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ENGINEERING & TECHNOLOGY MANAGEMENT

Title: Flathead Indian Reservation Development of an Even-Aged Harvest Scheduler

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Abstract: Linear programming techniques were applied in the development of an even-aged harvest scheduling model for the Flathead Indian Reservation in western Montana. Stand types depicting the various size and condition of the even-aged forest strata served as the principle decision variables. High and moderate site qualifiers were also applied. Silvicultural treatments, yield projections, and economic forecasts comprised the necessary inputs. A 120 year time horizon depicted the planning horizon.

Flathead Indian Reservation Development of an Even-Aged Harvest Scheduler

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EMP-P9323

Executive Summary:

PURPOSE OF HARVEST SCHEDULER

It is the policy of the Bureau of Indian Affairs, in accordance with 25 CFR (Code of Federal Regulations) 163, to require a current Forest Management Plan for all Indian forest lands in **federal trust status** prior to the commencement of forest management activities and the obligation of related funds. Forest Management Plans are vital to insure that forest resources are managed based upon the desires and goals of the Indian people, and to provide a means to monitor the effectiveness of the Bureau's administration of the **trust responsibility**. Forest Management Plans are updated annually with major revisions scheduled on a 10-year basis. This coincides with the measurement of a system of permanent plot samples which are situated throughout the entire reservation. These plots represent the myriad of physical, vegetative, and developmental characteristics indicative of the land base.

During the dormant season of 1989, the forestry staff at the Flathead Indian Reservation (located in western Montana and comprising approximately 460,000 timbered acres) conducted a remeasurement of their Continuous Forest Inventory (CFI) system. This data base provided the needed inputs in the development of a harvest scheduling model for the proposed 1994-2003 Forest Management Plan for the Flathead Indian Reservation. The harvest model is comprised of five major components: A Land Classification System; A Forest Growth and Yield Model; Silvicultural Prescriptions; Product Prices and Management Cost Schedules; A Linear Programming (LP) Package. The LP provides the analytical framework needed to bring together all other components. Goals stated by the Confederated Salish and Kootenai Tribes (Flathead) drive the objective functions. In light of the complexity of such a harvest scheduling problem, the goal of our team was to isolate the "Even-Aged Stand Types" and prepare an allowable annual cut for the Flathead forest.

SYNOPSIS OF MODELLING RESULTS

Forestry practices are activities that are performed to achieve the goals and objectives of the decision maker (timberland owner). "Decision Variables", in a forestry sense, represent the level of activity that can be undertaken on a given resource. The primary resource foresters deal with is a forest stand. The primary unit is therefore acres. The number of acres by stand or stand type to be allocated to each activities drives the optimal solution.

The primary component of our Even-Aged Harvest Scheduling Model for the Flathead Indian Reservation were:

1. <u>Decision Makers</u>
   The Combined Council of the Kootenai and Salish Tribes

2. <u>Goals and Goal Criteria</u>
   a) Provide sustained level of employment
      - Nondeclining/Even-Flow of Sawtimber Volume
        (Board Feet per year)
   b) Provide sustained level of income
      - Nondeclining/Even-Flow of Net Revenue
        (Dollars per year)

3. <u>Decision Variables</u>
   a) HRR - High Risk Replacement
   b) GRM - Growing, Mature
   c) GRP - Growing, Poles
   d) CLM - Culminated
   e) LIB - Liberation
   f) REF - Reforestation
   g) FDR - Forest Development Rehab
      - Even-Aged Stand Types
      - High/Moderate Productivity
        (Acres)

4. <u>Resource Constraints</u>
   a) Harvest Volume
      (Board Feet per Acre)
   b) Economic Criteria
      (Dollars >>> Gross Revenue-Total Cost=Net Revenue)
   c) Area Accounting
      (Acreage per Stand Type)

The Flathead Even-Aged Harvest Scheduler was designed using the SARA-LINDO program package developed by the University of California, Berkeley. SARA (Spread Assisted Resource Analysis) performs the job duties of matrix generation

II. DEVELOPMENT OF AN EVEN-AGED HARVEST SCHEDULER

A. Literature Review

The concept of forest regulation has occupied foresters for decades. Forest regulation is deeply embedded in modern forest management and strongly relates to the concept of sustained yield. The objective of a regulated forest is to assure a continuous yield of the various products and uses of the forest. According to Davis (1966):

> The essential requirements of a fully regulated forest are that age and size classes be represented in such proportion and be consistently growing at such rates that an approximately equal or periodic yield of products of desired size and quality may be obtained. There must be a progression of size and age classes so that harvestable trees in approximately equal volume are available for cutting.

Although this definition considers timber as the primary product derived from the forest ecosystem, contemporary forest regulation encompasses a broader context that includes recreation, wildlife, range, aesthetics, water, and air as valid "products" of the forest. Dykstra (1984) referred to resource management planning - linear programming applications as "Regulation Models". Materials presented by Deckro (1993) suggest that regulation models are a specialized version of "Production Scheduling Models".

Johnson and Scheurman (1977) coined the terms Model I and Model II to label fundamentally different ways to define decision variables for a timber harvesting problem, the distinction being the way regenerated stands are handled. In Model I formulations, regenerated stands are coupled directly to and identified by the existing stands to which they are associated. Model II detaches the regenerated stands from the existing stands and defines new decision variables for them. Figure II-1 graphically displays how a stand that has been regenerated in period 1 can pass through several decision variables in a Model II formulation. Several processing program was developed by Vandendriesche, 1993. This program produced yield tables from Stand Prognosis model runs. Flat files were created that could be directly imported into the spreadsheet. Refer to Appendix 2 for a description of the "STAND" program. A time frame of 120 years in 10-year increments formed the planning horizon. This essentially represents the life cycle for a forest stand of the Flathead. Refer to Figure II-6 for an example of the HRR - High Risk Replacement yield tables developed from the representative CFI plots and Stand Prognosis model. Appendix 3 contains yield tables for all of the even-aged stand types.

3. <u>Management Prescriptions</u>

"**Silviculture** is the art of producing and tending a forest; the application of the knowledge of silvics in the treatment of a forest; the theory and practice of controlling forest establishment, composition, and growth" (Smith, 1962). Silviculture is the basic tool foresters use to manipulate a stand of trees toward desire future conditions. A silvicultural prescription is a 'blueprint' of recommended activities to be applied throughout the life cycle of a given stand. Cultural treatments for existing stands are usually quite different than for future stands. Existing even-aged stand are often left alone until they are entered for regeneration purposes. Future stands, by contrast, are more intensively managed. On the Flathead, regenerated stands receive site preparation, planting, precommercial and commercial thinnings, and other various release treatments. In the context of formulating the Flathead Even-Aged Harvest Scheduler, we considered only the existing stand type and their associated volumes. It was a directed effort to isolate one facet of the scheduling problem. Also, the allowable annual cut will be based primarily on the harvest of existing stand volumes. Future stands lend credence to the perpetual nature of growing trees on into the future but add little to proposed harvest levels

15. Tedder, Phillip L., LaMont, Richard N. 1990. TRIM-PLUS, Timber Resource Inventory Model Plus Harvest Scheduling. Resource Economics International Inc. User's Manaual.

16. Wykoff, William R., et al. 1990. "User's Guide to the Stand Prognosis Model. Release Notes: Version 6". U.S. Forest Service. Intermountain Research Station. General Technical Report.

