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A COMPUTER MODEL FOR DETERMINING THE OPTIMUM SIZE OF A MINE PROJECT

by

R.G. Bagnall

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ABSTRACT

The primary function of the computer model presented here is to calculate the optimum level of investment necessary for the development of a particular mineral deposit. However, the most important applications of the model would be to help answer a variety of more general economic questions. For example, an important application would be to compare the effect of different tax and royalty policies on a Province's stock of ore reserves. Another application would be to compare different mining and processing methods for a particular mineral deposit. These applications, plus others, suggest that a model of this kind would be of value to both industry and governments. A most significant consequence of planners using a model such as this is that in the process of optimizing the use of capital and human resources, they will also be maximizing the possible mineral resources that can be utilized.

Preface and Acknowledgements

The computer program described in this study was developed in the Mineral Resources Division, Department of Mines, Resources and Environmental Management, Province of Manitoba. The study was financed jointly by the Federal and Provincial Governments under the Non-Renewable Resource Evaluation Program (NREP) agreement (Project Number MN 7511-3). Federal Government consultant for the study was Dr. Asman Azis, Economist, Mineral Development Sector, Department of Energy, Mines and Resources. The study began in March of 1976 and was completed in March 1977.

To complete a study such as this requires the effort and skills of many different people. Individuals who have made valuable contributions during the course of the study include:

Heinz Ambach, Computer Programmer, Department of Mines, Resources and Environmental Management;

Dr. John Gray, Economist, University of Manitoba;

Mark Judd, Computer Programmer, Department of Renewable Resources and Transportation Services;

Marian Minjoot, Clerk-Typist, Department of Mines, Resources and Environmental Management;

Richard Werstler, Contract Economist, Department of Mines, Resources and Environmental Management.

I would particularly like to thank Professor Brian MacKenzie, Director, Mining Program, McGill University, Montreal for taking the time to read a draft of this report and offer some useful suggestions. Professor MacKenzie's comments along with some discussions are contained in an appendix to the final chapter.

Any deficiencies that remain in the computer model or in the written report are the responsibility of the author.

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CHAPTER 1

INTRODUCTION

1.1 Purpose of the Model

This computer model calculates the optimum size and life of a project needed to develop an ore body. The optimizing process is one of adjusting the size and productive life of the project until either (i) the maximum rate of return is achieved, or (ii) the marginal rate of return is at least equal to a pre-determined minimum rate. The evaluator will select one of these alternatives. It should be noted that the latter process gives a solution identical to the solution that would be obtained by using the pre-determined minimum rate as the discount rate and maximizing the present value of the project.

The model would normally optimize a project from the point of view of a private investor, meaning that money costs and values would be used throughout. However, for purposes of evaluating public policy, provision should be made for the inclusion of all costs and benefits from a project. That is, the evaluation could be done from a social rather than a private point of view.

The most important applications of a model of this kind are in the analysis of economic problems relating to the mining industry. One use would be to evaluate the effects on mining firms of different tax and royalty systems. Areas affected would be calculated ore reserves, the rate of extraction, and overall project profitability. Another use would be to estimate the level of mining activity needed to support the development of new town sites. These and other possible applications are discussed in more detail in the final chapter.

The description of the model that follows is done in two main parts. Chapter 2 is entirely devoted to a technical description of the computer program. It describes in detail what the program does and how it does it. Chapter 3 provides an example of an evaluation of a mineral deposit using the model. The emphasis here is on the preparation of the data to be used in the analysis.

1.2 Overview of the Model

Two contrasting types of data are used by the program in evaluating a mining project. The first consists of geological data relating to the mineral deposit being evaluated. Sufficient information must be provided to enable the program to calculate two grade-tonnage functions: one function will express the relationship of tonnage to average grade; the other will express the relationship of tonnage to cut-off grade.

The second kind of information which must be provided is of a financial nature. For purposes of calculating income tax and royalty liabilities, five catefories of capital costs are used. These are: (i) pre-production exploration costs; (ii) pre-production development costs; (iii) mining investment; (iv) processing investment; and (v) social capital investment. For purposes of calculating annual profits, information is needed on mining costs, processing costs and value per unit of production. As with the geological data, sufficient information must be provided to enable the program to calculate functions of cost against annual capacity. There are five capital cost functions and two operating cost functions.

Once the program has been provided with the above data, the following sequence of operations occurs. Initially, the program calculates the cost-size and mineral grade-size functions; each function will be either linear, log-linear or hyperbolic. This is done once for each mineral deposit being evaluated. Then initial values for the size and production life of the project are assigned.

Following this, the program begins an iterative process designed to calculate the optimum size and life of a mining operation which would develop the mineral deposit. The steps in this process are as follows: (1) assign the project a pre-production period (based on the size of the project being evaluated) and a total life (this being the sum of the pre-production period and the productive life being tested); (2) calculate the annual revenue the assumed project could expect from the mineral deposit; (3) calculate working capital, distribute the capital investment over the pre-production period, and calculate the annual gross profit; (4) calculate the total royalty the proposed project could anticipate; (5) calculate the capital taxes and income taxes the project could anticipate; (6) calculate four cash flows, each assuming different tax liabilities; (7) calculate the internal rate of return for each of the cash flows; and (8) compare the internal rate of return for the assumed project to the internal rate of return for a project either of different size or of different productive life.

Depending on the results of the comparison, the life or size of the project will be incremented up or down. The process will then be repeated until the maximum IRR is determined. At the discretion of the evaluator, once the size of project yielding the maximum return is determined, the project can be gradually increased in size to test if an additional increment of investment is able to earn the minimum acceptable return. This incrementing would continue so long as each increment of investment earns the minimum return.

After the optimum project is determined, a sensitivity analysis and probabilistic analysis can be carried out. Sensitivity analysis involces varying up to 11 parameters affecting profitability from 5% to 20% to note the effect on the anticipated rate of return. Probabilistic analysis involves using Monte Carlo techniques to generate a rate of return distribution.

CHAPTER 2

DESCRIPTION OF THE COMPUTER PROGRAM

This Chapter will be entirely devoted to a technical description of the computer model. Section 2.1 of this Chapter will describe the activities that take place in the main part of the program while sections 2.2 to 2.7 will describe the various subroutines used.

2.1 The Complete Model

The program is written in standard Fortran. As such it shoud be compatible with all computers having a Fortran compiler and a memory in excess of 140 K. It is written in double precision for maximum possible accuracy although it could readily be converted to single precision with reduced accuracy where memory core may be a constraint. In situations where reduced capability is quite acceptable many of the subroutines can be simplified, and in one instance, even removed with minimum complications.

A simplified flow chart of the complete program is shown in Figure 2.1. The MAIN compiler listing is provided in the Appendix at the end of the chapter.

2.1.1 MAIN Variables

The REAL variables in the main part of the program are defined alphabetically as follows:

- A — 7 element array contains the first constant for each of the two mineral reserve equations.
- AA — 7 element array contains the first constant for each of the 7 cost equations.
- B — 7 element array contains the second constant for each of the two mineral reserve equations.
- BB — 7 element array contains the second constant for each of the 7 cost equations.

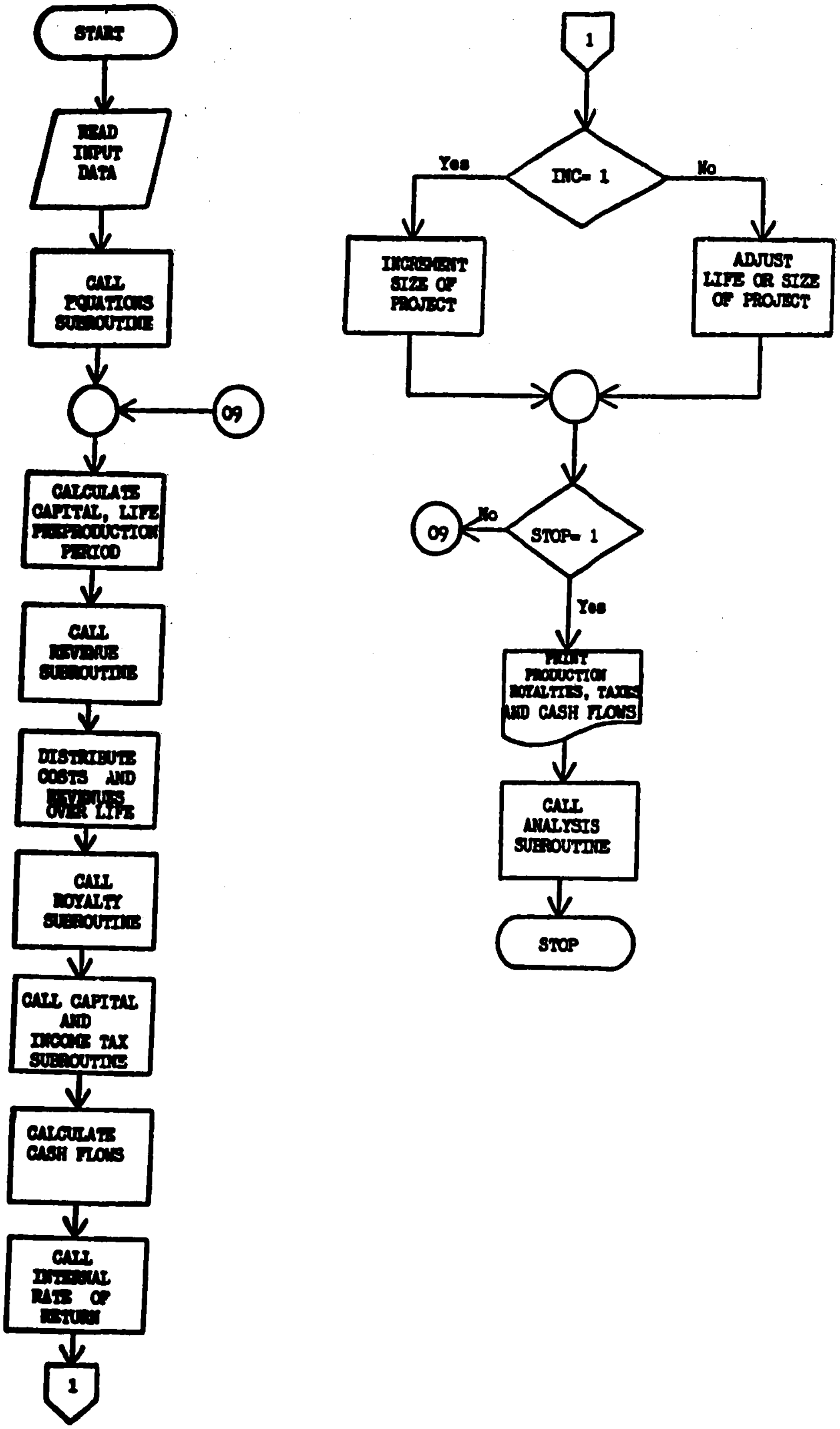


Figure 2.1 Simplified Flow Chart of the Computer Program

BORCAP - 50 element array which contains the assumed borrowed capital by year.

BORROW - total amount of pre-production capital which is assumed to be borrowed.

CAPCOS - 10 by 8 matrix stores the input capital and operating cost data. Each input card will contain the relevant cost data for a particular size of project. The first 7 entries on a card will contain capital and operating cost data and the eighth entry will specify the annual capacity in tons for that project. Up to 10 cards can be read in.

CAPTAX - 50 element array contains the capital tax calculated in the INCTAX subroutine.

CASFLO - 5 by 50 matrix contains the 4 cash flows generated.

CASH - 50 element array contains the cash flow for the current size of project before the investment is incremented.

COST - 7 element array contains the 5 capital cost and a operating cost values calculated for each size of project.

EQUIT - the assumed equity capital for the project.

EXPLOR - 50 element array containing the annual exploration costs.

FEDTAX - 50 element array containing the annual federal income tax liability. This is not being printed by the model in its present form.

G - this is the value for the size increments.

GRADE - 50 element array contains the average grade values calculated for the project.

GROPRO - 50 element array contains the calculated gross annual profit.

INTRST - 50 element array contains the calculated annual interest charges for the payback period.

MAX - maximum tonnage for the ore body as indicated on the options card.

MAXTON - the maximum tonnage for the ore body as calculated from the cut-off grade function.

MCAFLO - 50 element array contains the calculated marginal cash flow for the incremental investment.

MININV - 50 element array contains the calculated annual mining investment.

MINRAL - 10 by 8 matrix stores input mineral reserve data. Each input card will contain 3 entries. The first will be an average grade figure, the second a cut-off grade figure, and the third the tonnage of mineral above the assumed cut-off grade. Again, up to 10 sets of data can be stored.

OH - overhead operating costs, presently at 5% of production operating costs.

OLDR - rate of return for previous assumed project.

OLDRM - rate of return on the incremental investment for the previous assumed project.

OPTR - the optimum rate of return value being passed to the ANALYS subroutine.

OSIZE - the size of the project that yeilds the maximum rate of return.

PREPRO - 50 element array containing the annual pre-production values for the project.

PRIN - 50 element array containing the annual amount of principal being paid on the assumed debt.

PROINV - 50 element array containing the annual processing investment.

R - 5 element array containing the rates of return for the four cash flows.

RCVRAT - assumed value for the concentrator recovery rate.

RMIN - assumed value for the minimum acceptable rate of return on incremental investment.

REVENV - 50 element array containing the annual revenue the project could expect.

R1, R2 - constants for the concentrator recovery rate function.

S - interest rate for borrowed capital.

SIZE - the annual capacity of the project in tons of ore.

SIZZ - 50 element array containing the annual production in tons of ore. This array is passed to the ANALYS subroutine for the sensitivity and probabilistic analysis.

SM, SC - salvage values for the mining and concentrating assets.

SOCINV - 50 element array containing the annual investment in social capital.

T - discount rate for the project; used in the ROYALT subroutine.

TAPCOS - total capital invested during the pre-production period.

TAX - 50 element array containing the anticipated annual income tax for the project.

TL - tons of ore processed in the final year of operation and fraction of final year during which production occurs.

TOTCOS - total capital investment (excluding working capital).

TOTINV - 50 element array containing total annual capital investment.

TOTROY - 50 element array containing the anticipated annual royalty for the project.

VALUE - net smelter return from all recoverable metals expressed as value per pound of the principal recoverable mineral.

WORCAP - 50 element array containing the assumed working capital used for the project.

YX - stores the value for the project size where a tonnage constraint occurs.

YY - stores the value for the project size during normal optimization.

The interger variables listed in alphabetical order are as follows:

BET - used in the SIZE adjustment part of the program to indicate when the size is optimum.

C - first year of production for the project.

CBL - book life of concentrator assets.

D - last year of the pre-production period for the project.

E - second year of production for the project.

F - set at a period of 1 year; used in the part of the program which optimizes the life of the project.

H - 7 element array containing the information as to the kind of equation which best represents each of the 7 various cost functions.

HG - instruction to the program as to how the ore body is to be mined (high-graded or mined at the average grade of the reserves).

HH - 7 element array containing the information as to the kind of equation which best represents each of the 2 mineral grade functions.

IC - instruction to the IRR subroutine that four cash flows will be passed from the MAIN.

ID - instruction to the IRR subroutine that one cash flow will be passed from the MAIN.

INC - used to indicate that once the maximum rate or return has been calculated, the investment will be incremented (if the average rate of return is sufficiently large).

IOP - instruction to the program as to how secondary ore reserves are to be included in the evaluation.

ISEN - instruction to the program as to whether a sensitivity analysis and/or a probabilistic analysis is to be done.

IY - years of additional possible production once the primary ore reserves have been mined.

LET - used in the part of the program where project life is optimized to indicate when this has been done.

LIFE - this is the period of production for the primary ore reserves.

LIM - signal to the program indicating that a tonnage constraint is in effect.

LL - stores value of primary ore reserves life is an ore tonnage constraint exists.

MBL - book value of mine assets.

N - this is the life of the complete project.

P - this indicates to the EQUATN subroutine that 7 equations are to be calculated.

PG - instruction to the program that will indicate whether or not the equations are to be printed.

PP - this indicates to the EQUATN subroutine that two equations are to be calculated.

SET - used in the investment increment section of the program to indicate if the marginal cash flow is to be calculated or if the size is to be incremented first.

STOP - used to signal that the project has been optimized. All financial data can be printed and the analysis of the project can begin.

WW - second last year of operation for the project.

2.1.2 Input Data

Data is provided to the MAIN routine by statements 0003 through 0008. The first two cards read are a data card and an options card. The anticipated net smelter return (VALUE), debt equity ratio (DER), interest rate (S), the discount rate (T), the maximum size for the ore body (MAX), and the minimum acceptable rate of return (RMIN), are project parameters. L and M indicate the number of cost data cards and mineral reserve data cards respectively. HG is the mining sequence option. 00 is instruction to mine the primary ore at average grade of the primary reserves; 01 means mine the primary ore taking the highest grade material first. ISEN is the analysis option. 00 means do not do any analysis; 01 means do a probabilistic analysis; 02 means do a sensitivity and probabilistic analysis, and 03 means do a sensitivity analysis. IOP is the secondary ore reserve option. 00 means exclude the secondary ore reserves from all calculations till the very end; 01 means include the secondary reserves in all calculations; 02 means do not include the secondary ore reserves till the maximum rate of return for the project has been calculated. PG is the graph option. 00 means do not print graphs; 01 means print graphs. These will be for the 7 cost equations and 2 mineral reserve equations.

Statements 0005 and 0006 read in the capital and operations cost data. Each card will contain data for 5 classes of capital, mine operating costs, processing operationg costs, and the size of operation these costs apply to. There is one card per project size. Because this cost data is used to calculate continuous functions, a minimum of 3 sets of data should be provided.

Statements 0007 and 0008 read in the mineral reserve data. Each card will contain an average grade figure, a cut off grade figure, and the total mineral tonnage to which these figures apply. As with the cost data, a minimum of three sets of data should be provided. If one data card is provided, the program assumes that the tonnage figure is for the whole deposit so that the average grade figure will be that for the whole deposit. A log-linear relationship between tons of mineral and average grade is assumed.

2.1.3 Calculate Equations

The first time the EQUATN subroutine is called (statement 0015) the seven cost equations are calculated using the data in CAPCOS. L is the number of sets of data, AA and BB will contain the equation constants that are calculated, H will indicate which of three kinds of equation is to be used for each function, P will indicate how many equations are to be calculated, and PG will instruct the subroutine as to whether or not graphs of the equations are to be printed. MAX is the maximum tonnage of mineral for the deposit.

At statement 0016 this subroutine is called again to calculate the mineral reserve equations. The subroutine parameters have the same meaning as before. In this case, however, only two equations are being calculated rather than seven.

Statements 0019 to 0025 calculate a maximum tonnage for the mineral deposit. Either this or the value MAX will be the total tonnage constraint, depending which is the smaller.

Statements 0026 to 0028 initialize SIZE and LIFE for the project before the iterative process begins.

2.1.4 Calculate Capital, Life, and Preproduction Period

Statement 0031 is the starting point for that part of the program which will be continuously used in the iterative process that will optimise the project.

Statements 0032 to 0040 determine if a tonnage constraint is in effect. If so, this will alter the optimizing sequence for the program.

Statements 0041 to 0048 calculate the total capital costs in the five categories that have been established plus the mine operating costs and the processing operating costs. Note that in each case the cost is a function of SIZE, the annual rated capacity for the project. From statements 0049 to 0054 the appropriate pre-production period is determined. This is a function of the total project size as measured by the total capital investment. Statements 0055 to 0057 identify specific points of time during the complete life of the project. D is the end of the pre-production period; E is the second year of production; N is the sum of the pre-production period and the life of the primary ore reserves.

2.1.5 Calculate Annual Revenue

In statement 0060 the annual revenue subroutine (ANNREV) is called. Parameters fed to the subroutine are: LIFE, the production period for the primary ore reserve; SIZE, the annual capacity of the project in tons of ore; VALUE, the net smelter return; A, B, and HH, the mineral reserve equations; D,C,N; R1, R2, the recovery rate constants for the principal mineral; TOPCOS, the total operating costs per ton of ore, and; MAXTON, the size of the orebody. Information returned from the subroutine is as follows: REVENUE, the annual revenue the project could anticipate; GRADE, the average grade of ore mined each year; IY, the number of years of secondary ore production, and; TL, the tons of ore mined in the assumed final year of operation. Options to the subroutine are: HG, instruction as to whether the deposit is to be high-graded or not, and; IOP, instruction as to how the secondary ore reserves are to be included in the evaluation of the project.

2.1.6 Distribute Costs and Profit Over the Life

In statements 0061 to 0097 costs and revenues are allocated to each year of the project in preparation for the income tax and royalty calculations. The capital costs are distributed equally over the pre-production period in statements 0065 to 0069. The equality assumption can be changed without much difficulty although many more statements would be necessary. Doing this would alter the rate of return calculation only slightly.

Working capital is assigned to the project in statements 0070 to 0081. Included in the working capital recovered in the final year is any salvage value for the mining and processing assets. Statements 0082 to 0097 are used to assign on-going investment to the project as well as calculate the annual gross profit.

2.1.7 Calculate Royalties

Statement 0098 calls the ROYALT subroutine. This subroutine calculates the royalties that the project could anticipate under the Metallic Minerals Royalty Act. Through proper depreciation claims it also calculates the minimum royalty the project could anticipate. Information fed to the subroutine is: GROPRO, the gross profit; MININV, PROINV, EXPLOR, SOCINV, and PREPRO, the five categories of capital investment, and; N, C, and T, the latter being the discount rate. Information returned is TOTROY, the total annual royalty the project could anticipate.

2.1.8 Calculate Capital and Income Taxes

Statement 0099 calls the INCTAX subroutine. This subroutine calculates project income taxes, capital taxes, and the interest and principal per year for the pay back period on any borrowed capital. Information to the subroutine includes: GROPRO, the gross profit; five kinds of capital cost; A, C, and S, the latter being interest rate; WORCAP, working capital; DER, the debt-equity ratio; IY, number of years of secondary ore production, and; SM and SC, the assumed salvage value of mining and processing assets. Information returned is: TAX, the income tax; INTRST, annual interest payments; PRIN, annual payments on the principal, and; CAPTAX, the capital tax.

2.1.9 Calculate Cash Flows

The cash flows are calculated in statements 0100 to 0106. Four cash flows are calculated although only three are printed by the program as it is at present. The first cash flow is for the overall project as it would be evaluated by a private investor. The second cash flow is that from the point of view of an investor providing equity capital (add borrowed capital and deduct debt repayment and interest). The third cash flow is the result of adding back royalty and tax payments. Thus it is the cash flow a publicly owned project could anticipate (assuming that the project would not have been otherwise undertaken by a private firm so that taxes and royalties are not a cost to the project either as a direct cost or as forgone revenue to the government from a private firm). The fourth cash flow assumes that the project would be undertaken privately if not done by the government, thus the only gain to the province by doing it would be the federal income tax payable.

2.1.10 Call the IRR Subroutine

Statement 0108 calls the internal rate of return subroutine which calculates the rates of return for the four cash flows. Besides the cash flows, the subroutine is given the total length of the project, N, and it is told the number of cash flows to evaluate, IC. The rates of return are returned in vector R. Statement 0114 terminates the analysis if on the first trial, the rate of return is less than zero. Statement 0115 terminates the analysis if SIZE or LIFE are reduced to 10,000 ton/year or 1 year respectively. In either case, transfer is made to the end of the program where an appropriate statement is printed.

2.1.11 Adjust Life or Size of Project

Statements 0119 to 0158 are used to incremat the size or life of the project depending on the result of the IRR calculation.

The sequence of events in the optimizing process is best understood from Figure 2.2. SIZE and LIFE for the project are initialized at some reasonable value at the beginning of the program (see statements 0026 to 0028). Also OLDR, the previous rate of return, is set at a very low value. Assuming a positive rate of return is generated, then with INC=0 and LET=0, the program increases the life of the project by F which is set at +1 year. OLDR is assigned to the value of R(1). Control passes to label (statement 0187) 30 and from there to label 09 (see Figure 2.1). A new rate of return is calculated and compared to the previous rate. If the new rate is larger, the life is again increased by 1 year. This continues till the new rate of return is smaller than the previous one. The life of the project is reduced by 1 year and F is changed to -1. LET is incremented by 1. The life of the project is further reduced by 1 year (since LET=1 and R(1)$<$OLDR). In this case the new rate of return will still be less than OLDR, so a year is added back to the life and F made equal to +1 again. LET is again incremented by 1 (to a total of 2). The size of the project is now increased by G (equal to 10000 tons per year) and a new evaluation done. Since LET is now equal to 2, the size of the project will be increased or decreased in the same manner as was the life. When a size adjustment no longer results in an increase in the rate of return, the life of the project is again adjusted up or down. When this is optimum, the size is once more adjusted. If no further increase in the rate of return is possible, then INC is set equal to 1 so that the incremental rate of return to a small increase in the size of the project can be determined.

If at this time IOP=2, meaning that marginal ore down to the operating cost cut-off grade has not been included in the evaluation, IOP is now set equal to 1. In the incremental analysis it will now be included.

If a tonnage limit was specified for the deposit, then if this should be exceeded at any time in the process of maximizing the rate of return, a change in the procedure takes place. A year is deducted from the life of the project and only SIZE optimizing takes place. When the rate of return has been maximized, the results of the calculation are printed and sensitivity and probabilistic analysis takes place. No increment is made to the investment.

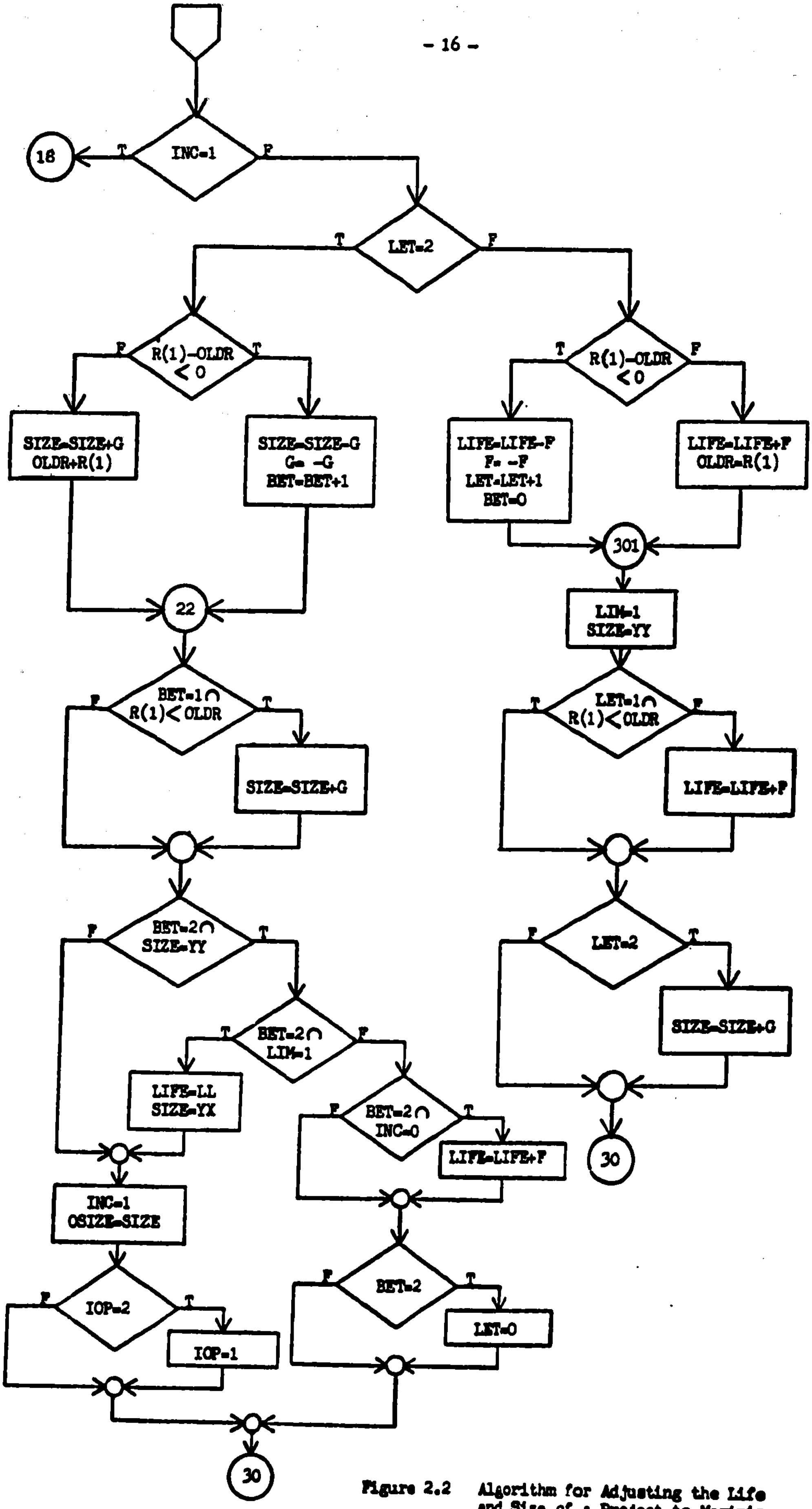


Figure 2.2 Algorithm for Adjusting the Life and Size of a Project to Maximise the Rate of Return

2.1.12 Calculate the Return to the Incremental Investment

The investment in the project is incremented by small steps and the marginal rate of return determined in statements 0159 to 0186. The algorithm for doing this is shown in Figure 2.3.

Assuming that the maximum rate of return exceeds a specified minimum, the incremental investment analysis occurs automatically. Initially SET will equal 1 so that the size of the project will be increased by G while the cash flow yielding the maximum rate of return will be stored in CASH. The cash flow for the project at its new size is now calculated. The previous cash flow (in CASH) is deducted from this to arrive at the marginal cash flow. So long as the rate of return to the marginal cash flow exceeds the specified minimum, the size of the project continues to be increased in small steps.

When the optimum project is determined the results are printed.

2.1.13 Print Details of Optimum Project

Statements 0190 to 0238 print the details of the optimum size of mine and processing facility.

Statement 0192 calls PRNPRO which is in the REVENU subroutine. This prints the production data for the last calculation. It will show the annual tons of ore milled, the average grade of ore, the mine cut-off grade, the pounds of principal mineral in the concentrate, and the total value of the concentrate. The value will reflect the assumed by-product content.

Statements 0194 to 0203 summarize the financial data. The average and marginal rates of return are printed, the various capital and operating cost totals are printed, and the assumed borrowed capital and equity capital totals are printed.

Statements 0204 to 0211 print the various amounts of capital investment as they are distributed over the life of the project. This will show the amount of investment by year for the 5 classes of capital plus the amount of working capital assumed.

Statement 0212 calls PRNROY. This will print the details of the

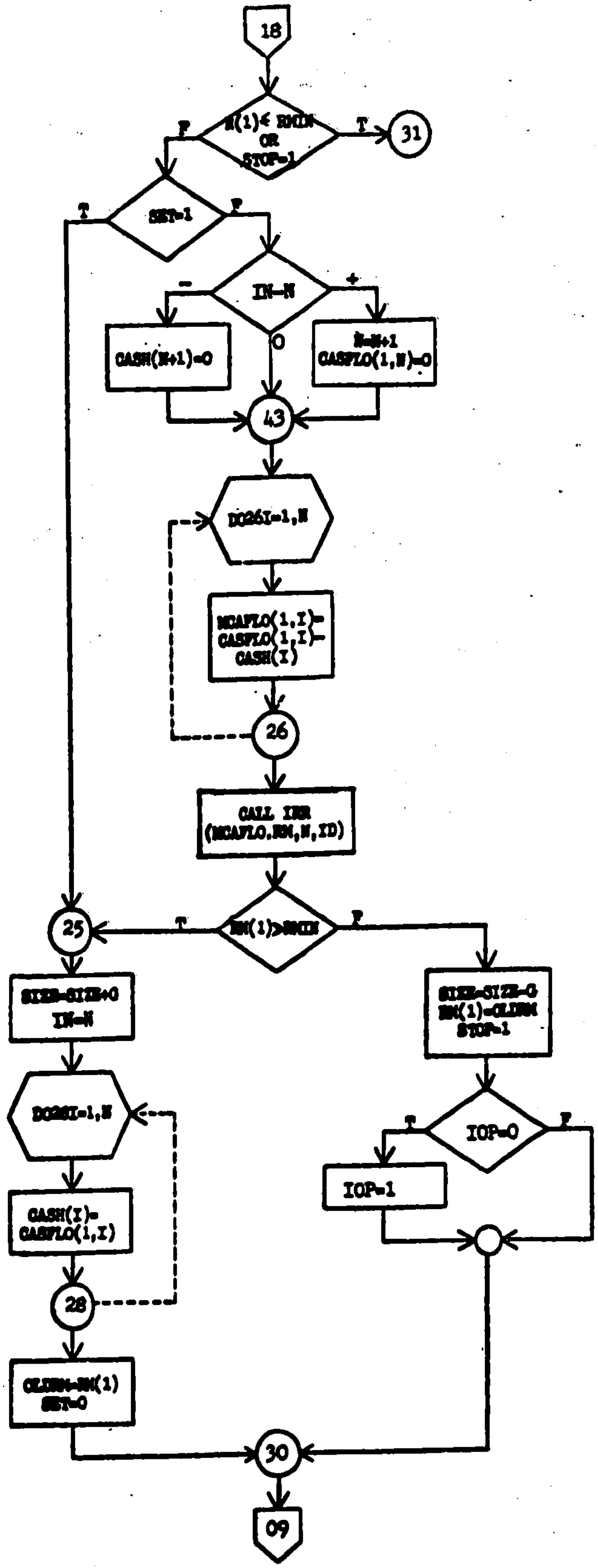


Figure 2.3 Algorithm for Incrementing the Size of a Project and Determining the Marginal Rate of Return.

last royalty calculation in the ROYALT subroutine. The first page of the printout details the royalty calculation; the second page records the investment made and the undepreciated balance for the two classes of capital asset.

Statement 0213 calls PRNTAX in the INCTAX subroutine. The first page of this printout will detail the annual capital tax calculation. This is assessed on the firms paid up capital which includes borrowed and equity capital plus any surpluses. The second page of this printout shows the annual allowable deductions from gross profit in order to arrive at the taxable income. The third page shows the annual tax calculation and the undepreciated balances for the various classes of capital.

Statements 0215 to 0238 print the three cash flow calculations. The first page of the printout details the cash flow calculation for the overall project. Deducted from gross profit are all taxes, royalties, and capital expenditures. The second page details the cash flow calculation if taxes and royalties are not a cost to the project as would be the case if the project would only be undertaken by the Crown. The third page details the cash flow to equity calculation. This separates the debt capital from the equity capital and deducts interest and debt repayment from the project cash flow.

2.1.14 Call ANALYS Subroutine

Statement 0241 calls the subroutine which will undertake the sensitivity and probabalistic analysis. Parameters fed to the subroutine are all those affecting the economic worth of the project. These are in order: net smelter return (VALUE); tons of ore milled per year (SIZE); the total capital and operating costs (COST); the recovery rate constants (R1,R2); the working capital (WORCAP); the annual exploration costs (EXPLOR); the annual pre-production costs PREPRO); the annual mining investment (MININV); the annual processing investment (PROINV); the annual social capital investment (SOCINV); the annual ore grade (GRADE); the project life (N); the first year of production (C); the year preceeding production (D); the interest rate (S); the debt-equity ratio (DER); instruction as which analysis

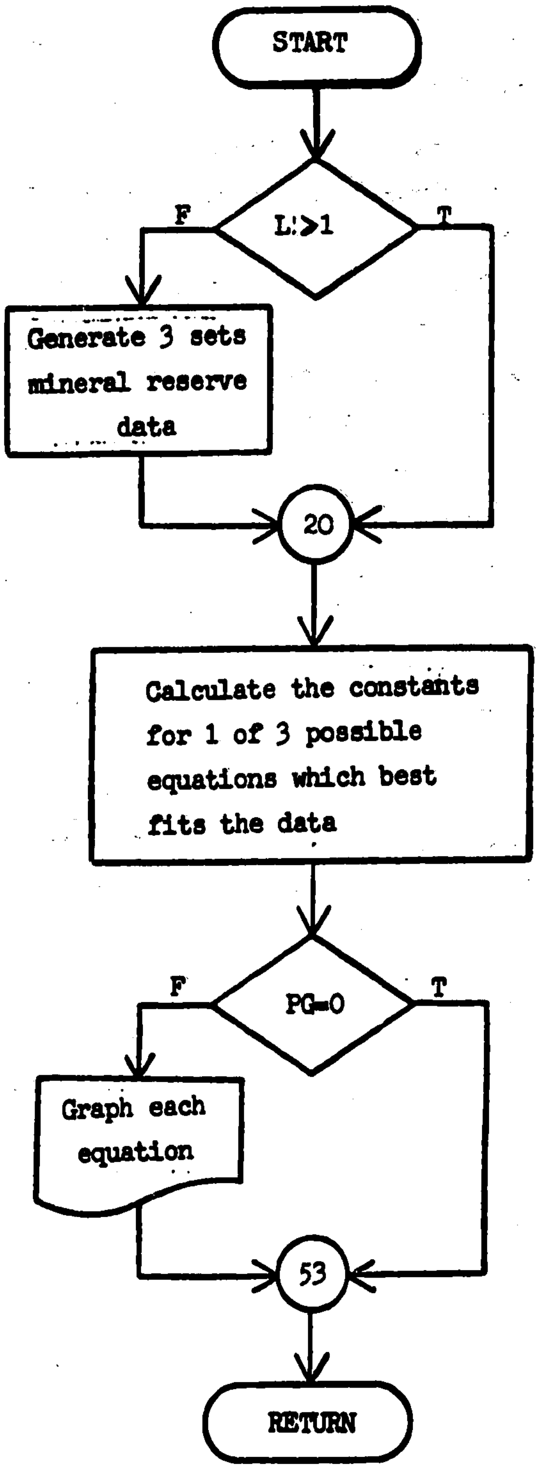


Figure 2.4 Simplified Algorithm for the EQUATN Subroutine.

is to be done (ISEN); the optimum project rate of return (OPTR); the number of years of secondary ore production (IY), the discount rate to be used (T); the salvage values (SM and SC), and; the fraction of the final year during which production occurs (TL).

