMT(4)
      DIMENSION DMEAN(5),TSTD(4),DSTD(5),USST(4),USSD(5),CSST(4),CSSD(5)
      COMMON/ONE/ZETA(3,8),MONTHS,I1,I2,I3,P(12),G(12),PZ(8),GZ(8)
      COMMON/THREE/NBLK,NCEL,ME,MH,MC,ML,MV,MW,MX,MY,MCYR,MCM,MCC,MTACE,
     2          DG(5),DMH(5),DSIZE(5),NCSLIP(5),ICELL,IECS,CELLS,
     3          MROAD,MTYPE
      COMMON/FOUR/TSIZE(4,162),NTSLIP(4,162),NSEGS,NBLKS,NCELS,NYR,
     2          NYEARS,J,NR(162),NM(162),NS(162),NU(162),NV(162),
     3          NW(162),NX(162),NY(162),RLG(162),WD(162),NBK(162),
     4          NA(162),NCL(162,10),I6,NALT,IEVENT(2207),KSKIP
      IF(I6.NE.0)GO TO 300
C
C  WHEN TIME IS NOT EQUAL TO ZERO, SKIP PAST WRITTING THE TABLE HEADINGS.
C
      I6=I6+1
C
C  WRITE TABLE HEADINGS FOR ONE TABLE TYPE SUMMARY, EVENT BY EVENT.
C
      WRITE(45,450) NALT
  450 FORMAT(1H1,30X,*ROAD EROSION STATISTICS*/
     2         1H ,31X,*FOR ALTERNATIVE NO.*,1X,I3/
     3         1H ,27X,29(*=*)//
     4         1H ,5X,*OFF ROAD EROSION*,16X,*ROAD DAMAGE*,19X
     :,*ROAD FAILURE*/
     5         1H ,3(25(*-*),5X)//
     6         1H ,3(1X,*YEAR MONTH SEG- SIZE IN*,6X)/
     7         1H ,3(12X,*MENT CUBIC YD.*,4X)/
     8         1H ,3(1X,*---- ----- ---- --------*,5X)/)
      WRITE(45,460) NALT
  460 FORMAT(1H1,46X,*SLOPE EROSION STATISTICS*/
     2         1H ,47X,*FOR ALTERNATIVE NO.*,1X,I3/
     3         1H ,43X,30(*=*)//
     4         1H ,8X,*ROCKSLIDES*,14X,*DEBRIS AVALANCHE/FLOWS*,11X
     (,*SLUMP EARTHFLOWS*,12X,*CREEP ACCELERATIONS*/
     5         1H ,4(*-------------------------*,5X)//
     6         1H ,4(*YR. MON. BLK, CELL SIZE IN*,4X)/
     7         1H ,4(20X,*CUBIC*,5X)/
     8         1H ,4(20X,*YARDS*,5X)/
     9         1H ,4(*--- ---- ---- ---- -------*,4X)/)
C
C  SET STATISTICAL SUMMATION VARIABLES TO ZERO.
C
      DO 298 K=1,4
      SUMTTT(K)=0.0
      USST(K)=0.0
      CSST(K)=0.0
```

```
          TSTD(K)=0.0
          VART(K)=0.0
          NUMT(K)=0
      299 CONTINUE
          DO 299 K=1,5
          SUMD(K)=0.0
          USSD(K)=0.0
          CSSD(K)=0.0
          DSTD(K)=0.0
          VARD(K)=0.0
          NUMD(K)=0
      299 CONTINUE
C
C  WRITE OUT EACH EVENT DATA SET, EVENT BY EVENT.
C
C  DO ROAD EROSION EVENTS FIRST.
C
      300 DO 302 N=1,NSEGS
            DO 301 K=2,4
            IF(NTSLIP(K,N).EQ.0) GO TO 301
            USST(K)=USST(K)+TSIZE(K,N)*TSIZE(K,N)
            NUMT(K)=NUMT(K)+NTSLIP(K,N)
            SUMTT(K)=SUMTT(K)+TSIZE(K,N)
            IF(K.EQ.2) GO TO 22
            IF(K.EQ.3) GO TO 23
            IF(K.EQ.4) GO TO 24
       22   WRITE(45,2) NYR,J,N,TSIZE(K,N)
            GO TO 301
       23   WRITE(45,3) NYR,J,N,TSIZE(K,N)
            GO TO 301
       24   WRITE(45,4) NYR,J,N,TSIZE(K,N)
        2   FORMAT(1H ,1X,I3,3X,I3,2X,I4,F10.1)
        3   FORMAT(1H ,31X,I3,3X,I3,2X,I4,F10.1)
        4   FORMAT(1H ,61X,I3,3X,I3,2X,I4,F10.1)
      301   CONTINUE
      302 CONTINUE
C
C  DO SLOPE EROSION EVENTS SECOND.  KSKIP IS THE VARIABLE DENOTING THE
C  PRESENCE (KSKIP=0) OR ABSENCE (KSKIP=1) OF "ANY" MONTHLY EVENTS
C  AT ALL.  WHEN THERE ARE NONE, THIS WHOLE SECTION IS SKIPPED.
C
          IF(KSKIP.EQ.1) GO TO 340
          DO 304 KI=1,NCELS
          IF(IEVENT(KI).EQ.0) GO TO 304
          ICELL=KI
          CALL READECS(NBLK,IECS*(ICELL-1),IECS)
            DO 303 K=2,5
            IF(NDSLIP(K).EQ.0) GO TO 303
            USSD(K)=USSD(K)+DSIZE(K)*DSIZE(K)
            NUMD(K)=NUMD(K)+NDSLIP(K)
            SUMD(K)=SUMD(K)+DSIZE(K)
            IF(K.EQ.2) GO TO 25
            IF(K.EQ.3) GO TO 26
            IF(K.EQ.4) GO TO 27
            IF(K.EQ.5) GO TO 28
       25   WRITE(46,12) NYR,J,NBLK,NCEL,DSIZE(K)
            GO TO 303
       26   WRITE(46,13) NYR,J,NBLK,NCEL,DSIZE(K)
            GO TO 303
       27   WRITE(46,14) NYR,J,NBLK,NCEL,DSIZE(K)
            GO TO 303
       28   WRITE(46,15) NYR,J,NBLK,NCEL,DSIZE(K)
       12   FORMAT(1H ,I3,1X,I3,2X,I4,1X,I4,F10.1)
       13   FORMAT(1H ,30X,I3,1X,I3,2X,I4,1X,I4,F10.1)
       14   FORMAT(1H ,60X,I3,1X,I3,2X,I4,1X,I4,F10.1)
       15   FORMAT(1H ,90X,I3,1X,I3,2X,I4,1X,I4,F10.1)
      303   CONTINUE
      304 CONTINUE
      340 IF(NYR.LT.NYEARS.OR.J.LT.MONTHS) GO TO 307
```