FLATHEAD INDIAN RESERVATION
DEVELOPMENT OF AN EVEN-AGED HARVEST SCHEDULER

Prepared in partial fulfillment of the requirements for:

EMGT 540

OPERATIONS RESEARCH IN ENGINEERING MANAGEMENT

by:

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Spring Term

1993

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During the dormant season of 1989, the forestry staff at the Flathead Indian Reservation (located in western Montana and comprising approximately 460,000 timbered acres) conducted a remeasurement of their Continuous Forest Inventory (CFI) system. This data base provided the needed inputs in the development of a harvest scheduling model for the proposed 1994-2003 Forest Management Plan for the Flathead Indian Reservation. The harvest model is comprised of five major components: A Land Classification System; A Forest Growth and Yield Model; Silvicultural Prescriptions; Product Prices and Management Cost Schedules; A Linear Programming (LP) Package. The LP provides the analytical framework needed to bring together all other components. Goals stated by the Confederated Salish and Kootenai Tribes (Flathead) drive the objective functions. In light of the complexity of such a harvest scheduling problem, the goal of our team was to isolate the "Even-Aged Stand Types" and prepare an allowable annual cut for the Flathead forest.

and LINDO (Linear INteracter and Discrete Optimizer) handles the responsibilities of linear programming solution and report writing. Even-Flow Board Foot Volume and Even-Flow Net Revenue models were generated through SARA-LINDO. The following table summarizes important output values:

	ENTRY PERIOD											
EVEN-FLOW	01	02	03	04	05	06	07	08	09	10	11	12
	Millions Board Feet per Year											
Bd. Ft. Vol.	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.7
Net Rev.	26.4	27.0	26.0	27.0	22.0	21.4	22.8	22.1	20.4	20.3	20.8	22.1
	Millions Dollars per Year											
Bd. Ft. Vol.	7.67	7.68	7.50	7.66	9.34	9.48	8.09	9.19	9.09	10.99	8.94	9.24
Net Rev.	8.55	8.55	8.55	8.55	8.55	8.55	8.55	8.55	8.55	8.55	8.55	8.55
	Acres Treated per Year											
Bd. Ft. Vol.	2018	1631	948	934	1547	1456	1092	843	1288	1706	1076	2122
Net Rev.	2234	1428	1640	981	1412	1312	1363	784	1425	991	1123	1968

Realization of tribal goals for self determination requires the ability to be totally informed of all pertinent details. The primary objective in our development of the even-aged harvest scheduler was to produce a tool which would allow multiple objectives stated by the Flathead Tribal Council to be reflected in modelled runs. Thus, comparative data would be available to enable informed decisions. With knowledge comes freedom.

the growth at the same rate over the next decade, and propose an allowable cut based on growth and available land base. Following the 1989 remeasurement of the Flathead Continuous Forest Inventory (CFI) System, a meeting was held in Portland, Oregon with the Flathead Agency, Portland Area, and Central Office BIA forestry staffs in attendance. The intent was to determine appropriate methods for analyzing the Flathead data. At that time, Portland Area Office was promoting TRIM+ (Timber Resource Inventory Model Plus Harvest Scheduling, Tedder, 1987), a binary search model for analysis purposes. The TRIM+ package is a powerful program capable of handling mass data such as that supplied from timber inventories. A major limitation of this heuristic is that many of the important decisions regarding land allocation and choices of silvicultural prescription are made external of the model, and the solution cannot be considered optimal unless all of the external decisions were indeed optimal. The Flatheads, like all major timberland owners, are facing new environmental standards. "New Forestry", "Ecosystem Management", and "Biodiversity" are the emphasized terms of today.

Central Office had gained exposure to a Linear Programming (LP) based model developed by the University of California, Berkeley, Department of Forestry and Resource Management, referred to as SARA-LINDO (Spreadsheet Assisted Resource Analysis, Davis, 1991 - Linear INteractive and Discrete Optimizer, Schrage, 1991). A forest inventory analysis project with the Hoopa Valley Indian Reservation in California demonstrated the robustness of LP in handling multi-resource allocation problems. Faced with the prospects of producing an Environmental Impact Statement and an associated Integrated Forest Resource Management Plan, the Flathead Forestry Staff choose to pursue development of a SARA-LINDO model and submitted a formal request to Central Office for assistance in their planning effort. Refer to Appendix 1 for pertinent memorandums.

Much work had to be done prior to building a LP model for the Flathead

I. DESCRIPTION OF THE FLATHEAD INDIAN RESERVATION

A. Location

The Flathead Indian Reservation is located in Northwestern Montana approximately 80 miles south of the Canadian border and 40 miles east of Idaho. The boundaries of the Reservation include portions of Lake, Flathead, Sanders, and Missoula Counties. On the north, the Reservation is bounded by the 47 53' North Latitude, on the east by the Mission Mountains, on the west by the Cabinet Range, and on the south by the Coeur d'Alene Mountain Range. The northern boundary bisects Flathead Lake. The forested area is shown in Figure I-1.

B. Climate

The climate during summer months is generally dry with occasional light rains and dry lightning storms. Normal temperature range between 85 and 95 degrees Fahrenheit, with infrequent highs of 100 to 105 degrees. Winter months are generally mild except for infrequent cold fronts that will drop the temperature to a minus 20 or 30 degrees Fahrenheit. Daily weather is influenced by frontal systems moving eastward from the Pacific Coast and southerly from the Alaskan and Canadian mainlands. Annual precipitation ranges from 13 inches in the vicinity of Niarada, Montana, to over 100 inches at the highest elevations of the Mission Range. Average precipitation is approximately 20 inches per year in the forest zone.

C. Topography

The Flathead Reservation exhibits great diversity in form and relief. On the east side are the towering Mission Mountains with deep narrow canyons, sharp angular ridges, barren peaks, and perennial snowfields. Elevations span from 6,000 to 10,000 feet. The Cabinet Mountain Range forms the western boundary. These mountains are timbered, moderately rugged, and range from 4,000 to 7,000 feet in elevation. The Coeur d'Alene Mountain Range forms the southern boundary and is characterized by deep canyons and forests interspersed by talus slopes, rock ledges, and barren cliffs. Several peaks are above timberline. The Little Bitterroot Mountains dissect the center of the Reservation. These mountains are rolling hills with grassy lower slopes and timbered ridge tops.