2.2. The Equations Subroutine (EQUATN)

This is the first subroutine called from the main part of the program. It is called only twice, first to calculate the five capital cost and two operating cost functions, and second, to calculate the two mineral reserve functions. A simplified algorithm for this subroutine is shown in Figure 2.4. The compiler listing is at the end of the Chapter.

2.2.1 EQUATN Variables

The REAL variables in this subroutine are defined alphabetically as follows:

- A – 3 by 7 matrix containing the first constant for each of three possible equations, up to seven equations.
- AA – 7 element array containing the appropriate first constants from A for transfer to the main part of the program.
- B – 3 by 7 matrix containing the second constant for each of three possible equations, up to seven equations.
- BB – 7 element array containing the appropriate second constant from B for transfer to the main part of the program.
- CAPCOS – same as in subsection 2.1.1.
- CPACTY – 20 by 3 matrix will contain the independent variable in linear, hyperbolic, and natural log form for up to 20 sets of data.
- LABEL – used in the graphing part of the subroutine; this will be assigned the Hollerith string used to label the vertical axis.
- MAX – same as in subsection 2.1.1.
- MAXTON – same as in subsection 2.1.1.

MINGRA - if only one data card for the mineral reserve is provided (thereby assuming an exponential grade-tonnage relationship), this will be assigned the average grade figure for use in calculating the 3 sets of mineral reserve data.

R - 3 by 7 matrix which will contain the correlation coefficient for each possible kind of function, up to seven equations.

SIZE - in the graphing part of the subroutine this will be assigned the value for the independent variable while the dependent variable is calculated; it is used for all equations.

SUM - 10 by 3 by 7 matrix, used to store the summations necessary in the least squares method of deriving the best equation from the raw data.

TOTMIN - see MINGRA above. This variable will be assigned the total tonnage figure for the deposit.

VALUES - 50 element array; in the graphing part of the subroutine this will contain the values of the dependent variable for the equation being graphed.

Y,YY,YYY - these three variables store the Hollerith strings for the labeling of the vertical axis.

Z,ZZ,ZZZ - in the equation part of the subroutine, these variables are assigned the numerator and denominator values for the equations that determine the correlation coefficients and equation constants.

The integer variables in alphabetical order are:

AST - assigned '*' for the graphing of the various functions.

BLANK - assigned a space for the graphing.

H - 7 element array that is used to pass information to the MAIN as to the kind of equation that best expresses the raw data provided in CAPCOS.

L - number of sets of data being provided.

LINE - 100 element array stores the characters for each line of the graph.

P - number of equations to be derived.

PERIOD - assigned '.' for the graphing.

PG - same as in subsection 2.1.1.

POINTS - the 100 possible real values in VALUE are converted to 50 possible integer values for the graphing.

Q - the last value on each data card (which is the abscissa value for each set of data).

YLABEL - assigned the vertical axis value for the graphs.

2.2.2 Preparation of the Data for Least-Squares Analysis

Statements 0004 to 0021 prepare the data passed from the MAIN for use in the determination of the appropriate equations.

In the case of the mineral reserve data, if only one card is provided, then an exponential grade-tonnage relationship is assumed. Statements 0010 to 0015 will then generate 3 sets of data based on this assumption which will then be used to generate the two constants for the average and cut-off grade functions.

The exponential grade-tonnage relationship produces two separate equations as follows:

Given a mineral deposit of size D tons with average grade b, for a cut-off grade c, the amount of ore E will be:

$$E=De^{-c/b}$$

This is rewritten so that c=b Ln(D/E) as in statement 0014. Assuming we choose a cut-off grade greater than zero, the average grade g of the ore will be:

$$g=b+c$$

These two functions are then used to generate the 3 sets of data. The equations that will be generated by least squares techniques from the data are:

$$g=a_1 + b \ln E$$

and

$$c=a_2 + b \ln E$$

For both the cost and reserve relationships, three kinds of function are fitted to the raw data. The first will be a simple linear function, the second will be a hyperbolic function, and the third will be a log-linear function. The equation chosen will be the one with the highest correlation coefficient.

The correlation coefficients and constants for each kind of function can be calculated in exactly the same manner if each is expressed in a linear form. The linear form for the hyperbolic and log-linear functions are:

$$Y = a + bX' \quad \text{where } X' = \frac{1}{X}$$

$$Z = c + dX'' \quad \text{where } X'' = \text{Ln}X$$

The subroutine does this by converting the abscissa for each set of data to the appropriate form in statements 0020 and 0021.

2.2.3 Calculating the Appropriate Equations

Statements 0022 to 0071 calculate the two constants and the correlation co-efficient for the three functions that are fitted to each set of data. With the exception of the mineral reserve cut-off grade function, all equations are calculated the same way. The constants are determining by solving the normal equations for the least square line $Y = a + bX'$.

Thus:

$$\begin{bmatrix} n & \sum X_i' \\ \sum X_i' & \sum X_i'^2 \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} \sum Y_i \\ \sum X_i' \ Y_i \end{bmatrix}$$

where X_i' can be X_i , $\frac{1}{X_i}$, or $\text{Ln}X_i$

$$\text{Therefore } b = \frac{n\sum X_i'Y - (\sum X_i')(\sum Y_i)}{n\sum X_i'^2 - (\sum X_i')^2}$$

$$\text{and } a = \frac{\sum Y_i - b\sum X_i'}{n}$$

The correlation coefficient R is:

$$R = \frac{n\sum X_i'Y - (\sum X_i')(\sum Y_i)}{((n\sum X_i'^2 - (\sum X_i')^2)(n\sum Y_i^2 - (\sum Y_i)^2))^{\frac{1}{2}}}$$

Statements 0048 to 0071 choose the constants for the equation which best fits the raw data, i.e.: the equation with the correlation co-efficient closest to 1. These constants are fed back to the MAIN in the AA and BB arrays while the kind of equation is indicated by the H array. If the constants are for a linear function, H(K)=1; if for a hyperbolic function, H(K)=2, and; if for a log-linear function, H(K)=3.

The procedure for calculating the mineral reserve cut-off grade function varies from the procedure for the other equations. This is because the method of calculating both the cut-off grade function and average grade from geological data that is often not too reliable can lead to equations which are logically inconsistent. In the extreme case, one equation could be linear while another could be logarithmic. In a more practical situation, the two linear equations or two logarithmic equations can be inconsistent. In this program, the equation that is calculated in the normal manner is the average grade function. The assumed cut-off grades are entered on the mineral reserve data card but are not normally used. The cut-off grade function which will then be consistent with the average grade function is derived as follows:

Assume an average grade function $Y = a + bX$. Y is the average grade and X is the total tons of mineral. The metal M in this deposit is the average grade Y times the tonnage X.

That is:
$$M = XY$$
$$= aX + bX^2$$

The cut-off grade C, can be expressed as a small change in the quantity of metal divided by a small change in the tons of ore containing the metal or,

$$C = \frac{dM}{dX} = a + 2bX$$

In other words, both the average grade and cut-off grade functions logically have the same intercept "a" but the latter has twice the absolute value of slope (which is 2b). In the program, the cut-off grade function is automatically assigned a first constant "a" equal to that calculated for the average grade function, and a second constant "b" equal to 2 times that calculated for the average grade function.

The same procedure applies if the first equation is log-linear.

Assume $Y = a + b\text{Ln}X$

$$M = XY = aX + bX \cdot \text{Ln}X$$

$$\frac{dM}{dX} = a + b(X \cdot \frac{1}{X} + \text{Ln}X) = a + b(1 + \text{Ln}X) = C$$

i.e. $C = (a + b) + b\text{Ln}X$.

In the program, the first constant for the cut-off grade function is the sum of the two constants for the average grade function and the second constant is the same as that for the average grade function.

This procedure applied to a hyperbolic function yields a cut-off function C = a. That is, the cut-off grade function consistent with a hyperbolic function is a constant to which the average grade function is asymptotic. This is not realistic, but in the unlikely event the best average grade function should be hyperbolic, the assumed geological cut-off grade data will be used to calculate the cut-off grade function.

2.2.4 Graphing Each Function

If a graph is to be printed for each function, this will be done by statements 0072 to 0186.

The tonnage constraint for the mineral reserve is determined by statements 0099 to 0106. This constraint will be printed as a vertical line on the two mineral reserve graphs.

Statements 0114 to 0123 print the equation for each function after the title on the graph.

Statements 0124 to 0141 determine the interger ordinate values for 100 real abscissa values. Because a vertical space is about twice the width of a horizontal space, only 50 lines are printed for the 100 possible abscissa values. This is accomplished in statements 0136, 0138, and 0140 where the POINTS value (between 1 and 10 or 1 and 100) is further divided by 2.

From statements 0143 to 0186 the actual printing of the graphs takes place. There are three basic kinds of graph each with different labels and size of axis. These are for the capital cost functions, the operating cost functions, and the mineral reserve functions.

2.3 The Annual Revenue Subroutine (ANNREV)

This subroutine is called from the main program every time a change is made in the size or production life of a project. Its main purpose is to calculate the annual gross revenue a project of given size and life could anticipate. Figure 2.5 is a simplified algorithm for this subroutine. The compiler listing is at the end of the Chapter.

2.3.1 ANNREV Variables

The real variables in alphabetical order are as follows:

A - same as in subsection 2.1.1.

AVGRAD - this variable will be assigned the average grade of the primary ore reserves. This value will be used in the part of the subroutine that is calculating the production of the marginal ore reserves after the primary ore reserves have been depleted.

B - same as in subsection 2.1.1.

CCGRAD - 50 element array containing the value for the ore cut-off grade for each year.

COGRAD - operating cost cut-off grade.

GRAD - 2 element array will be assigned the average and cut-off grades for the ore reserve if it is to be mined at those grades for each year of production (rather than high-graded).

GRADE - same as in subsection 2.1.1.

MAXTON - same as in subsection 2.1.1.

METAL - 50 element array contains amount of recoverable metal per year in the concentrate.

PAVGRA - average grade of total production of ore for previous years.

PCGRAD - cut-off grade of total production of ore for previous years.

PMETAL - metal content of total production of ore for previous years.

PROD - 50 element array, contains annual amount of ore milled.

PTONS - total production of ore for previous years.

R1, R2 - same as in subsection 2.1.1.

RCV - 50 element array, contains recovery rate for each year.

REVENU - same as in subsection 2.1.1.

SIZE - same as in subsection 2.1.1.

TAVGRA - average grade of total ore mineable to operating cost cut-off grade.

TL - same as in subsection 2.1.1.

TONS - total tonnage of primary ore.

TMETAL - metal content of total ore milled.

TOPCOS - same as in subsection 2.1.1.

TTONS - total ore milled.

VALUE - same as in subsection 2.1.1.

XAVGRA - average grade of secondary ore.

XTONS - tons of secondary ore.

XYEARS - years of secondary ore production.

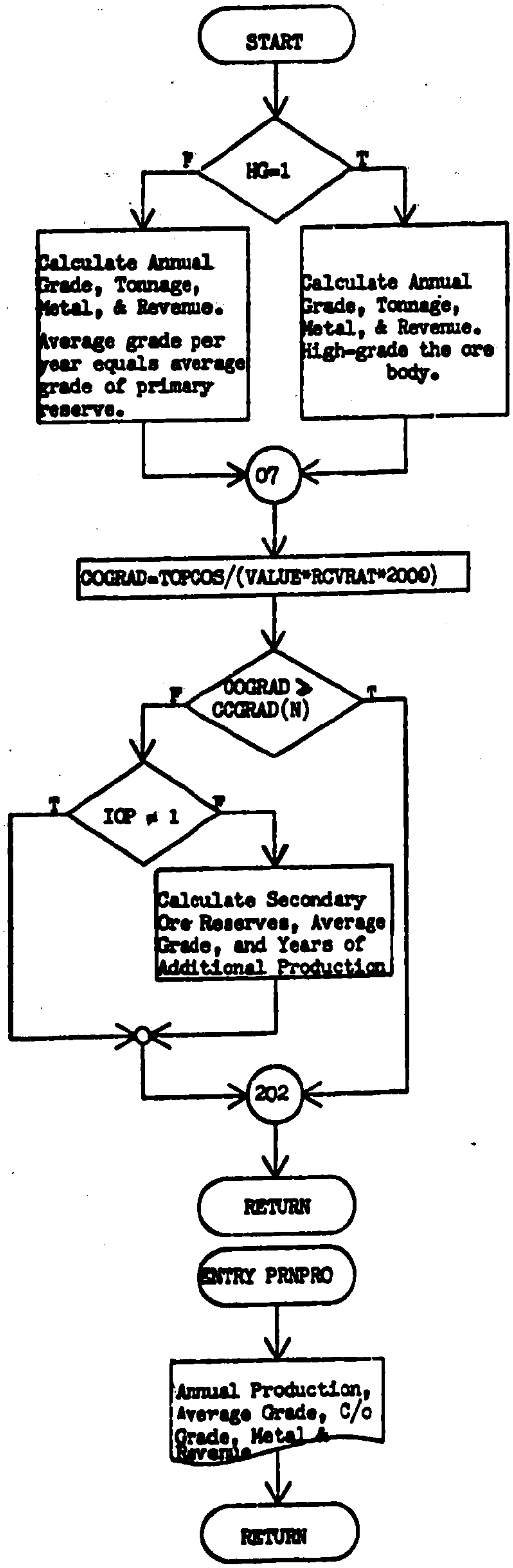


Figure 2.5 Simplified Algorithm for the ANNREV Subroutine

The integer variables are:

C	-	same as in subsection 2.1.1
D	-	" " " " "
HG	-	" " " " "
HH	-	" " " " "
IY	-	" " " " "
LIFE	-	" " " " "
N	-	" " " " "

2.3.2 Production Grade is at Average Grade of Primary Reserves

Assuming that the options card has indicated that the mineral deposit is to be mined so that the average grade of production is at the average grade of the primary reserves, the calculations will be done by statements 0013 to 0028. The average and cut-off grades are calculated by statements 0013 to 0020. Statements 0021 to 0027 place the production figures on the appropriate arrays for transfer back to the main part of the program and for later printing.

2.3.3 The Mineral Deposit is to be High-Graded

If the mineral deposit is to be high-graded the production figures will be calculated by statements 0030 to 0072. The average and cut-off grades for total production prior to the current year are calculated by statements 0033 to 0046. Previous metal production is calculated by statement 0040. The average and cut-off grades for total production including the current year are determined by statements 0053 to 0066. Total metal is calculated by statement 0067. Statements 0068 to 0072 place the production figures in the appropriate arrays for transfer back to the main part of the program and for later printing.

2.3.4 Calculate Production of Secondary Reserves

The operating cost cut-off grade is calculated at statement 0080. Assuming this is less than the cut-off grade of the primary reserves and assuming that the options card or the main part of the program has indicated that the production figures for the secondary ore reserves are to be calculated, this will be undertaken by statements 0082 to 0130.

Since the cut-off grade is a function of the recovery rate (which for the secondary reserves is initially unknown) the value applicable to the primary reserves cut-off grade is used (see statement 0077). The average grade of the secondary reserves is then calculated and the recovery rate re-calculated. If this value differs from the initial assumption by more than .001, then a new recovery rate is used, a new cut-off grade is calculated, and the secondary reserves are re-calculated. This process is repeated 3 or 4 times till the cut-off grade assumption for the cut-off grade is compatable with that for the secondary reserves.

Total tonnage of ore for the deposit is determined by statements 0082 to 0088. The average grade of this ore is determined by statements 0089 to 0095. The secondary ore tonnage, average grade, and years of additional production are determined by statements 0097 to 0109. Statement 0110 converts the year(s) of additional production from a real to an integer variable. Statement 0111 increases the total life of the project by the years of additional production. Statements 0112 to 0130 place the secondary ore production figures at the end of the primary reserve production figures in the appropriate arrays.

2.3.5 Print the Final Production Figures

Statements 0136 to 0144 will print the final production figures for the optimum sized project. This will be printed when called from the main part of the program after the optimum project has been determined.

2.4 The Royalty Subroutine (ROYALT)

This subroutine is also called every time a change is made in the project size and life. The royalty is calculated according to M125, The Metallic Minerals Royalty Act. This subroutine not only calculates the annual royalty but attempts to minimize the total royalty assessment by making the appropriate annual depreciation claims. Since the real rate of return is being calculated for the project, the inflation rate is assumed to be zero. The algorithm for this subroutine is shown in figures 2.6(A), (B), and (C). The compiler listing is at the end of the Chapter.

2.4.1 ROYALT Variables

The real variables in this subroutine are defined alphabetically as follows:

BASROY - 50 element array containing the annual basic royalty payable by the project.

CMPROC - 50 element array containing the cumulative processing investment for each year.

D - the amount by which a depreciation rate is to be varied up or down.

DEPREC - 50 element array containing the annual depreciation claim.

DISROY - 50 element array containing the annual total royalty payable after being discounted by the real opportunity cost of capital, S.

DSUM1 - sum of annual depreciation rates.

EXPLOR - same as in subsection 2.1.1.

GROPRO - same as in subsection 2.1.1.

INCROY - 50 element array containing the annual incremental royalty payable by the project.

MININV - same as in subsection 2.1.1.

MINVB - 50 element array containing the annual undepreciated balance for the mining and service investments.

MSINV - 50 element array containing the annual mining plus social capital investment (in the pre-production period it will also include pre-production plus exploration investment).

MININV	-	same as in subsection 2.1.1.
MINUB	-	50 element array containing the annual undepreciated balance for the mining and service investments.
MSINV	-	50 element array containing the annual mining plus social capital investment (in the pre-production period it will also include pre-production plus exploration investment).
NETPRO	-	gross profit minus the depreciation allowance.
OLDROY	-	stores value of minimum total discounted royalty.
PALLOW	-	50 element array containing the annual processing allowance.
PREPRO	-	same as in subsection 2.1.1.
PROBAS	-	the annual profit base; indicates the maximum amount of profit which will be assessed at the low royalty rate.
PROFIT	-	50 element array containing the profit after the exploration deduction.
PROINV	-	same as in subsection 2.1.1
R	-	50 element array containing the annual depreciation rates.
ROYPRO	-	50 element array containing the annual amount of profit subject to a royalty assessment.
S	-	discount rate; same as T in subsection 2.1.1.
SOCINV	-	same as in subsection 2.1.1.
SUMROY	-	total discounted royalty for the project.
TBASRO	-	total base royalty for any three year averaging period.
TINCRO	-	total incremental royalty for any three year averaging period.
TOTINV	-	50 element array containing total annual capital investment in a project.
TOTROY	-	same as in subsection 2.1.1.
TOTUB	-	50 element array containing the annual undepreciated balance of total capital invested in the project.
TPROBA	-	sum of profit bases for any three year averaging period.
TPROF	-	sum of taxable profit for any three year averaging period.

The integer variables in alphabetical order are:

C	-	same as in subsection 2.1.1.

H	-	same as D in subsection 2.1.1.
K	-	in the depreciation rate adjustment part of the program this will indicate the year in which the rate is being changed.
L	-	in the depreciation rate adjustment part of the program, this will indicate the number of years since a depreciation rate change was able to reduce the total royalty
LET	-	when set equal to 1, indicates that no further reduction in total discounted royalty is possible, given the size of the adjustment increment.
P	-	records how often the depreciation rate adjustment increment has been halved.
Q	-	this will limit the number of times the depreciation rate adjustment increment will be halved.
SET	-	when set equal to 1, this will indicate that the depreciation rate R(K) is to be incremented by $\pm$ D.
STOP	-	when set equal to 1, indicates total royalty is at a minimum

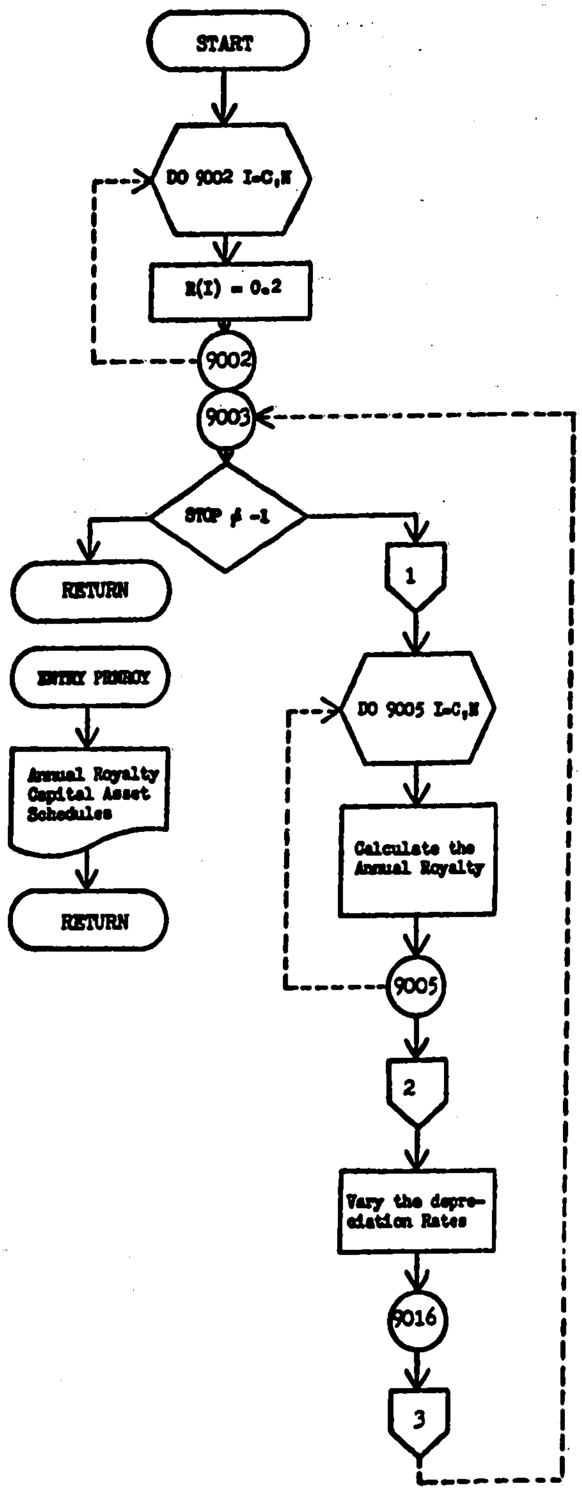


Figure 2.6(A) Simplified Algorithm for Calculating the Annual Royalties and Varying the Depreciation Rates to Minimise the Total Royalty.

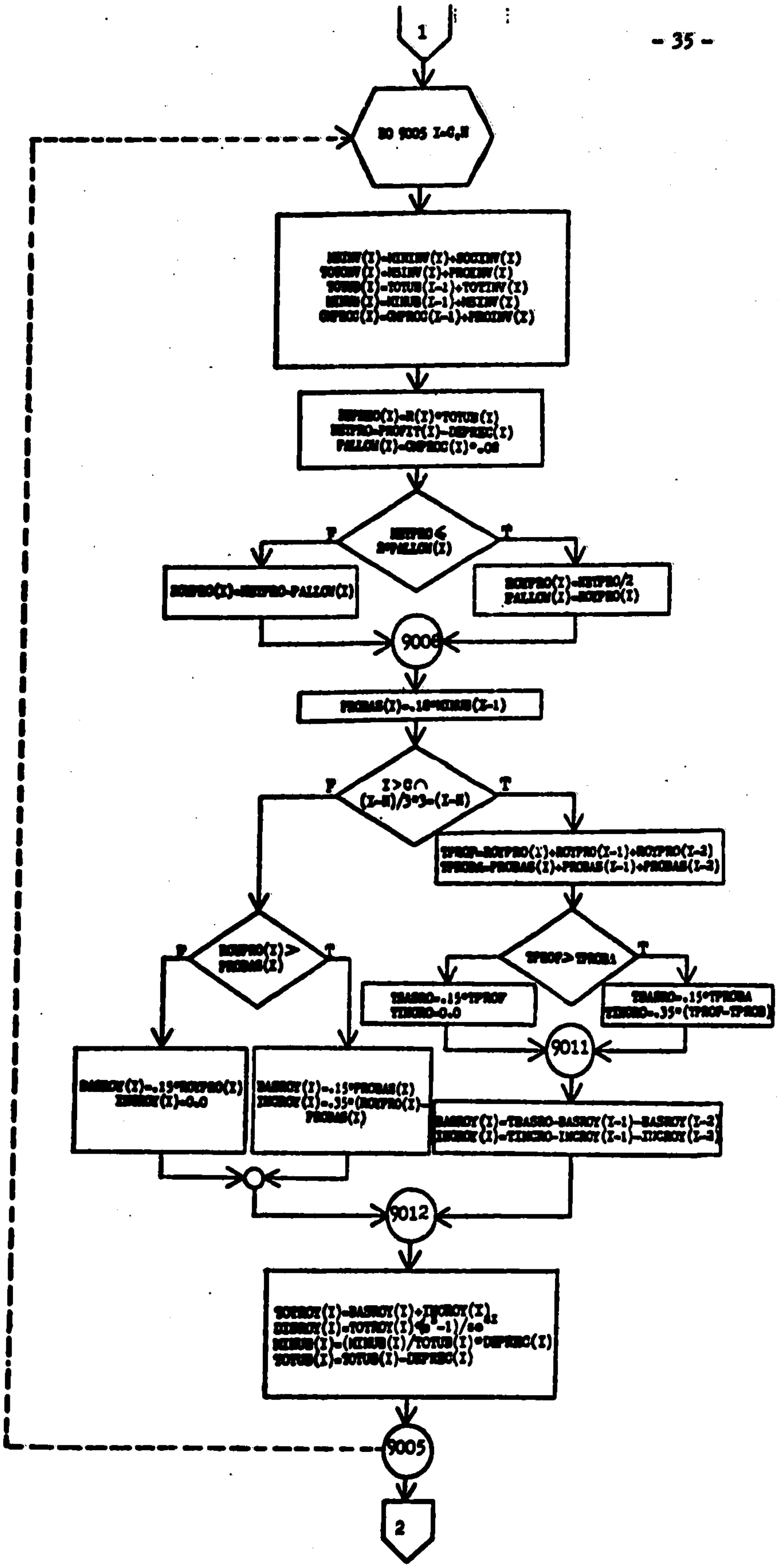


Figure 2.6(B) Simplified Algorithm for Calculating the Annual Royalty

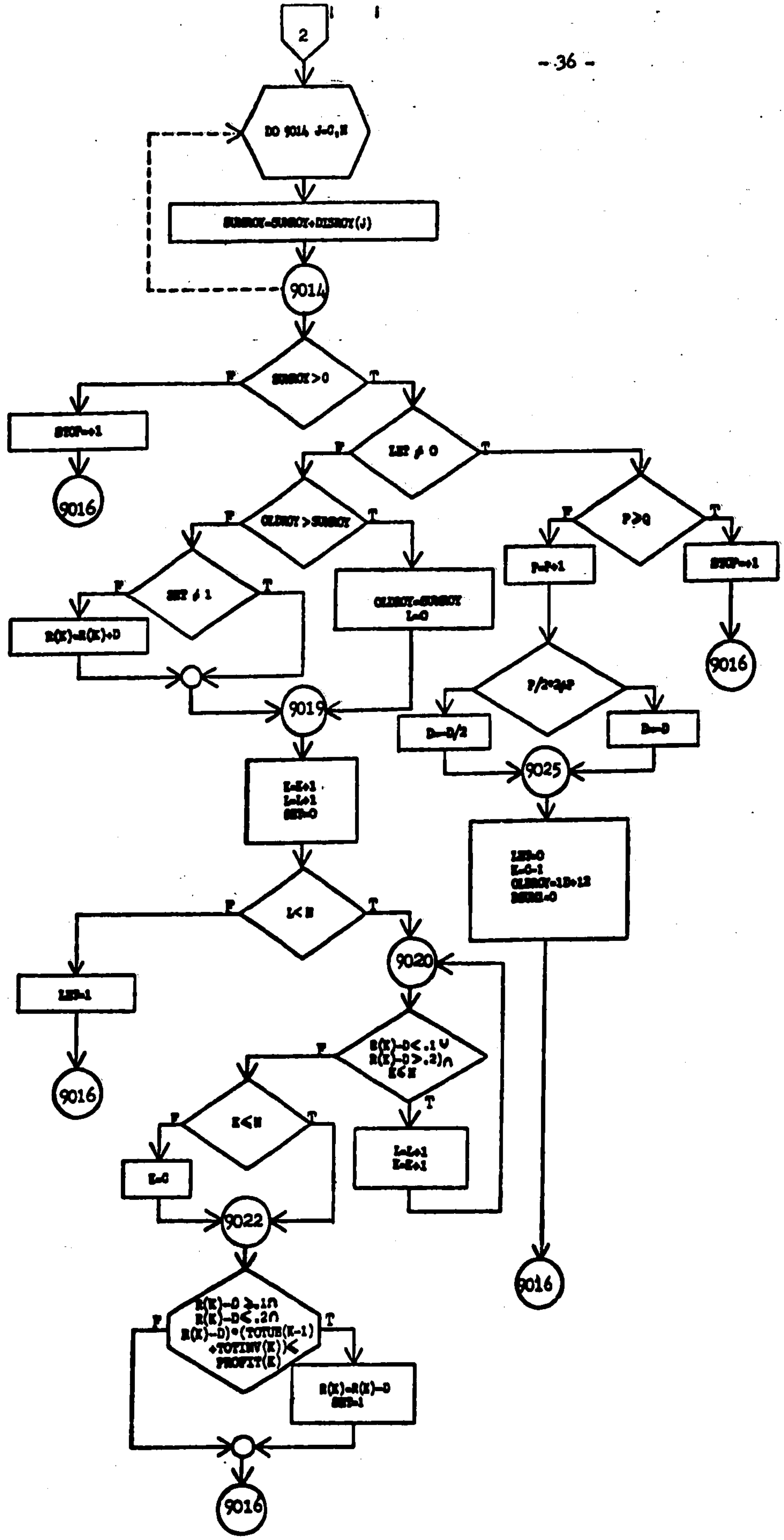


Figure 2.6(C) Simplified Algorithm for Changing the Depreciation Rates to Minimize the Total Royalty.

	1	2	3	4	5
Year	Mine and Service Investment	Cumulative Processing Investment	Total Investment	Mine and Service U.B.	Total U.B.
1	1,500,000	0.0	1,500,000	1,500,000	1,500,000
2	500,000	500,000	1,000,000	2,000,000	2,500,000
3	0.0	500,000	0.0	1,600,000	2,000,000
4	0.0	500,000	0.0	1,280,000	1,600,000
5	0.0	500,000	0.0	1,024,000	1,280,000
6	0.0	500,000	0.0	819,200	1,024,000

6	7	8	9	10	11	12
Gross Profit	Depreciation on Total Assets	Processing Allowance	Net Profit	Profit Base 18% of M & S Asset	Base Royalty	Incremental Royalty
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	$270,000	0.0	0.0
500,000	500,000	0.0	0.0	$360,000	0.0	0.0
500,000	400,000	40,000	60,000	$288,000	$9,000	0.0
500,000	320,000	40,000	140,000	$230,400	$21,000	0.0
500,000	256,000	40,000	204,000	$184,320	$27,648	$6,888

Table 2.1 Example of Royalty Calculation Assuming no Inflation

2.4.2 Initialization and Preproduction Period

Statements 0004 to 0048 prepare the subroutine for the royalty minimization procedure. Statements 0004 to 0008, 0020, and 0045 to 0048 apply specifically to that part of the subroutine which will be adjusting the annual depreciation rates. Statements 0010 to 0019, and 0027 to 0036 set the preproduction values for the various arrays to zero. Statements 0021 to 0025, and 0037 to 0042 establish the yearly amounts for the mine and service asset undepreciated balance, and determine the cumulative processing investment.

Statements 0043 and 0044 are particularly significant in that they set all depreciation rates at the upper limit of 20% (allowed by the royalty legislation, M125). From this upper limit, they will be systematically reduced to determine if the total royalty payable by the project can be reduced.

2.4.3 Calculating the Annual Royalty

Statements 0049 to 0096 will calculate the annual total royalty a project might anticipate. The algorithm for this is shown in figure 2.6(B). The Metallic Minerals Royalty Act also provides for adjustments in the royalty assessed because of inflation. Since the project is being evaluated in constant dollars, no inflation adjustments are necessary. A sample calculation is shown in Table 2.1.

During years 1 and 2 investment is made in: (1) mining and service assets, and, (2) processing assets. The mining and service assets include investment in pre-production exploration and pre-production development. Columns 1 through 5 record the investments made, and the undepreciated balances for the two categories of assets. From years 3 through 6, the project is assumed to earn a gross profit of $500,000 per year (column 6). The assumed annual depreciation rate is 20% (maximum normally allowed) which is applied to the total undepreciated balance for the year (and includes any new investment). The amount of depreciation is shown in column 7. The processing allowance (column 8) is 8% of the cumulative processing investment. Deducting the depreciation and processing allowance from gross profit leaves the profit subject to a royalty assessment (column 9). The profit base (column 10) is defined as 18% of the mine and service asset undepreciated balance, as of the end of the previous year (or beginning of the current year). Net profit equal to or less than this amount is assessed at a rate of 15% (column 11) while any net profit in excess of the profit base is assessed at the rate of 35% (column 12).

Three other features of the royalty system should be noted:

(1) The processing allowance is either 8% of the cumulative processing assets (as above) or 50% of the profit after deducting the depreciation, whichever is the lesser.

(2) There is a three year averaging feature which moderates the effects of fluctuations in annual gross profit. It is not a moving average however. It functions as follows: In the third year of a three year period: (a) sum the net profit for the 3years; (b) sum the profit bases for the 3 years; (c) determine total royalty for the three years by multiplying the total net profit up to the amount of the total profit bases by .15 and by multiplying any profit in excess of the total profit bases by .35. The base royalty in the third year is the total base royalty less that paid in the first two years. The incremental royalty in the third year is the total incremental royalty less that paid for the first two years. The total royalty is the sum of the base and incremental royalty (and can be negative).

(3) The minimum depreciation rate is 10%. This rate must be used so long as there is sufficient gross profit. If there is insufficient gross profit, then the depreciation deduction will be the amount of gross profit in excess of zero.

2.4.4 Varying the Annual Depreciation Rates

The depreciation rates are adjusted and the best rates chosen by statements 0097 to 0151. The algorithm for this is shown in figure 2.6(C).

The depreciation rates used in the total royalty calculation are particularly important because of the two different royalty rates in effect: a low rate for the annual profit which would represent a reasonable before-tax rate of return to the mine and service capital investment, and; a high rate for any profit which would exceed this amount. The amount of profit in a year which may be subject to assessment at the high royalty rate is a function of (i) the gross profit, (ii) the profit base (.18 times the undepreciated balance of mining and service capital assets), and, (iii) the depreciation claim for the current year. However, the size of the profit base, as well as the amount of depreciation which can be claimed in the current year is also a function of the depreciation claims in prior years. If in prior years the maximum depreciation has always been claimed, the undepreciated balance of the total assets will be relatively small. This means that (i) the maximum possible amount of the depreciation claim in the current year (.2 times the undepreciated balance of total assets) will be relatively small, and, (ii) the profit base for the current year will be relatively small. If profit in the current year is relatively high, then a large portion of this profit is going to be assessed at the high royalty rate. If in prior years, in particular those years when profit was low, less depreciation had been claimed, the current profit base would have been larger, and a larger depreciation claim could have been made.

There are three factors which moderate the effect of a relatively small undepreciated balance of total assets in the latter years of a project. The first, and most obvious, is that gross profit can be expected to decline as the average grade of ore mined declines. This occurs in the model in two situations: (i) when the assumption is made that the ore body is to be high graded and, (ii) when the marginal ore is being mined.

The second moderating factor is the 3 year averaging feature. Any unused profit base from the first two years of any period can be used in the 3rd. year to reduce the possible effects of the high royalty rate being assessed in that year. The third moderating factor is the cost of capital over time. A dollar of royalty payable in year 1 of a project is a greater burden than that dollar being payable during the last year of the project. This means that there is an incentive to claim a large amount of depreciation during the early years of the project even if it means that more incremental royalty may be payable later. The subroutine takes this into account by discounting the annual royalty. What is minimized in the subroutine is the total discounted royalty.

The minimization procedure begins with all the depreciation rates set at 20% (statements 0043 to 0044) and the total discounted royalty at these rates determined. The depreciation rates are then reduced in turn by D beginning at the first year of production. If any depreciation rate reduction results in a reduction of the total discounted royalty, that rate is retained, otherwise the rate is restored to its previous value. Each rate is reduced in turn by D till a complete pass can be made for all years of production without resulting in a further reduction in the total discounted royalty. Then the sign of D is changed and each rate is increased in turn by D (where possible) again checking for a reduction in the total discounted royalty. If a complete pass can be made without a change in any of the royalty rates, then D is halved and the sign changed. The cycle begins again with each depreciation rate reduced by D in turn, so long as the total discounted royalty can be further reduced. D continues to be halved till such time as it is reduced to a predetermined size, at which time the calculation stops and the <u>undiscounted</u> total annual royalty is returned to the main part of the program.

D will normally be halved 19 times during a complete minimization procedure. Since D is initially set at 0.01, it will be at 1.91×10^{-8} at the end of the calculations. The two exceptions to this are when the maximum depreciation rates (20%) are the applicable rate or there is no royalty payable at all. In the former case, the calculation will stop after only 4 passes, and, in the latter case, only one calculation is necessary.

At the completion of the project optimization procedure, the royalty calculation details will be printed. This is done by statements 0156 through 0163. The first page of the printout will detail the annual royalty calculation; the second page will detail the annual investments and annual undepreciated balance for the two categories of capital asset.