```
      C
      C  IF ALL YEARS FOR THE ALTERNATIVE ARE FINISHED, CALCULATE AND WRITE
      C  OUT THESE SUMMARY STATISTICS.
      C
             DO 305 K=2,4
             IF (NUMT(K).EQ.0) GO TO 305
             TN(K)=FLOAT(NUMT(K))
             TNT(K)=FLOAT(NUMT(K)-1)
             TMEAN(K)=SUMTTT(K)/TN(K)
             CSST(K)=(SUMTTT(K)*SUMTTT(K))/TN(K)
             VART(K)=(USST(K)-CSST(K))/TNT(K)
             TSTD(K)=SQRT(VART(K))
         305 CONTINUE
             DO 306 K=2,5
             IF (NUMD(K).EQ.0) GO TO 306
             DNN(K)=FLOAT(NUMD(K))
             DNND(K)=FLOAT(NUMD(K)-1)
             DMEAN(K)=SUMD(K)/DNN(K)
             CSSD(K)=(SUMD(K)*SUMD(K))/DNN(K)
             VARD(K)=(USSD(K)-CSSD(K))/DNND(K)
             DSTD(K)=SQRT(VARD(K))
         306 CONTINUE
      C
      C  DO ROAD EROSION SUMMARY FIRST.
      C
             WRITE(45,451) (NUMT(K),SUMTTT(K),K=2,4)
         451 FORMAT(1H ,/85(*=*)//
            2         1H ,3(1X,*SUMMARY DATA*,17X)/
            3         1H ,3(*---------------*,16X)//
            4         1H ,3(2X,*TOTAL*,10X,*TOTAL*,8X)/
            5         1H ,3(2X,*EVENTS*,9X,*SIZE*,9X)/
            6         1H ,3(3X,I4,6X,F13.1,4X))
             WRITE(45,798)(TMEAN(K),TSTD(K),K=2,4)
         798 FORMAT(1H ,3(2X,*MEAN SIZE    STD. SIZE*,7X)/
            8         1H ,3(2X,F10.1,2X,F10.1,6X)//
            9         1H ,85(*=*))
      C
      C  NOW DO THE SLOPE EROSION SUMMARY.
      C
             WRITE(46,461) (NUMD(K),SUMD(K),K=2,5)
         461 FORMAT(1H ,/115(*=*)//
            2         1H ,4(1X,*SUMMARY DATA*,17X)/
            3         1H ,4(*---------------*,15X)//
            4         1H ,4(2X,*TOTAL*,10X,*TOTAL*,8X)/
            5         1H ,4(2X,*EVENTS*,9X,*SIZE*,9X)/


            6         1H ,4(3X,I4,5X,F13.1,4X))
             WRITE(46,807) (DMEAN(K),DSTD(K),K=2,5)
         807 FORMAT(1H ,4(2X,*MEAN SIZE    STD. SIZE*,7X)/
            8         1H ,4(2X,F10.1,2X,F10.1,6X)//
            9         1H ,115(*=*))
      C
      C  THIS SETS UP HEADINGS FOR THE SECOND TABLE TYPE--SUMMARY SATATISTICS
      C  CELL BY CELL.
      C
         307 IF (I6.NE.1) GO TO 308
      C
      C  WHEN TIME IS NOT EQUAL TO ZERO, DO NOT WRITE OUT THE TABLE HEAD-
      C  INGS, SKIP TO THE DATA WRITE OUT SEGMENT.
      C
             I6=100
             WRITE(47,470) NALT
         470 FORMAT(1H1,43X,*ROAD EROSION STATISTICS*/
            2         1H ,44X,*FOR ALTERNATIVE NO.*,1X,I3/
            3         1H ,40X,29(*=*)//)
             WRITE(47,499)
         499 FORMAT(1H ,2X,*SEGMENT SEGMENT EVENT  EVENT  ROAD  ROAD  ROAD*
            4,1X,*SLOPE SOIL LAND- BEDDING BEDDING  PRECIP-  SOIL   YEAR*
            4,1X,*MONTH*/
            5         1H ,*  NUMBER  LENGTH  TYPE   SIZE   AGE STAND- WIDTH*
            5,1X,*CLASS TYPE  FORM  PLANE   PLANE   ITATION  WATER*/
```

```
     6        1H ,38X,*DARD CLASS*,20X,*DIP    FRACTURE*,9X,*CONTENT*/
     7        1H ,25X,*CUBIC*,43X,*ANGLE*/
     8        1H ,11X,*(FEET)  T(K)  YARDS  R(K)  S(K)  H(K)  U(K)  V(K)*
     8,2X,*W(K)  X(K)     Y(K)     P(J)     G(J)*/
     9        1H ,120(*-*)//)
      WRITE(45,480) NALT
  480 FORMAT(1H1,42X,*SLOPE EROSION STATISTICS*/
     2        1H ,43X,*FOR ALTERNATIVE NO.*,1X,I3/
     3        1H ,39X,30(*=*)//
     4        1H ,4X,*CELL     CELL  EVENT  EVENT  TIM- HAR- SILVIC SLOPE*
     4,1X,*SOIL LAND- BEDDING BEDDING  PRECIP-  SOIL    YEAR MONTH*/
     5        1H ,*    NUMBER    SIZE    TYPE    SIZE  BER   VEST ULTURE*
     5,1X,*CLASS TYPE  FORM  PLANE    PLANE    ITATION  WATER*/
     6        1H ,32X,*AGE  TYPE  CLASS*,20X,*DIP   FRACTURE*
     6,9X,*CONTENT*/
     7        1H ,25X,*CUBIC*,43X,*ANGLE*/
     8        1H ,11X,*(ACRES) D(K)  YARDS  E(K)  H(K)  C(K)  U(K)  V(K)*
     8,2X,*W(K)  X(K)     Y(K)     P(J)     G(J)*/
     9        1H ,120(*-*)//)
C
C  WRITE OUT EVENT DATA FOR EACH EVENT CELL BY CELL.
C
C  DO ROAD EROSION FIRST.
C
  305 DO 310 N=1,NSEGS
        DO 309 K=2,4
        IF(NTSLIP(K,N).EQ.0) GO TO 309
        WRITE(47,471)      N ,RLG(N),K,ISIZE(K,N),NR(N),NS(N),NM(N),NU(N)
     2,NV(N),NW(N),NX(N),NY(N),P(J),G(J),NYR,J
  471   FORMAT(1H ,2X,I5,2X,F9.1,2X,I2,F9.1,4(2X,I2,2X),1X,3(I2,4X)
     2,3X,I2,4X,F7.2,1X,F7.2,2X,I3,3X,I2)
  309   CONTINUE


  310 CONTINUE
C
C  NOW DO SLOPE EROSION.
C
      IF(KSKIP.EQ.1) GO TO 341
      DO 312 KI=1,NCELS
      IF(IEVENT(KI).EQ.0) GO TO 312
      ICELL=KI
      CALL READECS(NBLK,IECS*(ICELL-1),IECS)
        DO 311 K=2,5
        IF(NOSLIP(K).EQ.0) GO TO 311
        WRITE(48,481) KI,CELLS,K,DSIZE(K),ME,MH,MC,MU,MV,MW,MX,MY
     2,P(J),G(J),NYR,J
  481   FORMAT(1H ,3X,I5,3X,F6.1,3X,I2,1X,F8.0,4(2X,I2,2X),1X,3(I2,4X)
     2,3X,I2,4X,F7.2,1X,F7.2,2X,I3,3X,I2)
  311   CONTINUE
  312 CONTINUE
  341 RETURN
      END
```

```
C
C
C  THIS ENDS THE MAIN PROGRAM AND ALL RELATED SUBROUTINES AND
C  FUNCTIONS.  HARASS IS NOW COMPLETE.
C
C
```

FILE 1 (ZCALCII)

```
35.000    65.000    1.000
50.000    50.000    1.000
65.000    35.000    1.000
19.000    48.000
```

FILE 1(ZCALCI)

```
2.122    55.850
2.369    50.58
2.704    45.17
```

FILE 2 (WTRSHED)