D. <u>Economic Environment</u>

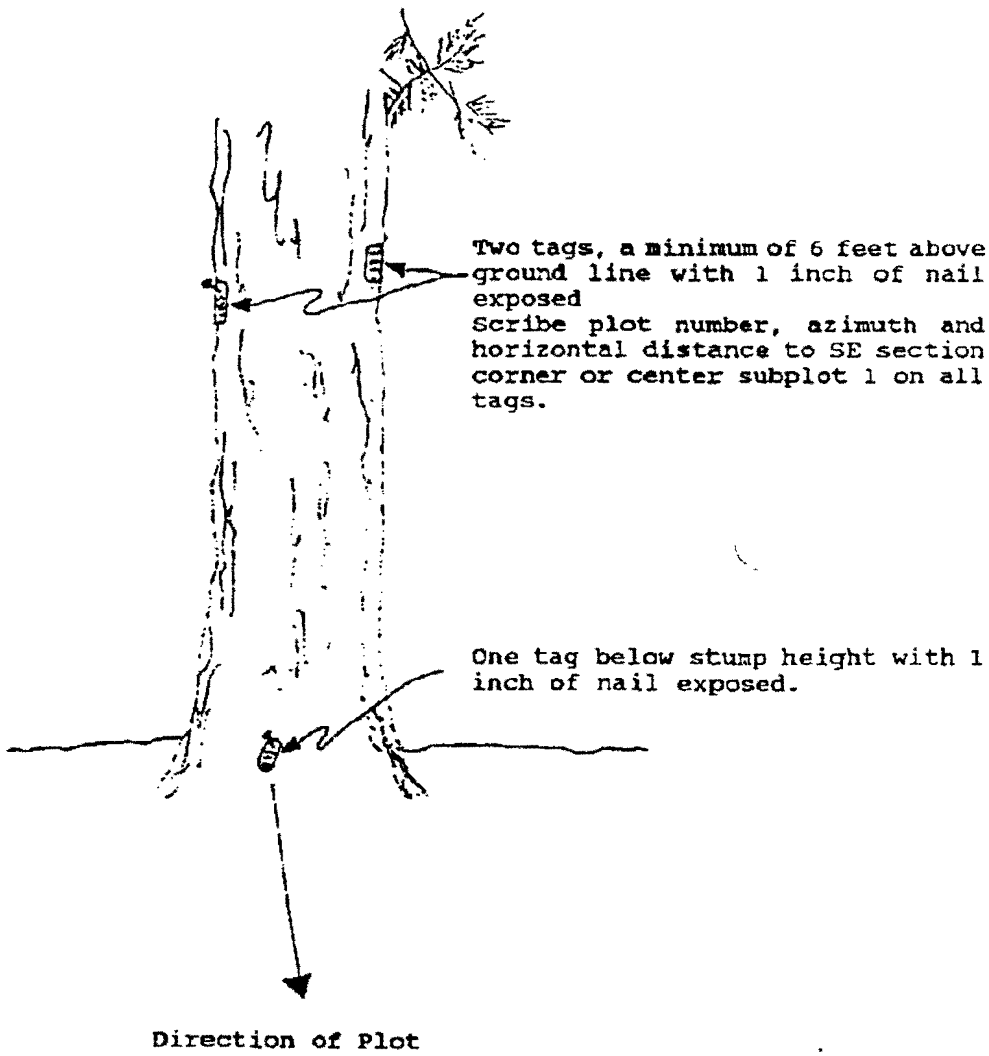
The Flathead Reservation was established by the Treaty of Hell Gate in 1855 as a homeland for the Pend d'Orielle, Kootenai, and later, for the Salish people from the Bitterroot Valley. The boundaries of the reservation as established encompassed some 1,248,000 acres. Approximately half of the original parcel was transferred to non-Indian ownership under the allotment policy of the federal government. The period between 1887 and 1934 included opening of the reservation to white settlement. Today, the federal government holds title to 620,000 acres in trust status for the Confederated Salish and Kootenai Tribe. The majority of tribal land is located in the outer periphery. This is basically the forested mountain areas while the valley agricultural land is, for the most part, in non-Indian ownership. The combination of forestry, fisheries, agriculture, and manufacturing (wood products industries) provide the major source of Indian employment and income.

E. <u>Forest Inventory</u>

The Bureau of Indian Affairs maintains permanent plot systems (referred to as Continuous Forest Inventory - CFI) on all major timbered reservations. Fixed area plots are established and remeasured at periodic intervals, usually ten years, which coincides with the scheduled forest plan updates. Sample trees are monumented with aluminum tags and measured for increment in diameter and height. Tree status (Survivor, Ingrowth, Harvest, or Mortality) and tree condition (Problem, Severity) are recorded in an effort to monitor forest trends. The

Figure I-2

Marking CFI Trees



heuristics (binary search algorithms) have been used to set harvest levels and are usually designed as variations of Model II. Schrage (1991) described Model I and Model II approaches to long term forest planning as "Path Formulations", under the topic of Project Network templates.

Regardless if a timber harvest scheduling problem is solved via Model I or Model II design, it can be safely stated that such models require many decision variables and accounting constraints. Thus, the employment of a "Matrix Generator-Report Writer" package is imperative. The chronological development of such programs by the U.S. Forest Service started with Timber RAM (Navon, 1971) which handled only Model I problems. They progressed through MUSYC (Johnson and Jones, 1979), FORPLAN I (Johnson, 1986), and FORPLAN II (Johnson et al., 1986) which handled both Model I and Model II and a variety of other options. Refer to Figure II-2 for a depiction of this sequence of modelling events.

A major draw back with many of the harvest schedulers of today is the perception of the developed model being a "Black Box" created by the computer. Decision makers see data go in one end and magically reappear as output at the other without interfacing with the process. Recently, a Matrix Generator-Report Writer system developed by the University of California, Berkeley, Department of Forest and Natural Resources, referred to as SARA-LINDO (Davis, 1991) seems to overcome this hurdle. By incorporating a commercially available spreadsheet package such as LOTUS 1-2-3 or Microsoft's EXCEL for matrix generation and LINDO as the Linear Programming optimizing software, a "Glass Box" approach to forest planning could be achieved. Administrators are familiar with spreadsheet technology. Associated duties of budgeting are often performed by such programs. Using the two-dimensional characteristics of a spreadsheet for base data compilations allows the decision maker to see the interaction of the input with the output generated by LINDO. It is a combination that Tribal Leaders have endorsed and our project team elected to pursue for the Flathead harvest scheduling model.

B. Scope of the Project

In light of our time constraint (approximately 6 weeks to formulate a working model) we simplified our project by considering timber regulation of Even-Aged Stands. We further specified our model to include only the life cycle of existing stands (an abbreviated Model I structure). Regenerated stand profiles, uneven-aged stand types, and other resource considerations will be pursued in future model developments. The harvest model is comprised of five main components: **A Land Classification System; A Forest Growth and Yield Projection Model; Silvicultural Prescriptions; Product Prices and Management Cost Schedules;** and, **A Linear Programming (LP) Package.** The LP provided the analytical chasis to bring together all other components. Goals stated by the Confederated Salish and Kootenai Tribes (Flathead) drove the objective functions.

1. Forest Land Classification

The classification of the forest land base was the initial step in the development of stand types to be carried into the harvest scheduling model. The classification of the potential timber base is extremely important insofar as it defines the basic units, the building blocks of the analysis. Once the land base is classified and incorporated into the scheduling model, it is very difficult to change. A change in the land classification essentially means starting from the beginning and redoing the analysis.

The 1989 remeasurement of Continuous Forest Inventory (CFI) plots on the Flathead Indian Reservation formed the basis of empirical data used in the harvest scheduler. The CFI plot locations represent the various stand types within the land classification strategy. The land classification scheme served as a flow chart for assigning stand types and associated CFI plot locations. The

<u>Physical Characteristics:</u> The set of attributes used to characterize the permanent, physical nature of the forest, including topography, soils, habitat type.
<u>Vegetative Characteristics:</u> The set of attributes used to characterize the vegetation currently growing on the forest, including cover type species, age, size, and volume.
<u>Developmental Characteristics:</u> The set of attributes used to characterize the organizational, developmental aspects of the forest, including political conditions, road network, administrative boundaries.
<u>Stand Type:</u> Forestland that has the same combination of physical, vegetative, and developmental characteristics chosen to classify the forest into homogeneous types.
<u>Stand:</u> A geographically contiguous parcel of land, all of the same stand type and larger than some minimum.
(Davis/Johnson, 1987)

Stand types are forestland that have the same combination of physical, vegetative, and development characteristics to classify the forest into homogeneous types. The development characteristics have been addressed in defining the resultant "Available--Capable--Unconstrained--Suitable" forest land base. The physical and vegetative characteristics (i.e. slope, site, and current cover type) were categorized and assigned. Refer to Figure II-4 for a breakdown of the accessible suitable land base to the stand type level. By and large, the even-aged and uneven-aged stand types represented the important stand structures on the Flathead Reservation.

c). Even-Aged Stand Types

Stand types generally respond in a like manner to management treatments. Stand types, when combined with silvicultural prescriptions and entry periods, formed the 'decision variables' in the harvest scheduling model. The scope of this project focused on the "Even-Aged Stand Types". Definition of several other forestry terms is in order.