2.5 The Income Tax Subroutine (INCTAX)

As is the case with the royalty subroutine, this subroutine is called every time a change is made in the project size and/or life. Two taxes are calculated: the first is the capital tax, assessed according to The Corporation Capital Tax Act, C226; the second is the corporate income tax assessed according to the Federal Income Tax Act, as of January 1, 1976. These two taxes are calculated in the one subroutine since the capital tax is an allowable deduction for purposes of the corporate income tax calculation. The INCTAX algorithm is shown in figure 2.7(A) and (B). The compiler listing is at the end of the Chapter.

2.5.1 INCTAX Variables

The REAL variables in this subroutine are defined alphabetically as follows:

ACCA - 50 element array, contains amount of accelerated capital cost allowance.

ACCWOR - accumulated working capital, used in the annual capital tax calculation.

BORCAP - 50 element array, contains assumed borrowed capital per year.

CAPTAX - 50 element array, contains the amount of the capital tax per year.

CAPUB - 50 element array containing the total borrowed capital plus interest for each year.

CMXPLR - 50 element array, contains the cumulative exploration costs for the project.

DEPLAL - 50 element array, contains the annual depletion allowance.

DEPLUB - 50 element array, contains the unclaimed balance of the depletion allowance pool.

DER - assumed debt-equity ratio.

EQUITY - 50 element array containing the assumed amount of capital subject to the capital tax, and which was not borrowed.

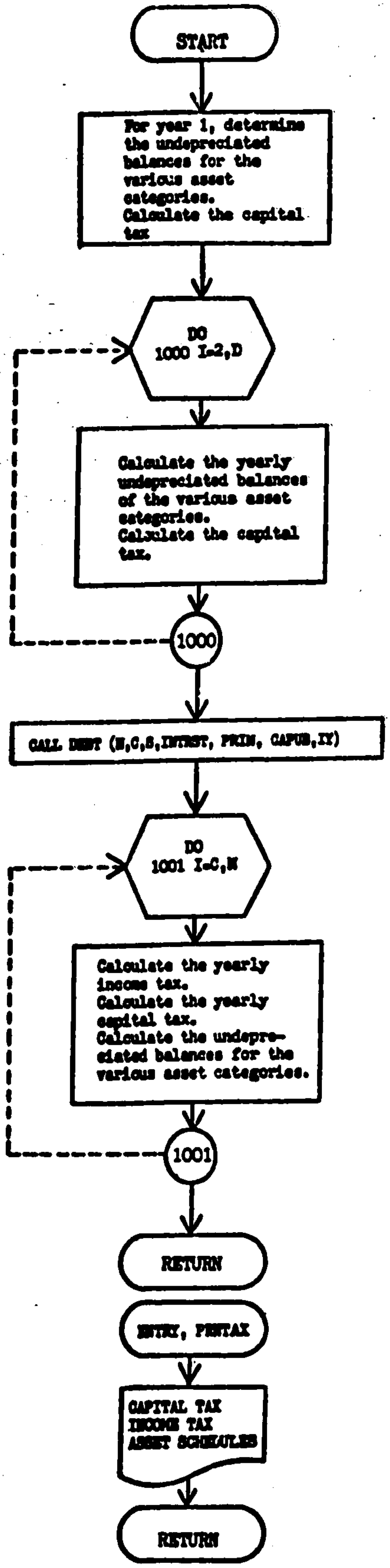
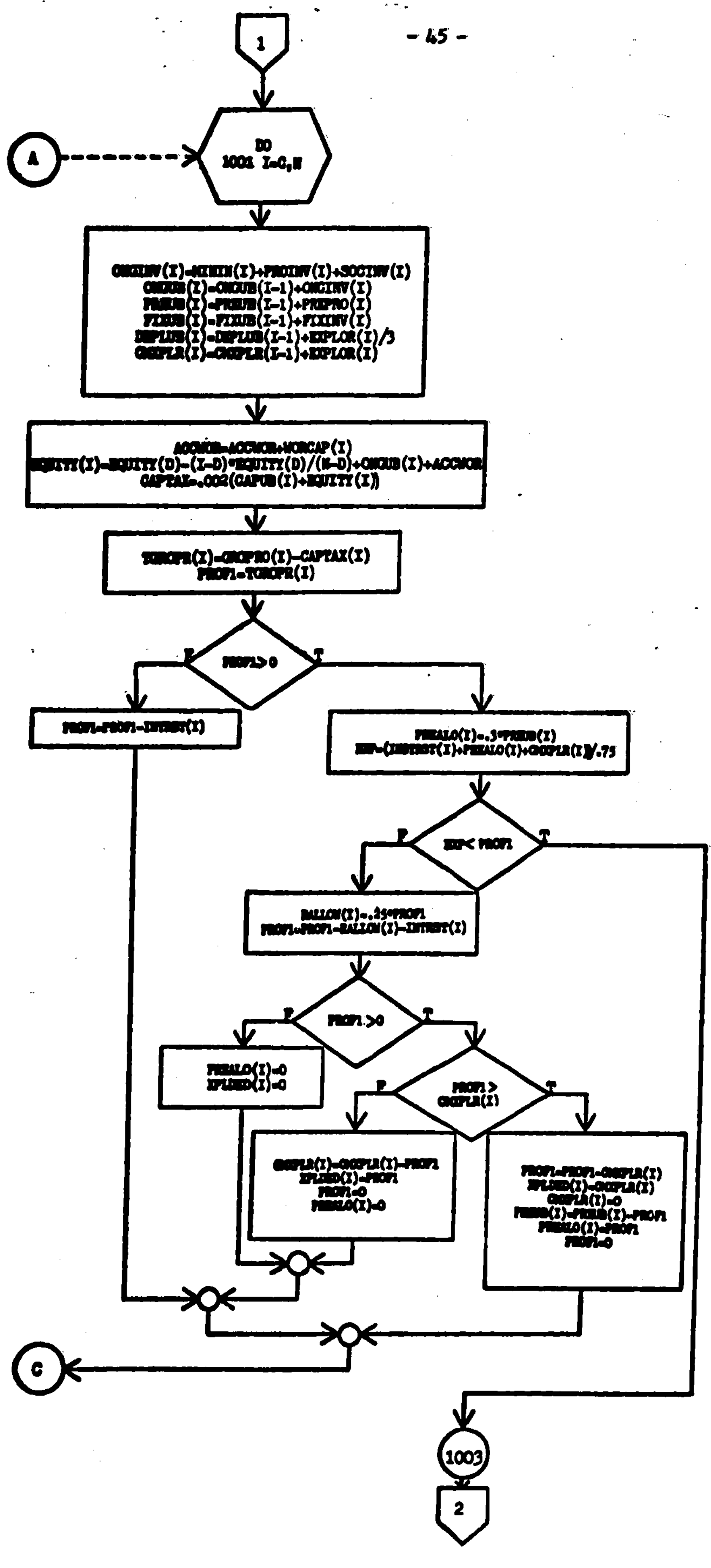
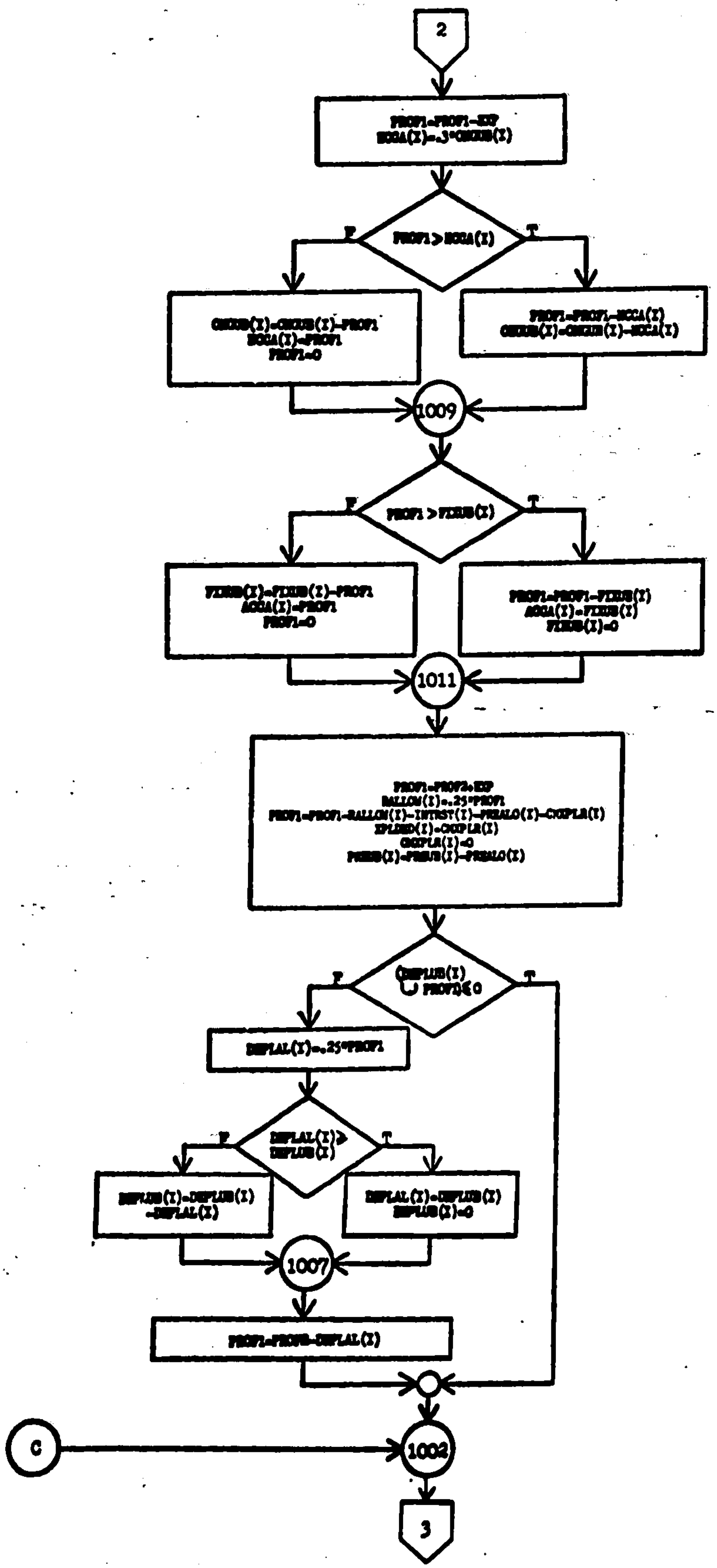
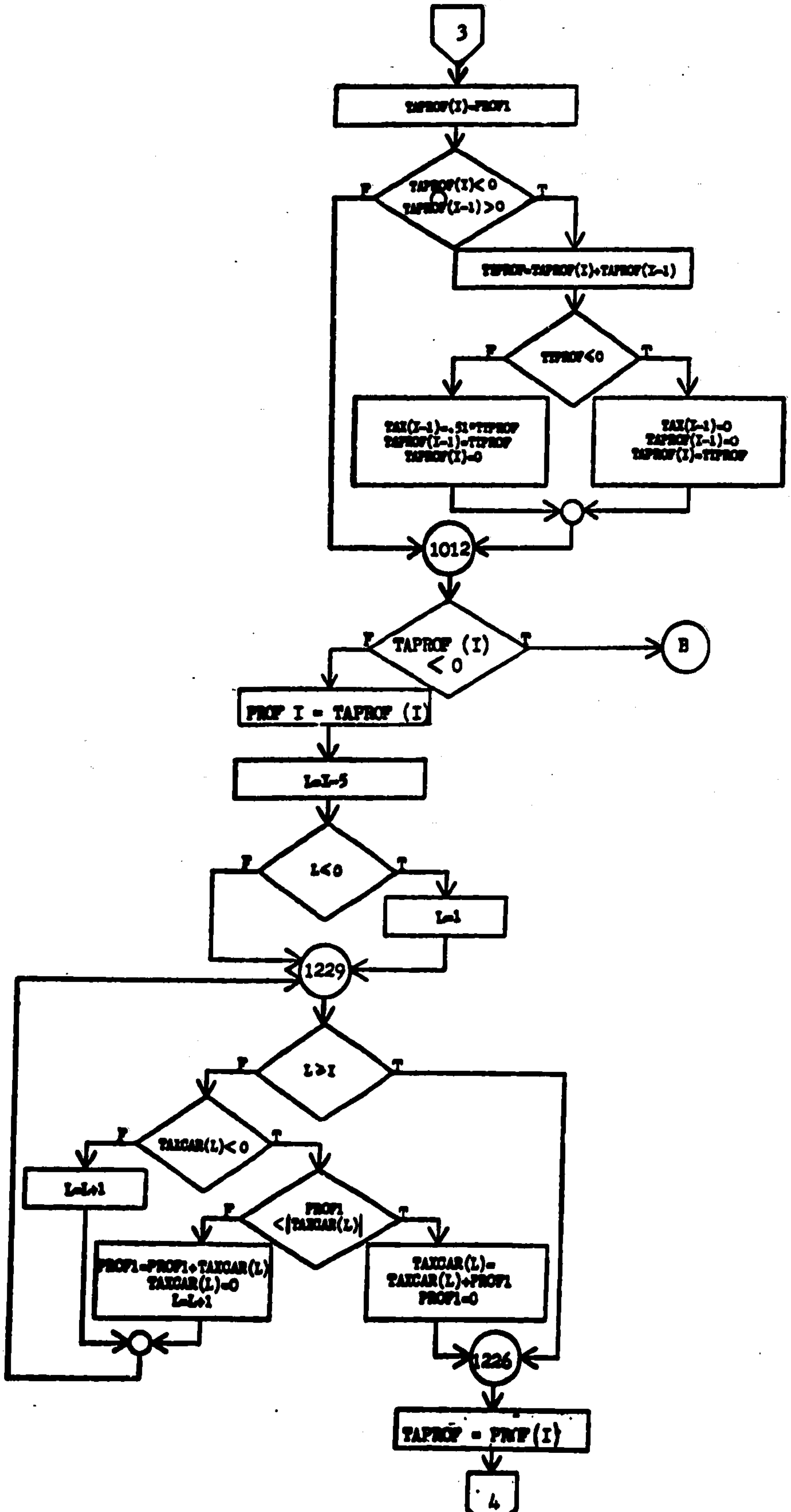


Figure 2.7(A) Simplified Algorithm for Calculating the Capital and Income Taxes.


1
A
DO
1001 I=0,N
ONGINV(I)=MINIM(I)+PROINV(I)+SOCINV(I)
ONGUB(I)=ONGUB(I-1)+ONGINV(I)
PREUB(I)=PREUB(I-1)+PREPRO(I)
FIXUB(I)=FIXUB(I-1)+FIXINV(I)
DEPLUB(I)=DEPLUB(I-1)+EXPLOR(I)/3
CMXPLR(I)=CMXPLR(I-1)+EXPLOR(I)
ACCWOR=ACCWOR+WORCAP(I)
EQUITY(I)=EQUITY(D)-(I-D)*EQUITY(D)/(N-D)+ONGUB(I)+ACCWOR
CAPTAX=.002(CAPUB(I)+EQUITY(I))
TOROPR(I)=GROPRO(I)-CAPTAX(I)
PROF1=TOROPR(I)
PROF1>0
F
T
PROF1=PROF1-INTRST(I)
PREALO(I)=.3*PREUB(I)
EXP=(INTRST(I)+PREALO(I)+CMXPLR(I))/.75
EXP< PROF1
F
T
RALLOW(I)=.25*PROF1
PROF1=PROF1-RALLOW(I)-INTRST(I)
PROF1>0
F
T
PREALO(I)=0
XPLDED(I)=0
PROF1 >
CMXPLR(I)
F
T
CMXPLR(I)=CMXPLR(I)-PROF1
XPLDED(I)=PROF1
PROF1=0
PREALO(I)=0
PROF1=PROF1-CMXPLR(I)
XPLDED(I)=CMXPLR(I)
CMXPLR(I)=0
PREUB(I)=PREUB(I)-PROF1
PREALO(I)=PROF1
PROF1=0
C
1003
2


2
F
T
1009
F
T
1011
F
T
F
T
1007
C
1002
3


3
TAPROF(I)=PROF1
TAPROF(I)< 0
TAPROF(I-1)>0
TIPROF=TAPROF(I)+TAPROF(I-1)
TIPROF<0
TAX(I-1)=.51*TIPROF
TAPROF(I-1)=TIPROF
TAPROF(I)=0
TAX(I-1)=0
TAPROF(I-1)=0
TAPROF(I)=TIPROF
1012
TAPROF (I) < 0
B
PROF I = TAPROF (I)
L=I-5
L<0
L=1
1229
L>I
TAXCAR(L)< 0
L=L+1
PROF1 < |TAXCAR(L)|
PROF1=PROF1+TAXCAR(L)
TAXCAR(L)=0
L=L+1
TAXCAR(L)=
TAXCAR(L)+PROF1
PROF1=0
1226
TAPROF = PROF(I)
4

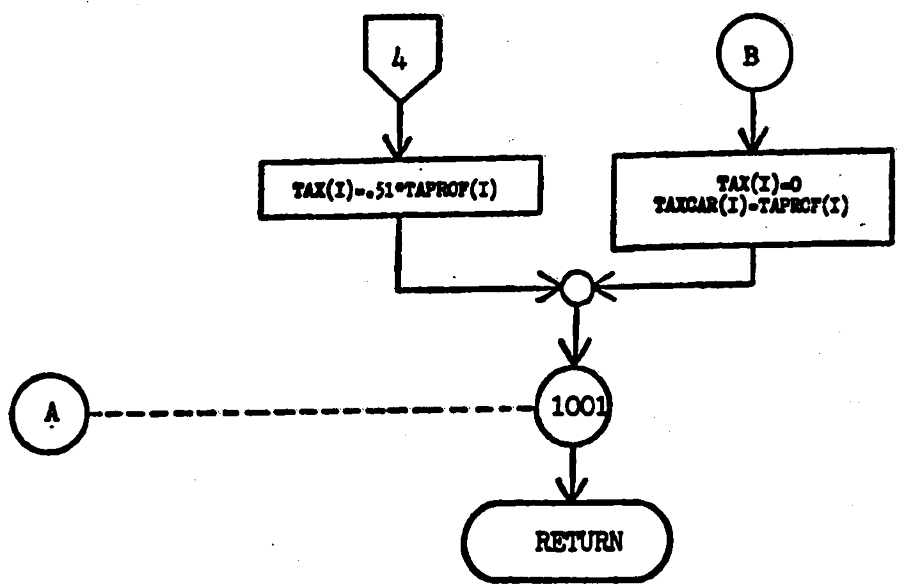


Figure.2.7(B) Algorithm for Calculating the Income Tax and Capital Tax for Years C to N

EXP - 1.33 times the value of deductions allowable following the resource allowance. This will indicate whether or not any capital cost allowances are to be claimed.

EXPLOR - 50 element array containing the annual exploration expenditure.

FIXCAP - 50 element array, contains the year-end total borrowed capital plus accumulated interest.

FIXINV - 50 element array contains the total mining, processing and social capital investment.

FIXUB - 50 element array, contains the undepreciated balance of total capital plus interest for the assets which can be written off on an accelerated rate.

GROPRO - same as in subsection 2.1.1.

INTRST - same as in subsection 2.1.1.

MININV - same as in subsection 2.1.1

NCCA - 50 element array, contains the annual capital cost allowance for class 10 assets.

ONGINV - 50 element array, contains the annual total investment in mining, processing, and social capital assets made after the beginning of production (class 10).

ONGUB - 50 element array, contains the undepreciated balance each year for the class 10 assets.

PREALO - 50 element array, contains the annual pre-production allowance claim.

PRECAP - 50 element array, contains the annual accumulated amount of borrowed capital plus interest.

PREPRO - same as in subsection 2.1.1.

PREUB - 50 element array, contains the undepreciated balance by year for the pre-production development investment.

PRIN - 50 element array, contains the portion of debt servicing which is applied against the principal.

PROF1 - throughout the annual tax calculation this is valued at the amount of profit left after each deduction.

PROINV - same as in subsection 2.1.1.

RALLOW - 50 element array, contains the annual resource allowance for the project.

S - same as in subsection 2.1.1.

SC - same as in subsection 2.1.1.

SOCINV - same as in subsection 2.1.1.

SV - net salvage value of mining and processing assets.

TAPROF - 50 element array, contains annual taxable income for the project.

TAX - 50 element array, contains the annual income tax payable.

TAXCAR - 50 element array, contains the losses for tax purposes which will be carried forward.

TGROPR - 50 element array, contains the annual gross profit after deducting the capital tax and prior losses.

TTPROF - value of total taxable profit for the current and previous year where a carryback of losses is contemplated.

WORCAP - same as in subsection 2.1.1.

XPLCAP - 50 element array, contains the cumulative exploration capital that is assumed to be borrowed, plus interest.

XPLDED - 50 element array, contains the annual amount of exploration deduction.

The integer variables in alphabetical order are:

C - same as in subsection 2.1.1.

D - same as in subsection 2.1.1.

IY - same as in subsection 2.1.1.

2.5.2 The Pre-production Period

Statements 0004 to 0046 determine the values for the various asset categories and for the various allowances that may be claimed. Since no production will have occurred in these years, the allowances along with the tax payable will be zero

The asset banks which are established in the pre-production period for later write-off in calculating the income taxes are as follows:

(1) Accelerated Capital Cost Bank

This includes class 28 capital investment plus any interest on capital borrowed for these assets. In the program this bank will contain the sum of mining, processing, and social capital investment, plus interest. Write-off is at up to 100% of the unclaimed balance.

(2) Pre-production Development Cost Bank

Pre-production development costs are accumulated in this bank for later write-off at a rate of up to 30% of the unclaimed balance. Included here will be interest costs on any capital borrowed.

(3) Pre-production Exploration Cost Bank

Surface and underground preproduction exploration costs which have not been expensed elsewhere will be accumulated in the exploration cost bank for later write-off at up to 100% of the unclaimed balance. As in the previous cases, interest on borrowed capital is included.

(4) Ongoing Investment Cost Bank

After the start of production investments made in mining, processing, and social capital assets are accumulated in the ongoing investment bank for write-off at up to 30% of the undepreciated balance.

(5) Depletion Bank

The depletion bank during the pre-production period amounts to one-third of all investments except that for working capital. After production begins, one-third of exploration expenditure is added to the bank. This can be written off at any rate so long as the amount does not exceed 25% of profit remaining prior to this deduction.

In statement 0019 FIXINV is defined. This is the sum of the mining, processing, and social capital investment. In the preproduction period, this will be the basis for an asset bank.

Statement 0020 establishes the total borrowed capital assumed for the year. This will be the total capital invested times the debt-equity ratio. The total borrowed capital, CAPUB, at the end of the year is the amount borrowed plus the interest payable. This is calculated by statement 0022. The total borrowed capital for the fixed investment, including interest for the year, is calculated in statement 0023.

Statements 0024 and 0025 determine the year-end values for the pre-production borrowed capital and the exploration borrowed capital. In statement 0026 the asset bank for assets which can be depreciated at up to 100% is established. This is the fixed investment, defined above, plus the interest on the borrowed capital for those assets. Statements 0027 and 0028 establish the asset banks for the pre-production investment and the exploration investment. Statement 0029 establishes the depletion bank.

Statements 0030 to 0032 determine the capital tax for the first year. The capital tax in any year is .002 times the taxable capital as of the end of the year. The taxable capital is determined in two steps; first, determine the sum of: (a) paid up capital stock, (b) surpluses, (c) loans and advances, (d) reserves, and (e) indebtedness. From this total deduct: (a) the goodwill allowance, (b) the investment allowance, and (c) deductions allowed in computing taxable income in excess of the amounts recorded on the books. The taxable capital as determined by statements 0030 and 0031 is the equity capital invested in the year and the working capital. The capital tax is .002 times the sum of the equity capital, the working capital and the borrowed capital (including interest).

Because the capital tax is a taxable loss before production begins, this taxable loss will be carried forward (and can be done so for up to 5 years). This is done in statement 0032.

Statements 0034 to 0046 update the various asset banks and set the allowance values to zero for pre-production years 2 to D. Statements 0035 determines the total unamortized balance of borrowed capital for the year. This is: the sum of the borrowed capital for the year and the accumulated borrowed capital for the previous year, both times 1 plus the interest rate S. Statements 0036, 0037, and 0038 determine the total borrowed capital for the fixed investment, the pre-production investment, and the cumulative exploration respectively. Statement 0039 updates the fixed investment bank. This is the sum of the current fixed investment, the current interest on borrowed capital used to purchase it, the current interest on previously borrowed capital, and the fixed investment bank at the end of the previous year. Statements 0040 and 0041 update the pre-production investment bank and the exploration investment bank respectively. Statements 0042 to 0044 determine the capital tax as before. Finally, statement 0046 updates the depletion bank. This is simply the sum of the depletion bank for the previous year and one-third of current investment (excluding working capital).

A final step before the calculation of taxes payable during the production phase is to calculate the annual interest and principle payable if there is any debt to recover. This is done by statement 0047 which calls the DEBT subroutine. This subroutine calculates a capital recovery factor which is then used to determine the annual payments.

2.5.3 Calculating the Annual Taxes

Statements 0048 to 0173 will calculate the yearly income tax and capital taxes payable by the project. Statements 0056 to 0062 update the capital cost banks prior to the tax calculation.

Statements 0063 to 0067 calculate the capital tax. Because paid up capital stock, surpluses and reserves are not specified anywhere in the program, and because the major capital items are quickly written off by way of the capital cost allowances, it was decided to approximate the taxable capital in any year by way of a formula. The formula is:

$$TC=CB(I) + E(D) - (I-D) * E(D)/(N-D) + O(I) + W$$

- TC - taxable capital
- CB(I) - unamortized debt
- E(D) - equity capital at the beginning of production
- I - current year
- D - pre-production period
- N - total project life
- O(I) - undepreciated balance of ongoing investment
- W - cumulative working capital

The capital tax is equal to .002 times TC. This tax is payable within six months from the end of the year it is assessed. During the pre-production period the tax may be paid from loan capital or equity capital. The program assumes it is always paid from equity capital.

Assuming there is profit remaining after deducting the capital tax, statement 0083 will commence the actual tax calculation for the current year. From there to statement 0138 the taxable income will be calculated. The taxable income is calculated as follows:

1	From:	Gross Profit (after capital tax)	
2	Deduct:	Accelerated Capital Cost Allowance	
3	Deduct:	Normal Capital Cost Allowance	
4	Leaves:		Net Profits 1
5	Deduct:	Resource Allowance	
6	Deduct:	Interest Costs	
7	Deduct:	Pre-production Development Costs	
8	Deduct:	Exploration Costs	
9	Leaves:		Net Profits 2
10	Deduct:	Depletion Allowance	
			Taxable Income

The accelerated capital cost allowance can be any amount up to the unclaimed balance in the accelerated capital cost allowance bank. The normal capital cost allowance is any amount up to 30% of the unclaimed balance of the normal capital cost allowance bank. The profit remaining after these two deductions, net profit 1, is the basis for the resource allowance. This allowance is 25% of net profit 1. From the remaining profit is deducted: any exploration costs (preproduction or current); the pre-production development allowance (up to 30% of the unclaimed balance); and, the interest charges on long term debt. This gives net profit 2. From this is deducted the depletion allowance which is the lesser of 25% of net profit 2 or the amount unclaimed in the depletion bank. The profit remaining is the taxable income.

The subroutine does not derive the taxable income by simply making the allowable deductions in order as above. It minimizes the total tax assessment for the project by posponing any assessment as long as possible. This process begins at statement 0084 where EXP is defined as being the sum of the interest deduction, the pre-production investment allowance, and the cumulative exploration which is then divided by .75. The difference between EXP and gross profit is available for the accelerated capital cost allowance and the normal capital cost allowance. If the difference between EXP and gross profit is claimed by the capital cost allowances, the profit remaining before the depletion allowance (Net Profits 2) will be zero. If the difference between EXP and gross profit cannot be entirely claimed, then Net Profits 2 will be greater than zero and a depletion allowance can be claimed. This will still leave profit which can be taxed.

An important feature of this procedure for calculating the tax is that it maximizes the benefits from the resource allowance. With marginally profitable projects, it is often possible to reduce taxable income to zero without making any claim from the accelerated capital cost allowance bank. The larger the interest deduction, the more likely this is to occur. Naturally, some marginal projects will never pay income taxes.

If it should happen that the current taxable income is less than zero and the taxable income in the previous year was positive, then a one year carry-back of losses is allowed. This is done by statements 0139 to 0150. The taxable income for the two years will be summed. If it is negative, the tax payable for the previous year will be reduced to zero and the net loss will appear for the current year and be subject to carry forward. If the net taxable income is positive, the previous year's tax will only be on that positive amount and the current year's taxable income will be zero.

Statements 0152-0168 deduct any loss carry forward from current taxable income. As noted before losses can be carried forward for up to 5 years.

The actual tax payable is calculated by statement 0169. The federal tax rate is 36% and the provincial rate is 15% for a total of 51%.

The detailed tax calculations will be printed by statements 0176 to 0189 if requested from the main part of the program.

2.6 The Analysis Subroutine (ANALYS)

Following the determination of the optimum SIZE of project, the ANALYS subroutine is called. This will undertake two kinds of analysis on the optimum project. The first is a sensitivity analysis. In this analysis, one of 11 factors affecting project profitability is increased or decreased by some percentage in order to measure the effect on the rate of return to the project. This analysis is done three times, each time the factors affecting profitability are varied by a different amount.

The second analysis is a probabilistic analysis in which probabilities are assigned to each of the factors affecting profitability. By way of Monte Carlo techniques a probability distribution is generated for the rate of return.

The compiler listing for this subroutine is at the end of the Chapter.

2.6.1 ANALYS Variables

The real variables for this subroutine are as follows:

A - 50 element array, contains first constant for function of average mine cost versus production.

AA - 50 element array, contains first constant for function of average processing cost versus production

B - second constant for equation of mine cost versus production.

BB - second constant for equation of processing cost versus production.

BORCAP - same as in subsection 2.1.1.

CAPTAX - same as in subsection 2.1.1.

CASFLO - same as in subsection 2.1.1.

COS - 3 by 50 matrix contains random normal values for the mining and processing operating costs.

DATA - 11 by 2 matrix containing the evaluator's estimates for the upper and lower ranges (at the 90% confidence level) of the factors affecting the projects rate of return.

DER - same as in subsection 2.1.1.

DEV - value by which a cost or revenue factor will be changed in the sensitivity analysis.

EXPLOR - same as in subsection 2.1.1.

GRADE - same as in subsection 2.1.1.

GROPRO - same as in subsection 2.1.1.

INTRST - same as in subsection 2.1.1.

MATRIX - 11 by 3 by 50 matrix used in the Monte Carlo analysis to contain the values for each of the 11 project parameters for each year of the project.

MININV - same as in subsection 2.1.1.

OH - same as in subsection 2.1.1.

OPTR - same as in subsection 2.1.1.

PCTCHA - in the sensitivity analysis this value is the percentage change in the rate of return.

PCTDEV - in the sensitivity analysis this value is the percentage change in the variable affecting profitability.

PREPRO - same as in subsection 2.1.1.

PRIN - same as in subsection 2.1.1.

PROINV - same as in subsection 2.1.1.

PT - 1000 element array used to record the number of times a rate of return occurs at each whole percent between 0% and 100%.

R1, R2 - same as in subsection 2.1.1.

R - same as in subsection 2.1.1.

RCV - 50 element arrays; in the analyses, this will contain the annual recovery rates.

RCVRAT - same as in subsection 2.1.1.

S - same as in subsection 2.1.1.

SC - same as in subsection 2.1.1.

SIZ - 50 element array; in the probabilistic analysis this will contain the values for annual ore production.

SM - same as in subsection 2.1.1.

SOCINV - same as in subsection 2.1.1.

T - same as in subsection 2.1.1.

TAX - same as in subsection 2.1.1.

TL - same as in subsection 2.1.1.

TOTINV - same as in subsection 2.1.1.

TOTROY - same as in subsection 2.1.1.

VAL - 50 element array; in the probabilistic analysis this will contain the annual values for the net smelter return.

VALUE - same as in subsection 2.1.1.

WORCAP - same as in subsection 2.1.1.

XX - during the probabilistic analysis this is assigned the value of the standard normal deviate.

YRAN - value of the randon number, between 0 and 1.

Z - during the probabilistic analysis this is the sum of 12 random variables.

ZN - sum of rates of return for all simulations and then the mean rate of return.

The integer variables are:

ASTER - assigned the character '*'.

C - same as subsection 2.1.1.

D - same as subsection 2.1.1.

ID - same as subsection 2.1.1.

IS - random number seed.

ISEN - same as subsection 2.1.1.

JI - label value for graph of probability distribution.

JS - integer value of the rate of return plus one; later it is assigned the integer value of the proportion of rates of return at each value between 0 and 100.

L - in probabilistic analysis this indicates which standard deviation (upper or lower) is to be used in deriving the new value for a parameter.

2.6.2 Initial Conditions

Statements 0004 to 0045 establish the initial conditions for the analysis to be undertaken. Statements 0004 and 0005 read a data card which will instruct the probabilistic part of the subroutine as to how many simulations to carry out. Statements 0006 and 0007 will read the data cards containing the evaluators estimates of the upper and lower limits for the various factors affecting project profitability. Statements 0013, 0014 and 0015 are used to generate an odd number between 0 and 100 for use as a seed for the random number generator. Since the seed will be a random number initiated external to the program, the sequence of random numbers will be different each time the program is run.

Statements 0017 to 0045 place the optimum values for 11 variables affecting profitability into a matrix. This matrix will be used in both the sensitivity analysis and probabilistic analysis. At statement 0046, a decision is made as to which analysis is to be done. Both may be undertaken (if ISENS equals 2); either one may be done (if ISENS equals 1 or 3), or; neither may be done (if ISENS equals 0).

2.6.3 Sensitivity Analysis

The sensitivity analysis is undertaken by statements 0048 to 0173. The subroutine alters each variable in turn by DEV and measures the effect of this change on the rate of return. The variables are changed in a manner that will reduce the calculated rate of return. That is, a variable such as VALUE is reduced while variables such as COST(6) or COST(7) are increased. The complete analysis is done three times. The first time DEV is initially set at -.05, the second time at -.1 and the third at -.2.

The percentage change in the rate of return is calculated and printed along with the actual rate of return.

2.6.4 Probabilistic Analysis

The probabilistic analysis is undertaken by statements 0176 to 0256.

Statements 0176 to 0181 use the estimates for the upper and lower limits of each variable to determine the values that represent ± 1 standard deviation. Since split-normal distributions are likely to occur most often, the upper and lower values for each variable will usually be different. (If a point value is to be used for any variable, the upper and lower estimates will be the same as the initial value; if a normal distribution is assumed, the upper and lower estimates will be equal).

Statements 0186 to 0190 will use the random number generator to derive random-normal deviates. These will be multiplied by the standard deviation for each variable and the result added to (or subtracted from) the initial value to arrive at the new value. For each simulation, this is done for each of the 11 variables for each year of the project. The rate of return which is determined for each simulation is rounded off to the nearest percent and its occurrence recorded for later presentation in the graph of the rate-of-return distribution.

The graph is obtained by statements 0229, 0230, and 0231 during the simulations, and by statements 0233 to 0256 following the simulations. Statement 0229 will round the rate of return value plus 1% by means of integer addition. The occurrence of a rate of return at this value is recorded by statement 0230. Statement 0231 accumulates the rates of return for later determination of the mean. This is calculated at statement 0234.

Statements 0237 to 0249 actually print the bar graph. At statement 0238 the number of rates of return at each percent is divided by the total to arrive at the probability (times 100) of a rate of return for that value. This is converted to an integer value at statement 0240. The probabilities (in percentage) are accumulated by statement 0241. A check is made later to see if all the rates of return have been taken into account. If so, the graphing stops. The axis value for the percent is determined at statement 0242. It is the count value I minus one. This sets the label value at the correct rate of return value which was previously recorded at one more than the actual return (statement 0299). Statement 0243 then prints: JI, the label; PT(I), the portion of the total returns at this value, and; ASTER 1,JS, the whole number of asterisks for PT(I).

Finally, at the bottom of the graph, statement 0252 will print the mean rate of return.

2.6.5 The Interdependence of Variables

One of the problems always encountered whenever sensitivity and probabilistic analyses are undertaken is the interdependence of one or more of the variables. There are a number of possible ways of dealing with it. If the interdependence is weak, it can be safely ignored (in most cases). Where the interdependence produces effects which tend to cancel out, the relevant factors can be excluded from variation in the analysis. Where the effects of interdependence are cumulative, the variables can be aggregated and treated as one. Whichever manner is used to deal with the interdependence, the evaluator should always be conscious of it and should adjust his conclusions accordingly.

In this subroutine, 5 of the 11 variables are assumed to interact to a significant extent. The most important interaction is between the average grade of ore mined and the concentrator recovery rate. The equation which expresses this interaction is:

$$RCV = R1/G + (R2-G)e^{G}$$

where RCV = the recovery rate

R1 = a constant of value - .00125

R2 = a constant of value .97

G = the average grade of mill feed

If the average grade of mill feed is 4% copper, the recovery rate is .9367; if the average grade is 1% copper, the recovery rate is .8446. The maximum recovery rate is about 95%. Variables R1 and R2 can be changed to reflect the kind of ore being processed.

The other interaction is between the quantity of ore processed and the average mining cost and the average milling cost. The independant variable for the two linear equations used is quantity of ore (SIZ). The slopes for the two equations, B and BB are fixed but the intercepts are different for each optimum size of project. In general, as SIZ decreases from its optimum, the average mining and milling costs increase. At present B and BB are set at .6 and .7 respectively. When better information is available, they can be revised.