```
 1.94      0.17
 0.66      0.90
 0.16      1.75
 0.00      1.96
 0.46      1.45
 0.77      1.39
 1.69      0.77
 2.67      0.38
 3.69      0.17
 4.78      0.09
 4.38      0.05
 3.25      0.06
1.681     7.859
2.551    16.135
3.094    15.674
2.690    18.987
2.904    14.052
3.150    13.156
2.257     7.116
1.911     4.590
1.759     2.190
0.845     0.565
0.792     0.815
1.262     3.409
 1.96      0.31
10.49      1.60
17.40     10.04
12.64     10.69
 3.73      3.08
 9.69      5.21
 3.73      3.04
 2.55      1.57
 2.71      0.78
 0.81      0.41
 0.94      0.25
 6.61      0.62
0.020     7.906
0.109    15.545
0.185    16.594
0.226    18.930
0.163    12.350
0.147    11.788
0.073     5.894
0.037     4.274
0.019     1.935
0.009     0.612
0.086     0.928
0.006     3.375
 6.50
 9.00
 0.98
25.00
48.00
19.00
100
1000
```

FILE 30 (HARASS)

```
0.62 0.38
0.59 0.41
0.56 0.24 0.13 0.07
0.23 0.28 0.35 0.14
0.45 0.21 0.21 0.13
0.03 0.18 0.34 0.49
0.07 0.16 0.19 0.27 0.31
0.07 0.15 0.24 0.27 0.27
0.35 0.64
0.44 0.56
0.05 0.13 0.26 0.55
0.35 0.24 0.20 0.21
0.11 0.24 0.21 0.44
0.58 0.24 0.10 0.09
0.40 0.20 0.17 0.12 0.10
0.41 0.21 0.14 0.13 0.11
0.38 0.62
0.45 0.55
0.07 0.16 0.28 0.49
0.30 0.24 0.20 0.26
0.11 0.25 0.25 0.39
0.49 0.25 0.14 0.12
0.40 0.21 0.17 0.12 0.10
0.44 0.20 0.13 0.11 0.12
0.40 0.60
0.43 0.57
0.06 0.16 0.28 0.59
0.24 0.28 0.19 0.29
0.12 0.23 0.26 0.39
0.48 0.25 0.14 0.13
0.45 0.19 0.15 0.11 0.09
0.43 0.22 0.13 0.11 0.12
```

FILE 31 (HARASS)

```
0.15 0.32 0.53
0.62 0.22 0.11 0.05
0.17 0.29 0.30 0.24
0.40 0.23 0.24 0.13
0.20 0.25 0.12 0.43
0.07 0.15 0.20 0.29 0.30
0.09 0.15 0.23 0.26 0.28
0.10 0.12 0.19 0.27 0.32
0.50 0.28 0.22
0.02 0.09 0.25 0.64
0.52 0.18 0.19 0.11
0.12 0.21 0.07 0.60
0.23 0.19 0.45 0.13
0.53 0.17 0.13 0.09 0.08
0.46 0.21 0.12 0.11 0.10
0.29 0.26 0.18 0.15 0.12
0.67 0.23 0.10
0.03 0.10 0.25 0.62
0.47 0.21 0.21 0.11
0.11 0.23 0.09 0.57
0.25 0.20 0.45 0.09
0.45 0.20 0.15 0.10 0.10
0.42 0.20 0.13 0.13 0.12
0.36 0.33 0.15 0.09 0.07
0.56 0.28 0.15
0.11 0.20 0.32 0.37
0.10 0.18 0.17 0.55
0.14 0.20 0.51 0.15
0.27 0.20 0.41 0.12
0.42 0.20 0.16 0.12 0.10
0.37 0.22 0.15 0.12 0.14
0.29 0.29 0.20 0.13 0.11
0.57 0.27 0.16
0.05 0.14 0.26 0.55
0.33 0.24 0.21 0.22
0.16 0.28 0.24 0.32
0.26 0.21 0.39 0.14
0.41 0.21 0.16 0.11 0.11
0.39 0.22 0.15 0.13 0.11
0.35 0.25 0.17 0.12 0.11
```

FILE 32 (HARASS)

0.01090	1.00	2.00	0.22
0.01030	1.00	1.00	0.51
0.00170	1.00	1.00	0.10
0.00001	1.00	1.00	0.00
0.01290	1.00	2.00	0.33
0.01000	1.00	1.00	0.42
0.00100	1.00	1.00	0.05
1.25000	75.000		
1.25000	125.000		
0.97690	6274.770		
1.01020	724.600		
1.13090	780.149		
0.91990	1041.229		
1.40660	4931.290		
1.14630	8736.690		
0.78610	4428.780		
1.66020	540.570		
1.65260	491.870		

FILE 33 (HARASS)

4134191	2069	1772721
7582650	2069	6615997
3604794	2085	1772721
194211	2085	6615997
7094520	4117	1772721
32288	4117	6615997
5666447	4133	1772721
7268393	4133	6615997
4757	2069	1772721
2992708	2069	6615997
3496037	2085	1772721
473398	2085	6615997
4361796	4117	1772721
712783	4117	6615997
2410461	4133	1772721
1368094	4133	6615937
7556247	2069	1772721
6935134	2069	6615997
1160184	2085	1772721
6108234	2085	6615997
7721499	4117	1772721
13156	4117	6615997
4189990	4133	1772721
3016392	4133	6615997
6657224	2069	1772721
3764039	2069	6615337
3040293	2085	1772721
2276518	2085	6615597
[illegible]	4117	1772721
356917	4117	6615337
7237742	4133	1772721
5086473	4133	6615997
2950752	2069	1772721
6550907	2069	6615997
5402491	2085	1772721
96097	2085	6615487
1456238	4117	1772721
6995055	4117	6615997
2619774	4133	1772721
4014530	4133	6615997

FILE 38 (HARASS)

20	7599.	1342.	4796.	805.	0.
30	17154.	2879.	10421.	1749.	0.
40	25909.	5329.	15311.	5000.	0.
50	33955.	9777.	19467.	9357.	0.
60	41591.	15195.	22838.	11045.	0.
70	49717.	21040.	25575.	13058.	0.
80	55332.	26247.	27527.	14559.	0.
90	61438.	31119.	28745.	14559.	0.
100	67034.	35515.	29229.	15497.	0.
110	72120.	39430.	28978.	15943.	0.
120	76695.	42951.	27992.	15304.	0.
130	80762.	46236.	26000.	14895.	0.
140	84317.	49977.	25090.	14521.	0.
150	87363.	51201.	24000.	14061.	0.

FILE 39 (HARASS -- Two Examples)

5	2	1	1	100	4	3
0.20	247.1	43560.	1.6	64	4	8
2207	88	88	162			
6	2	1	1	100	4	3
0.20	247.1	43560.	1.6	64	4	8
2207	88	98	162			

FILE 35 (HARASS - Example)

1	15	15	15	15	15	15	15
2	15	15	15	15	15	15	15
3	15	15	15	15	15	15	15
4	15	15	15	15	15	15	15
5	15	15	15	15	15	15	15
6	15	15	15	15	15	15	15
7	10	10	10	10	10	10	10
8	10	10	10	10	10	10	10
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
69	-43	-43	-43	-43	-43	-43	-150
70	-43	-43	-43	-43	-43	-43	-150
71	-150	-60	-60	-150	-60	-150	-150
72	-150	-60	-60	-150	-60	-150	-150
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
158	-150	-150	-52	-150	-150	-150	-150
159	-150	-150	-34	-150	-150	-150	-150
160	-150	-150	-35	-150	-150	-150	-150
161	-150	-150	-35	-150	-150	-150	-150
162	-150	-150	-35	-150	-150	-150	-150

FILE 34 (HARASS - Example)

1	15	32124232	250.	50.	1	6	11	0	0	0	0	0	0	0	0	
2	15	32124132	324.	50.	1	9	11	12	0	0	0	0	0	0	0	
3	15	32124432	663.	50.	1	14	20	0	0	0	0	0	0	0	0	
4	15	32121132	1056.	50.	3	51	53	54	57	0	0	0	0	0	0	
5	15	32124132	1848.	50.	3	57	61	65	70	71	72	79	86	94	0	
6	15	32121132	1430.	50.	4	100	131	133	139	147	226	0	0	0	0	
7	10	22114132	1930.	50.	10	227	229	229	230	316	317	309	309	0	0	
8	10	22114432	396.	50.	13	309	333	0	0	0	0	0	0	0	0	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
69-100	12111432	444.	50.	63	1561	1562	0	0	0	0	0	0	0	0		
70-100	12111132	317.	50.	62	1531	0	0	0	0	0	0	0	0	0		
71-100	11124432	666.	35.	1	13	18	19	0	0	0	0	0	0	0		
72-100	11121132	840.	35.	1	25	52	55	0	0	0	0	0	0	0		
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
158-100	11241431	1521.	35.	44	1976	1077	1391	1050	1059	0	0	0	0	0		
159-100	11231431	1125.	35.	55	1355	1354	1353	1352	0	0	0	0	0	0		
160-100	11233431	1855.	35.	55	1357	1363	1563	1670	1396	1397	0	0	0	0		
161-100	11233431	2379.	35.	56	1399	1654	1655	1651	1659	1699	1653	0	0	0		
162-100	11241431	658.	35.	68	1679	1650	0	0	0	0	0	0	0	0		

FILE 36 (HARASS - example)

1	1	54321432
1	2	54321432
1	3	54331431
1	4	54341431
1	5	54321132
1	6	54341431
1	7	54344131
1	8	54324132
1	9	54344131
1	10	54331331
1	11	54344131
1	12	54344131
1	13	54334431
1	14	54334431
1	15	54331331
1	16	54321432
1	17	54321432
1	18	54331431
1	19	54324432
1	20	54334131
1	21	54331331
1	22	54321332
1	23	54321432
1	24	54331431
1	25	54321432
2	26	54321332
2	27	54321432
2	28	54331431

46	1147	44331431
46	1148	44331431
46	1149	44331331
46	1150	44331331
47	1151	54341431
47	1152	54331431
47	1153	54341431
47	1154	54344431
47	1155	54344431
47	1156	54331431

88	2206	34312332
98	2207	34312332

FILE 37 (HARASS - Example)

1	1	1	2	1	1	1	3	1	2	2	1	2	1	2	4	3
60	2	3	2	1	1	1	3	1	2	2	1	2	2	1	4	3
2	3	1	2	1	1	1	3	1	2	2	1	2	1	2	4	3
3	4	1	2	1	1	1	3	1	2	2	1	2	1	2	4	3
59	5	1	2	1	1	1	3	1	2	2	1	2	2	1	4	3
4	6	1	2	1	1	1	3	1	2	2	1	2	1	2	4	3
58	7	1	2	1	1	1	3	1	2	2	1	2	2	1	4	3
57	8	1	2	1	1	1	3	1	2	2	1	2	2	1	4	3
5	9	1	2	1	1	1	3	1	2	2	1	2	1	2	4	3
6	10	2	2	1	1	1	3	1	2	2	1	2	1	2	4	3
15	11	1	2	1	1	1	3	1	2	2	1	2	1	2	4	3
61	12	1	2	1	1	1	3	1	2	2	1	2	2	1	4	3
16	13	2	2	1	1	1	3	1	2	2	1	2	1	2	4	3

52	43	1	2	1	1	1	3	1	2	2	1	2	2	1	4	3
92	44	2	2	1	1	1	3	1	2	2	1	2	1	1	4	3
34	45	4	2	1	1	1	3	1	2	2	1	2	1	1	4	3
33	46	4	2	1	1	1	3	1	2	2	1	2	1	1	4	3
73	47	1	2	1	1	1	3	1	2	2	1	2	2	1	4	3
72	48	1	2	1	1	1	3	1	2	2	1	2	2	1	4	3

28	82	1	2	1	1	1	3	1	2	2	1	2	1	1	4	3
25	83	1	2	1	1	1	3	1	2	2	1	2	1	2	4	3
94	84	1	2	1	1	1	3	1	2	2	1	2	2	2	4	3
95	85	1	2	1	1	1	3	1	2	2	1	2	2	2	4	3
86	86	1	2	1	1	1	3	1	2	2	1	2	2	2	4	3
87	87	1	2	1	1	1	3	1	2	2	1	2	2	2	4	3
98	88	1	2	1	1	1	3	1	2	2	1	2	1	1	4	3

Appendix E. COMPUTER PROGRAM AND DATA FILES FOR HARP