<u>Even-Aged Stand Type:</u> A stand in which all trees form a single story and are at the same age or at least of the same age/size class. A stand type is considered even-aged if the difference in age between the oldest and youngest trees does not exceed 20 percent of the length of the rotation (age of harvest).
<u>Uneven-Aged Stand Type:</u> A stand in which there are considerable differences in age of trees and in which 3 or more age classes are represented.

FLATHEAD INDIAN RESERVATION
ACCESSIBLE/SUITABLE LAND CLASSIFICATION

- Accessibility Suitable 292,951 (437/669)
  - Cable Logging Ground 69,718 (105/156)
    - Habitat Type Group B,C
      - Standard Treatment
        - Mgt System E-A
          - Stand Type 2,495 (64/87)
            - HRR 700 (1/1)
            - CLM 11,902 (17/24)
            - GRM 3,500 (5/8)
            - GRP 2,800 (4/4)
            - GRS 7,001 (10/11)
            - LIB 1,400 (2/2)
            - REF 3,500 (5/12)
            - FDR 4,901 (7/8)
    - Habitat Type Group D,E
      - Standard Treatment
        - Mgt System E-A
          - Stand Type 27,223 (41/69)
            - HRR 2,800 (4/7)
            - CLM 11,203 (16/27)
            - GRM 4,900 (7/9)
            - GRP 700 (1/2)
            - GRS 3,500 (5/8)
            - LIB 3,500 (5/7)
            - REF 700 (1/3)
            - FDR (NS/3)
  - Tractor Logging Ground 223,233 (332/513)
    - Habitat Type Group A
      - Standard Treatment
        - Mgt System U-A
          - Stand Type 8,741 (13/18)
            - ITS 7,701 (11/16)
    - Habitat Type Group B,C
      - Standard Treatment
        - Mgt System U-A
          - Stand Type 75,308 (112/179)
            - ITS 23,803 (34/53)
            - UGS 51,805 (74/119)
      - Special Treatment
        - Mgt System E-A (T)
          - Stand Type 49,084 (73/120)
            - HRR 1,400 (2/5)
            - CLM 15,402 (22/39)
            - GRM 10,502 (15/26)
            - GRP 700 (1/3)
            - GRS 4,900 (7/9)
            - LIB 4,200 (6/8)
            - REF 8,401 (12/18)
            - FDR 4,900 (7/9)
    - Habitat Type Group D
      - Standard Treatment
        - Mgt System U-A
          - Stand Type 18,155 (27/37)
            - UGS 18,902 (27/37)
      - Special Treatment
        - Mgt System E-A (T)
          - Stand Type 41,688 (62/93)
            - HRR 2,800 (4/5)
            - CLM 16,102 (23/36)
            - GRM 6,301 (9/18)
            - GRP 2,100 (3/6)
            - GRS 3,500 (5/7)
            - LIB 2,800 (4/4)
            - REF 4,200 (6/8)
            - FDR 5,601 (8/8)
    - Habitat Type Group E
      - Standard Treatment
        - Mgt System E-A
          - Stand Type 24,878 (37/53)
            - HRR 2,100 (3/3)
            - CLM 9,802 (14/19)
            - GRM 2,800 (4/8)
            - GRP (NS/NS)
            - GRS 4,901 (7/9)
            - LIB 2,100 (3/4)
            - REF (NS/1)
            - FDR 2,100 (3/4)
    - Habitat Type Group F
      - Standard Treatment
        - Mgt System E-A
          - Stand Type 5,379 (8/13)
            - HRR (NS/NS)
            - CLM 700 (1/1)
            - GRM (NS/NS)
            - GRP (NS/NS)
            - GRS 3,500 (5/8)
            - LIB (NS/NS)
            - REF 700 (1/2)
            - FDR (NS/NS)

Note: Acreage (CFI Subplot 1/CFI Subplot 1 & 2)
NS = Non-Sampled Stand Type

Figure II-5

FLATHEAD INDIAN RESERVATION
FOREST INVENTORY ANALYSIS

CFI PLOT COUNT BY EVEN-AGED STAND TYPES
5/1/93

Stand Type		Productivity	# of CFI Plots		Associated
Name	Abbrev.	Class	Subplot 1	Subplot 1&2	Acres
High-Risk Replacement	HRR	High (H)	9	13	6,300
	HRR	Moderate (M)	3	6	2,100
Growing, Mature	GRM	High (H)	26	42	18,200
	GRM	Moderate (M)	20	32	14,000
Growing, Poles	GRP	High (H)	5	5	3,500
	GRP	Moderate (M)	5	6	3,500
Growing, Sapling	GRS	High (H)	14	23	9,800
	GRS	Moderate (M)	18	25	12,600
Culminated	CLM	High (H)	53	81	37,100
	CLM	Moderate (M)	45	77	31,500
Liberation	LIB	High (H)	8	12	5,600
	LIB	Moderate (M)	8	10	5,600
Reforestation	REF	High (H)	8	12	5,600
	REF	Moderate (M)	18	29	12,600
Forest Develop. Rehab.	FDR	High (H)	13	20	9,100
	FDR	Moderate (M)	17	23	11,900
		Subtotals =	**270**	**416**	**189,000**
Stream Buffer Zones	BZN	High (H)	2	2	1,400
	BZN	Moderate (M)	4	6	2,800
		Totals =	**276**	**424**	**193,200**

STAND TYPE = HIGH RISK REPLACEMENT - HIGH PRODUCTIVITY
PRESCRIPTION = LET GROW

	Board Feet/Acre				Cubic Feet/Acre				
YEAR	YELLOW PINE	20"+ OTHER SPECIES	10"-20" OTHER SPECIES	ALL SPECIES	YELLOW PINE	20"+ OTHER SPECIES	10"-20" OTHER SPECIES	6"-8" OTHER SPECIES	ALL SPECIES
1989	0.0	0.0	9313.1	9313.1	0.00	0.00	2072.29	1484.32	3556.61
1999	0.0	0.0	10548.0	10548.0	0.00	0.00	2318.23	1202.22	3520.45
2009	0.0	0.0	11573.4	11573.4	0.00	0.00	2509.55	901.79	3411.34
2019	0.0	114.8	12098.9	12213.8	0.00	20.36	2587.25	670.82	3278.43
2029	119.7	123.2	12699.4	12942.3	20.93	21.55	2675.96	464.99	3183.43
2039	133.4	225.8	13284.7	13643.9	22.90	39.57	2751.40	315.12	3128.98
2049	139.0	225.3	13820.2	14184.5	23.64	39.10	2808.99	205.53	3077.26
2059	148.8	569.0	13941.7	14659.6	24.81	96.88	2792.10	125.25	3039.03
2069	152.1	1070.3	13791.2	15013.5	25.20	179.71	2717.43	78.97	3001.31
2079	150.7	1557.4	13686.1	15394.2	24.68	261.28	2648.64	46.05	2980.65
2089	151.4	2388.1	13192.6	15732.1	24.63	399.14	2514.11	28.88	2966.75
2099	156.5	3248.6	12696.7	16101.7	25.13	539.43	2385.50	12.89	2962.95
2109	159.9	4070.1	12212.5	16442.4	25.50	668.30	2262.31	8.99	2965.10