2.7 Other Subroutines

2.7.1 The Debt Amortization Subroutine

This subroutine is called from the INCTAX subroutine prior to the calculation of the annual income taxes. Information supplied to the subroutine includes: the life of the project, N; the year production commences, C; the interest rate, S; the number of years of secondary ore production, IY; and the total borrowed capital (including accumulated interest) as of the beginning of production, CAPUB. The subroutine then calculates: a pay back period; a capital recovery factor; and the total payment. The annual payments are separated into the interest and principal constituent parts before being returned to the INCTAX subroutine.

2.7.2 The Internal Rate of Return Subroutine

After the calculation of the cash flows in the MAIN routine or ANALYS subroutine, the internal rate of return is calculated. Up to four cash flows are passed to this subroutine along with the value for the life of the project, and the value indicating the number of cash flows.

The internal rate of return is that rate of interest which will equate the discounted negative and positive cash flows. That is:

$$\sum_{i=1}^{n} CF_i \cdot (e^r - 1)/re^{ri} = 0$$

As the equation indicates, continuous discounting is used. This produces a little more realistic result , particularly for the early (and most important) years of the project where capital is not utilized for a whole period but rather is continually invested throughout the year. An example of the effect of this method is as follows. Assume a single investment of \$100 discounted for 1 year using a rate of 10%. Using the continuous method of discounting the present value is \$95.16. Using the period method of discounting the present value is \$90.91. If i=10 years, then the present value by the continuous method is \$38.69 and by the period method is \$38.55. The overall effect of the continuous method then is to produce a slightly lower internal rate of return for the project.

One of the problems encountered while developing this subroutine was the occurrence of multiple roots. This can become serious, particularly with marginal cash flows where the final two values of a stream may be a large positive value followed by a large negative value. In an actual case of this kind, two positive roots were found, a first at just over 6% and a second root at nearly 13%. Both are realistic so the problem for the subroutine was to select the correct one. The solution was suggested by an article on project evaluation which stated that the rate of return "is the first positive root R of the (discounted cash flow) polynomial" (see bibliography E/MJ - July 1974). This information became the basis for a method of selection in the subroutine. In order to find the correct root, the subroutine starts at an interest rate just over 0%, calculates the present value, and then increments the rate by 1%. The present value at each rate is calculated and stored. This process continues till such time as the present value switches from a positive value to a negative value or visa-versa. When this occurs, the exact root is determined using the Bolzano-Weirerstrauss method. If no switch over occurs, the incrementing continues till the discount rate equals 1. The calculation is then stopped and if the present value is negative the IRR is set equal to 0%; if the present value is positive the IRR is set equal to 100%.

2.7.3 The Random Number Subroutine

This subroutine is called from the ANALYS subroutine. Its purpose is to provide random values between 0 and 1, which are the basis for deriving the normally distributed values for the various factors affecting project profitability. The value of the random number is fed to ANALYS by way of Y1. IR is the random number seed and N is the continuation indicator. IR can be any value between 0 and 2**29. N=1 means restart and N=2 means continue. The numbers are generated by the Transworthe method. This subroutine was obtained directly from Bennett, J. et. al. Financial Evaluation of Mineral Deposits Using Sensitivity and Probabilistic Methods, U.S. Bureau of Mines, Information Circular 8495.

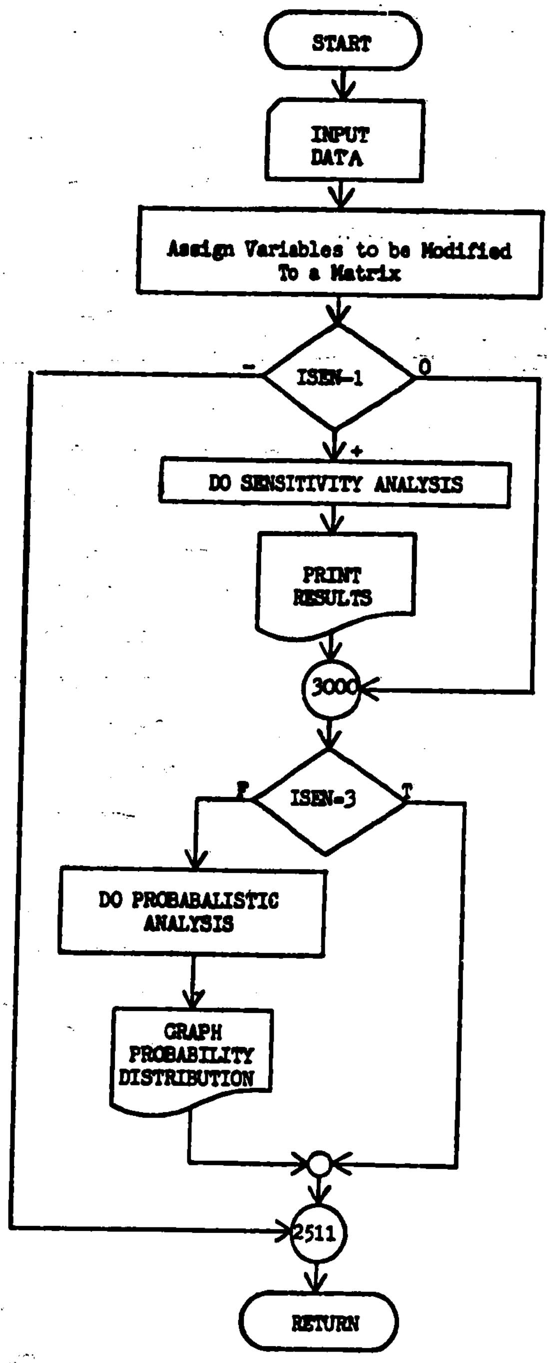


Figure 2.8 Simplified Algorithm for the ANALYS Subroutine

APPENDIX

Compiler Listing For The Complete Program

```
0001             REAL*8 CAPCOS(10,8),GROPRO(50),  BORCAP(50),DFLOAT,  VALUE,AA(7),
                *SIZE,XR,YX,OPTR,COST(7),PROINV(50),TOTROY(50),TOPCOS,BB(7),DLOG,
                *TAX(50),INTRST(50),MAXTON,  PRIN(50),DEXP,MAX,CASFLO(05,50),SM,SC,
                *S,CAPTAX(50),SIZZ(50),OLDRM,DER,FEDTAX(50),RMIN,BORROW,R(5),T,OH,
                *TOTCOS,EQUIT, YY,MCAFLO(5,50)/250*0.D0/,TOTINV(50),OLDR/0.001D0/,
                *G/ 10000.D0/,CASH(50),RM(5)/5*0.D0/,TONS,REVENU(50),EXPLOR(50),TL,
                *MININV(50),WORCAP(50),SOCINV(50),TAPCOS,PREPRO(50),A(7)/7*0.D0/,
                *B(7)/7*0.D0/,MINRAL(10,8)/80*0.D0/,GRADE(50),OSIZE,
                *R1/-.00125D0/,R2/0.97D0/
0002             INTEGER H(7),C,MBL/5/,D,SET/1/,LET/0/,BET/0/,F/1/,HH(7)/7*0/,E,
                *STOP/0/,IC/4/,INC/0/,CBL/10/,WW,P/7/,PP/2/,HG,PG,ID/1/,LIM/0/,LIFE
0003             READ 04,VALUE,DER,S,T,MAX,RMIN,L,M,HG,ISEN,IOP,PG
0004       04    FORMAT(6F12.4,/,6(I2,3X))
0005             READ 05,((CAPCOS(I,J),J=1,8),I=1,L)
0006       05    FORMAT(5F12.0,2F5.2,F10.0)
0007             READ 06,((MINRAL(I,J),J=1,3),I=1,M)
0008       06    FORMAT(3F15.5)
0009             PRINT 300
0010       300   FORMAT('1',//,40X,'INPUT DATA',/,'+', 39X,10('_'))
0011             PRINT 03,VALUE,DER,S,T,MAX,RMIN,L,M,HG,ISEN,IOP,PG,
                *((CAPCOS(I,J),J=1,8),I=1,L)
0012       03    FORMAT(//,40X,'TWO OPTIONS CARDS',//,20X,4(F7.4,1X),F9.0,1X,F5.2,
                *//,25X,6(I2,3X),///,40X,'COST CARDS',//,((5F12.0,2F5.2,F10.0)/))
0013             PRINT303,((MINRAL(I,J),J=1,3),I=1,M)
0014       303   FORMAT(/,40X,'MINERAL RESERVE DATA',//,3(20X,3F15.5,//))
0015             CALL EQUATN(CAPCOS,L,AA,BB,H,P,PG,MAX)
0016             CALL EQUATN(MINRAL,M,A,B,HH,PP,PG,MAX)
0017             PRINT01
0018       01    FORMAT('1',//,61X,'PROJECT ITERATIONS',/,'+',60X,18('_'),//,
                *21X,'PREPRODUCTION',03X,'PRIMARY',06X,'SECONDARY',07X,'TOTAL',08X,
                *'PROJECT',5X,'INTERNAL',6X,'MARGINAL',/,24X,'PERIOD',6X,'ORE LIFE'
                *,7X,'ORE LIFE',7X,'LIFE',8X,'CAPACITY',2X,'RATE OF RETURN',1X,
                *'RATE OF RETURN')
0019             IF(HH(2)-2)210,220,230
0020       210   MAXTON=-A(2)/B(2)
0021             GO TO 240
0022       220   MAXTON=-B(2)/A(2)
0023             GO TO 240
0024       230   MAXTON=DEXP(-A(2)/B(2))
0025       240   CONTINUE
0026             ISIZE=MAXTON/200000.D0
0027             SIZE=DFLOAT(ISIZE)*25000.D0
0028             LIFE=(ISIZE+4)/2
0029             IF(MAX.LT.MAXTON.AND.MAX.GT.0.D0)MAXTON=MAX
0030             XR=0.001D0
0031       09    CONTINUE
0032             TONS=LIFE*SIZE
0033             IF(TONS.LE.MAXTON)GO TO 250
0034             LIFE=LIFE-1
0035             LET=2
0036             BET=0
0037             RMIN=100.D0
0038             OLDR=0.001D0
0039             LIM=1
0040       250   CONTINUE
0041             DO 10 K=1,7
0042             IF(H(K)-2)11,12,13
0043       11    COST(K)=AA(K)+BB(K)*SIZE
```

```
          GO TO 10
   12     COST(K)=AA(K)+BB(K)/SIZE
          GO TO 10
   13     COST(K)=AA(K)+BB(K)*DLOG(SIZE)
   10     CONTINUE
          TOTCOS=COST(1)+COST(2)+COST(3)+COST(4)+COST(5)
          IF(TOTCOS.LE.1.5D+07)C=3
          IF(TOTCOS.GT.1.5D +07.AND.TOTCOS.LE.5.0D +07)C=4
          IF(TOTCOS.GT.5.0D +07.AND.TOTCOS.LE.2.5D +08)C=5
          IF(TOTCOS.GT.2.5D +08.AND.TOTCOS.LE.5.0D +08)C=6
          IF(TOTCOS.GT.5.0D +08)C=7
          D=C-1
          E=C+1
          N=D+LIFE
          OM=0.05D0*(COST(6)+COST(7))
          TOPCOS=COST(6)+COST(7)+OM
          CALL ANNREV(LIFE,SIZE,VALUE,A,B,MM,D,C,N,REVENU,TOPCOS,MG,
         *R1,R2, GRADE,IY,TL,IOP,MAXTON)
          DO 15 I=1,D
          WORCAP(I)=0.D0
          GROPRO(I)=0.D0
          SIZZ(I)=0.D0
          EXPLOR(I)=COST(1)/D
          PREPRO(I)=COST(2)/D
          MININV(I)=COST(3)/D
          PROINV(I)=COST(4)/D
   15     SOCINV(I)=COST(5)/D
          WORCAP(D)=0.10D0*TOTCOS
          WORCAP(C)=0.15D0*TOTCOS
          WW=N-1
          DO 46 I=E,WW
   46     WORCAP(I)=0.D0
          SM=DFLOAT(MBL-N+D)/DFLOAT(MBL)*COST(3)/2.D0
          IF(SM.LT.0.D0)SM=0.D0
          SC=DFLOAT(CBL-N+D)/DFLOAT(CBL)*COST(4)/2.D0
          IF(SC.LT.0.D0)SC=0.D0
          SM=0.D0
          SC=0.D0
          WORCAP(N)=-(WORCAP(D)+WORCAP(C)+SM+SC)
          DO 16 I=C,N
          WORCAP(I)=0.D0
          SIZZ(I)=SIZE
          IF(I.EQ.N)SIZZ(I)=TL
          EXPLOR(I)=0.D0
          PREPRO(I)=0.D0
          IF(I.GE.(N-IY))GO TO 161
          IF((I-D)/4*4.EQ.(I-D))GO TO 160
  161     MININV(I)=0.D0
          PROINV(I)=0.D0
          SOCINV(I)=0.D0
          GO TO 16
  160     MININV(I)=COST(3)*0.10D0
          PROINV(I)=COST(4)*0.06D0
          SOCINV(I)=COST(5)*0.04D0
   16     GROPRO(I)=REVENU(I)-TOPCOS*SIZZ(I)
          CALL ROYALT(GROPRO,MININV,PROINV,EXPLOR,SOCINV,PREPRO,
         *N,C,T,TOTROY)
          CALL INCTAX(GROPRO,MININV,PROINV,EXPLOR,SOCINV,PREPRO,WORCAP,
```

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     *N,C,S,TAX,INTRST,PRIN,WORCAP,CAPTAX,DEP,IY,SM,SC)
      DO 17 I=1,N
      TOTINV(I)=MININV(I)+PROINV(I)+EXPLOR(I)+SUCINV(I)+PREPRO(I)
      CASFLO(1,I)=GROPRO(I)-TAX(I)-CAPTAX(I)-TOTROY(I)-TOTINV(I)-
     *WORCAP(I)
      CASFLO(2,I)=CASFLO(1,I)-INTRST(I)-PRIN(I)+WORCAP(I)
      CASFLO(3,I)=CASFLO(1,I)+TAX(I)+TOTROY(I)+CAPTAX(I)
      FEDTAX(I)=0.36D0/0.51D0*TAX(I)
   17 CASFLO(4,I)=CASFLO(1,I)+FEDTAX(I)
      TL=TL/SIZE
      CALL IRR(CASFLO,R,N,IC,TL)
      IF(R(1).LT.XR)GO TO 60
      YX=SIZE
      LL=LIFE
      XR=R(1)
   60 CONTINUE
      IF(OLDR.EQ.0.001D0.AND.R(1).EQ.0.D0)GO TO 5131
      IF(LIFE.EQ.1.OR.SIZE.EQ.10000.D0)GO TO 5133
      IF(INC.EQ.1)GO TO 18
      PRINT 02,D,LIFE,IY,N,SIZE,R(1),RM(1)
   02 FORMAT(19X,4(6X,I2,6X),F12.2,2X,2(F10.5,4X))
      IF(LET.EQ.2)GO TO 19
      IF(R(1)-OLDR.LT.0.D0)GO TO 20
      LIFE=LIFE+F
      OLDR=R(1)
      GO TO 301
   20 LIFE=LIFE-F
      F=-F
      LET=LET+1
      BET=0
  301 CONTINUE
      YY=SIZE
      LIM=0
      IF(LET.EQ.1.AND.R(1).LT.OLDR)LIFE=LIFE+F
      IF(LET.EQ.2)SIZE=SIZE+G
      GO TO 30
   19 CONTINUE
      IF(R(1)-OLDR.LT.0.D0)GO TO 21
      SIZE=SIZE+G
      OLDR=R(1)
      GO TO 22
   21 SIZE=SIZE-G
      G=-G
      BET=BET+1
   22 CONTINUE
      IF(BET.EQ.1.AND.R(1).LT.OLDR)SIZE=SIZE+G
      IF(BET.EQ.2.AND.SIZE.EQ.YY)GO TO 23
      IF(BET.EQ.2.AND.LIM.EQ.1)GO TO 50
      GO TO 24
   50 CONTINUE
      LIFE=LL
      SIZE=YX
   23 INC=1
      IF(IOP.EQ.2)IOP=1
      IF(IOP.EQ.0.AND.R(1).LE.RMIN)IOP=1
      OSIZE=SIZE
      GO TO 30
   24 CONTINUE
```

```
      IF(BET.EQ.2.AND.INC.EQ.0)LIFE=LIFE+F
      IF(BET.EQ.2)LET=0
      GO TO 30
18    CONTINUE
      IF(R(1).LE.RMIN.OR.STOP.EQ.1)GO TO 37
      IF(SET.EQ.1)GO TO 25
      IF(IN-N)40,43,42
40    CASH(N+1)=0.D0
      GO TO 43
42    N=N+1
      CASFLO(1,N)=0.D0
43    CONTINUE
      DO 26 I=1,N
26    MCAFLO(1,I)=CASFLO(1,I)-CASH(I)
      CALL IRR(MCAFLO,RM,N,ID,TL)
37    CONTINUE
      PRINT 07,D,LIFE,IY,N,SIZE,R(1),RM(1)
07    FORMAT(19X,4(6X,I2,6X),F12.2,2X,2(F10.5,'%'))
      IF(R(1).LE.RMIN.OR.STOP.EQ.1)GO TO 31
      IF(RM(1).GT.RMIN)GO TO 25
      SIZE=SIZE-G
      RM(1)=OLDRM
      STOP=1
      IF(IOP.EQ.0)IOP=1
      GO TO 30
25    SIZE=SIZE+G
      IN=N
      DO 28 I=1,N
28    CASH(I)=CASFLO(1,I)
      OLDRM=RM(1)
      SET=0
30    GO TO 09
31    CONTINUE
      IF(R(1).LE.RMIN.OR.SIZE.EQ.OSIZE)RM(1)=R(1)
      PRINT32
32    FORMAT('1',39X, 'DETAILED DATA FOR OPTIMUM RETURN',/,
     *' ',39X,32('_'),//,45X,'PRODUCTION DATA',/,' ',44X,15('_'),//)
      CALL PRNPRO
      PRINT33
33    FORMAT('1',//,44X,'FINANCIAL DATA',/,' ',43X,14('_'))
      PRINT34,R(1),RM(1)
34    FORMAT('-',32X,'AVERAGE RATE OF RETURN:',F10.5,'%',
     *//,32X, 'MARGINAL RATE OF RETURN:',F10.5,'%')
      TAPCOS=TOTCOS+WORCAP(D)
      PRINT35,(COST(I),I=1,5),WORCAP(D),TAPCOS,COST(6),COST(7),OH,TOPCOS
35    FORMAT('-',38X,'EXPLORATION COSTS',F15.5,/,25X,'PREPRODUCTION DEVE
     *LOPMENT COSTS',F15.5,/,
     *39X,'MINING INVESTMENT',F15.5,/,35X,'PROCESSING INVESTMENT',
     *F15.5,/,31X,'SOCIAL CAPITAL INVESTMENT',F15.5,/  ,27X,
     *'PREPRODUCTION WORKING CAPITAL',F15.5,/,' ',55X,15('_'),/,51X,
     *'TOTAL',F15.5,//,36X,'MINING COSTS PER TON',F15.5,/,35X,
     *'PROCESS COSTS PER TON',F15.5,/,28X,'ADMINISTRATIVE COSTS PER TON'
     *,F15.5,/,' ',55X,15('_'),/,51X,'TOTAL',F15.5)
      BORROW=TAPCOS*DER
      EQUIT=TAPCOS-BORROW
      PRINT36,DER,EQUIT,BORROW
36    FORMAT(//,39X,'DEBT-EQUITY RATIO', F15.5,/,
     *42X,'EQUITY CAPITAL',F15.5,/,40X,'BORROWED CAPITAL',F15.5)
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0204              DO 199 I=1,N
0205        199   TOTINV(I)=TOTINV(I)+WORCAP(I)
0206              PRINT200
0207        200   FORMAT('1',//,53X,'ANNUAL CAPITAL INVESTMENT'/,' ',52X,25('_'),//,
                 *15X,'PREPRODUCTION',1X,'PREPRODUCTION',5X,'MINING',6X,'PROCESSING'
                 *,3X,'SOCIAL CAPITAL',2X,'WORKING CAP.',4X,'TOTAL',/,16X,'EXPLORATI
                 *ON',3X,'DEVELOPMENT',4X,'INVESTMENT',4X,'INVESTMENT',4X,'INVESTMEN
                 *T',4X,'AND SALVAGE VAL',  2X,'CAPITAL',//)
0208              PRINT201,(I,EXPLOR(I),PREPRO(I),MININV(I),PROINV(I),
                 *SOCINV(I),WORCAP(I),TOTINV(I),I=1,N)
0209        201   FORMAT((1X,I2,12X,7(F12.2,2X))/)
0210              DO 202 I=1,N
0211        202   TOTINV(I)=TOTINV(I)-WORCAP(I)
0212              CALL PRNROY
0213              CALL PRNTAX
0214              S=S*100.000
0215              PRINT 5117
0216       5117   FORMAT('1',//,53X,'INTERNAL RATE OF RETURN',/,' ',52X,23('_'),//,
                 *56X,'PROJECT CASH FLOW',/ )
0217              PRINT 5118
0218       5118   FORMAT(15X,'OPERATING',9X,'CAPITAL',11X,'INCOME',11X,'MINING',11X,
                 *'TOTAL',8X,'WORKING CAPITAL',7X,'CASH',/,16X,'PROFIT',11X,'TAX',16
                 *X,'TAX',12X,'ROYALTY',7X,'INVESTMENT', 06X,'AND SALVAGE VALUE',6X,
                 *'FLOW',/)
0219              PRINT5119,(I,GROPRO(I),CAPTAX(I), TAX(I),TOTROY(I),TOTINV(I),
                 *WORCAP(I),CASFLO(1,I),I=1,N)
0220       5119   FORMAT((1X,I2,07X,7F17.5)/)
0221              PRINT5120,R(1)
0222       5120   FORMAT(//,055X,'IRR IS',F12.6,'%',//,5X,'NOTE: 1 THE CALCULATION I
                 *S STOPPED IF THE IRR IS LESS THAN ZERO OR GREATER THAN 100%.')
0223              PRINT5125
0224       5125   FORMAT('1',//,56X,'PUBLIC CASH FLOW1')
0225              PRINT5126
0226       5126   FORMAT( /,31X,'PROJECT',/,32X,'CASH',11X,'CAPITAL',12X,'INCOME',
                 *11X,'MINING',12X,'CASH',/,32X,'FLOW',14X,'TAX',14X,'TAX',
                 *11X,'ROYALTY',12X,'FLOW',/)
0227              PRINT5127,(I,CASFLO(1,I),CAPTAX(I),TAX(I),TOTROY(I),CASFLO(3,I),
                 *I=1,N)
0228       5127   FORMAT((1X,I2,21X,5F17.5)/)
0229              PRINT5128,R(3)
0230       5128   FORMAT(//,055X,'IRR IS',F12.6,'%',//,5X,'NOTE: 1 THE CALCULATION I
                 *S STOPPED IF THE IRR IS LESS THAN ZERO OR GREATER THAN 100%.',//,
                 *11X,'2 PUBLIC CASH FLOW1 ASSUMES THAT THE PROJECT WOULD NOT HAVE B
                 *EEN UNDERTAKEN BY',//,13X,'A PRIVATE COMPANY SO THAT TAXES AND ROY
                 *ALTIES ARE NOT A COST TO THE PROJECT.')
0231              PRINT5121
0232       5121   FORMAT('1',//,57X,'EQUITY CASH FLOW')
0233              PRINT5122
0234       5122   FORMAT( /,32X,'PROJECT',/,33X,'CASH',12X,'BORROWED',10X,'DEBT',
                 *10X,'INTEREST',13X,'CASH',/,33X,'FLOW',12X,'CAPITAL',9X,
                 *'REPAYMENT',8X,'ON DEBT',13X,'FLOW',/)
0235              PRINT5123,(I,CASFLO(1,I),BORCAP(I),PRIN(I),INTRST(I),
                 *CASFLO(2,I),I=1,N)
0236       5123   FORMAT((1X,I2,23X,5F17.5)/)
0237              PRINT5124,R(2),S
0238       5124   FORMAT(//,056X,'IRR IS',F12.6,'%',//,5X,'NOTE: 1 THE CALCULATION I
                 *S STOPPED IF THE IRR IS LESS THAN ZERO OR GREATER THAN 100%.',//,
                 *11X,'2 EQUITY CASH FLOW IS THAT AFTER ADDING BORROWED CAPITAL AND
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             *SUBTRACTING',//,13X,'DEBT REPAYMENT AND INTEREST.',//,11X,'3 THE I
             *NTEREST RATE IS',F6.2,'%.')
0239          OPTR=R(1)
0240          IF(OPTR.LE.S   /2.00)GO TO 5130
0241          CALL ANALYS(VALUE,SIZZ,COST,R1,R2, WORCAP,EXPLOR,PREPRO,MININV,
             *PROINV,SOCINV,GRADE,N,C,D,S,DER,ISEN,OPTR,IY,T,OR,SR,SC,TL)
0242          GO TO 5130
0243     5131 PRINT 5132,SIZE,D,LIFE
0244     5132 FORMAT('1',////,20X,'A POSITIVE RATE OF RETURN WAS NOT GENERATED B
             *Y THE INITIAL VALUES SET FOR THE PROJECT. THESE WERE:',//,30X,
             *'ANNUAL CAPACITY WAS',F10.1,1X,'TONS OF ORE PER YEAR;',//,30X,
             *'PREPRODUCTION PERIOD WAS',I2,1X,'YEARS, AND;',//,30X,
             *'PRIMARY RESERVES WERE EXPECTED TO LAST FOR',I3,1X,'YEARS.')
0245          GO TO 5130
0246     5133 PRINT5134,SIZE,LIFE
0247     5134 FORMAT('1',//,20X,'CHECK COST OR GRADE FUNCTIONS,IOP,MG',//,25X,
             *'PROJECT SIZE IS',F10.1,1X,'TONS',//,25X,
             *'LIFE OF PRIMARY RESERVES IS',I2,1X,'YEARS')
0248     5130 CONTINUE
0249          STOP
0250          END
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      SUBROUTINE EQUATN(CAPCOS,L,AA,BB,H,P,PG,MAX)
      REAL*8 CAPCOS(10,8),CPACTY(20,3),A(3,7),B(3,7),R(3,7),DABS,
     *SUM(10,3,7),MINGRA,   DLOG,DSQRT,AA(7),BB(7),Z,ZZ,ZZZ,TOTMIN,SIZE,
     *VALUES(100),      Y/'CAPITAL'/, YY/'COST($)'/,YYY/'GRADE(%)'/,
     *DFLOAT,LABEL,MAX,MAXTON/0.D0/,DEXP
      INTEGER LINE(100),YLABEL,POINTS(100),PERIOD/'.'/,AST/'*'/,
     *BLANK/' '/,H(7),P,Q,PG
      Q=P+1
      DO 15 K=1,7
      DO 15 J=1,3
      DO 15 I=1,10
   15 SUM(I,J,K)=0.D0
      IF(L.GT.1)GO TO 20
      MINGRA=CAPCOS(1,1)
      TOTMIN=CAPCOS(1,3)
      DO 25 J=1,3
      CAPCOS(J,3)=TOTMIN/(5-J)
      CAPCOS(J,2)=MINGRA*DLOG   (TOTMIN/CAPCOS(J,3))
   25 CAPCOS(J,1)=CAPCOS(J,2)+MINGRA
      L=3
   20 CONTINUE
      DO 01 I=1,L
      CPACTY(I,1)=CAPCOS(I,Q)
      CPACTY(I,2)=-1.0D0/CAPCOS(I,Q)
   01 CPACTY(I,3)=DLOG(CAPCOS(I,Q))
      DO 02 K=1,P
      DO 03 J=1,3
      DO 04 I=1,L
      SUM(1,J,K)=SUM(1,J,K)+CPACTY(I,J)
      SUM(2,J,K)=SUM(2,J,K)+CAPCOS(I,K)
      SUM(3,J,K)=SUM(3,J,K)+CPACTY(I,J)**2
      SUM(4,J,K)=SUM(4,J,K)+CPACTY(I,J)*CAPCOS(I,K)
   04 SUM(5,J,K)=SUM(5,J,K)+CAPCOS(I,K)**2
      SUM(6,J,K)=SUM(1,J,K)**2
      SUM(7,J,K)=SUM(1,J,K)*SUM(2,J,K)
      SUM(8,J,K)=SUM(2,J,K)**2
      Z=L*SUM(5,J,K)-SUM(8,J,K)
      ZZ=L*SUM(3,J,K)-SUM(6,J,K)
      ZZZ= L*SUM(4,J,K)-SUM(7,J,K)
      B(J,K)=ZZZ/ZZ
      A(J,K)=(SUM(2,J,K)-B(J,K)*SUM(1,J,K))/L
      IF(J.EQ.2)B(J,K)=-B(J,K)
      IF(Z)13,12,13
   13 IF(ZZ)11,12,11
   12 R(J,K)=1.D0
      GO TO 03
   11 R(J,K)=ZZZ/DSQRT(Z*ZZ)
   03 CONTINUE
      IF(P.NE.2.OR.K.NE.2)GO TO 200
      IF(H(K-1)-2)300,200,301
  200 CONTINUE
      IF(DABS(R(1,K))-DABS(R(2,K)))05,06,06
   05 IF(DABS(R(2,K))-DABS(R(3,K)))07,08,08
   06 IF(DABS(R(1,K))-DABS(R(3,K)))07,09,09
   09 AA(K)=A(1,K)
      BB(K)=B(1,K)
  300 CONTINUE
      H(K)=1
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      IF(P.NE.2.OR.K.NE.2)GO TO 02
      AA(K)=AA(K-1)
      BB(K)=2.D0*BB(K-1)
      GO TO 02
08    AA(K)=A(2,K)
      BB(K)=B(2,K)
      M(K)=2
      GO TO 02
07    AA(K)=A(3,K)
      BB(K)=B(3,K)
301   CONTINUE
      M(K)=3
      IF(P.NE.2.OR.K.NE.2)GO TO 02
      AA(K)=AA(K-1)+BB(K-1)
      BB(K)=BB(K-1)
02    CONTINUE
      IF(PG.EQ.0)GO TO 53
      DO 35 K=1,P
      PRINT 29
29    FORMAT('1')
      IF(P.EQ.2) GO TO 70
      GO TO (81,82,83,84,85,86,87),K
81    PRINT61
61    FORMAT(50X,'PREPRODUCTION EXPLORATION',/,'+',49X,25('_'))
      GO TO 71
82    PRINT62
62    FORMAT(50X,'PREPRODUCTION DEVELOPMENT',/,'+',49X,25('_'))
      GO TO 71
83    PRINT63
63    FORMAT(50X,'MINING INVESTMENT',        /,'+',49X,17('_'))
      GO TO 71
84    PRINT64
64    FORMAT(50X,'PROCESSING INVESTMENT',    /,'+',49X,21('_'))
      GO TO 71
85    PRINT65
65    FORMAT(50X,'SOCIAL INVESTMENT',        /,'+',49X,17('_'))
      GO TO 71
86    PRINT66
66    FORMAT(50X,'MINING COSTS(PER TON)',    /,'+',49X,21('_'))
      GO TO 71
87    PRINT67
67    FORMAT(50X,'PROCESSING COSTS(PER TON)',/,'+',49X,25('_'))
      GO TO 71
70    CONTINUE
      IF(M(2)-2)100,101,102
100   MAXTON=-AA(2)/BB(2)
      GO TO 103
101   MAXTON=-BB(2)/AA(2)
      GO TO 103
102   MAXTON=DEXP(-AA(2)/BB(2))
103   CONTINUE
      IF(MAX.LT.MAXTON.AND.MAX.NE.0.D0)MAXTON=MAX
      GO TO (88,89),K
88    PRINT 72
72    FORMAT(50X,'AVERAGE ORE GRADE',/,'+',49X,17('_'))
      GO TO 71
89    PRINT 73
73    FORMAT(50X,'CUTOFF  ORE GRADE',/,'+',49X,17('_'))
```

```
   71 CONTINUE
      IF(M(K)-2)90,91,92
   90 PRINT93,AA(K),BB(K)
   93 FORMAT(/ ,43X,'Y=',F15.5, '+(',F16.12,')X',/)
      GO TO 99
   91 PRINT94,AA(K),BB(K)
   94 FORMAT(/ ,43X,'Y=',F15.5, '+(',F15.5,')/X',/)
      GO TO 99
   92 PRINT95,AA(K),BB(K)
   95 FORMAT(/ ,43X,'Y=',F15.5, '+(',F15.5,')LN(X)',/)
   99 CONTINUE
      DO 34 I=1,100
      SIZE=DFLOAT(I)*10.D0**4
      IF(P.EQ.2)SIZE=DFLOAT(I)*10.D0**5
      IF(M(K)-2)30,31,32
   30 VALUES(I)=AA(K)+BB(K)*SIZE
      GO TO 33
   31 VALUES(I)=AA(K)+BB(K)/SIZE
      GO TO 33
   32 VALUES(I)=AA(K)+BB(K)*DLOG(SIZE)
   33 CONTINUE
      IF(P.EQ.2)GO TO 47
      IF(K.GT.5)GO TO 48
      POINTS(I)=(VALUES(I)/10.D0**5)/2.D0+0.5D0
      GO TO 34
   48 POINTS(I)=VALUES(I)/2.D0+0.5D0
      GO TO 34
   47 POINTS(I)=VALUES(I) *1000.D0/2.D0+0.5D0
   34 CONTINUE
      LIMIT=MAXTON/100000.D0+0.5D0
      DO 36 J=1,10
      DO 36 L=1,5
      I=51-(5*(J-1)+L)
      DO 37 M=1,100
   37 LINE(M)=BLANK
      DO 38 M=1,100
   38 IF(POINTS(M).EQ.I)LINE(M)=AST
      IF(P.EQ.2.AND.I.LE.25)LINE(LIMIT)=AST
      IF(L.EQ.1)GO TO 39
      IF(I.EQ.26.AND.P.NE.2.AND.K.LE.5)GO TO 55
      PRINT 40 ,LINE
   40 FORMAT(19X,'.',100A1)
      GO TO 36
   55 PRINT 56,LINE
   56 FORMAT(6X,'MILLIONS$',4X,'.',100A1)
      GO TO 36
   39 CONTINUE
      IF(P.EQ.2)GO TO 46
      IF(K.GT.5)GO TO 44
      LABEL=BLANK
      IF(I.EQ.25)LABEL=Y
      YLABEL=2*I/10
      GO TO 45
   44 LABEL=BLANK
      IF(I.EQ.25)LABEL=YY
      YLABEL=2*I
      GO TO 45
   46 LABEL=BLANK
```

```
              IF(I.EQ.25)LABEL=YYY
              YLABEL=2*I/10
      45      PRINT41,LABEL,YLABEL,LINE
      41      FORMAT(4X,A11,I3,' .',100A1)
      36      CONTINUE
              DO 42 I=1,100
      42      LINE(I)=PERIOD
              PRINT43,LINE,(I,I=1,10)
      43      FORMAT(17X,'0 .',100A1,//,19X,'0',10(7X,I3),//)
              IF(P.EQ.2)GO TO 50
              PRINT52
      52      FORMAT(50X,'ANNUAL CAPACITY (TONS 10**5)')
              GO TO 35
      50      PRINT 51
      51      FORMAT(50X,'MINERAL RESERVES (TONS 10**6)')
      35      CONTINUE
              PRINT 29
      53      CONTINUE
              RETURN
              END
```

```
0001          SUBROUTINE ANNREV(LIFE,SIZE,VALUE,A,B,HH,D,C,N,REVENU,TOPCOS,HG,
             *R1,R2, GRADE,IY,TL,IOP,MAXTON)
0002          REAL *8 METAL(50),PROD(50),DABS,SIZE,VALUE,TL,
             *REVENU(50),GRADE(50),CCGRAD(50),TONS,RCV(50),DLOG,MAXTON,R1,R2,
             *PTONS,PCGRAD,PAVGRA,PMETAL,TTONS,AVGRAD,TMETAL,COGRAD,TAVGRA,
             *TOPCOS,XTONS,    XAVGRA,XYEARS,DEXP,GRAD(02),A(7),B(7)
0003          INTEGER C,D,N,LIFE,HH(7),HG
0004          TONS=LIFE*SIZE
0005          TL=SIZE
0006          DO 10 I=1,D
0007          METAL (I)=0.D0
0008          PROD  (I)=0.D0
0009          GRADE (I)=0.D0
0010          REVENU(I)=0.D0
0011    10    CCGRAD(I)=0.D0
0012          IF(HG.EQ.1)GO TO 08
0013          DO 100 J=1,2
0014          IF(HH(J)-2)110,120,130
0015   110    GRAD(J)=A(J)+B(J)*TONS
0016          GO TO 100
0017   120    GRAD(J)=A(J)+B(J)/TONS
0018          GO TO 100
0019   130    GRAD(J)=A(J)+B(J)*DLOG(TONS)
0020   100    CONTINUE
0021          DO 09 I=C,N
0022          GRADE(I)=GRAD(1)
0023          CCGRAD(I)=GRAD(2)
0024          PROD(I)=SIZE
0025          RCV(I)=R1/GRADE(I)+(R2-GRADE(I))*DEXP(GRADE(I))
0026          METAL(I)=SIZE*RCV(I)*GRADE(I)*2000.D0
0027    09    REVENU (I)=METAL(I)*VALUE
0028          AVGRAD=GRAD(1)
0029          GO TO 07
0030    08    CONTINUE
0031          DO 11 I=C,N
0032          IF(I.EQ.C)GO TO 102
0033          PTONS =SIZE*(I-C)
0034          IF(HH(1)-2)107,108,109
0035   107    PAVGRA=A(1)+B(1)*PTONS
0036          GO TO 106
0037   108    PAVGRA=A(1)+B(1)/PTONS
0038          GO TO 106
0039   109    PAVGRA=A(1)+B(1)*DLOG(PTONS)
0040   106    CONTINUE
0041          IF(HH(2)-2)111,121,131
0042   111    PCGRAD=A(2)+B(2)*PTONS
0043          GO TO 101
0044   121    PCGRAD=A(2)+B(2)/PTONS
0045          GO TO 101
0046   131    PCGRAD=A(2)+B(2)*DLOG(PTONS)
0047   101    PMETAL=PTONS*PAVGRA
0048          GO TO 103
0049   102    PTONS=0.D0
0050          PCGRAD=0.D0
0051          PAVGRA=0.D0
0052          PMETAL=0.D0
0053   103    TTONS=SIZE*(I-D)
0054          IF(HH(2)-2)140,150,160
```