```
      PROGRAM HARP( INPUT, OUTPUT, TAPE30=72/80, TAPE31=TAPE30,
     2     TAPE21=OUTPUT, TAPE32=140/140, TAPE33, TAPE34=72/80,
     3     TAPE35=72/80, TAPE36=TAPE30, TAPE37=72/80, TAPE38=TAPE30,
     4     TAPE39=TAPE30, TAPE40, TAPE29=INPUT, TAPE1, TAPE2)
C
C  THIS PROGRAM CALCULATES THE PRESENT NET VALUE OF EACH HARVEST AND
C  ROAD ALTERNATIVE.  INPUT IS PROVIDED FROM THE HARASS PROGRAM.
C
      DIMENSION CONST(2,2,2),TLENGTH(2,2),TSIZE(88,4),COST(12),TL(2)
      DIMENSION CONCOST(8),GRVCOST(8),COSTMTN(2),COSTRPR(2),TS7(2,88)
      DIMENSION RCOST(88),REPAIRS(88),CMAINT(88),CONSTRC(88)
      DIMENSION ACRES(5,88),VOLTIM(5,88),TENERGY(88),HCOST(88)
      DIMENSION REGCOST(88),CEQUIP(88),CLABOR(88),CSETUP(88)
      DIMENSION VAL(5),TRETURN(88),CINDEX(3),RINDEX(3)
      DIMENSION NA(162),NU(162),RLG(162),WD(162),NAGE(7)
      DIMENSION MHALT(88,7),MCALT(88,7),BFVCL(88,5),BLOGS(88,5)
      DIMENSION RIGGERS(88),DELAY(5),BLANDG(5),CUTROAD(5),CHGTIME(5)
      DIMENSION SETUPCT(5),HLABOR(5),HEQUIP(5),ENERGY(5),CON(5),BF(5)
      DIMENSION BFBL(5),BL(5),SY(5),CD(5),CI(5),TA(5),RI(5),TURNS(5)
      DIMENSION TE(5),SYDIST(88,5),CDSLOPE(88,5),DISLAT(88)
      DIMENSION TAGLINE(88),RE(5),NS(162),NM(162)
C
C  INITIALIZE AND READ IN THE DRIVING DATA FILES.
C
      IWAY=0
      TTURNS=TENG=REG=RGHTWAY=0.0
      CONST(1,1,1)=CONST(1,1,2)=CONST(1,2,1)=CCNST(2,1,1)=0.0
      CONST(2,2,2)=CONST(2,2,1)=CONST(2,1,2)=CCNST(1,2,2)=0.0
C
C  THIS READ FILE CONTAINS THE BASIC INFORMATION THAT SETS UP THE
C  ALTERNATIVE BEING CONSIDERED.  NALT--ALTERNATIVE NUMBER:  NYEARS--
C  NUMBER OF YEARS FOR THE ALTERNATIVE:  NSEGS--NUMBER OF ROAD SEGMENTS
C  IN THE ALTERNATIVE:  NBLKS--NUMBER OF BLOCKS:  INDEX--ESTABLISHES
C  IF THE USER WISHES TO EXAMINE MORE THAN ONE LEVEL OF PRICE AND
C  COST INDICIES:  AND DETAIL--ALLOWS THE USER TO DECIDE TO READ IN
C  THE INFORMATION FOR THE HARVEST COST REGRESSION EQUATIONS BLOCK
C  BY BLOCK (FINE RESOLUTION) OR FOR DRAINAGE AVERAGES (=1.0 AND
C  =0.0 RESPECTIVELY.
C
      READ(29,800) NALT,NYEARS,NSEGS,NBLKS,INDEX,DETAIL
  800 FORMAT(5I10,F10.1)
      NAV=NALT
C
C  THIS READ FILE ESTABLISHES THE ORIGINAL LENGTH OF ANY EXISTING ROADS.
C
      READ(30,801) (TLENGTH(1,K),TLENGTH(2,K),K=1,2)
  801 FORMAT(4F10.2)
C
C  THIS READ FILE CONTAINS THE COST ELEMENTS FOR ROADS:  GRVCOST--
C  COST OF ROCKING FOR NEW CONSTRUCTION:  CONCOST--CONSTRUCTION COST
C  FOR VARIOUS ROAD STANDARDS:  COSTMTN--YEARLY MAINTENANCE COSTS
C  PER MILE:  PLANTB--FIXED COST PER ACRE FOR PLANTING:  PLANTPT--
C  COST OF PLANTING PER TREE:  TREESPA--NUMBER OF TREES PLANTED PER ACRE:
C  VAL--VALUE OF STUMPAGE PER 1000 BOARD FEET AT THE MILL:  CINDEX--
C  COST INDEX PER YEAR:  AND RINDEX--RETURNS (PRICE) INDEX PER YEAR.
C
      READ(31,810) (GRVCOST(K),K=1,8)
      READ(31,810) (CONCOST(K),K=1,8)
      READ(31,811) (COSTMTN(K),COSTRPR(K),K=1,2)
      READ(31,812) PLANTB,PLANTPT,TREESPA
      READ(31,813) (VAL(M),M=1,5)
      READ(31,814) (CINDEX(K),RINDEX(K),K=1,3)
  810 FORMAT(8F10.2)
  811 FORMAT(4F10.2)
  812 FORMAT(3F10.2)
  813 FORMAT(5F10.2)
  814 FORMAT(6F10.2)
```