STAND TYPE = HIGH RISK REPLACEMENT - MODERATE PRODUCTIVITY
PRESCRIPTION = LET GROW

	Board Feet/Acre				Cubic Feet/Acre				
YEAR	YELLOW PINE	20"+ OTHER SPECIES	10"-20" OTHER SPECIES	ALL SPECIES	YELLOW PINE	20"+ OTHER SPECIES	10"-20" OTHER SPECIES	6"-8" OTHER SPECIES	ALL SPECIES
1989	3662.1	0.0	6822.8	10484.9	617.82	0.00	1505.70	650.65	2774.17
1999	3938.0	0.0	7364.9	11302.8	663.57	0.00	1615.09	524.12	2802.77
2009	4341.4	0.0	7720.7	12062.0	727.78	0.00	1682.01	414.38	2824.17
2019	4831.4	222.6	7563.2	12617.2	805.09	40.61	1647.81	333.97	2827.49
2029	5192.9	221.9	7509.7	12924.4	862.47	40.04	1621.70	274.82	2799.02
2039	5252.1	218.6	7616.4	13087.0	865.79	38.86	1616.46	227.83	2748.94
2049	5509.7	183.3	7568.6	13261.6	904.57	32.33	1588.97	165.78	2691.65
2059	5813.3	346.0	7152.2	13311.5	950.85	61.54	1489.51	127.38	2629.27
2069	6387.2	307.8	6558.9	13253.9	1043.11	54.38	1362.66	90.01	2550.17
2079	6819.7	257.8	5990.7	13068.3	1111.79	45.17	1236.78	66.80	2460.54
2089	6901.2	212.3	5805.5	12919.0	1117.04	37.01	1179.85	48.62	2382.52
2099	6978.3	422.2	5423.0	12823.5	1122.26	73.89	1088.29	36.89	2321.32
2109	7469.5	404.1	4835.6	12709.3	1199.29	70.23	964.43	26.49	2260.44

Figure II-6

Figure II-7

ECONOMIC DATA

Guiding Discount Rate: 1.02

Stumpage		**$/MBF**	**Trend**
- Other SPC 10-20"	BV10OS	300.00	1.00
- Other SPC 20"+	BV20OS	350.00	1.00
- Yellow Pine	BV20YP	750.00	1.00
		$/MCF	**Trend**
- Other SPC 06-10"	CV06OS	457.00	1.00
- Other SPC 10-20"	CV10OS	205.00	1.00
- Other SPC 20"+	CV20OS	139.00	1.00
- Yellow Pine	CV20YP	45.00	1.00
Follow-up		**$/Acre**	**Trend**
- Planting Costs	PLANTC	115.00	1.00
- Precom. Thinning	PTHINC	60.00	1.00
- Slash Treatment	SLASHC	7.82	1.00
Admin. Cost		**$/Acre**	**Trend**
- Sale Follow-up	FSALEC	1.00	1.00
- Nat. Res. Dept.	NATRDC	1.00	1.00
- Overhead Cost	OVERHC	1.00	1.00
- Sale Preparation	PSALEC	1.00	1.00
- Sale Admin.	TSALEC	1.00	1.00

Figure II-8

SARA

SPREADSHEET ASSISTED RESOURCE ANALYSIS THE UC-SARA SYSTEM.

by
Lawrence S. Davis, Frieder Schurr, Joe Scott, Roger Church, Peter Daugherty,
Keith Gilless, University of California, Berkeley;
James Beck and Barbara Beck, University of Alberta, Edmonton.

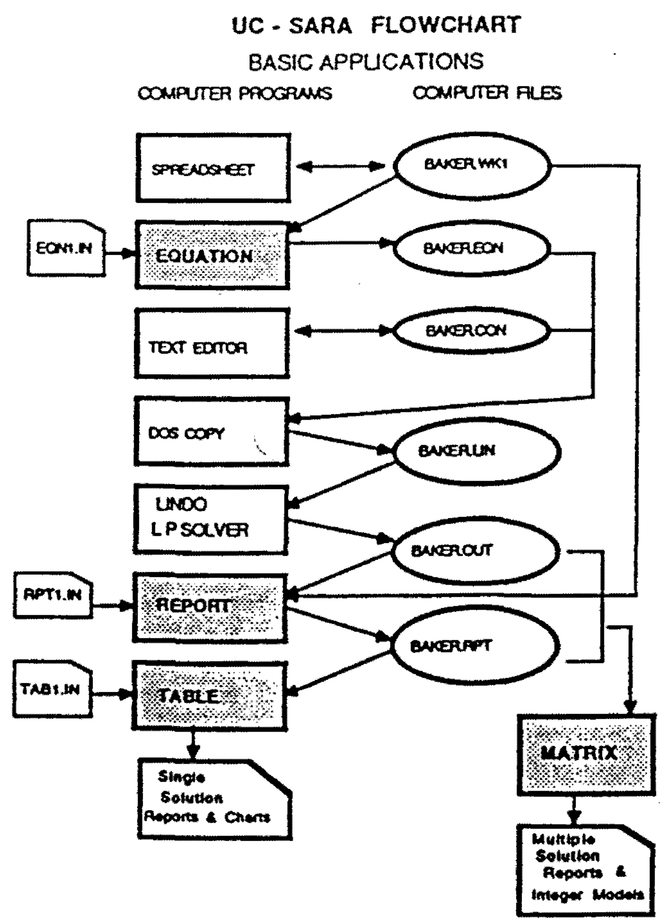
SARA is a set of computer programs and procedures organized to effectively use commercially available spreadsheet and mathematical programming software to facilitate land management planning. The programs and the system serve four main purposes:

1. **A generalized, freeform matrix generator** to translate problem concepts and data into linear programming input files for solution by LINDO or other linear programming software.

2. **A flexible report writer** that reads standard linear programming solution files and brings them back into the spreadsheets for table, chart and graph preparation.

3. **A method to easily construct integer models** from multiple linear program solution files. For modeling hierarchical aggregation of planning elements across time and space.

4. **Provide understandable, user friendly window on the important aspects of resource planning;** glass box rather than black box modeling.



The System Package

* executable code for the programs EQUATION, REPORT, TABLE, MATRIX

* Users Manual explaining in detail and with examples how to achieve the above functions and analytical goals

* Complete set of data files for the Baker and Daniel Pickett forests for self study and class use.

* Using the multiple spreadsheet technique, problems with 10,000 or more columns and any number of rows can be constructed. It works best on a 386/25 Pc with 4 MB of RAM

* Experience to date includes two years of classroom use and applied problems to construct 5000 column plus models in both Model I and Model II formulations.

* Cost is $250 for a site license. Contact Larry Davis or Keith Gilless, Department of Forestry and Resource Management, 145 Mulford Hall, U. C Berkeley, 94720 (415) 642-6489