```
      140  CCGRAD(I)=A(2)+B(2)*TTONS
           GO TO 135
      150  CCGRAD(I)=A(2)+B(2)/TTONS
           GO TO 135
      160  CCGRAD(I)=A(2)+B(2)*DLOG(TTONS)
      135  CONTINUE
           IF(MM(1)-2)170,180,190
      170  AVGRAD=A(1)+B(1)*TTONS
           GO TO 136
      180  AVGRAD=A(1)+B(1)/TTONS
           GO TO 136
      190  AVGRAD=A(1)+B(1)*DLOG(TTONS)
      136  TMETAL=TTONS*AVGRAD
           GRADE(I)=(TMETAL-PMETAL)/SIZE
           RCV(I)=R1/GRADE(I)+(R2-GRADE(I))*DEXP(GRADE(I))
           METAL(I)=(TMETAL-PMETAL)*RCV(I)*2000.D0
           PROD(I)=SIZE
       11  REVENU(I)=METAL(I)*VALUE
       07  CONTINUE
           IY=0
           TTONS=TONS
           IF(IOP .NE.1)GO TO 202
           RCV(N)=R1/CCGRAD(N)+(R2-CCGRAD(N))*DEXP(CCGRAD(N))
      300  CONTINUE
           RCV(N+1)=RCV(N)
           COGRAD=TOPCOS/(VALUE*RCV(N)*2000.0D0)
           IF(COGRAD.GE.CCGRAD(N))GO TO 202
           IF(MM(2)-2)141,151,161
      141  TTONS=(COGRAD-A(2))/B(2)
           GO TO 50
      151  TTONS=B(2)/(COGRAD-A(2))
           GO TO 50
      161  TTONS=DEXP((COGRAD-A(2))/B(2))
       50  CONTINUE
           IF(TTONS.GT.MAXTON)TTONS=MAXTON
           IF(MM(1)-2)171,181,191
      171  TAVGRA=A(1)+B(1)*TTONS
           GO TO 51
      181  TAVGRA=A(1)+B(1)/TTONS
           GO TO 51
      191  TAVGRA=A(1)+B(1)*DLOG(TTONS)
       51  CONTINUE
           XTONS= TTONS-TONS
           IF(XTONS.LE.0.D0 )GO TO 202
           XAVGRA= (TTONS*TAVGRA-TONS*AVGRAD)/XTONS
           IF(XAVGRA.LE.COGRAD)GO TO 203
           RCV(N)=R1/XAVGRA+(R2-XAVGRA)*DEXP(XAVGRA)
           IF(DABS(RCV(N)-RCV(N+1)).LE.0.001D0)GO TO 301
           IF(RCV(N)-RCV(N+1))302,301,303
      302  RCV(N)=RCV(N+1)-(RCV(N+1)-RCV(N))/2.D0
           GO TO 300
      303  RCV(N)=RCV(N+1)+(RCV(N)-RCV(N+1))/2.D0
           GO TO 300
      301  CONTINUE
           XYEARS=XTONS/SIZE
           IY=XYEARS+0.99D0
           N=N+IY
           IF(IY.EQ.1)GO TO 201
```

```
              NN=N-IY+1
              NNN=N-1
              DO 200 I=NN,NNN
              GRADE(I)=XAVGRA
              PROD(I)=SIZE
              CCGRAD(I)=COGRAD
              RCV(I)=R1/GRADE(I)+(R2-GRADE(I))*DEXP(GRADE(I))
              METAL(I)=SIZE*RCV(I)*GRADE(I)*2000.D0
        200   REVENU(I)=VALUE*METAL(I)
              TL=TTONS-(N-C)*SIZE
        201   CONTINUE
              IF(IY.EQ.1)TL=TTONS-TONS
              PROD(N)=TL
              GRADE(N)=XAVGRA
              CCGRAD(N)=COGRAD
              RCV(N)=R1/GRADE(N)+(R2-GRADE(N))*DEXP(GRADE(N))
              METAL(N)=TL*RCV(N)*GRADE(N)*2000.D0
              REVENU(N)=VALUE*METAL(N)
              GO TO 202
        203   TTONS=TONS
        202   CONTINUE
              RETURN
              ENTRY PRNPRO
              PRINT12
        12    FORMAT(20X,'TONS' ,12X,'AVERAGE',08X,'CUTOFF',07X,'RECOVERABLE',
             *05X,'CONCENTRATE',/,19X,'OF ORE',12X,'GRADE',09X,'GRADE',10X,
             *'METAL(LBS)',06X,'VALUE($)',//)
              DO14 I=C,N
              GRADE(I)=GRADE(I)*100.D0
        14    CCGRAD(I)=CCGRAD(I)*100.D0
              PRINT13,(I,PROD(I),GRADE(I),CCGRAD(I),METAL(I), REVENU(I),I=1,N)
        13    FORMAT((1X,I2,08X,F16.5,2(F16.5,'%') ,2F16.5)/)
              PRINT 45,TONS,TTONS
        45    FORMAT(////,38X,'PRIMARY ORE PRODUCTION',F12.1,'TONS',//,40X,
             *'TOTAL ORE PRODUCTION',F12.1,'TONS')
              RETURN
              END
```

```
0001        SUBROUTINE ROYALT(GROPRO,MININV,PROINV,EXPLOR,SOCINV,PREPRO,N,C,S,
           *TOTROY)
0002        REAL*8 MSINV(50), PROINV(50),MININV(50),R(50),S,DEPREC(50),
           *GROPRO(50),TPROF,TPROBA,TBASRO,TINCRO,      OLDROY,SUMROY,
           *DISROY(50),BASROY(50),INCROY(50),PALLOW(50),ROYPRO(50),TOTROY(50),
           *    PROBAS(50),TOTINV(50),TOTUB(50),MINUB(50),EXPLOR(50),
           *CMPROC(50),SOCINV(50),PREPRO(50),PROFIT(50),DEXP,D,NETPRO,DSUM1
0003        INTEGER C,M,P,Q,K,I,  LET,SET,STOP
0004        K=1
0005        LET=0
0006        P=1
0007        Q=40
0008        SET=0
0009        I=1
0010        R(I)=0.D0
0011        DEPREC(I)=0.D0
0012        PALLOW(I)=0.D0
0013        ROYPRO(I)=0.D0
0014        TOTROY(I)=0.D0
0015        INCROY(I)=0.D0
0016        BASROY(I)=0.D0
0017        DISROY(I)=0.D0
0018        PROBAS(I)=0.0D0
0019        PROFIT(I)=0.D0
0020        R(N+1)=1
0021        MSINV(I)=MININV(I)+PREPRO(I)+EXPLOR(I)+SOCINV(I)
0022        TOTINV(I)= MSINV(I)+PROINV(I)
0023        TOTUB(I)=TOTINV(I)
0024        MINUB(I)= MSINV(I)
0025        CMPROC(I)=PROINV(I)
0026        M=C-1
0027        DO 9001 I=2,M
0028        PROFIT(I)=0.D0
0029        INCROY(I)=0.D0
0030        BASROY(I)=0.D0
0031        DISROY(I)=0.D0
0032        TOTROY(I)=0.D0
0033        ROYPRO(I)=0.D0
0034        PALLOW(I)=0.D0
0035        DEPREC(I)=0.D0
0036        R(I)=0.D0
0037        MSINV (I)=MININV(I)+PREPRO(I)+EXPLOR(I)+SOCINV(I)
0038        TOTINV(I)= MSINV(I)+PROINV(I)
0039        TOTUB(I)=TOTUB(I-1)+TOTINV(I)
0040        MINUB(I)=MINUB(I-1)+MSINV(I)
0041        CMPROC(I)=CMPROC(I-1)+PROINV(I)
0042   9001 PROBAS(I)=0.18D0*MINUB(I-1)
0043        DO 9002 I=C,N
0044   9002 R(I)=0.2D0
0045        D=0.010D0
0046        OLDROY=1.0D+12
0047        STOP=-1
0048        II=N-C+1
0049   9003 CONTINUE
0050        IF(STOP.NE.-1)GO TO 9004
0051        DO 9005 I=C,N
0052        PROFIT(I)=GROPRO(I)-EXPLOR(I)
0053        IF(PROFIT(I).LT.0.D0)PROFIT(I)=0.D0
```

```
             MSINV(I)=MININV(I)+SOCINV(I)
             TOTINV(I)= MSINV(I)+PROINV(I)
             TOTUB(I)=TOTUB(I-1)+TOTINV(I)
             MINUB(I)=MINUB(I-1)+MSINV(I)
             CMPROC(I)=CMPROC(I-1)+PROINV(I)
             IF(R(I).LT.0.1D0)GO TO 9041
             DEPREC(I)=R(I)*TOTUB(I)
             IF(DEPREC(I)-PROFIT(I))9006,9041,9041
      9041   DEPREC(I)=PROFIT(I)
             R(I)=DEPREC(I)/TOTUB(I)
      9006   NETPRO=PROFIT(I)-DEPREC(I)
             PALLOW(I)=CMPROC(I)*0.08D0
             IF(NETPRO.LE.2.D0*PALLOW(I))GO TO 9007
             ROYPRO(I)=NETPRO-PALLOW(I)
             GO TO 9008
      9007   ROYPRO(I)=NETPRO/2.D0
             PALLOW(I)=ROYPRO(I)
      9008   PROBAS(I)=0.18D0*MINUB(I-1)
             IF(I.GT.C.AND.(I+1-C)/3*3.EQ.(I+1-C))GO TO 9225
             GO TO 9009
      9225   TPROF=ROYPRO(I)+ROYPRO(I-1)+ROYPRO(I-2)
             TPROBA=PROBAS(I)+PROBAS(I-1)+PROBAS(I-2)
             IF(TPROF.GT.TPROBA)GO TO 9010
             TBASRO=0.15D0*TPROF
             TINCRO=0.D0
             GO TO 9011
      9010   TBASRO=0.15D0*TPROBA
             TINCRO=0.35D0*(TPROF-TPROBA)
      9011   BASROY(I)=TBASRO-BASROY(I-1)-BASROY(I-2)
             INCROY(I)=TINCRO-INCROY(I-1)-INCROY(I-2)
             GO TO 9012
      9009   CONTINUE
             IF(ROYPRO(I).GT.PROBAS(I))GO TO 9013
             BASROY(I)=0.15D0*ROYPRO(I)
             INCROY(I)=0.D0
             GO TO 9012
      9013   BASROY(I)=0.15D0*PROBAS(I)
             INCROY(I)=0.35D0*(ROYPRO(I)-PROBAS(I))
      9012   TOTROY(I)=BASROY(I)+INCROY(I)
             DISROY(I)=TOTROY(I)*(DEXP(S)-1.0D0)/(S*DEXP(S*I))
             MINUB(I)=MINUB(I)-(MINUB(I)/TOTUB(I)*DEPREC(I))
             TOTUB(I)=TOTUB(I)-DEPREC(I)
      9005   CONTINUE
             SUMROY=0.D0
             DO 9014 J=C,N
      9014   SUMROY=SUMROY+DISROY(J)
             IF(SUMROY.GT.0.D0)GO TO 9015
             STOP=+1
             GO TO 9016
      9015   CONTINUE
             IF(LET.NE.0)GO TO 9017
             IF(OLDROY-SUMROY.LE.0.D0)GO TO 9018
             OLDROY=SUMROY
             L=0
             GO TO 9019
      9018   CONTINUE
             IF(SET.NE.1)GO TO 9019
             R(K)=R(K)+D
```

```
 9019 K=K+1
      L=L+1
      SET=0
      IF(L.LT.N)GO TO 9020
      LET=1
      GO TO 9016
 9020 CONTINUE
      IF((R(K)-D.LT.0.1D0.OR.R(K)-D.GT.0.2D0).AND.K.LE.N)GO TO 9222
      GO TO 9021
 9222 L=L+1
      K=K+1
      GO TO 9020
 9021 CONTINUE
      IF(K.LE.N)GO TO 9022
      K=C
 9022 CONTINUE
      IF(R(K)-D.GE.0.1D0.AND.R(K)-D.LE.0.2D0.AND.(R(K)-D)*(TOTUB(K-1)+
     *TOTINV(K)).LE.PROFIT(K))GO TO 9223
      GO TO 9016
 9223 R(K)=R(K)-D
      SET=1
      GO TO 9016
 9017 CONTINUE
      IF(P.GE.0)GO TO 9023
      P=P+1
      IF(P/2*2.NE.P)GO TO 9024
      D=-D/2.D0
      GO TO 9025
 9024 D=-D
 9025 LET=0
      K=C-1
      OLDROY=1.0D+12
      DSUM1=0.D0
      DO 8000 J=C,N
 8000 DSUM1=DSUM1+R(J)
      ISUM1=DSUM1*1000000.D0
      ISUM2=II*0.2D0*1000000.D0
      IF(ISUM1.EQ.ISUM2.AND.P.EQ.5)STOP=1
      GO TO 9016
 9023 STOP=+1
 9016 CONTINUE
      GO TO 9003
 9004 CONTINUE
      RETURN
      ENTRY PRNROY
      PRINT9030
 9030 FORMAT('1',54X,'ROYALTY MINIMIZATION',/,'+',54X,20('_'),/,
     *'-',9X,'PROFIT',10X,'ANNUAL', 8X,'PROCESSING',7X,'ROYALTY',09X,
     *'PROFIT',12X,'BASIC',8X,'INCREMENTAL',8X,'TOTAL',/,
     *6X, 'AFTER EXPLOR',4X,'DEPRECIATION',6X,'ALLOWANCE',08X,'PROFIT',
     *8X,'BASE (18%)',9X,'ROYALTY',9X,'ROYALTY',08X,'ROYALTY',//)
      PRINT9031,(I,PROFIT(I),DEPREC(I),PALLOW(I),ROYPRO(I),PROBAS(I),
     *BASROY(I),INCROY(I),TOTROY(I),I=1,N)
 9031 FORMAT((1X,I2,1X,8(F16.5))/)
      PRINT9032
 9032 FORMAT('1',///,9X,'YEARLY',7X,'MINING AND',6X,'CUMULATIVE',11X,
     *'ANNUAL',07X,'ANNUAL',10X,'TOTAL',9X,'MINING',10X,'DISCOUNTED',/,
     *' ',6X,'TOTAL INVEST',2X,'SERVICE INVEST',3X,'PROCESS INVEST',5X,
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                   *'DEPREC RATE',2X,'DEPRECIATION',2X,'UNDEPREC BALANCE',
                   *1X,'UNDEPREC BALANCE',4X,'ROYALTY',//)
0162                PRINT9033,(I,TOTINV(I), MSINV(I),CMPROC(I),R(I),DEPREC(I),TOTUB(I)
                   *,MINUB(I),DISROY(I),I=1,N)
0163          9033  FORMAT((1X,I2,1X,3(F16.5),F16.12,4(F16.5))/)
0164                RETURN
0165                END
```

```
0001            SUBROUTINE INCTAX(GROPRO,MININV,PROINV,EXPLOR,SOCINV,PREPRO,BORCAP
               *,N,C,S,TAX,INTRST,PRIN,WORCAP,CAPTAX,DER,IY,SM,SC)
0002            REAL*8 GROPRO(50),EXPLOR(50),WORCAP(50),PREPRO(50),BORCAP(50),
               *ONGINV(50),FIXUB(50),PREUB(50),DEPLUB(50),CAPUB(50),INTRST(50),
               *ONGUB(50),RALLOW(50),TAPROF(50),TAX(50),PRIN(50),SM,SC,SV,
               *DER,NCCA(50),ACCA(50),DEPLAL(50),ACCWOR(50),  PROF1,EXP,TTPROF,S,
               *DABS,PREALO(50),TAXCAR(50),EQUITY(50),CAPTAX(50),TGROPR(50),
               *FIXCAP(50),PRECAP(50),          CMXPLR(50),XPLCAP(50),XPLDED(50),
               *MININV(50),PROINV(50),SOCINV(50),FIXINV(50)
0003            INTEGER C,D
0004            D=C-1
0005            DO 1100 I=1,D
0006            TAX(I)=0.D0
0007            TAPROF(I)=0.D0
0008            RALLOW(I)=0.D0
0009            ONGINV(I)=0.D0
0010            PREALO(I)=0.D0
0011            TGROPR(I)=0.D0
0012            XPLDED(I)=0.D0
0013            DEPLAL(I)=0.D0
0014            ACCA  (I)=0.D0
0015            NCCA  (I)=0.D0
0016            ONGUB (I)=0.D0
0017            PRIN(I)=0.D0
0018            INTRST(I)=0.D0
0019            FIXINV(I)=MININV(I)+PROINV(I)+SOCINV(I)
0020       1100 BORCAP(I)=(FIXINV(I)+ PREPRO(I)+WORCAP(I)+EXPLOR(I))*DER
0021            I=1
0022            CAPUB (I)=BORCAP(I)*(1.D0+S)
0023            FIXCAP(I)=FIXINV(I)*DER*(1.D0+S)
0024            PRECAP(I)=PREPRO(I)*DER*(1.D0+S)
0025            XPLCAP(I)=EXPLOR(I)*DER*(1.D0+S)
0026            FIXUB (I)=FIXINV(I)*(1.D0+DER*S)
0027            PREUB (I)=PREPRO(I)*(1.D0+DER*S)
0028            CMXPLR(I)=EXPLOR(I)*(1.D0+DER*S)
0029            DEPLUB(I)=(FIXINV(I)+PREPRO(I)+EXPLOR(I))/3.D0
0030            ACCWOR(I)=WORCAP(I)
0031            EQUITY(I)=(1.0D0-DER)*(FIXINV(I)+PREPRO(I)+EXPLOR(I))
0032            CAPTAX(I)=0.002D0*(CAPUB(I)+EQUITY(I)+ACCWOR(I))
0033            TAXCAR(I)=-CAPTAX(I)
0034            DO 1000 I=2,D
0035            CAPUB (I)=(BORCAP(I)+CAPUB (I-1))*(1.D0+S)
0036            FIXCAP(I)=FIXINV(I)*DER*(1.D0+S)+FIXCAP(I-1)*(1.D0+S)
0037            PRECAP(I)=PREPRO(I)*DER*(1.D0+S)+PRECAP(I-1)*(1.D0+S)
0038            XPLCAP(I)=EXPLOR(I)*DER*(1.D0+S)+XPLCAP(I-1)*(1.D0+S)
0039            FIXUB (I)=FIXINV(I)*(1.D0+DER*S)+FIXCAP(I-1)*S+FIXUB (I-1)
0040            PREUB (I)=PREPRO(I)*(1.D0+DER*S)+PRECAP(I-1)*S+PREUB (I-1)
0041            CMXPLR(I)=EXPLOR(I)*(1.D0+DER*S)+XPLCAP(I-1)*S+CMXPLR(I-1)
0042            ACCWOR(I)=ACCWOR(I-1)+WORCAP(I)
0043            EQUITY(I)=EQUITY(I-1)+ (1.0D0-DER)*(FIXINV(I)+PREPRO(I)+EXPLOR(I))
0044            CAPTAX(I)=0.002D0*(CAPUB(I)+EQUITY(I)+ACCWOR(I))
0045            TAXCAR(I)=-CAPTAX(I)
0046       1000 DEPLUB(I)=(FIXINV(I)+PREPRO(I)+EXPLOR(I))/3.D0+DEPLUB(I-1)
0047            CALL DEBT(N,C,S,CAPUB,INTRST,PRIN,IY)
0048            DO 1001 I=C,N
0049            ACCA(I)=0.D0
0050            NCCA(I)=0.D0
0051            XPLDED(I)=0.D0
```

```
              DEPLAL(I)=0.D0
              TAXCAR(I)=0.D0
              PREALO(I)=0.D0
              RALLOW(I)=0.D0
              ONGINV(I)=MININV(I)+PROINV(I)+SOCINV(I)
              ONGUB(I)=ONGUB(I-1)+ONGINV(I)
              PREUB(I)=PREUB(I-1)+PREPRO(I)
              FIXINV(I)=0.D0
              FIXUB(I)=FIXUB(I-1)+FIXINV(I)
              DEPLUB(I)=DEPLUB(I-1)+EXPLOR(I)/3.D0
              CMXPLR(I)=CMXPLR(I-1)+EXPLOR(I)
              ACCWOR(I)=ACCWOR(I-1)+WORCAP(I)
              IF(I.EQ.N.AND.ACCWOR(I).NE.0.D0)ACCWOR(I)=0.D0
              EQUITY(I)=EQUITY(D)-(I-D)*EQUITY(D)/(N-C+1)+ONGUB(I)
              IF(I.EQ.N)EQUITY(I)=0.D0
              CAPTAX(I)=0.002D0*(CAPUB(I)+EQUITY(I)+ACCWOR(I))
              TGROPR(I)=GROPRO(I)-CAPTAX(I)
              IF(I.NE.N)GO TO 1060
              SV=SM+SC-FIXUB(N)-ONGUB(N)
              IF(SV.LE.0.D0)GO TO 1061
              TGROPR(N)=TGROPR(N)+SV
              ONGUB(N)=0.D0
              FIXUB(N)=0.D0
              GO TO 1060
       1061   SV=0.D0
       1060   CONTINUE
              PROF1=TGROPR(I)
              IF(TGROPR(I).LT.0.D0)TGROPR(I)=0.D0
              IF(PROF1.GT.0.D0)GO TO 1224
              PROF1=PROF1-INTRST(I)
              GO TO 1002
       1224   PREALO(I)=0.3D0*PREUB(I)
              EXP=(INTRST(I)+PREALO(I)+CMXPLR(I))/0.75D0
              IF(EXP.LT.PROF1)GO TO 1003
              RALLOW(I)=0.25D0*PROF1
              PROF1=PROF1-RALLOW(I)-INTRST(I)
              IF(PROF1.GT.0.D0)GO TO 1225
              PREALO(I)=0.D0
              XPLDED(I)=0.D0
              GO TO 1002
       1225   CONTINUE
              IF(PROF1.GT.CMXPLR(I))GO TO 1051
              CMXPLR(I)=CMXPLR(I)-PROF1
              XPLDED(I)=PROF1
              PROF1=0.D0
              PREALO(I)=0.D0
              GO TO 1002
       1051   PROF1=PROF1-CMXPLR(I)
              XPLDED(I)=CMXPLR(I)
              CMXPLR(I)=0.D0
              PREUB(I)=PREUB(I)-PROF1
              PREALO(I)=PROF1
              PROF1=0.D0
              GO TO 1002
       1003   PROF1=PROF1-EXP
              NCCA(I)=0.3D0*ONGUB(I)
              IF(PROF1.GT.NCCA(I))GO TO 1008
              ONGUB(I)=ONGUB(I)-PROF1
```

```
              NCCA(I)=PROF1
              PROF1=0.D0
              GO TO 1009
      1008    PROF1=PROF1-NCCA(I)
              ONGUB(I)=ONGUB(I)-NCCA(I)
      1009    CONTINUE
              IF(PROF1.GT.FIXUB(I))GO TO 1010
              FIXUB(I)=FIXUB(I)-PROF1
              ACCA(I)=PROF1
              PROF1=0.D0
              GO TO 1011
      1010    PROF1=PROF1-FIXUB(I)
              ACCA(I)=FIXUB(I)
              FIXUB(I)=0.D0
      1011    PROF1=PROF1+EXP
              RALLOW(I)=0.25D0*PROF1
              PROF1=PROF1-RALLOW(I)-INTRST(I)-PREALO(I)-CMXPLR(I)
              XPLDED(I)=CMXPLR(I)
              CMXPLR(I)=0.D0
              PREUB(I)=PREUB(I)-PREALO(I)
              IF(DEPLUB(I).LE.0.D0.OR.PROF1.LE.0.D0)GO TO 1002
              DEPLAL(I)=0.25D0*PROF1
              IF(DEPLAL(I).GE.DEPLUB(I))GO TO 1006
              DEPLUB(I)=DEPLUB(I)-DEPLAL(I)
              GO TO 1007
      1006    DEPLAL(I)=DEPLUB(I)
              DEPLUB(I)=0.D0
      1007    PROF1=PROF1-DEPLAL(I)
      1002    TAPROF(I)=PROF1
              IF(TAPROF(I).LT.0.D0.AND.TAPROF(I-1).GT.0.D0)GO TO 1223
              GO TO 1012
      1223    TTPROF=TAPROF(I)+TAPROF(I-1)
              IF(TTPROF.LE.0.D0)GO TO 1013
              TAX(I-1)=0.51D0*TTPROF
              TAPROF(I-1)=TTPROF
              TAPROF(I)=0.D0
              GO TO 1012
      1013    TAX(I-1)=0.D0
              TAPROF(I-1)=0.D0
              TAPROF(I)=TTPROF
      1012    CONTINUE
              IF(TAPROF(I).LT.0.D0)GO TO 1015
              PROF1=TAPROF(I)
              L=I-5
              IF(L.LE.0)L=1
      1229    CONTINUE
              IF(L.GE.I)GO TO 1226
              IF(TAXCAR(L).LT.0.D0)GO TO 1230
              L=L+1
              GO TO 1229
      1230    CONTINUE
              IF(PROF1.LT.DABS(TAXCAR(L)))GO TO 1231
              PROF1=PROF1+TAXCAR(L)
              TAXCAR(L)=0.D0
              L=L+1
              GO TO 1229
      1231    TAXCAR(L)=TAXCAR(L)+PROF1
              PROF1=0.D0
```

```
0168     1226  TAPROF(I)=PROF1
0169           TAX(I)=0.5100*TAPROF(I)
0170           GO TO 1001
0171     1015  TAX(I)=0.D0
0172           TAXCAR(I)=TAPROF(I)
0173     1001  CONTINUE
0174           RETURN
0175           ENTRY PRNTAX
0176           PRINT 202
0177     202   FORMAT('1',///,47X,'CAPITAL TAX CALCULATION',/,' ',46X,23('_'))
0178           PRINT203
0179     203   FORMAT(///,25X,'UNAMORTIZED',12X,'EQUITY',12X,'ACCUMULATED',11X,
              *'CAPITAL',/,26X,'DEBT',16X,'CAPITAL',09X,'WORKING CAPITAL',11X,
              *'TAX')
0180           PRINT204,(I,CAPUB(I),EQUITY(I),ACCWOK(I),CAPTAX(I),I=1,N)
0181     204   FORMAT(/ ,5X,I2,10X,4F20.5)
0182           PRINT1024
0183     1024  FORMAT('1',53X,'INCOME TAX CALCULATION',/,' ',53X,22('_'),/,
              *'-',5X,'GROSS PROFIT',06X,'ACCELERATED',5X,'NORMAL',/,9X,'AFTER',
              *             9X,'CAPITAL COST',4X,'CAPITAL COST',6X,'RESOURCE',
              *5X,'INTEREST ON',6X,'EXPLORATION',3X,'PREPROD-DEVELOP',4X,
              *'DEPLETION',/,6X,'CAPITAL TAX',      7X,'ALLOWANCE',7X,'ALLOWANCE',
              *7X,'ALLOWANCE',4X,'LONG TERM DEBT',5X,'DEDUCTION',7X,
              *'ALLOWANCE',  7X,'ALLOWANCE',//)
0184           PRINT1025,(I,TGROPR(I),ACCA(I),NCCA(I),RALLOW(I),INTRST(I),
              *XPLDED(I),PREALO(I),DEPLAL(I),I=1,N)
0185     1025  FORMAT((1X,I2,1X,8(F16.5))/)
0186           PRINT1026
0187     1026  FORMAT('1',///,4X,'TAXABLE PROFIT',7X,'INCOME',7X,'UNDEP-BALANCE',
              *4X,'UNDEP-BALANCE',4X,'UNAMORTIZED',4X,'CUMULATIVE',5X,
              *'UNDEP-BALANCE',4X,'UNDEP-BALANCE',/,3X,'(AFTER PRIOR LOSSES)',4X,
              *'TAX',09X,'ACCEL-CCA',8X,'NORMAL CCA',9X,   'DEBT',
              *8X,'EXPLORATION', 4X,'PREPRO-DEVELOP',4X,'DEPLETION',//)
0188           PRINT1027,(I,TAPROF(I),TAX(I),FIXUB(I),ONGUB(I),CAPUB(I),C
              *MXPLR(I),PREUB(I),DEPLUB(I),I=1,N)
0189     1027  FORMAT((1X,I2,1X,8(F16.5))/)
0190           RETURN
0191           END
```

```
      SUBROUTINE DEBT(N,C,S,CAPUB,INTRST,PRIN,IY)
      REAL*8 S,DETREP,INTRST(50),CAPUB(50),PRIN(50)
      INTEGER C  ,U,V
      U=N-IY-C+1
      IF(U.GE.20)V=20
      IF(U.GE.15.AND.U.LT.20)V=15
      IF(U.GE.10.AND.U.LT.15)V=10
      IF(U.LT.10)V=U
      I=C
      DETREP=CAPUB(I-1)*(S*(1.D0+S)**V)/((1.D0+S)**V-1)
      L=C+V-1
      DO 02 I=C,L
      INTRST(I)=S*CAPUB(I-1)
      PRIN(I)=DETREP-INTRST(I)
   02 CAPUB(I)=CAPUB(I-1)-PRIN(I)
      LL=L+1
      DO 03 I=LL,N
      INTRST(I)=0.D0
      PRIN(I)=0.D0
   03 CAPUB(I)=0.D0
      RETURN
      END
```

```
      SUBROUTINE IRR(CASFLO,R,N,IC,FY)
      REAL*8 CASFLO(5,50),DISS(102),R(5),G/1.D-08/,A,B,DISSUM,DABS,DEXP,
     *AI,DFLOAT,FY
      DO 20 K=1,IC
      R(K)=1.D-08
      DISSUM=1.0D0
      DISS(1)=0.0D0
      DO 10 I=1,N
      AI=DFLOAT(I)
      IF(I.EQ.N)AI=DFLOAT(I-1)+FY
10    DISS(1)=DISS(1)+CASFLO(K,I)*(DEXP(R(K))-1.D0)/(R(K)*DEXP(R(K)*AI))
      R(K)=0.01000001D0
      DO 14 J=2,101
      DISS(J)=0.0D0
      DO 11 I=1,N
      AI=DFLOAT(I)
      IF(I.EQ.N)AI=DFLOAT(I-1)+FY
11    DISS(J)=DISS(J)+CASFLO(K,I)*(DEXP(R(K))-1.D0)/(R(K)*DEXP(R(K)*AI))
      IF(DISS(J-1).GT.0.D0.AND.DISS(J).LE.0.D0)GO TO 15
      IF(DISS(J-1).LT.0.D0.AND.DISS(J).GE.0.D0)GO TO 16
      R(K)=R(K)+0.01D0
14    CONTINUE
      IF(DISS(101).LE.0.D0)GO TO 12
      IF(DISS(101).GT.0.D0)GO TO 13
15    CONTINUE
      B=R(K)
      A=R(K)-0.01D0
      GO TO 04
16    CONTINUE
      A=R(K)
      B=R(K)-0.01D0
04    CONTINUE
      IF(DABS(A-B)   .LE.G)GO TO 02
      R(K)=(A+B)/2.D0
      DISSUM=0.0D0
      DO 07 I=1,N
      AI=DFLOAT(I)
      IF(I.EQ.N)AI=DFLOAT(I-1)+FY
07    DISSUM =DISSUM +CASFLO(K,I)*(DEXP(R(K))-1.D0)/(R(K)*DEXP(R(K)*AI))
      IF(DISSUM)05,02,06
05    B=R(K)
      GO TO 04
06    A=R(K)
      GO TO 04
12    R(K)=0.D0
      GO TO 02
13    R(K)=1.D0
02    CONTINUE
      R(K)=R(K)*100.D0
20    CONTINUE
      RETURN
      END
```

```
          SUBROUTINE ANALYS(VALUE,SIZ ,COST,R1,R2, WORCAP,EXPLOR,PREPRO,
         *MININV,PROINV,SOCINV,GRADE,N,C,D,S,DER,ISEN,OPTR,IY,T,OM,SM,SC,TL)
          REAL*8 VALUE,VAL(50),OM,  SIZ(50),COST(7),COS(3,50),WORCAP(50),
         *EXPLOR(50),PREPRO(50),MININV(50),PROINV(50),SOCINV(50),GRADE(50),
         *MATRIX(11,3,50),DATA(11,2),Z,YRAN,XX,DEXP,  RCV(50),TOTROY(50),
         *GROPRO(50),TAX(50),INTRST(50),PRIN(50),CAPTAX(50),WORCAP(50),ZN,
         *DER,S,CASFLO(5,50)/250*0.D0/,TOTINV(50),T,   PT(1000)/1000*0.D0/,
         *OPTR,PCTCHA,PCTDEV,DEV/-0.05D0/,R(5)/5*0.D0/,SM,SC,R1,R2,TL,
         *A(50),AA(50),B/0.6D0/,BB/0.7D0/
          INTEGER C,D,ASTER/'*'/,IO/1/
          READ 499,NS
    499   FORMAT(I4,1X)
          READ500,((DATA(I,J),J=1,2),I=1,11)
    500   FORMAT(2F10.5)
          PRINT501,NS,((DATA(I,J),J=1,2),I=1,11)
    501   FORMAT('1',///,40X,'VARIABILITY DATA',/,'+',39X,16('_'),//,46X,I4,
         *//,(35X,2(F10.5,2X)),//)
          S=S/100.D0
          DO 400 I=C,N
    400   GRADE(I)=GRADE(I)/100.D0
          CALL ICLOCK(I1,I2,I3)
          IS =IABS(MOD(I3,100))
          IF(IS/2*2.EQ.IS)IS=IS+1
          NRAN=1
          DO 600 I=1,D
          MATRIX(1,3,I)=0.D0
          MATRIX(2,3,I)=0.D0
          MATRIX(3,3,I)=0.D0
          MATRIX(4,3,I)=0.D0
          MATRIX(5,3,I)=EXPLOR(I)
          MATRIX(6,3,I)=PREPRO(I)
          MATRIX(7,3,I)=MININV(I)
          MATRIX(8,3,I)=PROINV(I)
          MATRIX(9,3,I)=SOCINV(I)
          MATRIX(10,3,I)=0.D0
    600   MATRIX(11,3,I)=0.D0
          DO 601 I=C,N
          MATRIX(1,3,I)=GRADE (I)
          RCV(I)=R1/GRADE(I)+(R2-GRADE(I))*DEXP(GRADE(I))
          MATRIX(2,3,I)=RCV(I)
          MATRIX(3,3,I)=VALUE
          MATRIX(4,3,I)=SIZ (I)
          MATRIX(5,3,I)=EXPLOR(I)
          MATRIX(6,3,I)=PREPRO(I)
          MATRIX(7,3,I)=MININV(I)
          MATRIX(8,3,I)=PROINV(I)
          MATRIX(9,3,I)=SOCINV(I)
          MATRIX(10,3,I)=COST(6)
          MATRIX(11,3,I)=COST(7)
          COS(1,I)=COST(6)
          COS(2,I)=COST(7)
          A(I)=MATRIX(4,3,I)*(MATRIX(10,3,I)-B)
    601   AA(I)=MATRIX(4,3,I)*(MATRIX(11,3,I)-BB)
          IF(ISEN-1)2511,3000,2512
   2512   CONTINUE
          DO 3998 J=1,3
          PRINT 3999,J
   3999   FORMAT('1',///,51X,'SENSITIVITY ANALYSIS #',I2,/,'+',50X,20('_'),
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     *///,36X,'PARAMETER CHANGE',3X,'IRR CHANGE',6X,'RATE OF RETURN',//)
      DO 4201 I=1,D
      COS(1,I)=0.D0
      COS(2,I)=0.D0
 4201 GROPRO(I)=0.D0
      DO 3001 K=1,11
      GO TO(4001,4002,4003,4004,4005,4006,4007,4008,4009,4010,4011),K
 4001 CONTINUE
      DO 4100 I=C,N
      GRADE(I)=GRADE(I)*(1.D0+DEV)
 4100 RCV(I)=R1/GRADE(I)+(R2-GRADE(I))*DEXP(GRADE(I))
      GO TO 3002
 4002 CONTINUE
      DO 4012 I=C,N
 4012 RCV(I)=RCV(I)*(1.D0+DEV)
      GO TO 3002
 4003 VALUE=VALUE*(1.D0+DEV)
      GO TO 3002
 4004 CONTINUE
      DO 4106 I=C,N
      SIZ (I)=SIZ (I)*(1.D0+DEV)
      COS(1,I)=(A(I)+B*SIZ(I))/SIZ(I)
 4106 COS(2,I)=(AA(I)+BB*SIZ(I))/SIZ(I)
      GO TO 3002
 4005 DEV=-DEV
      DO 4101 I=1,N
 4101 EXPLOR(I)=EXPLOR(I)*(1.D0+DEV)
      GO TO 3002
 4006 CONTINUE
      DO 4102 I=1,N
 4102 PREPRO(I)=PREPRO(I)*(1.D0+DEV)
      GO TO 3002
 4007 CONTINUE
      DO 4103 I=1,N
 4103 MININV(I)=MININV(I)*(1.D0+DEV)
      GO TO 3002
 4008 CONTINUE
      DO 4104 I=1,N
 4104 PROINV(I)=PROINV(I)*(1.D0+DEV)
      GO TO 3002
 4009 CONTINUE
      DO 4105 I=1,N
 4105 SOCINV(I)=SOCINV(I)*(1.D0+DEV)
      GO TO 3002
 4010 CONTINUE
      DO 4013 I=C,N
 4013 COS(1,I)=COS(1,I)*(1.D0+DEV)
      GO TO 3002
 4011 CONTINUE
      DO 4014 I=C,N
 4014 COS(2,I)=COS(2,I)*(1.D0+DEV)
 3002 CONTINUE
      DO 4200 I=C,N
 4200 GROPRO(I)=VALUE*RCV(I)*SIZ (I)*2000.D0*GRADE(I)-SIZ (I)*(COS(1,I)+
     *COS(2,I))-OH*MATRIX(4,3,I)
      CALL ROYALT(GROPRO,MININV,PROINV,EXPLOR,SOCINV,PREPRO,N,C,T,
     *TOTROY)
      CALL INCTAX(GROPRO,MININV,PHOINV,EXPLOR,SOCINV,PREPRO,BORCAP,N,C,
```