```
      C
      C  THIS READ FILE ESTABLISHES THE VOLUME AND ACRES OF TIMBER HARVESTED
      C  EACH YEAR.  IT IS A FILE PRODUCED BY THE HARASS PROGRAM (FILE
      C  FROM LUN NUMBER 49).  ALSO:  TENERGY--TOTAL ENERGY PER YEAR USED
      C  TO HARVEST A UNIT;  RCOST--ANNUAL TOTAL ROAD COSTS;  REPAIRS--
      C  ANNUAL COSTS TO ROAD DUE TO UNPROGRAMMED DAMAGE AND FAILURES;
      C  CONSTRC--ANNUAL CONSTRUCTION COSTS PER ALTERNATIVE;  CMAINT--
      C  ANNUAL MAINTENANCE COSTS;  TRETURN--ANNUAL GROSS RETURNS;  REG-
      C  COST--ANNUAL REGENERATION COSTS;  TSIZE--THE SIZE OF
      C  RANDOM ROAD EROSION EVENTS THAT REQUIRE REPAIRS TO KEEP THE ROAD
      C  SYSTEM OPEN, TO BE READ IN NEXT READ FILE FROM FILE CREATED
      C  BY THE HARASS PROGRAM (FILE FROM LUN NUMBER 45).
      C
            DO 397 J=1,NYEARS
            TENERGY(J)=0.0
            RCOST(J)=REPAIRS(J)=CONSTRC(J)=CMAINT(J)=0.0
            HCOST(J)=TRETURN(J)=REGCOST(J)=0.0
            READ(32,820) (ACRES(M,J),VOLTIM(M,J),M=1,5)
        820 FORMAT(51X,5(F5.1,F10.1))
            TSIZE(J,3)=TSIZE(J,4)=0.0
        397 CONTINUE
            MR1=1
            MR2=1
      C
      C  THIS SECTION READS IN THE VARIOUS ROAD DAMAGE AND FAILURE EVENTS
      C  AND CREATES YEARLY TOTALS FOR ALL EVENTS LARGER THAN 10 CUBIC
      C  YARDS.  MR1 AND MR2--COUNTERS TO IDENTIFY EVENT TYPE;  TSZ--
      C  YEARLY TOTALS FOR ROAD DAMAGE AND ROAD FAILURE EVENTS.
      C
            DO 400 J=1,NYEARS
            TSZ(1,J)=TSIZE(J,3)
            TSZ(2,J)=TSIZE(J,4)
            IF(MR1.NE.J.AND.MR2.NE.J) GO TO 400
        399 READ(33,830) MTEN,MR1,TSIZE(J,3),MR2,TSIZE(J,4)
        830 FORMAT(I2,30X,I3,12X,F10.1,5X,I3,12X,F10.1)
            IF(MTEN.EQ.10) GO TO 400
            IF(MR1.EQ.J) TSZ(1,J)=TSZ(1,J)+TSIZE(J,3)
            IF(MR2.EQ.J) TSZ(2,J)=TSZ(2,J)+TSIZE(J,4)
            IF(MR1.EQ.0.AND.MR2.EQ.0) GO TO 399
            IF(MR1.EQ.J) GO TO 399
            IF(MR2.EQ.J) GO TO 399
            JK=J+1
            IF(MR1.EQ.JK) TSIZE(JK,3)=TSIZE(J,3)
            IF(MR2.EQ.JK) TSIZE(JK,4)=TSIZE(J,4)
            IF(MR1.NE.JK) TSIZE(MR1,3)=TSIZE(J,3)
            IF(MR2.NE.JK) TSIZE(MR2,4)=TSIZE(J,4)
            TSIZE(J,3)=TSIZE(J,4)=0.0

        400 CONTINUE
            DO 900 J=1,NYEARS
            WRITE(21,208) TSZ(1,J),TSZ(2,J)
        900 CONTINUE
        208 FORMAT(1H ,2F15.2)
      C
      C  THIS READ FILE IS THE SAME ONE UTILIZED IN HARASS UNDER THE SAME
      C  LUN NUMBER.  HERE, ROAD STANDARD, ROAD SURFACING, SLOPE TYPE, AND
      C  ROAD LENGTH AND WIDTH ARE READ IN (NS, NM, NU, RLG, AND WD RESPECTIVELY.)
      C  ALSO,LUN 35 CONTAINS THE ALTERNATIVE INFORMATION USED IN HARASS TO
      C  SCHEDULE THE YEAR OF CONSTRUCTION FOR EACH SEGMENT (NAGE--BY THE
      C  RESPECTIVE ALTERNATIVE NUMBER--NALT).  RGHTWAY IS THE TOTAL ACRES
      C  CLEARED FOR ROAD CONSTRUCTION.
      C
              DO 401 J=1,NSEGS
              READ(34,840) NS(J),NM(J),NU(J),RLG(J),WD(J)
        840   FORMAT(9X,3I1,4X,F6.1,F4.0,54X)
              READ(35,850) (NAGE(K),K=1,7)
        850   FORMAT(10X,7I10)
              NA(J)=NAGE(NALT)
              IF(NA(J).GT.0) RGHTWAY=RGHTWAY+RLG(J)*WD(J)/43560.0
        401   CONTINUE
            WRITE(21,211) RGHTWAY
        211 FORMAT(1H ,F20.2)
              DO 402 J=1,NBLKS
              READ(37,860) (MHALT(J,K),MCALT(J,K),K=1,7)
        860   FORMAT(10X,14I5)
```