FLATHEAD INDIAN RESERVATION
FOREST INVENTORY ANALYSIS

HARVEST SCHEDULING MODEL - SPREADSHEET ASSISTED RESOURCE ANALYSIS

		Stand Type	HRR	HRR	HRR	HRR	HRR	HRR	HRR	HRR	HRR	HRR	HRR	HRR
		Productivity	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
		Prescription	X0	X0	X0	X0	X0	X0	X0	X0	X0	X0	X0	X0
		Period	1	2	3	4	5	6	7	8	9	10	11	12
	Start of Matrix	!START	HRRHX001	HRRHX002	HRRHX003	HRRHX004	HRRHX005	HRRHX006	HRRHX007	HRRHX008	HRRHX009	HRRHX010	HRRHX011	HRRHX012
Board Foot	Yellow Pine	BV20YP01	0											
Volume	dbh > 20"+	BV20YP02		0										
		BV20YP03			0									
		BV20YP04				119.7								
		BV20YP05					133.4							
		BV20YP06						139						
		BV20YP07							148.8					
		BV20YP08								152.1				
		BV20YP09									150.7			
		BV20YP10										151.4		
		BV20YP11											156.5	
		BV20YP12												159.9
	Other Species	BV20OS01	0											
	dbh > 20"+	BV20OS02		0										
		BV20OS03			114.8									
		BV20OS04				123.2								
		BV20OS05					225.8							
		BV20OS06						225.3						
		BV20OS07							569					
		BV20OS08								1070.3				
		BV20OS09									1557.4			
		BV20OS10										2388.1		
		BV20OS11											3248.6	
		BV20OS12												4070.1
	Other Species	BV10OS01	10548											
	dbh = 10" - 20"	BV10OS02		11573.4										
		BV10OS03			12098.9									
		BV10OS04				12699.4								
		BV10OS05					13284.7							
		BV10OS06						13820.2						
		BV10OS07							13941.7					
		BV10OS08								13791.2				
		BV10OS09									13686.1			
		BV10OS10										13192.6		
		BV10OS11											12696.7	
		BV10OS12												12212.5
	All Species	BVTALL01	10548											
		BVTALL02		11573.4										
		BVTALL03			12213.8									
		BVTALL04				12942.3								
		BVTALL05					13643.9							
		BVTALL06						14184.5						
		BVTALL07							14659.6					
		BVTALL08								15013.5				
		BVTALL09									15394.2			
		BVTALL10										15732.1		
		BVTALL11											16101.7	
		BVTALL12												16442.4

Figure II-9

5	CLMM (15465)	CLMM (13247) CLMH (876)
6	CLMM (14559)	CLMM (13121)
7	GRMM (1048) CLMH (9872)	GRMM (2901) CLMM (5132) LIBH (5600)
8	GRMM (8431)	GRMM (7837)
9	GRMM (4521) LIBH (5600) REFM (2758)	GRMM (3262) GRPH (2696) REFM (8288)
10	GRPM (1622) LIBM (5600) REFM (9842)	LIBM (5600) REFM (4312)
11	GRPH (3500) GRPM (1878) REFH (5384)	GRPH (804) GRPM (3500) REFH (5600) FDRM (1325)
12	REFH (216) FDRH (9100) FDRM (11900)	FDRH (9100) FDRM (10575)

The numbers in parenthesis following the stand types are their associated harvest acres. The Even-Flow Revenue run selected stand types based on the availability of Yellow Pine volume. Older Ponderosa Pine have a substantially higher stumpage price ($750.00) compared to other species ($350.00). The LP solution smooth the selection of the higher stumpage with the lower to provide an overall higher net return compare to the Even-Flow Volume. Refer to Figure II-10 and II-11 for a graphical depiction of selected stand types by the Even-Flow Board Foot Volume and Even-Flow Revenue respectively. These graphs vividly display the fluctuation in the area treated in each of the time periods. Such yearly fluctuations would have an impact on the administrative staffing needed to prepare timber sales, treat harvest debris, and replant cutover sites. An additional model run was made with the objective of establishing an even-flow of treatment area. Results provided 7,117 acres of high productivity and 6,767