```
                 *S,TAX,INTRST,PRIN,WORCAP,CAPTAX,DEW,IY,SM,SC)
0106                DO 4300 I=1,N
0107                TOTINV(I)=MININV(I)+PROINV(I)+EXPLOR(I)+SUCINV(I)+PREPRO(I)
0108          4300  CASFLO(1,I)=GROPRO(I)-TAX(I)-CAPTAX(I)-TOTROY(I)-
                 *TOTINV(I)-WORCAP(I)
0109                CALL IRR(CASFLO,R,N,ID,TL)
0110                PCTCHA=(R(1)-OPTR)/OPTR*100.D0
0111                PCTDEV=DEV*100.D0
0112                GO TO (5001,5002,5003,5004,5005,5006,5007,5008,5009,5010,5011),K
0113          5001  PRINT 5101,PCTDEV,PCTCHA,R(1)
0114          5101  FORMAT(19X,'AVERAGE ORE GRADE',         5X,F5.1,'%',9X,F7.2,'%',
                 *8X,F10.5,'%',//)
0115                DO 5201 I=1,N
0116                RCV(I)=MATRIX(2,3,I)
0117          5201  GRADE (I)=MATRIX(1,3,I)
0118                GO TO 3001
0119          5002  PRINT 5102,PCTDEV,PCTCHA,R(1)
0120          5102  FORMAT(23X,'RECOVERY RATE',             5X,F5.1,'%',9X,F7.2,'%',
                 *8X,F10.5,'%',//)
0121                DO 5012 I=C,N
0122          5012  RCV(I)=MATRIX(2,3,I)
0123                GO TO 3001
0124          5003  PRINT 5103,PCTDEV,PCTCHA,R(1)
0125          5103  FORMAT(27X,'NET VALUE',                 5X,F5.1,'%',9X,F7.2,'%',
                 *8X,F10.5,'%',//)
0126                VALUE=MATRIX(3,3,C)
0127                GO TO 3001
0128          5004  PRINT 5104,PCTDEV,PCTCHA,R(1)
0129          5104  FORMAT(25X,'ORE TONNAGE',               5X,F5.1,'%',9X,F7.2,'%',
                 *8X,F10.5,'%',//)
0130                DO 5210 I=1,N
0131                COS(1,I)=MATRIX(10,3,I)
0132                COS(2,I)=MATRIX(11,3,I)
0133          5210  SIZ (I)=MATRIX(4,3,I)
0134                GO TO 3001
0135          5005  PRINT 5105,PCTDEV,PCTCHA,R(1)
0136          5105  FORMAT(11X,'PREPRODUCTION EXPLORATION',5X,F5.1,'%',9X,F7.2,'%',
                 *8X,F10.5,'%',//)
0137                DO 5205 I=1,N
0138          5205  EXPLOR(I)=MATRIX(5,3,I)
0139                GO TO 3001
0140          5006  PRINT 5106,PCTDEV,PCTCHA,R(1)
0141          5106  FORMAT(11X,'PREPRODUCTION DEVELOPMENT',5X,F5.1,'%',9X,F7.2,'%',
                 *8X,F10.5,'%',//)
0142                DO 5206 I=1,N
0143          5206  PREPRO(I)=MATRIX(6,3,I)
0144                GO TO 3001
0145          5007  PRINT 5107,PCTDEV,PCTCHA,R(1)
0146          5107  FORMAT(21X,'MINE INVESTMENT',           5X,F5.1,'%',9X,F7.2,'%',
                 *8X,F10.5,'%',//)
0147                DO 5207 I=1,N
0148          5207  MININV(I)=MATRIX(7,3,I)
0149                GO TO 3001
0150          5008  PRINT 5108,PCTDEV,PCTCHA,R(1)
0151          5108  FORMAT(15X, 'PROCESSING INVESTMENT',    5X,F5.1,'%',9X,F7.2,'%',
                 *8X,F10.5,'%',//)
0152                DO 5208 I=1,N
0153          5208  PROINV(I)=MATRIX(8,3,I)
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                GO TO 3001
          5009  PRINT 5109,PCTDEV,PCTCHA,R(1)
          5109  FORMAT(22X,'SOCIAL CAPITAL',          5X,F5.1,'%',9X,F7.2,'%',
               *8X,F10.5,'%',//)
                DO 5209 I=1,N
          5209  SOCINV(I)=MATRIX(9,3,I)
                GO TO 3001
          5010  PRINT 5110,PCTDEV,PCTCHA,R(1)
          5110  FORMAT(16X,'MINE OPERATING COSTS',    5X,F5.1,'%',9X,F7.2,'%',
               *8X,F10.5,'%',//)
                DO 5013 I=C,N
          5013  COS(1,I)=MATRIX(10,3,I)
                GO TO 3001
          5011  PRINT 5111,PCTDEV,PCTCHA,R(1)
          5111  FORMAT(13X, 'PROCESS OPERATING COSTS', 5X,F5.1,'%',9X,F7.2,'%',
               *8X,F10.5,'%',////)
                DO 5014 I=C,N
          5014  COS(2,I)=MATRIX(11,3,I)
                PRINT6000,OPTR
          6000  FORMAT(51X,'OPTIMUM RETURN',F10.5,'%')
          3001  CONTINUE
                DEV=-DEV*2.D0
          3998  CONTINUE
          3000  CONTINUE
                IF(ISEN.EQ.3)GO TO 2511
                DO 700 I=1,N
                DO 700 J=1,11
                MATRIX(J,1,I)=DATA(J,1)     *MATRIX(J,3,I)
                MATRIX(J,2,I)=DATA(J,2)     *MATRIX(J,3,I)
                MATRIX(J,1,I)=(MATRIX(J,3,I)-MATRIX(J,1,I))/1.64D0
           700  MATRIX(J,2,I)=(MATRIX(J,2,I)-MATRIX(J,3,I))/1.64D0
                ZN=0.D0
                DO 800 M=1,NS
                DO 925 I=1,N
                DO 924 J=1,11
                Z=0.D0
                DO 950 K=1,12
                CALL RAND(IS,NRAN,YRAN)
           950  Z=Z+YRAN
                XX=Z-6.D0
                L=1
                IF(XX.GT.0.D0)L=2
                GO TO(901,902,903,904,905,906,907,908,909,910,911),J
           901  GRADE (I)=XX*MATRIX(J,L,I)+MATRIX(J,3,I)
                GO TO 924
           902  CONTINUE
                IF(I.LE.D)GO TO 924
                RCV(I)=R1/GRADE(I)+(R2-GRADE(I))*DEXP(GRADE(I))
                RCV(I)=RCV(I)+XX*MATRIX(J,L,I)
                GO TO 924
           903  VAL    (I)=XX*MATRIX(J,L,I)+MATRIX(J,3,I)
                GO TO 924
           904  SIZ    (I)=XX*MATRIX(J,L,I)+MATRIX(J,3,I)
                IF(I.LE.D)GO TO 924
                COS(1,I)=(A(I)+B*SIZ(I))/SIZ(I)
                COS(2,I)=(AA(I)+BB*SIZ(I))/SIZ(I)
                GO TO 924
           905  EXPLOR(I)=XX*MATRIX(J,L,I)+MATRIX(J,3,I)
```

```
                GO TO 924
      905       PREPRO(I)=XX*MATRIX(J,L,I)+MATRIX(J,3,I)
                GO TO 924
      907       MININV(I)=XX*MATRIX(J,L,I)+MATRIX(J,3,I)
                GO TO 924
      906       PROINV(I)=XX*MATRIX(J,L,I)+MATRIX(J,3,I)
                GO TO 924
      909       SOCINV(I)=XX*MATRIX(J,L,I)+MATRIX(J,3,I)
                GO TO 924
      910       COS (1,I)=XX*MATRIX(J,L,I)+COS(1,I)
                GO TO 924
      911       COS (2,I)=XX*MATRIX(J,L,I)+COS(2,I)
      924       CONTINUE
      925       GROPRO(I)=VAL(I)*RCV(I)*SIZ(I)*GRADE(I)*2000.D0-SIZ(I)*(COS(1,I)+
               *COS(2,I))-OM*MATRIX(4,3,I)
                CALL ROYALT(GROPRO,MININV,PROINV,EXPLOR,SOCINV,PREPRO,N,C,T,
               *TOTROY)
                CALL INCTAX(GROPRO,MININV,PROINV,EXPLOR,SOCINV,PREPRO,WORCAP,N,C,
               *S,TAX,INTRST,PRIN,WORCAP,CAPTAX,DEN,IY,SM,SC)
                DO 1000 I=1,N
                TOTINV(I)=MININV(I)+PROINV(I)+EXPLOR(I)+SOCINV(I)+PREPRO(I)
      1000      CASFLO(1,I)=GROPRO(I)-TAX(I)-CAPTAX(I)-TOTROY(I)-
               *TOTINV(I)-WORCAP(I)
                CALL IRR(CASFLO,R,N,ID,TL)
                JS=R(1)+1.5D0
                PT(JS)=PT(JS)+1.D0
                ZN=ZN+R(1)
      800       CONTINUE
                Z=0.D0
                ZN=ZN/NS
                PRINT 2000,NS
      2000      FORMAT('1',//,40X,'EXPECTED RATE OF RETURN DISTRIBUTION',/,
               *'+',39X,36('_'),///,45X,'NUMBER OF SIMULATIONS',I5,///)
                DO 2500 I=1,101
                PT(I)=PT(I)/NS*100.D0
                IF(PT(I))2501,2501,2502
      2502      JS=PT(I)+0.5D0
                Z=Z+PT(I)
                JI=I-1
                PRINT 2503,JI,PT(I),(ASTER,K=1,JS)
      2503      FORMAT(30X,I2,  '%',2X,'OCCURS',1X,F6.2,'%',2X,'|',100A1)
                GO TO 2500
      2501      IF(Z-99.9999D0)2504,2506,2506
      2504      PRINT 2505
      2505      FORMAT(51X,'|',' ')
      2500      CONTINUE
      2506      PRINT 2508
      2508      FORMAT(5(51X,'|',/))
                PRINT 2507,ZN
      2507      FORMAT(///,45X,'MEAN RATE OF RETURN',F10.5,'%')
                PRINT2510,IS
      2510      FORMAT(//,45X,'RANDOM NUMBER SEED',I5)
      2511      CONTINUE
                RETURN
                END
```