```
C
C  THESE NEXT FEW READ FILES CONTAIN THE INFORMATION NECESSARY TO RUN
C  THE HARVEST COST EQUATIONS.  DEPENDING ON WHETHER THE USER WISHES TO
C  READ IN DATA BY BLOCKS (DETAIL=1.0) OR BY DRAINAGES (DETAIL=0.0),
C  CERTAIN PROCEDURES ARE DICTATED.  BFVOL--BORAD FEET PER TURN;
C  BLOGS--NUMBER OF LOGS PER TURN;  SYDIST--ACTUAL SLOPE DISTANCE FOR
C  YARDING;  COSLOPE--SLOPE OF LINE DRAWN FROM SPAR TOWER TOP TO
C  PLACE OF HOOKING;  DISLAT--DISTANCE IN FEET FOR LATERAL
C  YARDING FOR PARTIAL CUT SYSTEMS;  TAGLINE--LENGTH OF THE TAGLINE IN
C  FEET FOR HELICOPTER YARDING;  RIGGERS--NUMBER OF RIGGERS.
C
         IF(DETAIL.EQ.0.0) GO TO 402
           DO 390 K=1,5
         READ(40,861) BFVOL(J,K),BLOGS(J,K),COSLOPE(J,K),SYDIST(J,K)
  861      FORMAT(4F10.3)
  390      CONTINUE
         READ(40,862) DISLAT(J),TAGLINE(J),RIGGERS(J)
  862    FORMAT(3F10.3)
  402     CONTINUF
      IF(DETAIL.EQ.1.0) GO TO 404
         DO 405 K=1,5
         READ(36,870) BFVOL(1,K),BLOGS(1,K),COSLOPE(1,K),SYDIST(1,K)
  870    FORMAT(4F10.3)
  405    CONTINUE
      READ(36,871) DISLAT(1),TAGLINE(1),RIGGERS(1)
  871 FORMAT(3F10.3)
C
C  HARVEST COST EQUATION VARIABLES READ IN HERE ARE:  DELAY--THE
C  DELAY TIME  FACTOR FOR EACH YARDING SYSTEM;  BLANDG--NUMBER OF
C  LANDINGS PER UNIT HARVESTED;  CUTROAD--NUMBER OF YARDING ROADS TO


C  HARVEST A UNIT (BLOCK FOR THIS STUDY);  CNGTIME--TIME REQUIRED
C  TO CHANGE ROADS (YARDING);  SETUPCT--COSTS OF INITIAL SETUP PER LANDING;
C  HLABOR--COSTS OF LABOR FOR EACH SYSTEM FOR ONE HOUR OF OPERATION;
C  HEQUIP--COSTS OF EQUIPMENT FOR EACH SYSTEM PER HOUR OF OPERATION;
C  AND ENERGY--AMOUNT OF FUEL CONSUMED PER 1000 BOARD FEET OF TIMBER
C  HARVESTED FOR EACH SYSTEM.
C
  404 READ(38,880) (DELAY(K),K=1,5)
      READ(38,880) (BLANDG(K),K=1,5)
      READ(38,880) (CUTROAD(K),K=1,5)
      READ(38,880) (CNGTIME(K),K=1,5)
      READ(38,880) (SETUPCT(K),K=1,5)
      READ(38,880) (HLABOR(K),K=1,5)
      READ(38,880) (HEQUIP(K),K=1,5)
      READ(38,880) (ENERGY(K),K=1,5)
  880 FORMAT(5F10.2)
C
C  HARVEST COST EQUATION COEFFICIENTS ARE:  CON--THE CONSTANT;
C  BF--COEF. FOR BFVOL;  BFBL--COEF. FOR BFVOL/BLOGS;  BL--COEF. FOR
C  BLOGS;  SY--COEF. FOR SYDIST;  CO--COEF. FOR COSLOPE;  DI--COEF.
C  FOR DISLAT;  TA--COEF. FOR TAGLINE;  RI--COEF. FOR RIGGERS.
C
      READ(39,881) (CON(K),K=1,5)
      READ(39,881) (BF(K),K=1,5)
      READ(39,881) (BFBL(K),K=1,5)
      READ(39,881) (BL(K),K=1,5)
      READ(39,881) (SY(K),K=1,5)
      READ(39,881) (CO(K),K=1,5)
      READ(39,881) (DI(K),K=1,5)
      READ(39,881) (TA(K),K=1,5)
      READ(39,881) (RI(K),K=1,5)
  881 FORMAT(5F10.5)
C
C  NOW ALL THE DRIVING INFORMATION HAS BEEN READ IN.  THE LOOP ON 410
C  IS A YEARLY LOOP FOR THE LENGTH OF THE ALTERNATIVE IN WHICH YEARLY
C  TOTALS FOR COSTS, RETURNS, AND CERTAIN VOLUMES OF PRODUCTS ARE
C  DETERMINED.  AFTER THIS LOOP, THEN THE PRESENT NET VALUE (PNV) FOR
C  SEVERAL INTEREST RATES AND VARIOUS PRICE AND COST INDICIES ARE
C  CALCULATED.
C
```

```
          DO 410 NYR=1,NYEARS
C
C  THIS SECTION SETS UP AND CALCULATES THE BASIC CONSTRUCTION
C  AMOUNTS BY ROAD TYPE AND SLOPE PLACEMENT EACH YEAR.  VALUES FOR TYPE
C  OF ROAD, AMOUNT CONSTRUCTED FOR EACH TYPE ON BASIC SLOPES AND RIGHT
C  OF WAY CLEARED ARE DETERMINED.
C
          DO 520 N=1,NSEGS
          NA(N)=NA(N)+1
          IF(NA(N).NE.0) GO TO 520
          NSS=NS(N)
          NMM=NM(N)
          NUU=NU(N)
          IF(NUU.EQ.1.OR.NUU.EQ.2) NPP=1
          IF(NUU.EQ.3.OR.NUU.EQ.4) NPP=2
          CONST(NSS,NMM,NPP)=CONST(NSS,NMM,NPP)+(RLG(N))/5280.0
          RGHTWAY=RGHTWAY+RLG(N)*WD(N)/43560.0