Even Flow Revenue

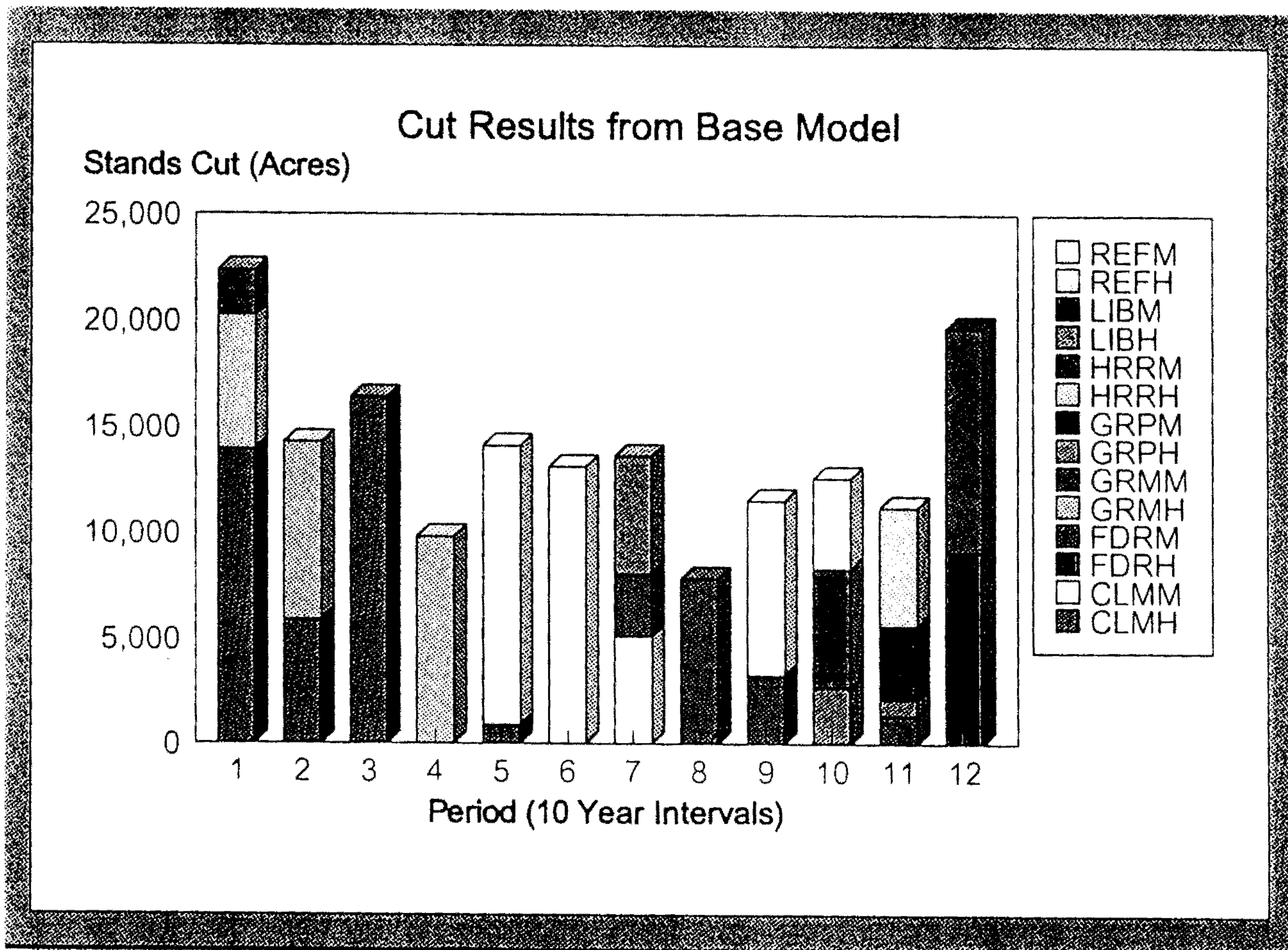


Figure II-11

Even Flow Board Foot Volume

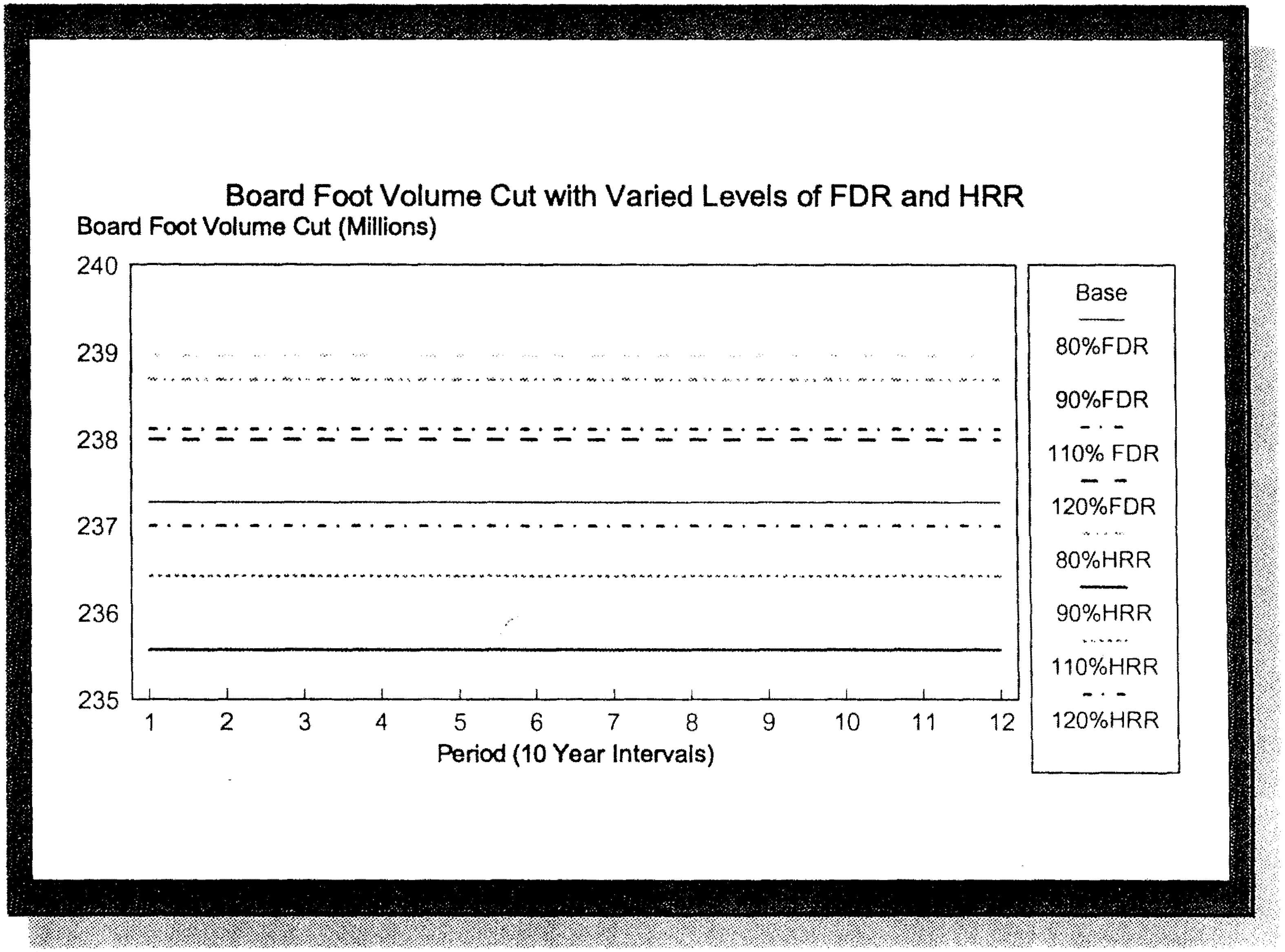


Figure II-12

Pine (Yellow Pine) Stand Types. Of interest are the effects of changes in HRRH and FDRH at either end of the revenue line. HRRH flares in the first period and FDRH in the last, as expected. Varying the level of available volume had relatively no effect on the middle time periods.

Figures II-14 overlays the board foot harvest level derived from the Even-Flow Board Foot base model and the Even-Flow Revenue base model. Figure II-15 overlays the net revenue returns from the Even-Flow Revenue base model and the Even-Flow Board Foot base model. An added feature of these two figures is the variance portrayed by fluctuating the available volume of the HRRH and FDRH stand types.

b). Species Stumpage

Recall that the potential price received for uncut timber is referred to as stumpage. For our model, value was assigned based on species and size class. Older (150+ years), larger (20"+ diameter) Ponderosa Pine is called "Yellow Pine". When cut for timber, it produces straight gain, free from knots and other defects and demands $750.00 per thousand board feet. Other species, such as Douglas-Fir, Western Larch, Lodgepole Pine, Engelmann Spruce, True Firs, Mountain Hemlock, and Western Redcedar, depending on size return $350.00 (20"+ diameter) and $300.00 (10"-20" diameter). To determine the sensitivity of our base models to fluctuation in stumpage prices, model runs with 10% and 50% increases and decreases were analyzed by Yellow Pine, Other Species 20"+, Other Species 10"+, and All Species combined. Over twenty different combinations were modeled. Figures II-16 and II-17 graphically display the results of these runs. The board foot harvest levels did not fluctuate as dramatically as the net revenue returns from the base models. Once again, the implied linear effects are demonstrated by the revenue charts.