```
      SUBROUTINE RAND(IR,N,Y1)
      REAL*8 Y1,POW(30)
      INTEGER IA1(30),IA2(30),IA3(30)
      N1=29
      Y1=0.D0
      MAX=26+IR
      IF(N-2) 10,40,40
   10 DO 20 I=1,29,2
      IA2(I)=0
      IA2(I+1)=1
      POW(I)=0.5D0**I
   20 POW(I+1)=0.5D0**(I+1)
      IA2(29)=1
   30 N1=N1+29
      N2=N1-MAX
   40 DO 110 I=1,29
      IF(I-2)50,60,70
   50 ITEMP=IA2(28)
      GO TO 80
   60 ITEMP=IA2(29)
      GO TO 80
   70 ITEMP=IA3(I-2)
   80 IA3(I)=ITEMP+IA2(I)
      IF(IA3(I)-2)100,90,90
   90 IA3(I)=0
  100 IA1(I)=IA2(I)
  110 IA2(I)=IA3(I)
      IF(N-2)120,170,170
  120 IF(N2)30,170,130
  130 N1=29-N2
      N2=N1+1
      N=2
      IZ=0
      DO 140 I=N2,29
      IZ=IZ+1
  140 IA2(IZ)=IA1(I)
      IF(N1)150,170,150
  150 DO 160 I=1,N1
      IZ=IZ+1
  160 IA2(IZ)=IA3(I)
  170 DO 180 I=1,29
      IZ=30-I
      ITEMP=IA2(IZ)
  180 Y1=Y1+POW(I)*ITEMP
      RETURN
      END
```

CHAPTER 3

USING THE COMPUTER PROGRAM TO EVALUATE A MINING PROJECT

3.1 Introduction

This Chapter will describe in detail the procedures to follow in order to carry out an economic evaluation of a mineral deposit using the computer program. The mineral reserve data and the capital cost data were derived from two consultants' feasibility studies that were carried out on a small mineral deposit in the Province, however, the evaluation undertaken here should not be considered as anything more than a demonstration of how to use the computer program.

The description that follows will be done in three parts. The first part will outline the kinds of data that must be obtained; the second part will discuss the results of a successful optimization, and; the final part will discuss the analyses undertaken by the program.

3.2 Input Data

Two basic kinds of data are necessary for an evaluation. The first kind of information needed is mineral reserve data. This should indicate the tonnages and grade of material available. The second kind of information needed is the capital and operating costs that would be incurred in order to mine and process the mineral into a saleable product.

In addition to this basic information, the evaluator will be required to instruct the program on such things as the amount of information being provided, the amount of information to print out, the constraints in effect, and so on. This information is provided on options cards.

3.2.1 The Options Cards

The first two cards in the data deck are options cards. An example of each is shown in Figure 3.1. The 6 entries on the first card occupy fields of width 12. A decimal point for each number should be provided. The six entries on the second occupy fields of width 2 followed by 3 spaces. The digit in each field is right justified.

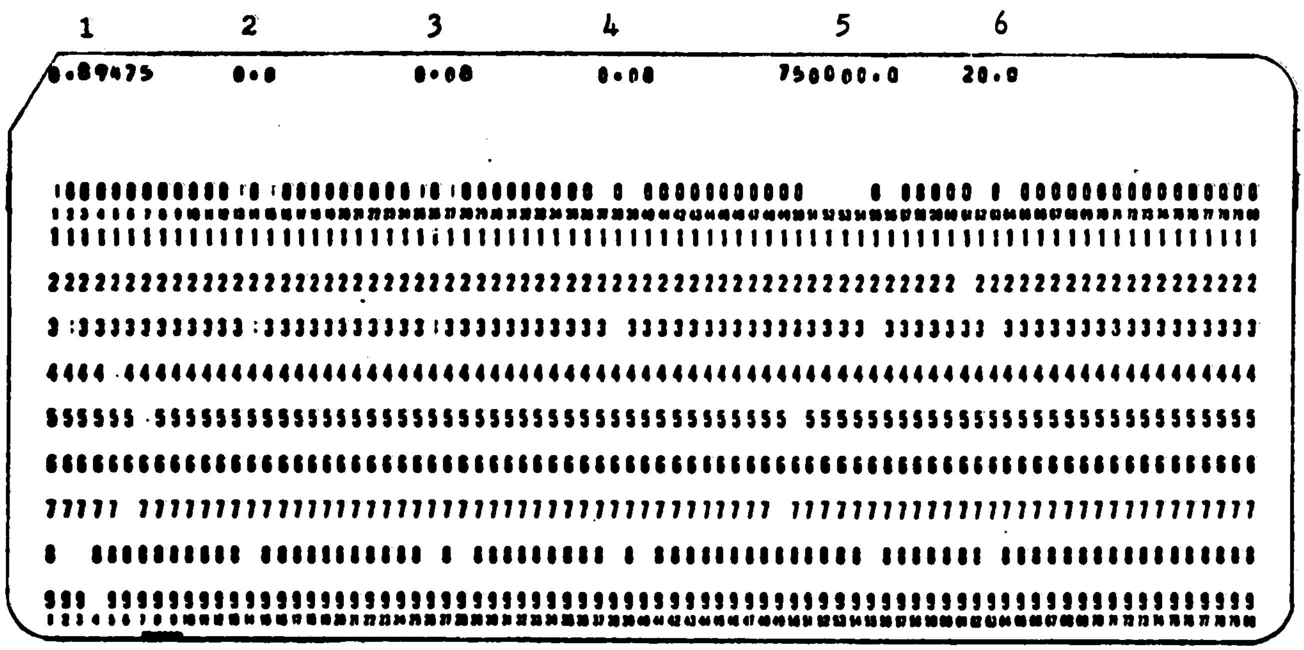
The first entry on the first data card is the anticipated revenue per pound of principal metal. It takes into account the value of all by-products which may be recovered from the ore. An example will illustrate how it is to be derived. Table 3.1 contains the grades, recovery rates, and values of the metals in the concentrate produced from a ton of ore.

Metal	Ore Grade	Concentrator Recovery Rate	N.S.R.	Value/ton
Copper	2.0%	92%	$ 0.59/lb	$21.712
Zinc	2.0%	75%	$ 0.22/lb	$ 6.600
Silver	0.60 oz/ton	56%	$ 5.52/oz	$ 1.855
Gold	0.04 oz/ton	50%	$138.00/oz	$ 2.760
			TOTAL	$32.927

Table 3.1 Value of a Ton of Ore in Concentrate

The net smelter return (N.S.R.) takes into account the costs of smelting and refining each metal as well as the associated losses while doing this. The value of the concentrate produced from a ton of ore is $32.927. This is converted back to the value for the principal metal, copper. Thus:

$$N.S.R.^* = \$32.927/(.02 \times 2000 \times .92) = \$.89475$$



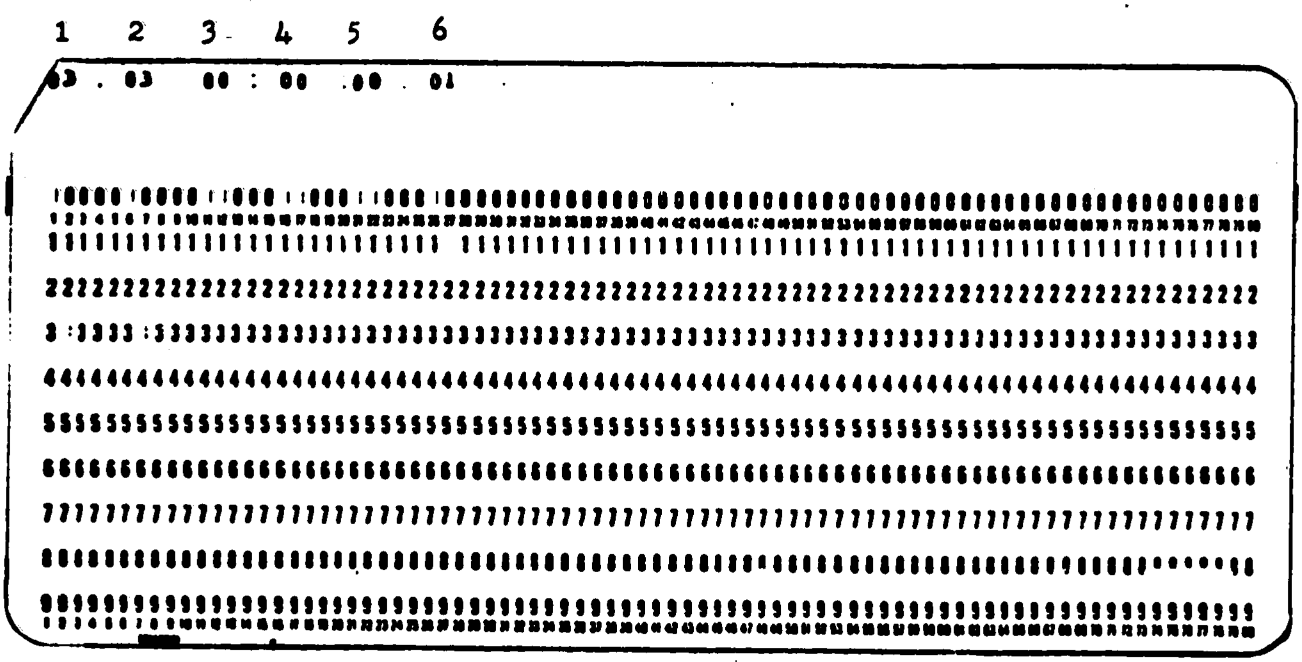


Figure 3.1 First Two Options Cards

The value of the metal in the concentrate, expressed in terms of the principal metal, is unique to the mineral deposit being evaluated. An implicit (and sometimes dubious) assumption in this method of concentrate valuation is that when a higher grade of principal metal is mined, the grades of the other metals are assumed to be correspondingly higher. However, this method does provide simplicity while taking into account the values and recovery rates for by-products.

The second entry on the options card is the assumed portion of the investment which will be financed by debt capital. It will be some value between 0 and 1. Again, a decimal point should be used. This value is only used during the pre-production development stage of the project and will be the same for each year.

The third entry is the assumed rate of interest on borrowed capital. In the pre-production phase of the project it will be used to calculate the interest on any borrowed capital. This will be accumulated for later recovery when the debt is to be repaid and it will also become part of the capital asset banks for income tax purposes. After production commences, interest will be payable on the unamortised part of the debt.

The fourth entry is the discount rate to be used in the ROYALT subroutine. It might represent the opportunity cost of capital for an investor in the project. As such it could be set equal to the value in entry three, but it could also be different. It will be a value between 0 and 1, again with a decimal point.

The fifth entry is the tonnage constraint for the mineral deposit. There frequently will be one where the mineral exists in sharply defined lenses or pockets. In this kind of deposit, the average ore grade will remain relatively high right to the boundary with the host rock and then drop sharply. If there is no tonnage constraint except that specified by the cut-off grade function, then the constraint should be set equal to 0.

The sixth entry on the options card is the minimum rate of return which would be desirable on any incremental investment in the project.

Normally, it would be more than the rate at which capital could be borrowed at. Note that the value here is expressed as a percent rather than a value between 0 and 1. As before, a decimal should be used.

The first entry on the second options card is the number of data cards containing capital cost data for different sizes of project. 03 means there are 3 cards for 3 different possible size of project.

The second entry is the number of data cards containing mineral reserve data.

The third entry is instruction to the program as to the mining sequence to use. 00 means that mining is to take place in a manner that the average grade of ore mined each year will equal the average grade of the total primary ore reserves. 01 means that mining will commence with the highest grade material first. The average grade of material mined will decline year by year. The former sequence is normally used. It will provide a more conservative rate of return estimate than the high-grading assumption.

The fourth entry is instruction to the ANALYS subroutine as to the kind of analysis to undertake. 00 means do no analysis; 01 means do only a probabilistic analysis; 02 means do both, a sensitivity analysis and a probabilistic analysis; and, 03 means do only a sensitivity analysis. Normally, neither kind of analyses would be undertaken the first time a new project is evaluated. It could be undertaken after the evaluator is satisfied that the "optimum" project reflects the best information that is reasonably obtainable and that the possible profitability is sufficient to warrant further analysis.

The fifth entry instructs the program as to how secondary ore reserves are to be treated in the evaluation. Secondary ore reserves will be any ore remaining after the primary ore reserves are depleted. The secondary reserves cut-off grade is determined by the operating costs alone while the primary ore cut-off grade will also allow for a profit. 00 here means that secondary ore reserves will not be included in the optimizing stage of the evaluation. 01 means that the secondary ore reserves will be included throughout the evaluation while 02 means that the secondary reserves will only be included if and when the investment would be incremented.

The sixth entry will instruct the EQUATN subroutine as to whether or not a graph of each function is to be printed. Normally, graphs would be printed the first time or two that an evaluation is made since they provide the evaluator with the equation for each function as well as a graph of the function. This information will usually tell the evaluator if the derived functions are realistic and therefore if the solution is realistic. Upon examination of the functions, it may be the case that the evaluator will want to obtain more data or improve on the accuracy of available data. 00 means do not print graphs while 01 means that graphs are to be printed.

3.2.2 The Capital Cost Cards

Following the options card will be a series of capital cost cards. An example is shown in Figure 3.2. The first five entries occupy fields of width 12; the next two entries occupy fields of width 5, and; the last entry occupies a field of width 10. Each card will contain the capital cost and operating cost data for one size of mine and concentrator project that could be used to develop the mineral deposit being evaluated. This data will be used by the program to derive 7 functions of size versus cost. A minimum of three cards will be needed to derive non-linear functions. If these few are used, however, the costs needed to be determined to a high degree of accuracy if the function that will be derived is to be reliable.

The first entry on each card will be the cost of the pre-production exploration needed to outline sufficient ore for a project of the size indicated (entry 8). An important point here is that this entry will contain only estimated <u>future</u> expenditure necessary. Expenditures already made do not enter the evaluation except to the extent that they may be included in capital asset banks for purposes of calculating the taxes and royalties payable by a future

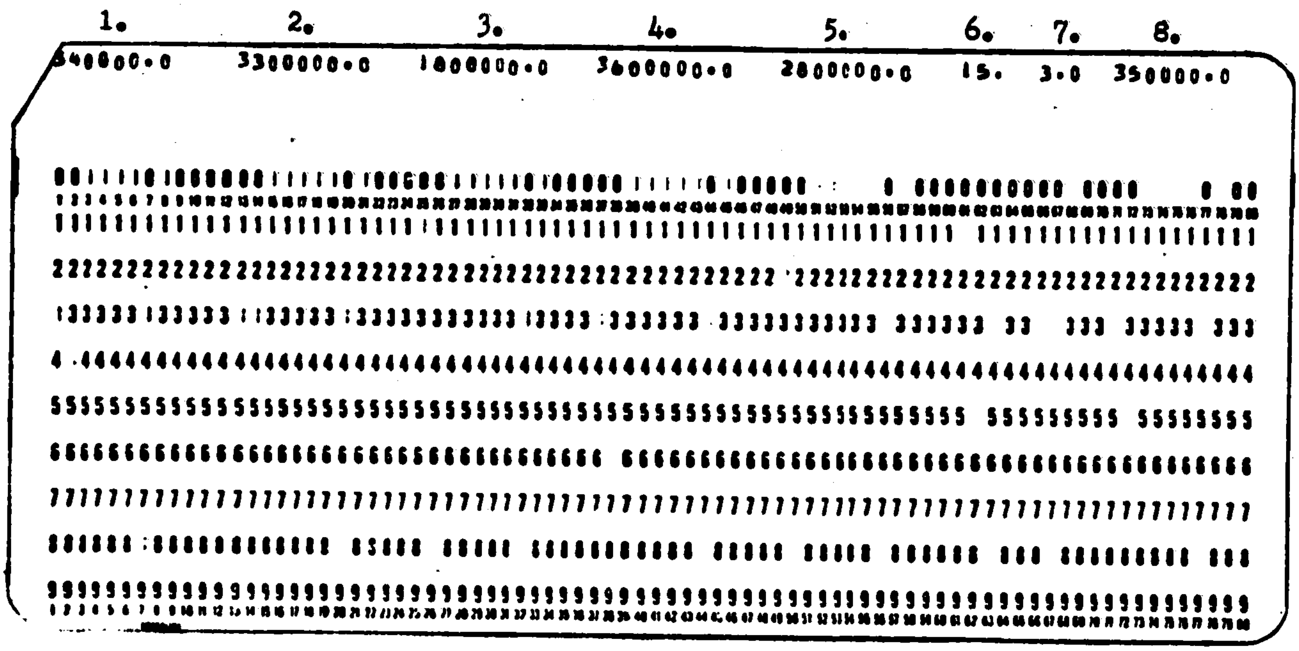


Figure 3.2   Capital Cost Data Card

possible project. At present, the program is not able to include such sunk costs in the analysis.

The second entry on the card is the estimated pre-production development costs necessary for a project of the size indicated. The largest part of this entry will be the labor costs necessary for mine shaft and stope development, the installation of machinery and equipment, and concentrator construction.

The third entry on the card is the mine equipment costs. This would include underground crushers, underground transport systems and the head frame and hoist.

The fourth entry is the processing capital costs. This will be the concentrator and contained equipment.

The fifth entry is the social capital investment. This will include a wide variety of investment necessary to the operation of the project and not included in other categories. Included here could be a power plant, roads, living quarters for employees, and so on.

The sixth and seventh entries are the estimated mining and processing costs for this size of project. Mining costs will usually be the most difficult to estimate since they will vary widely with the mining method used and the scale of operation. Also more uncertainty exists here than in the processing part of the operation. For example, unexpected poor ground conditions could require changes in mining methods which frequently tend to be more costly.

The final entry is the mill (and mine) capacity for this size of project. The mill capacity will be in tons of ore per year.

3.2.3 Mineral Reserve Cards

Following the capital cost cards are the mineral reserve cards. An example is shown in Figure 3.3. The three entries occupy fields of width 15. Again, note that a decimal point is required. As with the cost cards, a minimum of three should be provided in order that the

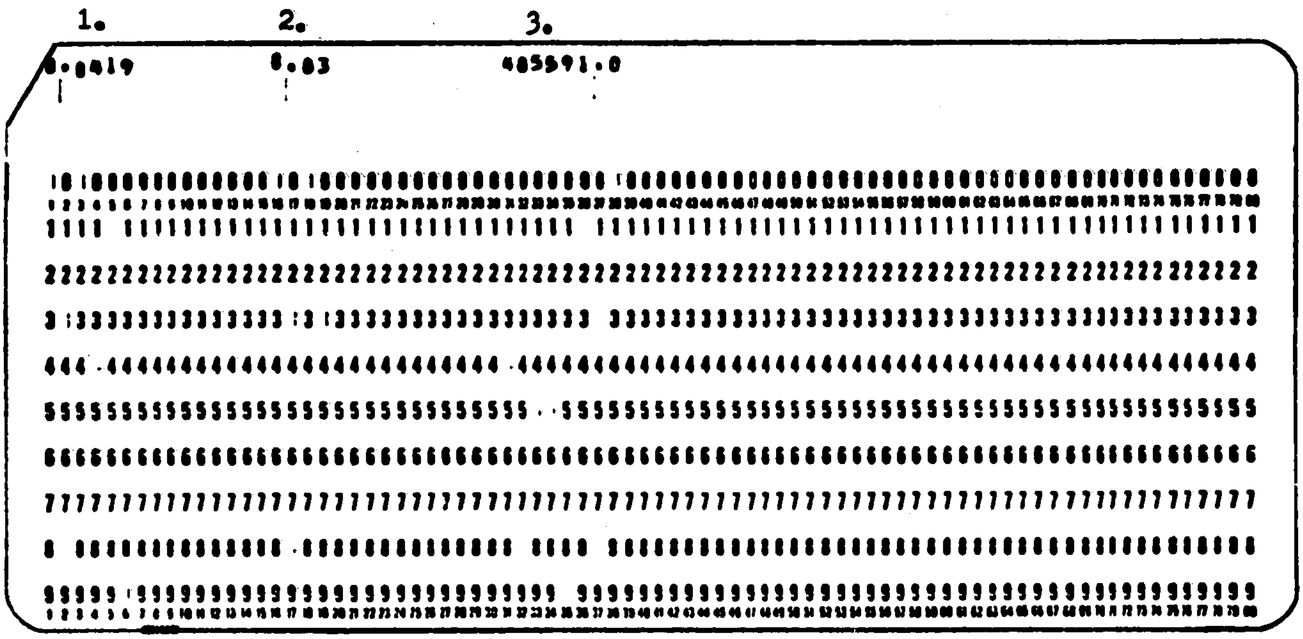


Figure 3.3 Mineral Reserve Data Card

program can derive non-linear functions where applicable. An exception to this would be if the mineral reserve average grade is estimated to vary directly as the log of the tons of material included in the grade calculation. In this instance, one data card is sufficient showing the total tons of ore in the mineral deposit and the average grade of the deposit. The cut-off grade in this case is 0.0

The first entry on the data card is the average grade of the tons of material in entry three.

The second entry is the assumed cut-off grade. This figure will be the first chosen (arbitrarily) after which the total tonnage and average grade figures will be calculated using geologist's estimates of the amount of mineral at each assay value.

The final entry is the total amount of material in tons above the specified cut-off grade.

It is important that the tonnage and grade figures estimated reflect the mineable material in the deposit. Estimates of mineable material will take into account dilutionnof the possible ore by waste rock, and it will take into account possible pillars and support structures which cannot be removed even though they may be of a mineable grade.

3.2.4 Data for the Probabilistic Analysis

Following the mineral reserve cards is a third options card. This has one entry occupying a field of width 4. It will indicate the number of simulations to carry out in the probabilistic analysis. An example is shown in Figure 3.4. No decimal point is required but the entry must be right justified.

The evaluator's estimates of the variability of any of the factors affecting profitability is provided on the final series of cards. Since the program in its present form will modify 11 factors, 11 data cards must be provided. A sample is shown in Figure 3.5. There are two entries on the card, each occupying a field of width 10. A decimal

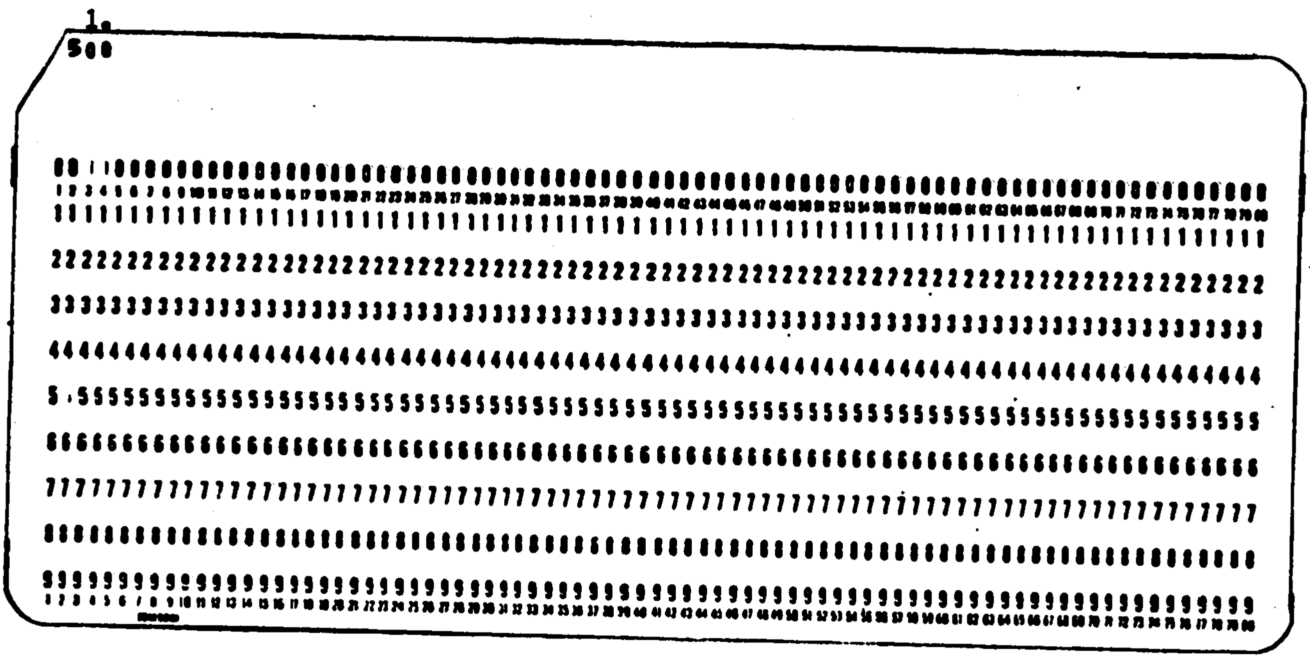


Figure 3.4 Third Options Card

point should be used.

A normal probability distribution is assumed for the values of all factors in this analysis. To represent a skewed distribution (the most likely), a split-normal distribution is used. An example of the split-normal distribution is shown by the estimates in Figure 3.5.

The evaluator is required to obtain estimates for the upper and lower limits for values of a factor at the 90% confidence level. If a point value for, say, concentrating costs is $3.00, and the evaluator is 90% confident that the cost will not be less than $2.85 or more than $3.30, then the two values to be entered on the data card are: $2.85/ $3.00 = .95 and; 3.30/3.00 = 1.1 respectively.

The 11 cards in order are: Average Grade of Ore; Concentrator Recovery Rate, Net Smelter Return; Tons of Ore Mined/year; Pre-production Exploration Costs; Pre-production Development costs; Mine Investment; Processing Investment; Social Capital Investment; Mine Operating Costs, and; Concentrator Operating Costs.

3.3 The Evaluation of a Mineral Deposit

The data for this evaluation undertaken here is based on information from two feasibility studies on a proposed project in Northwestern Manitoba. The studies are somewhat out-of-date; also, they contain different estimates of probable ore reserves and project costs. However, they were useful in that they indicated what the relative capital and operating costs would be. The estimates of probable mineable ore were the most uncertain. The ore reserve data used in this evaluation only approximates that contained in the studies. The information was summarized and re-arranged in order to indicate the probable grade-tonnage relationship in the deposit. Where the studies made very conservative estimates of ore grades and tonnages, these estimates were relaxed somewhat.

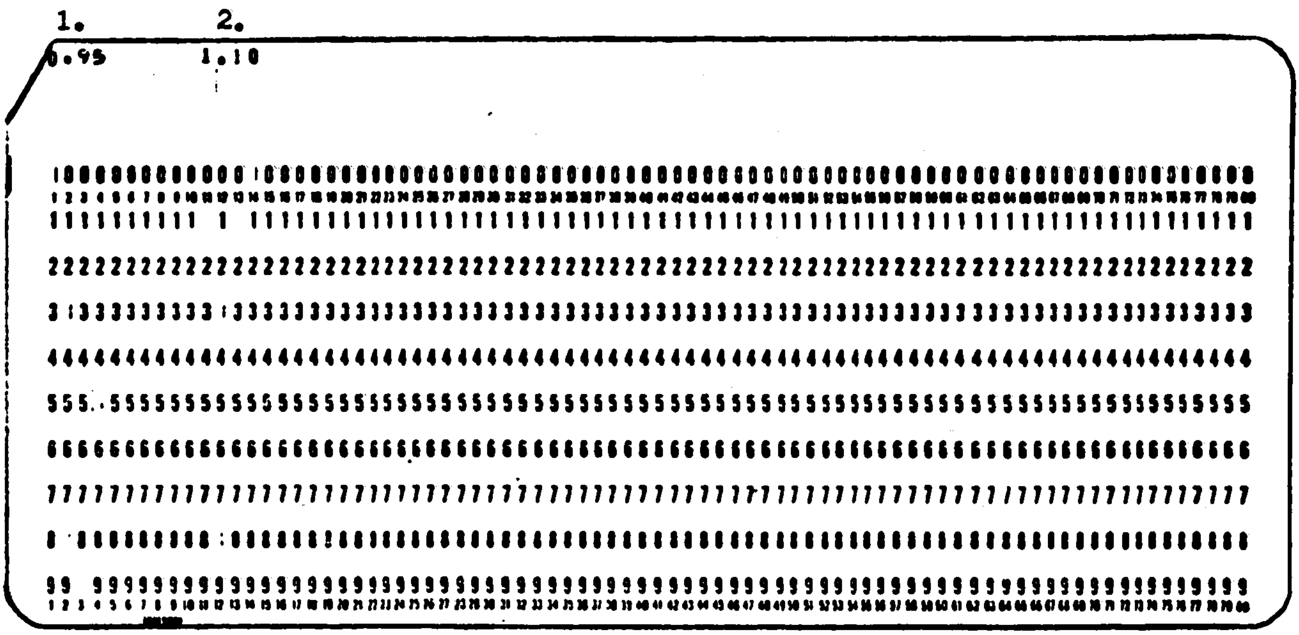


Figure 3.5 Variability Estimates Data Card

3.3.1 Mineral Reserve Data

For this evaluation, the ore reserve data was summerized to 3 cards, plus a tonnage constraint entered on the first options card. This is shown in the following table. The estimates include dilution by waste rock and exclude high grade material which may be unmineable because of location or possible use as a pillar.

	Average Grade	Cut-off Grade	Total Tons
Card 1	0.0525	0.05	44899.0
Card 2	0.047	0.04	270000.0
Card 3	0.0419	0.03	485591.0
Constraint			7.5×10^5

Table 3.2 Mineral Reserve Data

The grade-tonnage functions calculated by the program are shown in Figure 3.6 (also see Appendix I to this chapter). Note that the functions are linear over the range of possible quantities of ore and at the constraint tonnage the cut off grade drops to zero. The extensions of the linear functions beyond the constraint are of no significance.

3.3.2 Capital and Operating Cost Data

Cost data is estimated for 3 possible size of projects. This is shown in Table 3.3

	Exploration	Development	Mining	Processing	Social	Mine Op.	Process Op.	Capacity
Card 1	$86,500	$1,000,000	$700,000	$1,100,000	$1,400,000	$23.00	$15.00	87,500
Card 2	$170,000	$1,900,000	$1,100,000	$2,000,000	$1,900,000	$18.00	$ 8.00	175,000
Card 3	$340,000	$3,300,000	$1,800,000	$3,600,000	$2,800,000	$15.00	$ 3.00	350,000

Table 3.3 Capital and Operating Cost Data

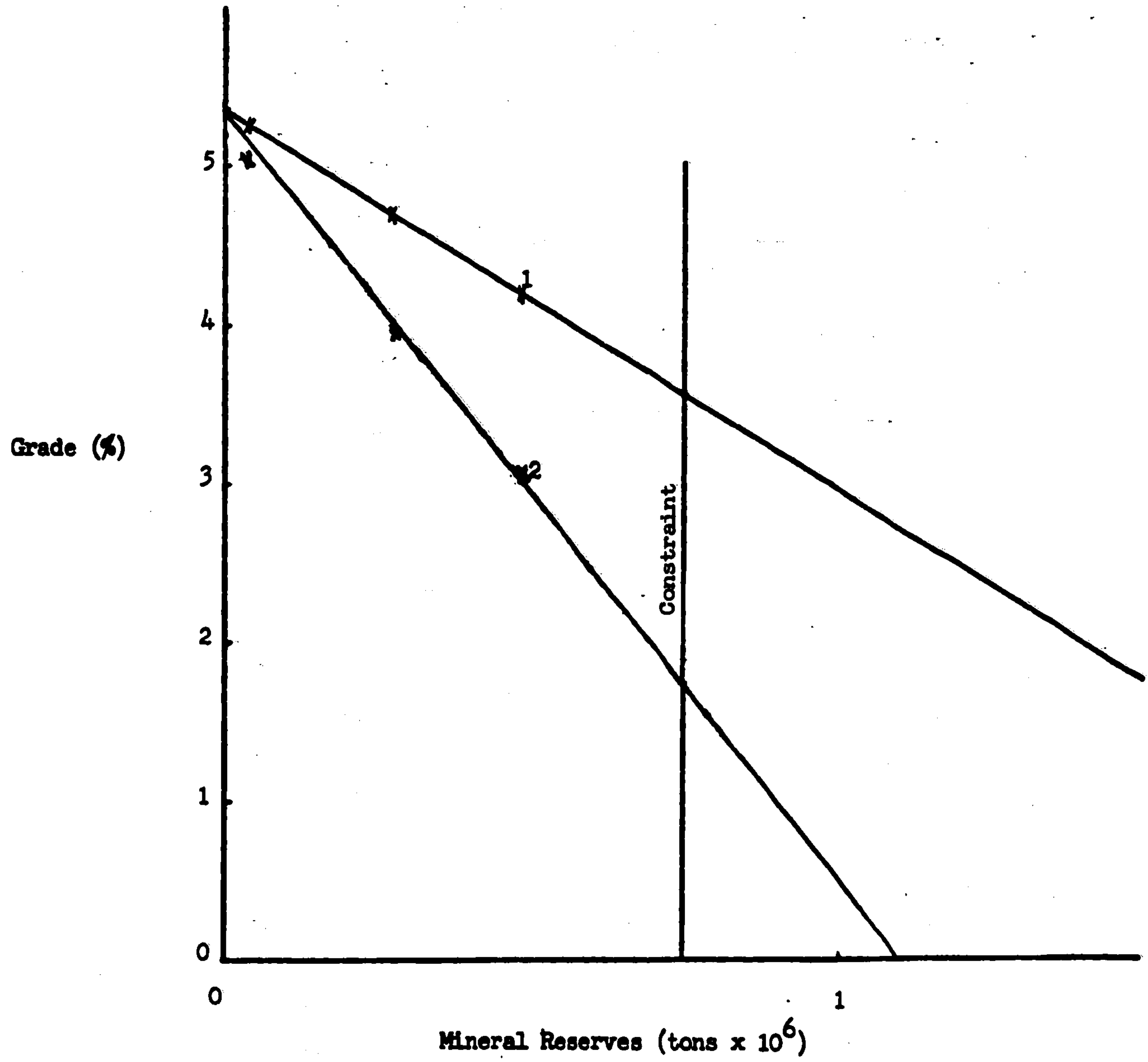


Figure 3.6 Average Grade and Cut-off Grade Functions

1. Average Grade Y=.05355 - .000000024056 X

2. Cut-off Grade Y=.05355 - .000000048112 X

The 7 equations derived by the program from this data are shown in Figure 3.7 and 3.8. Note that the capital cost functions are linear with total costs directly proportioned to annual capacity while the operating cost functions are hyperbolic with costs per ton of capacity decreasing as capacity is increased.

All these costs are specific to the mineral deposit being evaluated. Exploration and development costs, for example, were low because some of this work had been done by a previous owner. The social capital costs reflected the fact that Manitoba Hydro could supply power for the project relatively cheaply. If more generalized use is to be made of the model, cost data will have to be accumulated which pertains to a wide variety of possible mining situations. Geographic location, deposit size, deposit type, and mining methods are all factors which have significant effects on capital and operating costs.

3.3.3 First Options Data Card

The options cards for the first evaluation of the mineral deposit is shown in Figure 3.1. The principal metal value was determined to be $0.89475 per pound of copper in concentrate form. The procedure for arriving at this value is shown in Table 3.1 and the accompanying text.

For the first evaluation, it was assumed that equity capital was the only source of financing. This generally produces a lower IRR than when we assume capital is borrowed.

The real interest rate, the third entry, was assumed to be 8%. This was also the value assumed for the opportunity cost of the capital, the fourth entry.

The fifth entry is the tonnage constraint for the deposit. Such a constraint will normally occur for massive sulphide deposits in Manitoba. The constraint should express the evaluator's estimate of the mineable material.

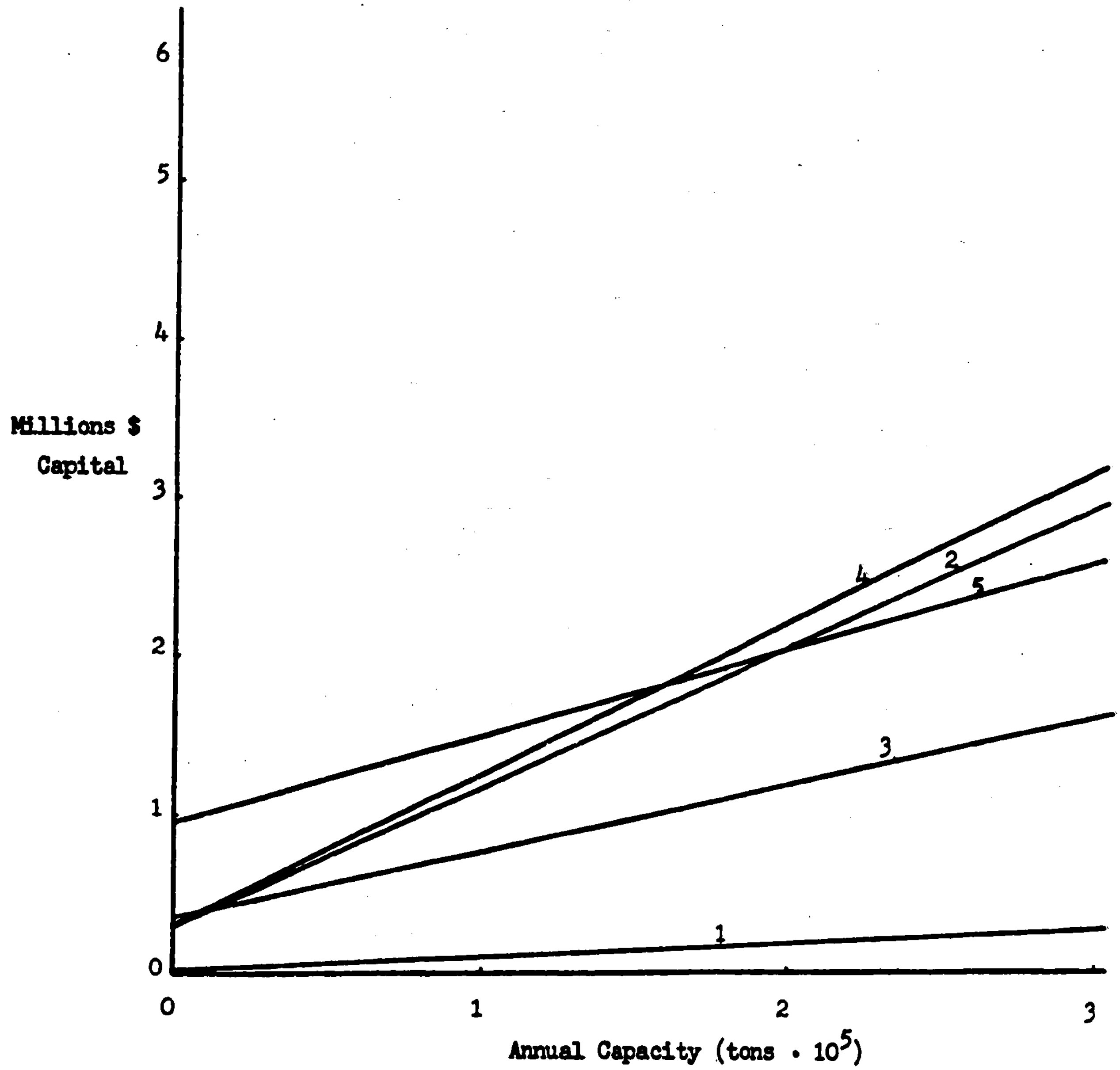


Figure 3.7 Capital Cost Functions

1.	Exploration	Y = 1500 + .9665 X
2.	Development	Y = 300,000 + 8.6531 X
3.	Mine	Y = 350,000 + 4.1633 X
4.	Processing	Y = 300,000 + 9.4694 X
5.	Social	Y = 950,000 + 5.3061 X

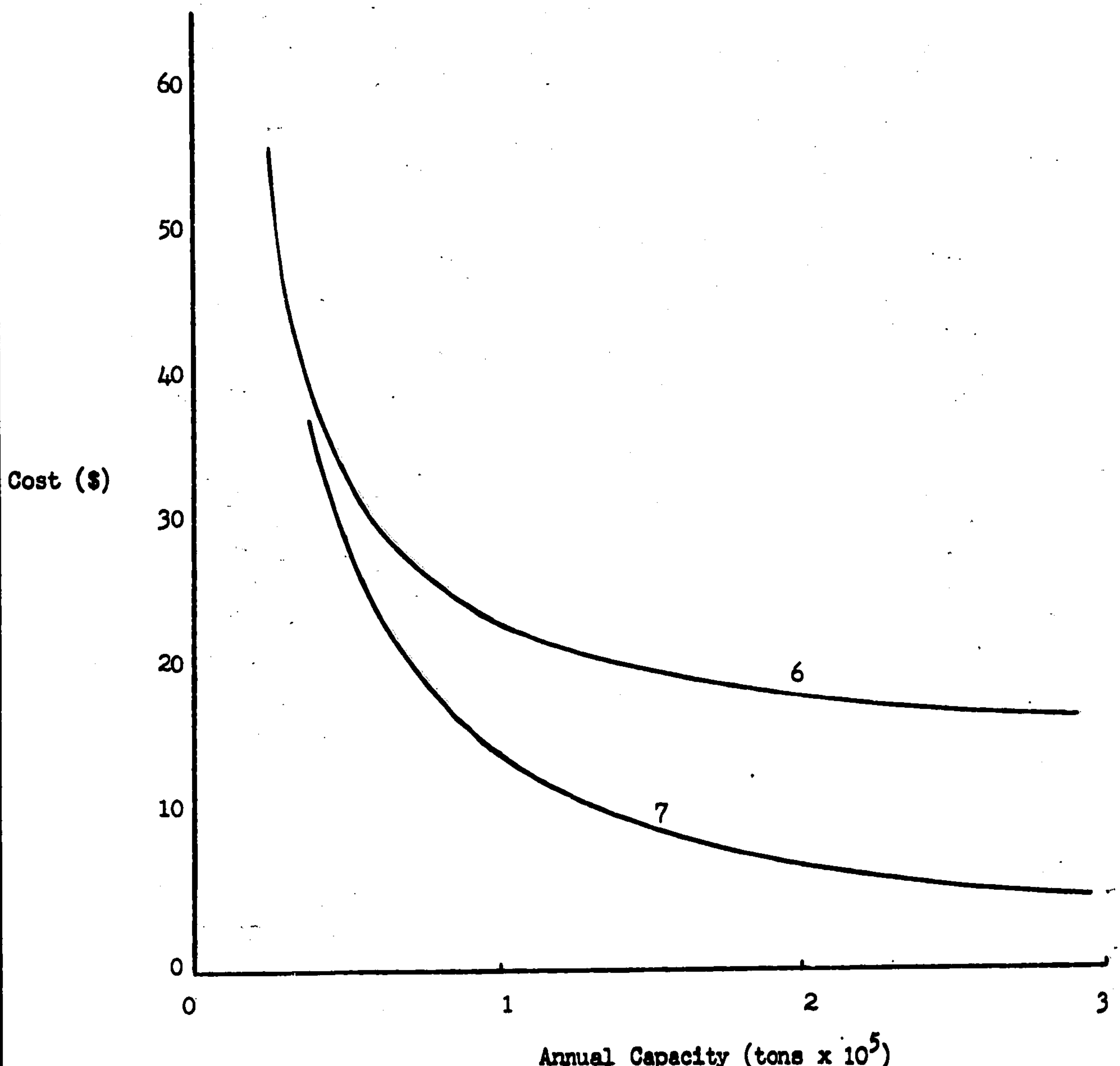


Figure 3.8 Operating Cost Functions

6. Mining Costs $Y = 12.5 + \frac{925000}{X}$

7. Processing Costs $Y = .5 + \frac{1,375,000}{X}$

The minimum acceptable rate of return was assumed to be 20%. This happens to be higher than the maximum return from this project so the investment is not incremented. (Because a constraint is in effect for this mineral deposit, incremental investment would not occur anyway). Based on past reported company behavior, a rate of return of about twice the prime interest rate would be typical. A real rate of return this high can mean that the risk element is large and/or that the expected return in alternate projects is high.

Entries one and two on the second options card indicate the number of cost and mineral reserve data cards respectively. The minimum number of 3 each was provided.

Entry three is zero indicating that the ore is to be mined at the average grade of the primary ore reserves.

Entry four is two indicating that both sensitivity and probabilistic analyses are to be undertaken.

Entry five is zero indicating that secondary ore reserves will not be included in the optimizing stage of the evaluation but will be included in the final calculation which will subsequently be printed. 01 should not normally be used here. If it were to be used, the program would proceed to reduce the life of the primary reserves (and total primary tonnage) so that the highest grade material would be mined first with the lower grade material being relegated to the later years of secondary ore production. In effect, the resulting solution is one of high-grading the ore body. Since this would not likely be practical, or at most, only possible to a limited extent, the use of 01 as a code should be avoided. It can be used (but not in all cases) if the assumption is made that the ore body is to be high-graded in the first place (entry three). 01 can also be used when the assumption is made that the project is to be financed by a large proportion of debt capital. Since debt capital is only recovered over the life of the primary reserves, the program will, in effect, calculate the optimum pay back period.

Entry six is 01 indicating that we want to print graphs of all the functions. When we are satisfied that we have the best data available and a plausible optimum solution exists, then this entry would be changed to 00 while further analysis is undertaken.

3.3.4 Data for the Probabilistic Analysis

The third options card will head the part of the data deck concerned with the probabilistic analysis. This card will indicate the number of simulations to undertake. The number is mainly a function of the number of variables subject to variation. A project with 11 variables subject to variation, will require more simulations in order to provide a reliable probabilistic distribution for the rate of return than would a project with only 3 or 4 variables subject to variation. 500 simulations were done for this evaluation. Because of the uneveness of the rate of return distribution generated for this project, this number would appear to be a minimum.

The proportional variability estimated for each of the 11 factors affecting profitability are shown in the following table.

Factor	Lower Range	Upper Range
Average grade	0.90	1.10
Recovery rate	0.90	1.05
Net smelter return	0.80	1.20
Annual tone processed	0.80	1.05
Exploration costs	0.95	1.20
Development costs	0.95	1.20
Mine equipment costs	0.95	1.20
Process equipment costs	0.95	1.20
Social capital costs	0.95	1.30
Mine operating costs	0.95	1.10
Process operating costs	0.95	1.10

Table 3.4 Factor Variability

These estimates are at the 90% confidence level. That is, the evaluator is 90% certain that the probable value of a factor, F, in any year will be within the range, say, $.95F < F < 1.1\ F$.

3.3.5 Results of the Evaluation

The series of iterations leading to the optimum solution for this evaluation are shown in Table 3.5 below, and in Appendix 1 to this Chapter.

Primary Ore Life	Project Capacity	Average Return (%)
4	125,000	18.714
5	125,000	17.956
3	125,000	17.125
4	135,000	19.101
4	145,000	19.327
4	155,000	19.415
4	165,000	19.385
4	145,000	19.327
4	155,000	19.415
4	165,000	19.385
4	145,000	19.327
4	155,000	19.743

Table 3.5 Optimising Iterations

The program automatically assigned a primary ore life of 4 years to the project and an initial size of 125,000 tons/year. Then it proceeded to increase the life 1 year at a time, and would continue to do so as long as a higher rate of return could be realised. For this initial size of project, the optimum life proved to be 4 years yielding a rate of return of 18.71%. With the life of 4 years, the size of the project was increased in size by increments of 10,000 tons/year. The maximum rate of return was obtained with a size of 155,000 tons/year. The LIFE was increased to 5 years but then the tonnage constraint of 750,000 tons was exceeded. The primary ore life was reduced by 1 year and the size incrementing continued. At a life of 4 years for the primary ore reserves, and a SIZE of 155,000 tons/year, the maximum rate of return which could be achieved was 19.42%. This solution required a total of 11 iterations.

The detailed production data is provided in Table 3.6. This is from the actual computer printout. Note that in addition to the primary ore of 620,000 tons, there is some secondary ore amounting to 130,000 tons, The cut-off grade for the secondary ore was 1.73% while the cut-off grade for the primary ore was 2.37%.

The financial data summary is shown in table 3.7. This shows the total capital and operating costs for the project, the assumed debt and equity capital, and the average and marginal rate of return. Since the average rate of return is at maximum, the marginal rate of return will also be this value.

Table 3.8 shows the detailed calculation for arriving at the cash flow for the project. Note that the internal rate of return here is 19.74% whereas the maximum rate of return was initially determined to be 19.42%. This difference results from including secondary ore in the final calculation whereas it was excluded in previous calculations. The inclusion of extra revenue (and net profit) has increased the rate of return.

Table 3.9 shows the cash flow for the project if taxes and royalties are added back as might be the case for a Crown corporation. An important assumption here is that the project would not have been undertaken by a private firm in the absence of the Crown. In this case, taxes and royalties are not a cost to the project. Note that the rate of return to the project approximately doubles.

Appendix II to this Chapter contains a detailed printout for the project under completely different assumptions. Firstly, the tonnage-grade function for the deposit is assumed to be logarithmic. Secondly, 50% of the project would be financed by debt capital. Thirdly, incremental investment occurs so long the marginal rate of return exceeds 8%.

The project yielding the maximum rate of return is one of SIZE 120,000 tons/year with LIFE equal to 3 years. The size is then incremented to a size of 160,000 tons of ore per year where the marginal rate of

	TONS OF ORE	AVERAGE GRADE	CUTOFF GRADE	RECOVERABLE METAL (LBS)	CONCENTRATE VALUE($)
1	0.0	0.0 %	0.0 %	0.0	0.0
2	0.0	0.0 %	0.0 %	0.0	0.0
3	155000.0	3.86%	2.37%	11207472.85	10027886.33
4	155000.0	3.86%	2.37%	11207472.85	10027886.33
5	155000.0	3.86%	2.37%	11207472.85	10027886.33
6	155000.0	3.86%	2.37%	11207472.85	10027886.33
7	130000.0	2.06%	1.73%	4864719.43	4352707.71

PRIMARY ORE PRODUCTION 620000.0 TONS

TOTAL ORE PRODUCTION 750000.0 TONS

Table 3.6 Production Data for Optimum Project

FINANCIAL DATA

EXPLORATION COSTS	151312.24490
PREPRODUCTION DEVELOPMENT COSTS	1641224.48980
MINING INVESTMENT	995306.12245
PROCESSING INVESTMENT	1767755.10204
SOCIAL CAPITAL INVESTMENT	1772448.97959
PREPRODUCTION WORKING CAPITAL	632804.69388
TOTAL	6960851.63265
MINING COSTS PER TON	18.46774
PROCESS COSTS PER TON	8.37097
ADMINISTRATIVE COSTS PER TON	1.34194
TOTAL	28.18065
DEBT-EQUITY RATIO	0.0
EQUITY CAPITAL	6960851.63265
BORROWED CAPITAL	0.0
AVERAGE RATE OF RETURN:	19.74337%
MARGINAL RATE OF RETURN:	19.74337%

Table 3.7 Financial Data Summary

	OPERATING PROFIT	CAPITAL TAX	INCOME TAX	MINING ROYALTY	TOTAL INVESTMENT	WORKING CAPITAL AND SALVAGE VALUE	CASH FLOW
1	0.0	6328.05	0.0	0.0	3164023.47	0.0	-3170351.52
2	0.0	13921.70	0.0	0.0	3164023.47	632804.69	-3810749.87
3	5659886.33	13288.90	62208.33	1324329.28	0.0	949207.04	3310852.78
4	5659886.33	10757.68	1488762.43	1445756.04	0.0	0.0	2714610.19
5	5659886.33	8226.46	1529037.98	1542897.45	0.0	0.0	2579724.45
6	5659886.33	5695.24	2030942.33	1620610.57	0.0	0.0	2002638.19
7	689223.84	0.00	203337.25	12812.2	0.0	-1582011.73	2055086.06

IRR IS 19.743374%

Table 3.8 Project Cash Flow

	PROJECT CASH FLOW	CAPITAL TAX	INCOME TAX	MINING ROYALTY	CASH FLOW
1	-3170351.52	6328.05	0.0	0.0	-3164023.47
2	-3810749.87	13921.70	0.0	0.0	-3796828.16
3	3310852.78	13288.90	62208.33	1324329.28	4710679.29
4	2714610.19	10757.68	1488762.43	1445756.04	5659886.33
5	2579724.45	8226.46	1529037.98	1542897.45	5659886.33
6	2002638.19	5695.24	2030942.33	1620610.57	5659886.33
7	2055086.06	0.00	203337.25	12812.27	2271235.58

IRR IS 41.504660%

NOTE: This cash flow assumes that the project would not have been undertaken by a private company so that taxes and royalties are not a cost to the project.

Table 3.9 Cash Flow After Adding Back Taxes and Royalties return is 8.72% and the average is 16.7%.

Note that although there are 1.2 million tons of material in the deposit, only 507,641 tons of it are ore. Had the project been financed entirely by equity capital, the calculated ore reserves would have been even less.

Table 3.10 shows the project cash flow and equity cash flow under the assumption of 50% borrowed capital. The rates of return are 16.7 and 21.4% respectively. This illustrates the leverage effect of borrowing capital which costs less than the project can yield.

3.4 The Sensitivity and Probabilistic Analyses

Analyses were carried out on the project shown in Appendix I to this Chapter. This project assumed that financing was by equity capital alone and that the grade-tonnage relationship was linear.

3.4.1 Sensitivity Analysis

Tables 3.11, 3.12 and 3.13 contain the results of 3 separate sensitivity tests done on each of the 11 factors affecting project profitability. In the first test, each parameter is changed by 5%. As the table shows, profitability is least sensitive to changes in the capital investment. Operating cost changes result in larger changes in the rate of return, with the largest changes occuring when factors affecting gross revenue are varied.

Doubling the amount of change in the capital cost parameters as in Table 3.12 and again in Table 3.13, results in roughly a doubling of the change in the rate of return. Doubling the change in factors affecting gross profit such as average ore grade or tonnage of ore processed more than doubles the change in the rate of return. This is because of the interaction between some of the parameters. This interaction affects 5 of the 11 variables. First, a change in the anticipated grade of concentrator feed leads to a significant change in the recovery rate. Second, a shortage of ore results in higher than normal average mining and processing costs.

	OPERATING PROFIT	CAPITAL TAX	INCOME TAX	MINING ROYALTY	TOTAL INVESTMENT	WORKING CAPITAL AND SALVAGE VALUE	CASH FLOW
1	0.0	6729.67	0.0	0.0	3235419.39	0.0	-3242149.06
2	0.0	15731.90	0.0	0.0	3235419.39	647083.88	-3898235.17
3	5834213.76	13601.37	0.0	1370586.72	0.0	970625.82	3479399.85
4	5834213.76	9333.27	1300744.94	1494699.77	0.0	0.0	3029435.78
5	5834213.76	4853.13	1527953.60	1593990.21	0.0	0.0	2707416.82
6	24227.83	0.0	0.0	0.0	0.0	-1617709.69	1641937.53

IRR IS 16.652563%

	PROJECT CASH FLOW	BORROWED CAPITAL	DEBT REPAYMENT	INTEREST ON DEBT	CASH FLOW
1	-3242149.06	1617709.69	0.0	0.0	-1624439.37
2	-3897588.08	1941251.63	0.0	0.0	-1956336.45
3	3479399.85	0.0	1227035.59	318675.87	1933688.39
4	3029435.78	0.0	1325198.44	220513.02	1483724.32
5	2707416.82	0.0	1431214.32	114497.15	1161705.36
6	1641937.53	0.0	0.0	0.0	1641937.53

IRR IS 21.432497%

NOTE: 1 EQUITY CASH FLOW IS THAT AFTER ADDING BORROWED CAPITAL AND SUBTRACTING DEBT REPAYMENT AND INTEREST.

2 THE INTEREST RATE IS 8.00%

Table 3.10 Project Cash Flow and Equity Cash Flow Assuming Borrowed Capital

The magnitude of the change in the rate of return can be used to indicate these factors which require special care when values are determined. As these tables suggest, ore grade, concentrator recovery rates, and the net smelter return are the most important parameters.

3.4.2 The Probabilistic Analysis

The results of the probabilistic analysis are shown in Figure 3.9. 500 simulations were carried out using the parameter variabilities contained in Table 3.4. Most of the factors were assumed to have a value distribution that was skewed. As the rate of return distribution shows, the mean rate of return of 16.74% is well below the point estimate. The mean or expected return is the proper one to use in project evaluation. Note that the point value (or greater) for the rate of return of 19.74% could be expected to occur only 19% of the time. In other words, it is most probable that the project would not achieve the optimum rate of return that was originally calculated. An important consequence of using the expected rate of return determined here is that the risk factor in the minimum acceptable return for the project can be reduced. This has important implications for total calculated ore reserves and the optimum size of project.

As was the case with the sensitivity analysis, there is interdependence between (i) the concentrator recovery rate and average ore grade, and (ii) the quantity of material processed per year and average mining and processing costs. The effect of this interdependence has been to increase the difference between the calculated point value for the rate of return and the expected value. In one series of trials, the increase amounted to a little over one half of one percent.

	PARAMETER CHANGE	IRR CHANGE	RATE OF RETURN
AVERAGE ORE GRADE	-5.0%	-10.37%	17.69%
RECOVERY RATE	-5.0%	-10.00%	17.76%
NET VALUE	-5.0%	-10.00%	17.76%
ORE TONNAGE	-5.0%	-9.76%	17.81%
PREPRODUCTION EXPLORATION	5.0%	-0.08%	19.72%
PREPRODUCTION DEVELIPMENT	5.0%	-1.07%	19.52%
MINE INVESTMENT	5.0%	-0.63%	19.61%
PROCESSING INVESTMENT	5.0%	-1.11%	19.52%
SOCIAL CAPITAL	5.0%	-1.11%	19.52%
MINE OPERATING COSTS	5.0%	-3.02%	19.14%
PROCESS OPERATING COSTS	5.0%	-1.37%	19.47%

OPTIMUM RETURN 19.74

Table 3.11 Sensitivity Analysis #1

	PARAMETER CHANGE	IRR CHANGE	RATE OF RETURN
AVERAGE ORE GRADE	-10.0%	-21.45%	15.50%
RECOVERY RATE	-10.0%	-20.66%	15.66%
NET VALUE	-10.0%	-20.66%	15.66%
ORE TONNAGE	-10.0%	-20.17%	15.75%
PREPRODUCTION EXPLORATION	10.0%	-0.16%	19.70%
PREPRODUCTION DEVELOPMENT	10.0%	-2.12%	19.32%
MINE INVESTMENT	10.0%	-1.24%	19.49%
PROCESSING INVESTMENT	10.0%	-2.19%	19.30%
SOCIAL CAPITAL	10.0%	-2.20%	19.30%
MINE OPERATING COSTS	10.0%	-6.19%	18.51%
PROCESS OPERATING COSTS	10.0%	-2.74%	19.19%

OPTIMUM RETURN 19.74

Table 3.12 Sensitivity Analysis #2

	PARAMETER CHANGE	IRR CHANGE	RATE OF RETURN
AVERAGE ORE GRADE	-20.0%	-49.79%	9.91%
RECOVERY RATE	-20.0%	-47.74%	10.31%
NET VALUE	-20.0%	-47.74%	10.31%
ORE TONNAGE	-20.0%	-46.50%	10.56%
PREPRODUCTION EXPLORATION	20.0%	-0.32%	19.67%
PREPRODUCTION DEVELOPMENT	20.0%	-4.16%	18.91%
MINE INVESTMENT	20.0%	-2.46%	19.25%
PROCESSING INVESTMENT	20.0%	-4.41%	18.86%
SOCIAL CAPITAL	20.0%	-4.42%	18.86%
MINE OPERATING COSTS	20.0%	-12.91%	17.19%
PROCESS OPERATING COSTS	20.0%	-5.57%	18.63%

OPTIMUM RETURN 19.74

Table 3.13 Sensitivity Analysis #3