          TLENGTH(NSS,NMM)=TLENGTH(NSS,NMM)+CONST(NSS,NMM,1)+
     2                     CONST(NSS,NMM,2)
  520     CONTINUE
        WRITE(21,212) RGHTWAY,TLENGTH(1,1),TLENGTH(1,2),TLENGTH(2,1),
     2       TLENGTH(2,2)
  212 FORMAT(1H ,5F15.2)
C
C  THIS SECTION CALCULATES ANNUAL ROAD RELATED COSTS.
C
        COST(1)=CONST(2,1,1)*(CONCOST(1)+GRVCOST(1))
        COST(2)=CONST(2,1,2)*(CONCOST(2)+GRVCOST(2))
        COST(3)=CONST(2,2,1)*(CONCOST(3)+GRVCOST(3))
        COST(4)=CONST(2,2,2)*(CONCOST(4)+GRVCOST(4))
        COST(5)=CONST(1,1,1)*(CONCOST(5)+GRVCOST(5))
        COST(6)=CONST(1,1,2)*(CONCOST(6)+GRVCOST(6))
        COST(7)=CONST(1,2,1)*(CONCOST(7)+GRVCOST(7))
        COST(8)=CONST(1,2,2)*(CONCOST(8)+GRVCOST(8))
        TL(1)=TLENGTH(1,1)+TLENGTH(1,2)
        TL(2)=TLENGTH(2,1)+TLENGTH(2,2)
        COST(9)=TL(1)*COSTMTN(1)
        COST(10)=TL(2)*COSTMTN(2)
        COST(11)=TSZ(1,NYR)*COSTRPR(1)
        COST(12)=TSZ(2,NYR)*COSTRPR(2)
        REPAIRS(NYR)=COST(11)+COST(12)
        CMAINT(NYR)=COST(9)+COST(10)
        CONSTRC(NYR)=COST(1)+COST(2)+COST(3)+COST(4)+COST(5)+COST(6)
     2             +COST(7)+COST(8)
        RCOST(NYR)=REPAIRS(NYR)+CMAINT(NYR)+CONSTRC(NYR)
          DO 600 KL=1,12
          COST(KL)=0.0
  600     CONTINUE
          DO 630 L=1,2
            DO 620 K=1,2
              DO 610 J=1,2
              CONST(J,K,L)=0.0
  610         CONTINUE
  620       CONTINUE
  630     CONTINUE
C
C  THIS SECTION CALCULATES ANNUAL TIMBER HARVEST RELATED ECONOMIC
C  AND ENERGY OUTLAYS.  VALUES FOR TOTAL DOLLAR COST AND TOTAL ENERGY
C  CONSUMPTION FOR A HARVEST OPERATION ON ONE BLOCK ARE DETERMINED
C
        N=NYR
        IF(DETAIL.EQ.1.0) GO TO 750
          DO 740 K=1,5
          BFVOL(N,K)=BFVOL(1,K)
          BLOGS(N,K)=BLOGS(1,K)
          SYDIST(N,K)=SYDIST(1,K)
          COSLOPE(N,K)=COSLOPE(1,K)
  740     CONTINUE
        DISLAT(N)=DISLAT(1)
        TAGLINE(N)=TAGLINE(1)
        RIGGERS(N)=RIGGERS(1)
  750 MC=MCALT(N,NALT)
      MM=MHALT(N,NALT)
      IF(MC.EQ.3.AND.MM.EQ.4) GO TO 770
```

```
      IF(MC.EQ.1.AND.MH.EQ.3) K=1
      IF(MC.EQ.1.AND.MH.EQ.1) K=2
      IF(MC.EQ.2.AND.MH.EQ.1) K=3
      IF(MC.EQ.1.AND.MH.EQ.2) K=4
      IF(MC.EQ.2.AND.MH.EQ.2) K=5
      TTIME=CON(K)+BF(K)*BFVOL(N,K)+BFBL(K)*(BFVOL(N,K)/BLOGS(N,K))
     2    +BL(K)*BLOGS(N,K)+SY(K)*SYDIST(N,K)+CO(K)*COSLOPE(N,K)
     3    +CI(K)*DISLAT(N)+TA(K)*TAGLINE(N)+RI(K)*RIGGERS(N)
        DO 760 JL=1,5
        TE(JL)=(ENERGY(K)*VOLTIM(JL,N))/1000.0
        TENG=TENG+TE(JL)
        RE(JL)=ACRES(JL,N)*(PLANTB+PLANTPT*TREESPA)
        REG=REG+RE(JL)
        TURNS(JL)=VOLTIM(JL,N)/BFVOL(N,K)
        TTURNS=TTURNS+TURNS(JL)
  760   CONTINUE
      HTIME=((TTIME*TTURNS*DELAY(K))+(CNGTIME(K)*(CUTROAD(K)-1.0)))/60.0
      CLABOR(NYR)=HTIME*HLABOR(K)
      CEQUIP(NYR)=HTIME*HEQUIP(K)
      CSETUP(NYR)=SETUPCT(K)*BLANDG(K)
      HCOST(NYR)=CLABOR(NYR)+CEQUIP(NYR)+CSETUP(NYR)+REG
      TENERGY(NYR)=TENG
      REGCOST(NYR)=REG
      TTURNS=TENG=REG=HTIME=0.0
      GO TO 780
  770 HCOST(NYR)=TENERGY(NYR)=REGCOST(NYR)=0.0
      CEQUIP(NYR)=CSETUP(NYR)=CLABOR(NYR)=0.0
C
C  THIS SECTION RETURNS A VALUE FOR GROSS RETURNS FOR THE ANNUAL
C  VALUE OF TOTAL TIMBER HARVESTED
C
  780   DO 790 J=1,5
        TRETURN(NYR)=TRETURN(NYR)+((VAL(J)*VOLTIM(J,NYR))/1000.0
  790   CONTINUE
C
C  STATEMENT 410 IS THE END OF THE LOOP ON ANNUAL CALCULATIONS.
C
  410   CONTINUE
C
C  THIS SECTION WRITES OUT ANNUAL TOTALS FOR ALL MAJOR COST COMPONENTS
C  FOR EACH HARVEST ALTERNATIVE.
C
      ENGY=0.0
      WRITE(1,890) NALT
  890 FORMAT(1H1,59X,≠SUMMARY TABLE FOR≠/
     2        1H ,56X,≠COSTS AND RETURNS FOR≠/
     3        1H ,51X,≠HARVEST AND ROAD ALTERNATIVE≠,I3/
     4        1H ,40X,52(≠=≠)///
     5        1H ,11X,43(≠-≠),2X,63(≠-≠),3X,12(≠-≠)/
     6        1H ,27X,≠ROAD COSTS≠,39X,≠HARVEST COSTS≠,36X,≠TOTAL≠/
     7        1H ,24X,17(≠-≠),31X,20(≠-≠),32X,≠RETURNS≠/
     8        1H ,122X,12(≠-≠)//)
      WRITE(1,891)
  891 FORMAT(1H ,11X,≠CONSTRUC-  MAINTE-   REPAIRS  TOTAL ROAD≠,5X,
     1        ≠ENERGY IN   REGENER-  EQUIP-     LABOR     SETUP≠,3X,
     1        ≠TOTAL HARVEST≠/
     2        1H ,3X,≠YEAR≠,6X,≠TION≠,6X,≠NANCE≠,16X,≠COSTS≠,7X,

     2        ≠  GALLONS     ATION      MENT≠,27X,≠COSTS≠//
     3        1H ,2X,6(≠-≠),3X,43(≠-≠),2X,63(≠-≠)//)
      DO 791 NYR=1,NYEARS
      N=NYR
      TENG=TENERGY(N)
      WRITE(1,892) N,CONSTRC(N),CMAINT(N),REPAIRS(N),RCOST(N),
     2             TENERGY(N),REGCOST(N),CEQUIP(N),CLABOR(N),CSETUP(N),
     3             HCOST(N),TRETURN(N)
  892 FORMAT(1H ,I6,4X,3F10.2,F12.2,4X,5F10.2,F12.2,4X,F12.2)
      ENGY=ENGY+TENERGY(N)
  791 CONTINUE
      WRITE(1,893) RGHTWAY
  893 FORMAT(1H ,/////25X,≠THE AMOUNT OF FOREST CLEARED≠,
     2      1X,≠FOR FOREST ROAD RIGHT-OF-WAY WAS=≠,F10.2,2X,≠ACRES≠)
      WRITE(1,894) ENGY
  894 FORMAT(1H ,/////25X,≠THE TOTAL ENERGY CONSUMED PER≠,
     2       1X,≠HARVEST ALTERNATIVE WAS≠,F15.2,2X,≠GALLONS≠)
```