Revenue Comparison

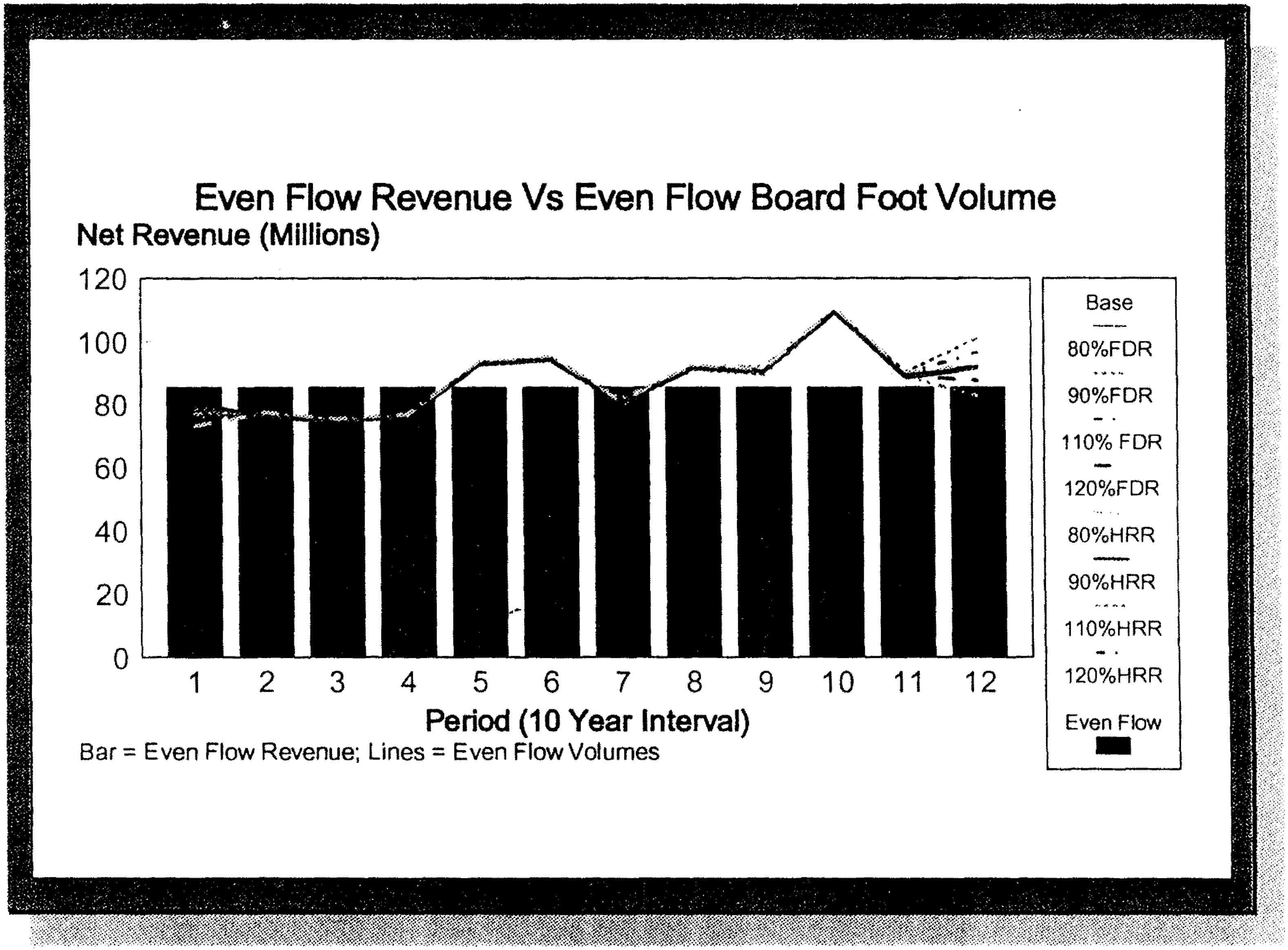


Figure II-15

Revenue Comparison

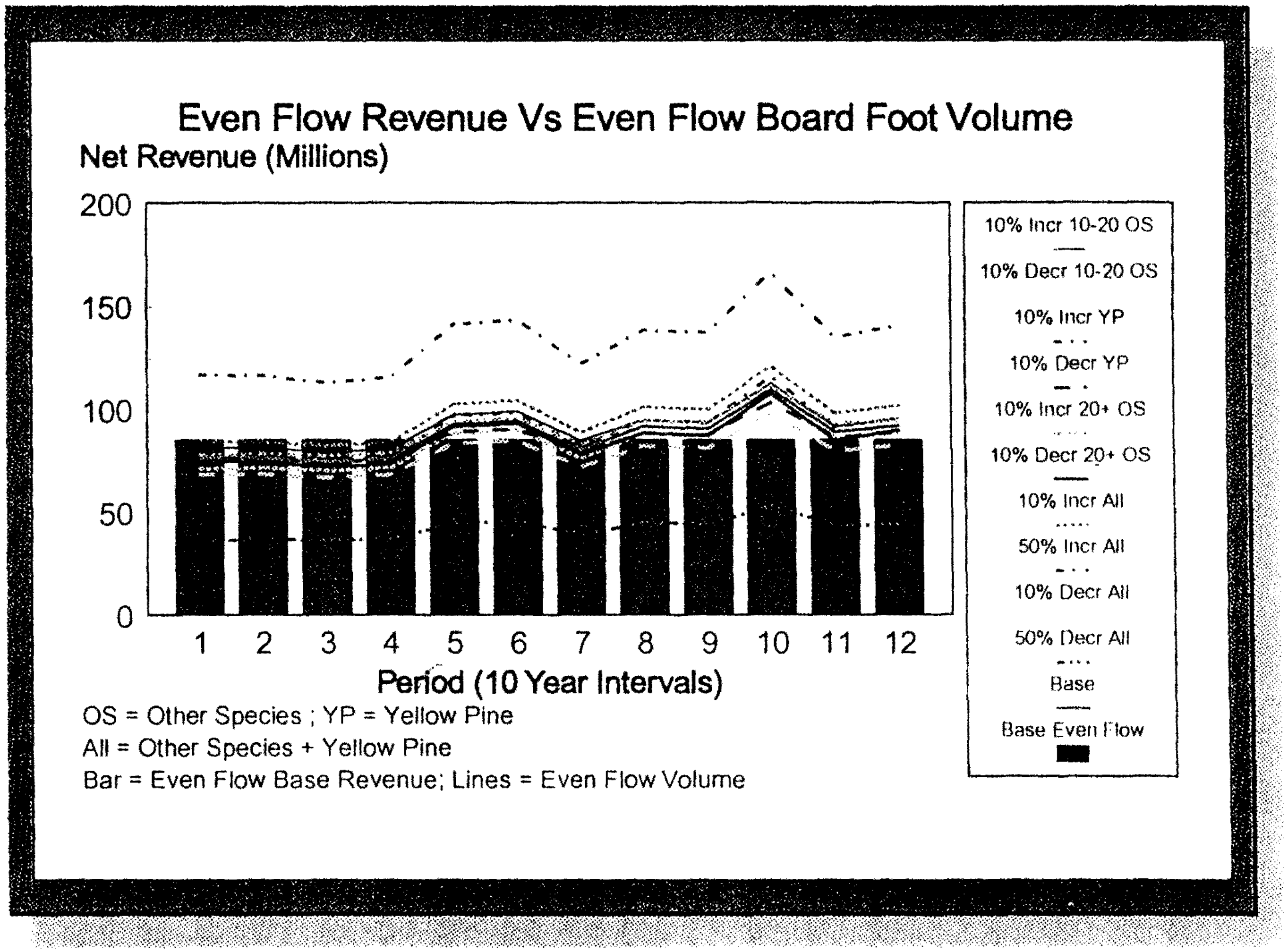


Figure II-17

mathematical statements which then could be entered into a linear programming package. The solution to our LP is an abstraction of the real world situation. Through sensitivity analysis, we were able to determine how stable our solution results were relative to changes in stand type volume and stumpage prices received. Refer to Figure III-1.

The results of the Even-Flow Board Foot Volume base model indicate a continual supply of 23.7 MMBF annually for a 120 years. Net revenues would range from a low of $75 million in the third decade to a high of $110 million in the tenth decade. The results of the Even-Flow Net Revenue base model levied a constant $8.5 million annually derived from the even-aged stand types. Board foot volume cut would fluctuate by period from a low of 20.3 MMBF in the tenth decade to a high of 27.0 MMBF in the second and forth decades. Sensitivity analysis demonstrated linear dependency. An increase or decrease in volume per stand type or value per stumpage price showed an associated increase or decrease in the objective function. However, selection of Stand Types to cut in associated periods remain unchange from base model results.

The ultimate path which to follow will be decided by the Flathead Tribal Council. Our role as analyst was to provide sound data with creditable forecast using linear programming as the primary tool.

B. <u>Recommendations for Future Enhancements</u>

There is still much work to be done in the development of a comprehensive harvest scheduling model for the Flathead Indian Reservation. Modelling of the Uneven-Aged Stand types, testing of alternative silvicultural prescription, and consideration for non-timber forest resources are paramount projects. However, development of the Even-Aged Stand Type harvest scheduling module is a significant first step. Many hurdles have been jumped and the lessons learned should help in the development of other submodels. There are additioanl features that we would like to incorporate into the Even-Aged Model.

Further model enhancements include:

1) Incorporation of regenerated stand yields into our stand types.

2) Break down by tractor logging sites versus cable logging sites.

3) Inclusion of alternative regeneration silvicultural prescriptions.

Further analysis enhancements include:

1) Sensitivity of stand type acreage.

2) Parametric analysis of price changes.

3) Goal programming of multiple objectives.

Our project group work well together. Thank goodness that it was such a dreary spring in the great Pacific Northwest. That made it a little easier to give up seven weekends in secession (including Memorial) to work on this project. Our group work as a team and accomplished a lot both in the development of a real world model and in our understanding of linear programming methodologies.

15. Tedder, Phillip L., LaMont, Richard N. 1990. TRIM-PLUS, Timber Resource Inventory Model Plus Harvest Scheduling. Resource Economics International Inc. User's Manaual.

16. Wykoff, William R., et al. 1990. User's Guide to the Stand Prognosis Model. Release Notes: Version 6. U.S. Forest Service. Intermountain Research Station. General Technical Report.