```
      C
      C  THIS CONCLUDES WRITING OUT ALL ANNUAL GROSS FIGURES.  NOW THE
      C  PROGRAM ENTERS THE LOOPS NECESSARY TO CALCULATE VARIOUS PRESENT
      C  NET VALUES FOR EACH ALTERNATIVE.  THE LOOPS INVOLVED ARE ON STATE-
      C  MENTS 440,430, AND 420.
      C
             DO 440 IDE=1,INDEX
             RIN=0.01
               DO 430 INT=1,15
               PNV=CTT=RTT=0.0
               CCTRC=CCTRM=CCTRR=CCTHR=CCTHE=CCTHL=CCTHS=0.0
                 DO 420 NY=1,NYEARS
                 ANNRIN=(1.0+RIN)**NY
                 CINY=(1.0+CINDEX(IDE))**NY
                 RINY=(1.0+RINDEX(IDE))**NY
                 CTRC=CONSTRC(NY)*CINY
                 CTRM=CMAINT(NY)*CINY
                 CTRR=REPAIRS(NY)*CINY
                 CTRT=RCOST(NY)*CINY
                 CTHR=REGCOST(NY)*CINY
                 CTHE=CEQUIP(NY)*CINY
                 CTHL=CLABOR(NY)*CINY
                 CTHS=CSETUP(NY)*CINY
                 CTHH=HCOST(NY)*CINY
                 CTRC=CTRC/ANNRIN
                 CTRM=CTRM/ANNRIN
                 CTRR=CTRR/ANNRIN
                 CTRT=CTRT/ANNRIN
                 CTHR=CTHR/ANNRIN
                 CTHE=CTHE/ANNRIN
                 CTHL=CTHL/ANNRIN
                 CTHS=CTHS/ANNRIN
                 CTHH=CTHH/ANNRIN
                 CT=CTRC+CTRM+CTRR+CTHR+CTHE+CTHL+CTHS
                 CCTRM=CCTRM+CTRM
                 CCTHS=CCTHS+CTHS
                 CCTRR=CCTRR+CTRR
                 CCTHR=CCTHR+CTHR
                 CCTHE=CCTHE+CTHE
                 CCTHL=CCTHL+CTHL
                 CCTRC=CCTRC+CTRC
                 RT=(TRETURN(NY))*((1.0+RINDEX(IDE))**NY)
                 RT=RT/ANNRIN
                 PNV=RT-CT+PNV
                 CTT=CTT+CT
                 RTT=RTT+RT
        420      CONTINUE
      C
      C  THIS ENDS THE FIRST LOOP AND A NET PRESENT VALUE FOR A SINGLE
      C  DISCOUNT RATE IS DETERMINED.  NOW A NEW DISCOUNT RATE WILL BE
      C  EMPLOYED TO CALCULATE ANOTHER PRESENT NET VALUE.
      C
      C
      C  THIS SECTION WRITES OUT THE ANNUAL COST AND PRICE INDICIES, THE
      C  ANNUAL DISCOUNT RATE, DISCOUNTED RETURNS, DISCOUNTED COSTS, AND
      C  THE PRESENT NET VALUE FOR EACH COMPLETE HARVEST AND ROAD ALTERNATIVE.
      C
           IF(IWAY.NE.0) GO TO 792
           IWAY=IWAY+1
           WRITE(2,1000) NAV
       1000 FORMAT(1H1,37X,*SUMMARY TABLE FOR*/
          2        1H ,35X,*THE PRESENT NET VALUE*/
          3        1H ,30X,*CALCULATIONS AT VARIOUS INTEREST*/
          4        1H ,30X,*RATES AND PRICE AND COST INDICIES*/
          5        1H ,29X,*FOR HARVEST AND ROAD ALTERNATIVE*,I4/
          6        1H ,18X,56(*=*)///)
           WRITE(2,1010)
       1010  FORMAT(1H ,2X,*ANNUAL PRICE    ANNUAL COST   ANNUAL DISCOUNT*,5X,
          2        * DISCOUNTED      DISCOUNTED       PRESENT*/
          3        1H ,3X,*INDEX    *,7X,*INDEX    *,9X,*RATE    *,10X,*RETURNS*,
          3        9X,*COSTS*,8X,*NET VALUE*//
          4        1H ,6(1X,*---------------*,1X)//)
```

```
  792 C=100.0*CINDEX(IDF)
      R=100.0*RINDEX(IDF)
      RA=100.0*RIN
      WRITE(2,1020) R,C,RA,RTT,CTT,PNV
 1020 FORMAT(1H ,3(6X,F4.1,5X),3F15.2)
      IF(INT.EQ.15) GO TO 793
      WRITE(21,213) CCTRC,CCTRM,CCTRR,CCTHR,CCTHE,CCTHL,CCTHS
  213 FORMAT(1H ,7F15.2)
      GO TO 794
  793 WRITE(2,1030)
 1030  FORMAT(1H ,//)
 794        RIN=RIN+0.01
C
C  THIS ENDS THE INTEREST RATE CHANGE DO LOOP.
C
  430     CONTINUE
  440 CONTINUE
C
C  THIS ENDS THE DO LOOP WHICH CHANGES THE COST INDEX RELATIVE TO
C  THE PRICE INDEX.
C
      STOP
      END
```

FILE 29 (HARP - Seven Examples)

1	88	162	88	3	0.0
2	88	162	88	3	0.0
3	88	162	88	3	0.0
4	88	162	88	3	0.0
5	88	162	88	3	0.0
6	88	162	88	3	0.0
7	88	162	88	3	0.0

FILE 30 (HARP)

0.00	6.09	0.00	0.00

FILE 31 (HARP)

24000.00	24000.00	0.30	0.00	12000.00	12000.00	0.00	0.00
200000.00	100000.00	250000.00	100000.00	150000.00	50000.00	150000.00	80000.00
250.00	1.75	500.00	2.50				
15.00	0.10	375.00					
175.00	150.00	150.00	125.00	0.00			
0.027	0.027	0.020	0.027	0.035	0.027		

FILE 32 (HARP -- road construction and harvest output file from HARASS)

FILE 33 (HARP -- road erosion output file from HARASS)

FILE 34 (HARP -- same as FILE 34 for HARASS)

FILE 35 (HARP -- same as FILE 35 for HARASS)

FILE 36 (HARP)

250.000	2.000	-60.000	750.000
500.000	2.000	-60.000	1200.000
350.000	2.000	-60.000	1200.000
1700.000	4.000	-30.000	5500.000
1700.000	4.000	-30.000	5500.000
75.000	250.000	2.000	

FILE 38 (HARP)

1.15	1.10	1.25	1.30	1.30
1.00	1.00	1.00	1.00	1.00
15.00	10.00	10.00	1.00	1.00
15.00	30.00	40.00	0.00	0.00
725.00	750.00	750.00	1000.00	1000.00
31.90	31.90	31.90	143.90	143.90
12.30	15.70	15.70	1363.60	1363.60
3.50	1.90	2.30	19.30	19.30

FILE 37 (HARP -- same as FILE 37 for HARASS)

FILE 39 (HARP)

3.69500	3.05900	1.94400	1.85900	1.37200
0.00258	0.00091	0.00096	-0.00005	0.00006
-0.00403	-0.00106	-0.00039	0.00006	-0.00095
0.00090	0.00009	0.03946	0.04773	0.03120
0.00170	0.00194	0.00212	0.00036	0.00025
0.00090	0.00000	0.00134	-0.00539	0.01253
0.00000	0.00003	0.01196	0.00000	0.00000
0.00090	0.00030	0.00390	-0.00110	0.00030
0.00000	0.00000	-0.11473	0.00000	0.00000