```
 7%  OCCURS   0.20% | *
 8%  OCCURS   0.80% | *
 9%  OCCURS   1.20% | *
10%  OCCURS   1.60% | **
11%  OCCURS   2.40% | **
12%  OCCURS   5.60% | ******
13%  OCCURS   5.20% | *****
14%  OCCURS   5.40% | *****
15%  OCCURS   9.20% | *********
16%  OCCURS  12.40% | ************
17%  OCCURS  12.20% | ************
18%  OCCURS  14.40% | **************
19%  OCCURS  10.80% | ***********
20%  OCCURS   7.40% | *******
21%  OCCURS   5.40% | *****
22%  OCCURS   3.00% | ***
23%  OCCURS   1.40% | *
24%  OCCURS   0.80% | *
25%  OCCURS   0.40% | *
26%  OCCURS   0.20% | *
```

NUMBER OF SIMULATIONS 500

MEAN RATE OF RETURN 16.74111%

Figure 3.9 Expected Rate of Return Distribution

APPENDIX I

COMPUTER PRINTOUT

Grade-Tonnage Relationship - Linear with Constraint

Graphs of Functions - Yes

Financing - Equity Capital Only

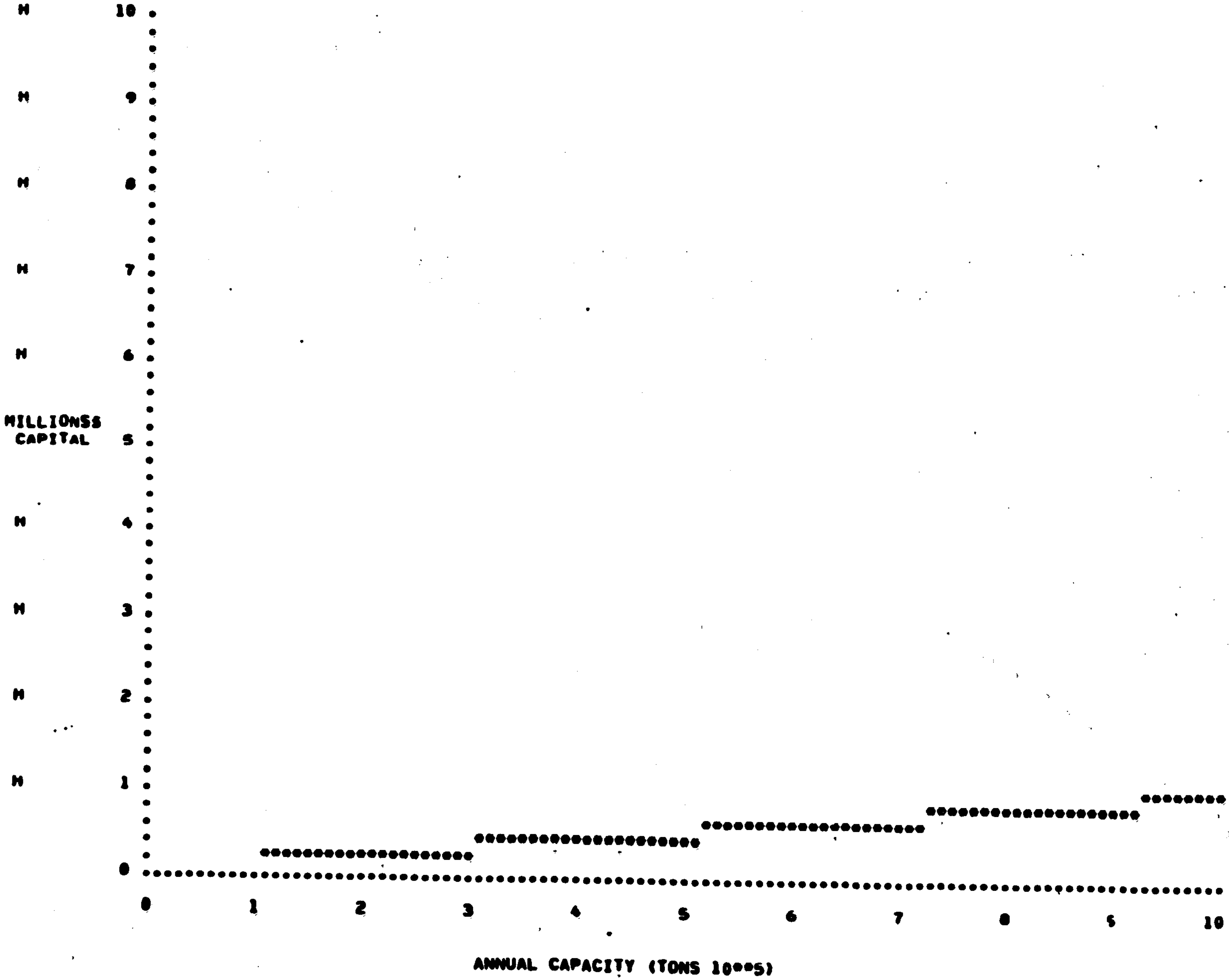
Sensitivity Analysis - Yes

Probabilistic Analysis - Yes

Incremental Investment - No

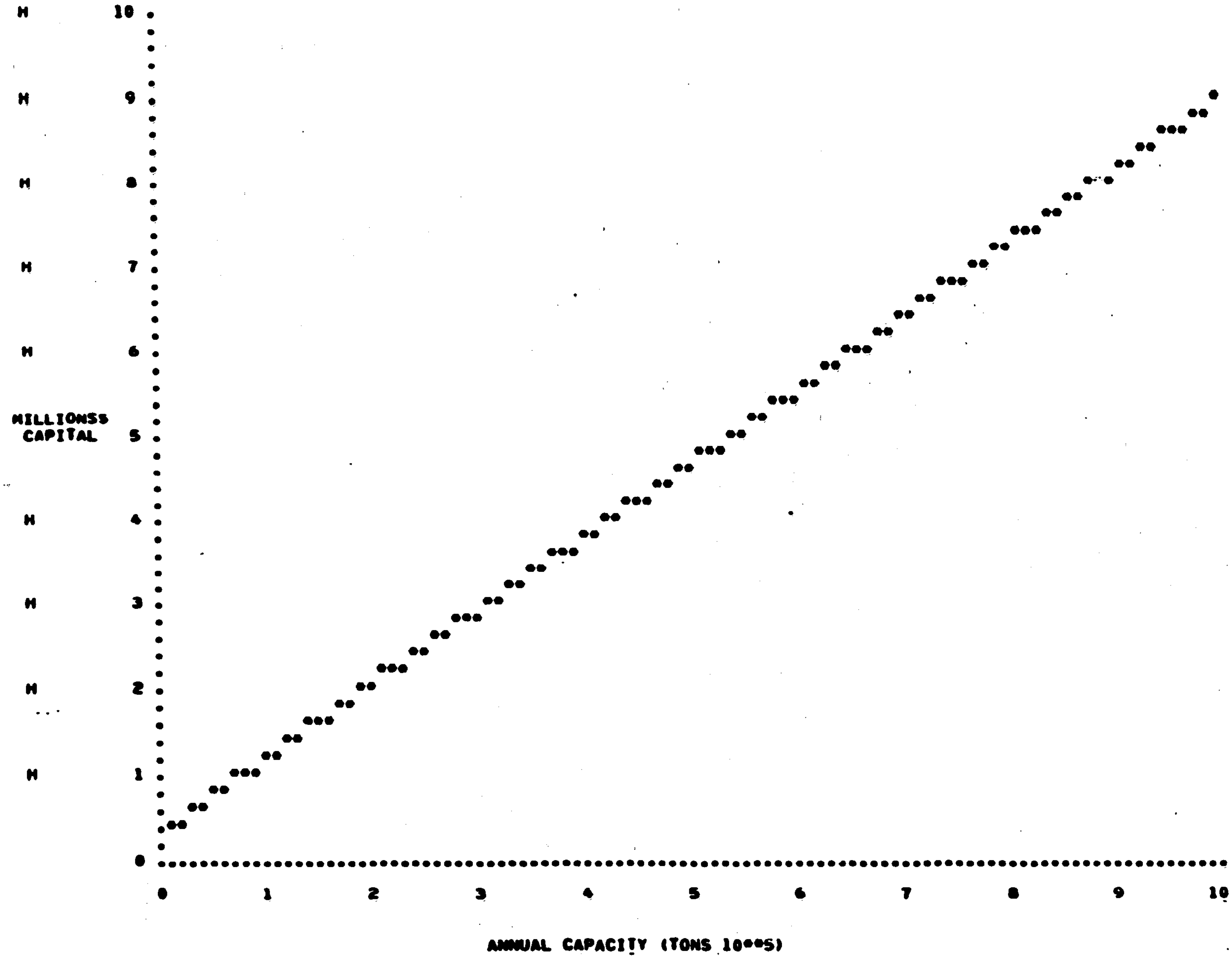
PREPRODUCTION EXPLORATION

Y= 1500.00000+(0.966530612245)X



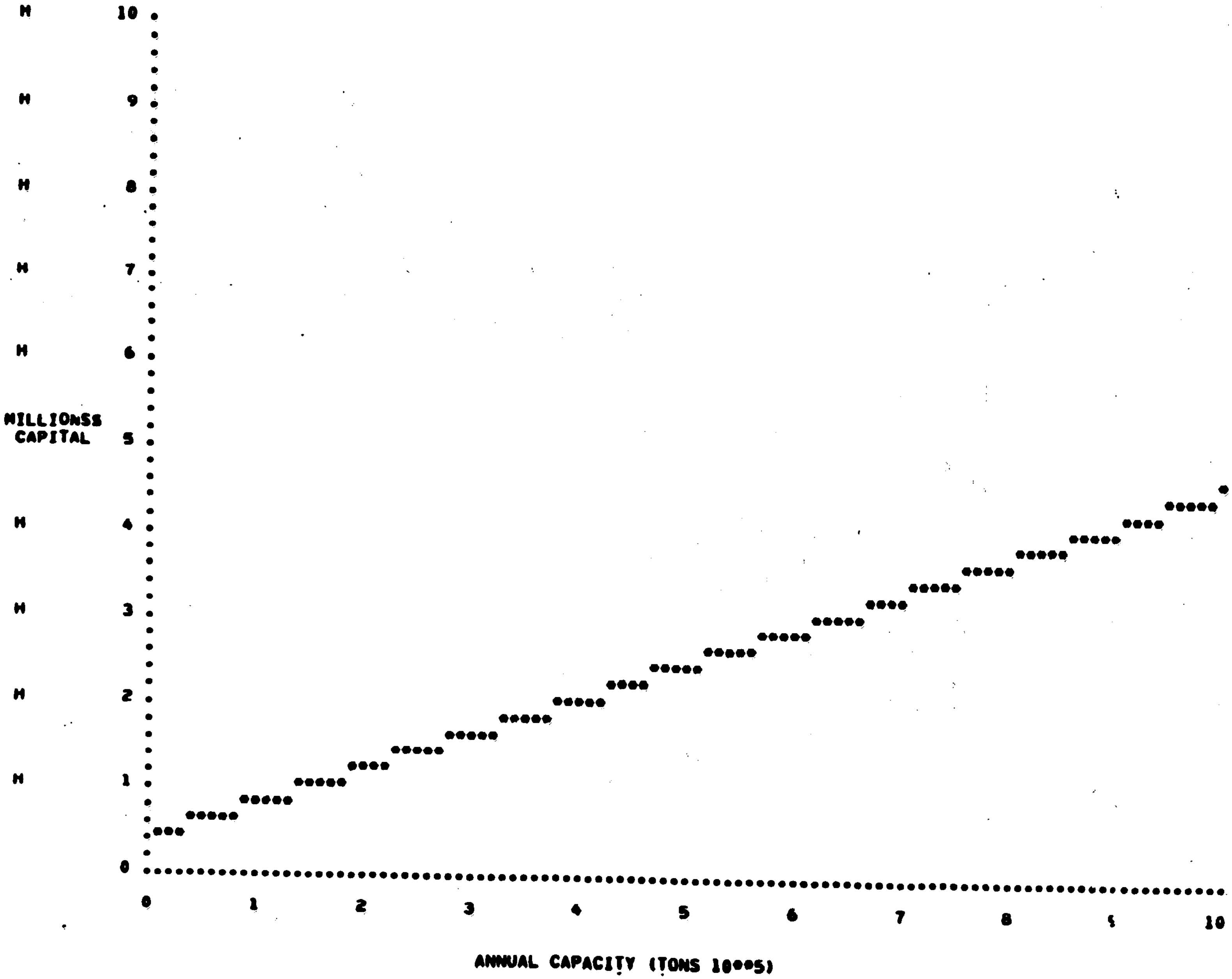
PREPRODUCTION DEVELOPMENT

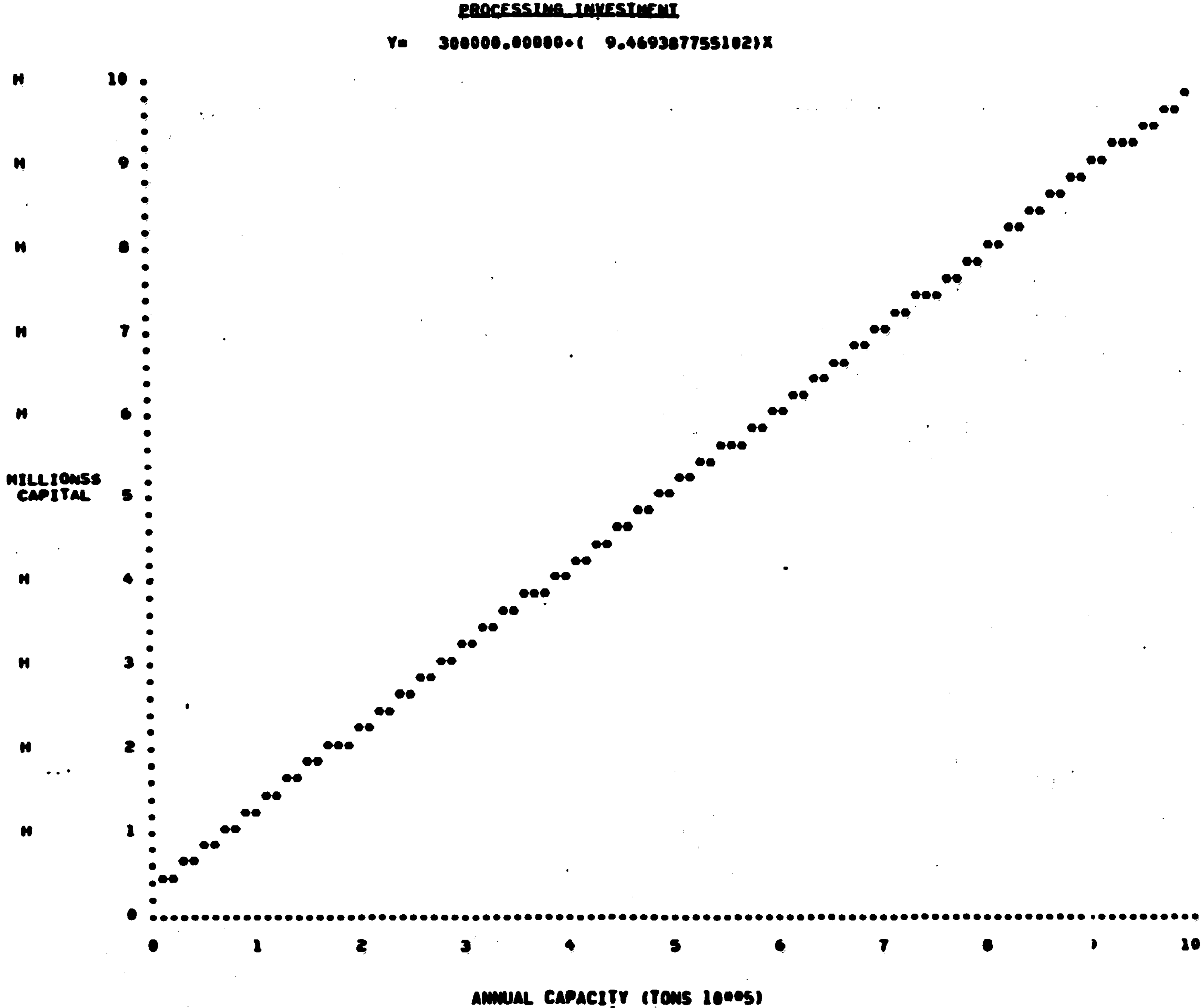
Y= 300000.00000+(8.6530612244490)X



MINING INVESTMENT

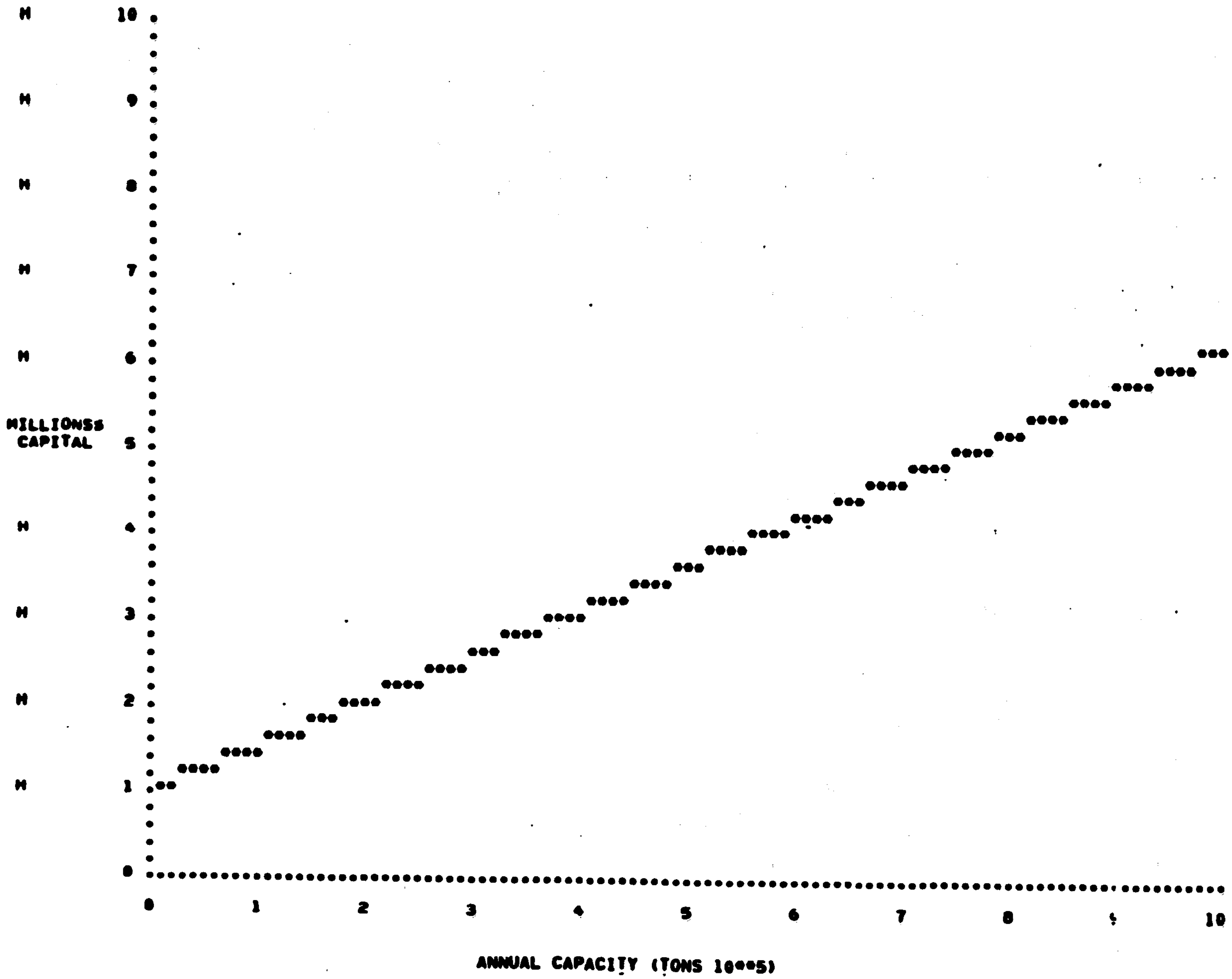
Y= 350000.00000+(4.163265306122)X




PROCESSING INVESTMENT
Y= 300000.00000+(9.469387755102)X
MILLIONS$ CAPITAL
M
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
10
ANNUAL CAPACITY (TONS 10**5)

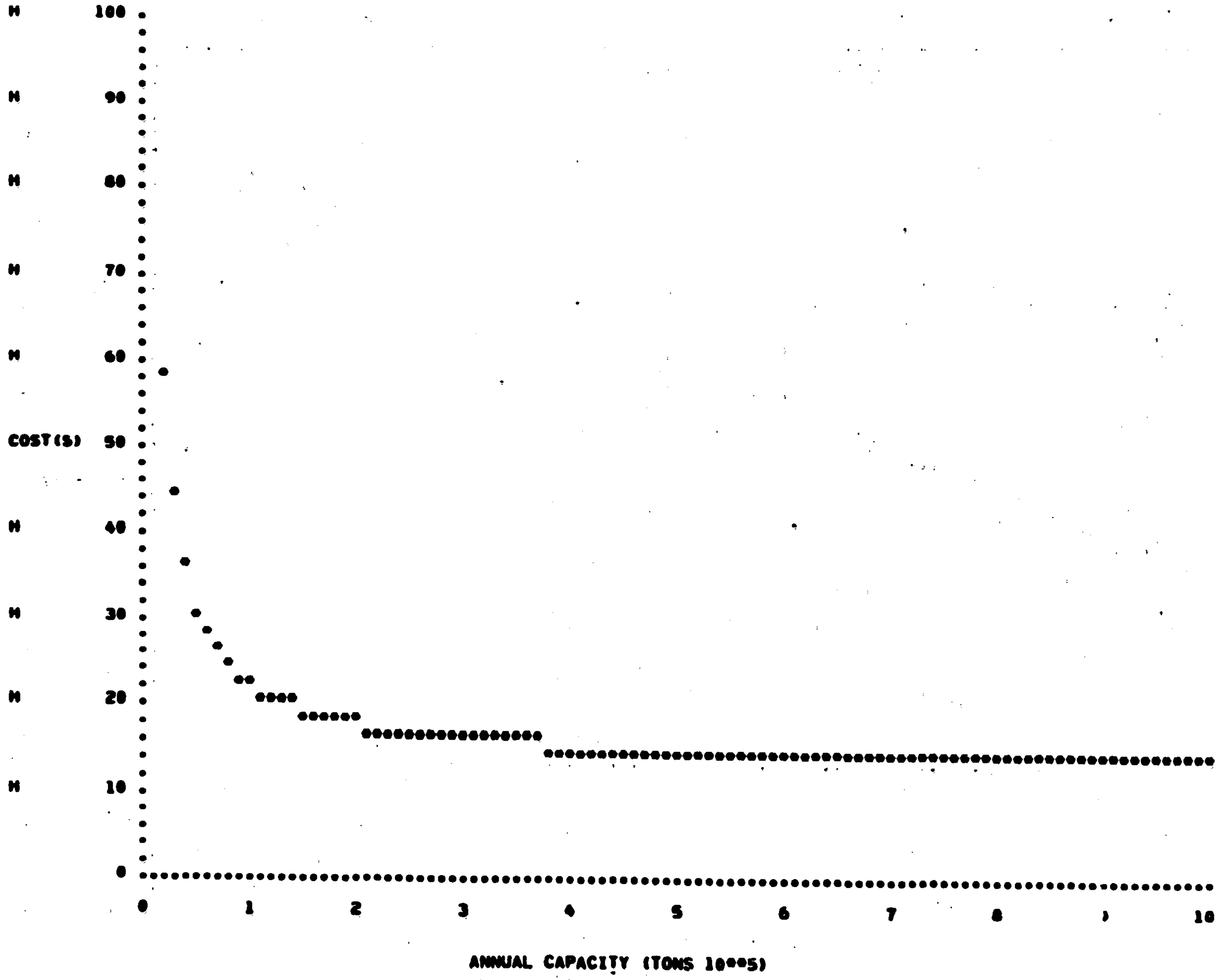
SOCIAL INVESTMENT

Y= 950000.00000+(5.3061224489980)X



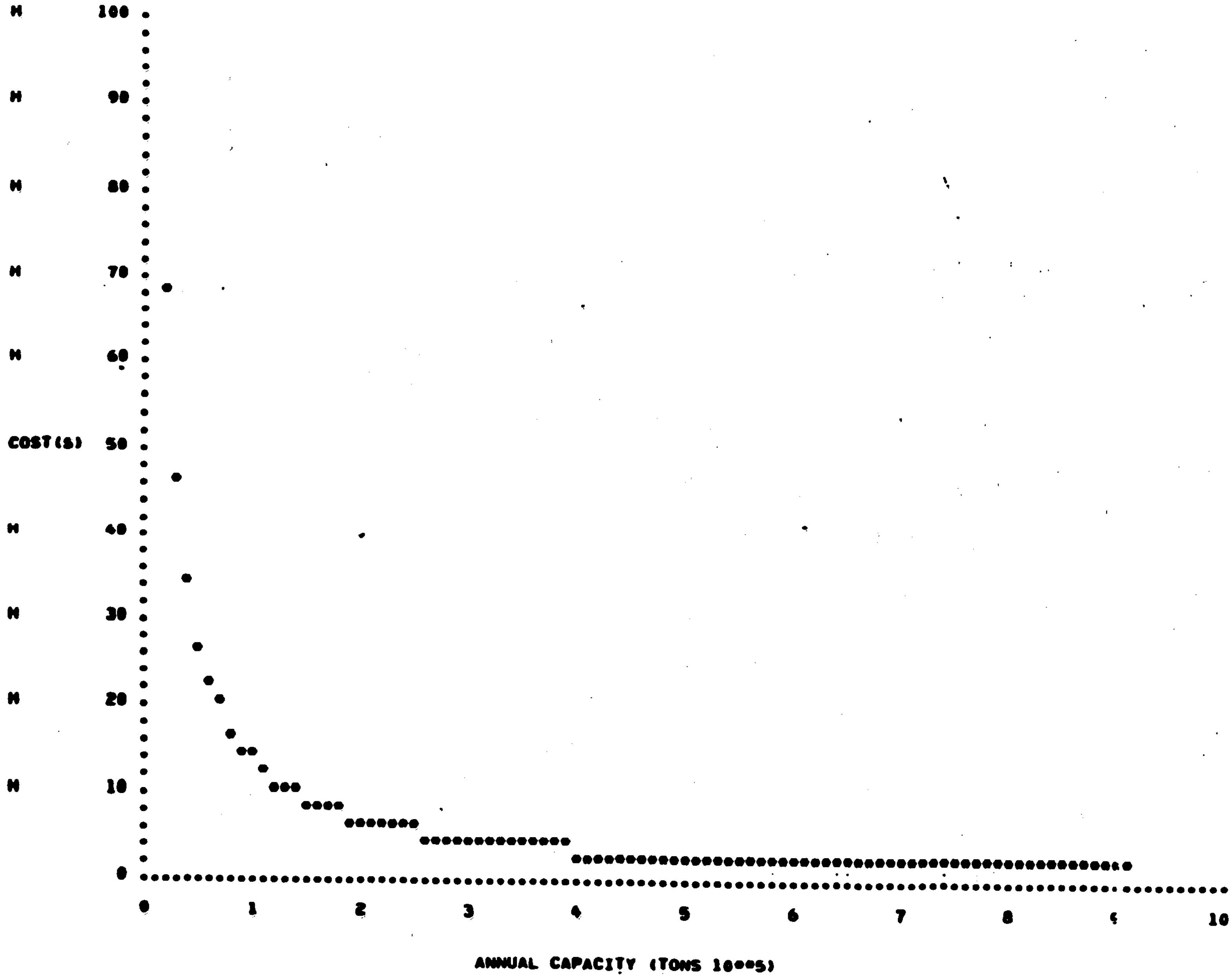
MINING COSTS(PER TON)

Y= 12.50000+(925000.00000)/X



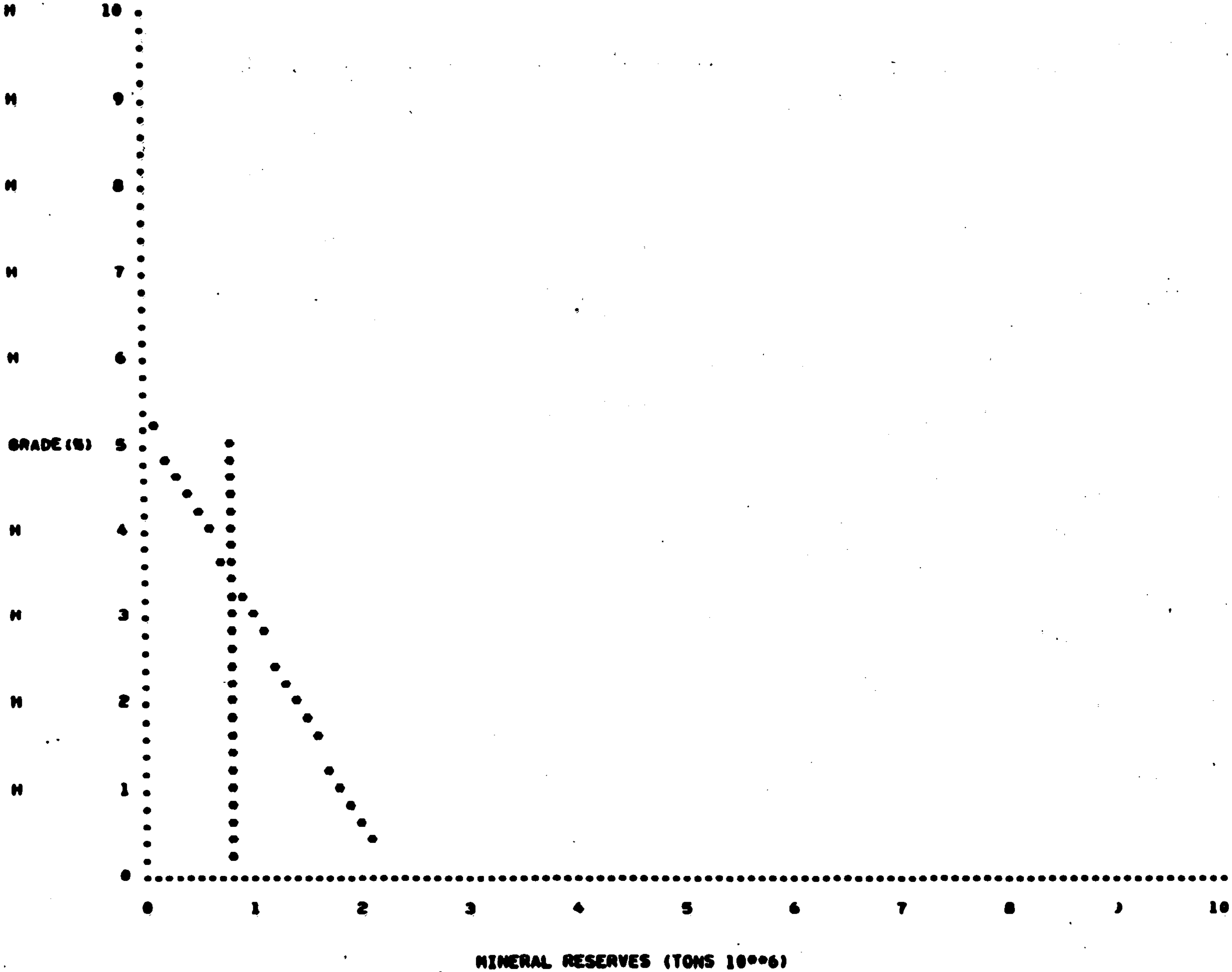
PROCESSING COSTS(PER TON)

Y= -0.50000+(1375000.00000)/X



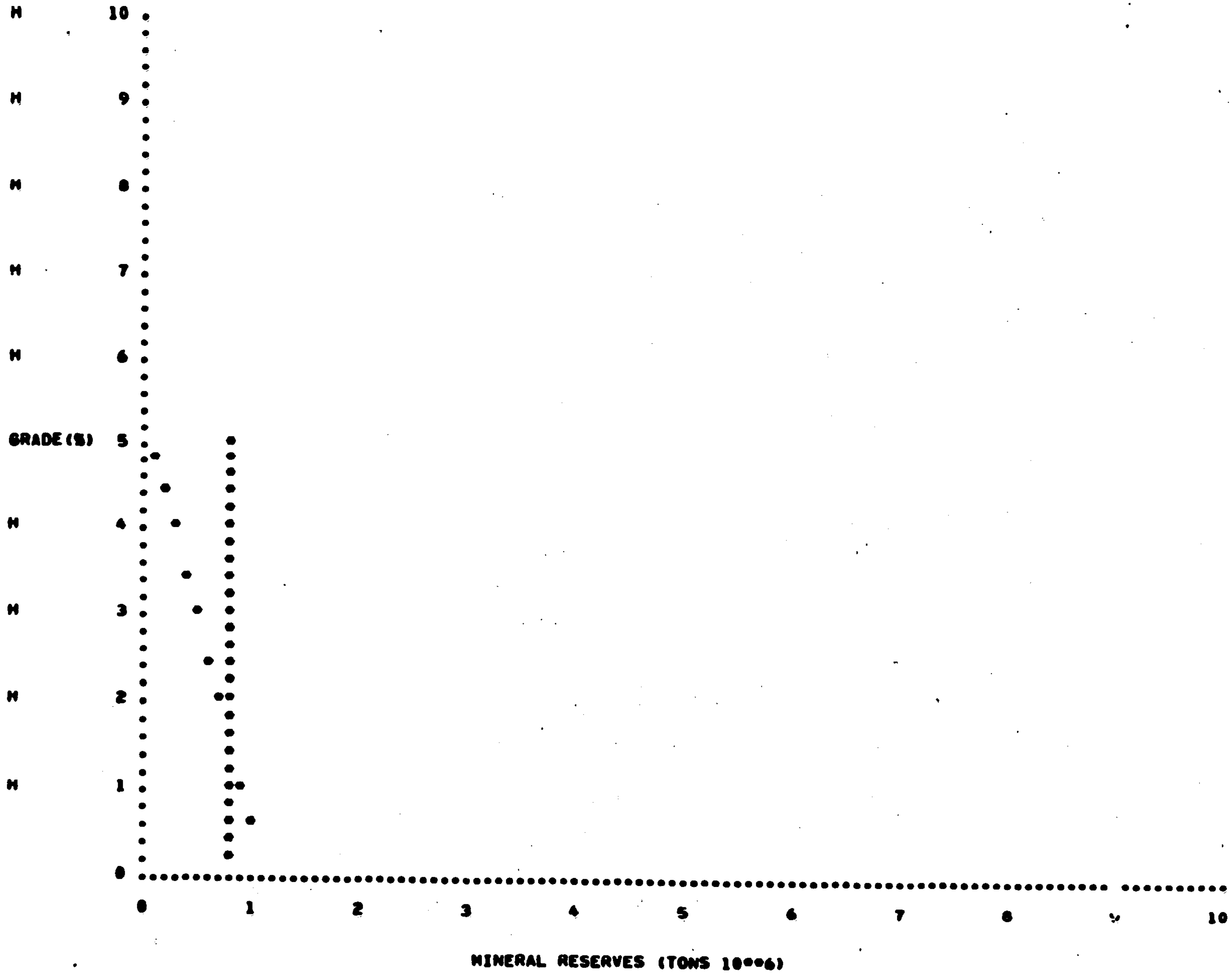
AVERAGE ORE GRADE

Y= 0.05355+(-0.000000024056)X



CUTOFF ORE GRADE

Y= 0.05355+(-0.000000048112)X



INPUT DATA

TWO OPTIONS CARDS

0.8948	0.0	0.0800	0.0800	750000.	20.00
3	3	0	2	0	0

COST CARDS

86500.	1000000.	700000.	1100000.	1400000.23.0015.00	87500.
170000.	1900000.	1100000.	2000000.	1900000.18.00 0.00	175000.
340000.	3300000.	1800000.	3600000.	2800000.15.00 3.00	350000.

MINERAL RESERVE DATA

0.05250	0.05000	44899.00000
0.04700	0.04000	270000.00000
0.04190	0.03000	485591.00000

PROJECT ITERATIONS

PREPRODUCTION PERIOD	PRIMARY ORE LIFE	SECONDARY ORE LIFE	TOTAL LIFE	PROJECT CAPACITY	INTERNAL RATE OF RETURN	MARGINAL RATE OF RETURN
2	4	0	6	125000.00	18.71351	0.0
2	5	0	7	125000.00	17.95553	0.0
2	3	0	5	125000.00	17.14254	0.0
2	4	0	6	135000.00	19.10077	0.0
2	4	0	6	145000.00	19.32668	0.0
2	4	0	6	155000.00	19.41545	0.0
2	4	0	6	165000.00	19.38534	0.0
2	4	0	6	145000.00	19.32668	0.0
2	4	0	6	155000.00	19.41545	0.0
2	4	0	6	165000.00	19.38534	0.0
2	4	0	6	145000.00	19.32668	0.0
2	4	1	7	155000.00	19.74337	0.0

DETAILED DATA FOR OPTIMUM RETURN

PRODUCTION DATA

	TONS OF ORE	AVERAGE GRADE	CUTOFF GRADE	RECOVERABLE METAL (LBS)	CONCENTRATE VALUE ($)
1	0.0	0.0 %	0.0 %	0.0	0.0
2	0.0	0.0 %	0.0 %	0.0	0.0
3	155000.00000	3.86375%	2.37229%	11207472.85261	10027886.33487
4	155000.00000	3.86375%	2.37229%	11207472.85261	10027886.33487
5	155000.00000	3.86375%	2.37229%	11207472.85261	10027886.33487
6	155000.00000	3.86375%	2.37229%	11207472.85261	10027886.33487
7	130000.00000	2.05956%	1.73158%	4864719.43364	4352707.71325

PRIMARY ORE PRODUCTION 620000.0TONS

TOTAL ORE PRODUCTION 750000.0TONS

FINANCIAL DATA

AVERAGE RATE OF RETURN: 19.74337%

MARGINAL RATE OF RETURN: 19.74337%

EXPLORATION COSTS	151312.24490
PREPRODUCTION DEVELOPMENT COSTS	1641224.48980
MINING INVESTMENT	995306.12245
PROCESSING INVESTMENT	1767755.10204
SOCIAL CAPITAL INVESTMENT	1772448.97959
PREPRODUCTION WORKING CAPITAL	632804.69388
TOTAL	6960851.63265

MINING COSTS PER TON	18.46774
PROCESS COSTS PER TON	8.37097
ADMINISTRATIVE COSTS PER TON	1.34194
TOTAL	28.18065

DEBT-EQUITY RATIO	0.0
EQUITY CAPITAL	6960851.63265
BORROWED CAPITAL	0.0

ANNUAL CAPITAL INVESTMENT

	PREPRODUCTION EXPLORATION	PREPRODUCTION DEVELOPMENT	MINING INVESTMENT	PROCESSING INVESTMENT	SOCIAL CAPITAL INVESTMENT	WORKING CAP. AND SALVAGE VAL	TOTAL CAPITAL
1	75656.12	820612.24	497653.06	883877.55	886224.49	0.0	3164023.47
2	75656.12	820612.24	497653.06	883877.55	886224.49	632804.69	3796828.16
3	0.0	0.0	0.0	0.0	0.0	949207.04	949207.04
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	-1582011.73	-1582011.73

ROYALTY MINIMIZATION

	PROFIT AFTER EXPLOR	ANNUAL DEPRECIATION	PROCESSING ALLOWANCE	ROYALTY PROFIT	PROFIT BASE (18%)	BASIC ROYALTY	INCREMENTAL ROYALTY	TOTAL ROYALTY
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	410426.26531	0.0	0.0	0.0
3	5659886.33487	1265609.38776	141420.40816	4252856.53895	820852.53061	123127.87959	1201201.40292	1324329.28251
4	5659886.33487	1012487.51020	141420.40816	4505978.41650	656682.02449	98502.30367	1347253.73720	1445756.04088
5	5659886.33487	809990.00816	141420.40816	4708475.91854	525345.61959	78801.84294	1464095.60463	1542897.44757
6	5659886.33487	647992.00653	141420.40816	4870473.92017	420276.49567	63041.47435	1557569.09858	1620610.57293
7	689223.84228	518393.60522	85415.11853	85415.11853	336221.19654	12812.26778	0.0	12812.26778

	YEARLY TOTAL INVEST	MINING AND SERVICE INVEST	CUMULATIVE PROCESS INVEST	ANNUAL DEPREC RATE	ANNUAL DEPRECIATION	TOTAL UNDEPREC BALANCE	MINING UNDEPREC BALANCE	DISCOUNTED ROYALTY
1	3164023.46939	2280145.91837	883877.55102	0.0	0.0	3164023.46939	2280145.91837	0.0
2	3164023.46939	2280145.91837	1767755.10204	0.0	0.0	6328046.93878	4560291.83673	0.0
3	0.0	0.0	1767755.10204	0.200000000000	1265609.38776	5062437.55102	3648233.46939	1084558.27235
4	0.0	0.0	1767755.10204	0.200000000000	1012487.51020	4049950.04082	2918586.77551	1092970.31416
5	0.0	0.0	1767755.10204	0.200000000000	809990.00816	3239960.03265	2334869.42041	1076730.09716
6	0.0	0.0	1767755.10204	0.200000000000	647992.00653	2591968.02612	1867895.53633	1044010.58422
7	0.0	0.0	1767755.10204	0.200000000000	518393.60522	2073574.42090	1494316.42906	7619.18787

CAPITAL TAX CALCULATION

	UNAMORTIZED DEBT	EQUITY CAPITAL	ACCUMULATED WORKING CAPITAL	CAPITAL TAX
1	0.0	3164023.46939	0.0	6328.04694
2	0.0	6328046.93878	632804.69388	13921.70327
3	0.0	5062437.55102	1582011.73469	13288.89857
4	0.0	3796828.16327	1582011.73469	10757.67980
5	0.0	2531218.77551	1582011.73469	8226.46102
6	0.0	1265609.38776	1582011.73469	5695.24224
7	0.0	0.0	0.0	0.0

INCOME TAX CALCULATION

	GROSS PROFIT AFTER CAPITAL TAX	ACCELERATED CAPITAL COST ALLOWANCE	NORMAL CAPITAL COST ALLOWANCE	RESOURCE ALLOWANCE	INTEREST ON LONG TERM DEBT	EXPLORATION DEDUCTION	PREPROD-DEVELOP ALLOWANCE	DEPLETION ALLOWANCE
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	5646597.43630	4535510.20408	0.0	277771.80805	0.0	151312.24490	492367.34694	47408.95808
4	5649128.65507	0.0	0.0	1412282.16377	0.0	0.0	344657.14286	973047.33711
5	5651659.87385	0.0	0.0	1412914.96846	0.0	0.0	241260.00000	999371.22635
6	5654191.09262	0.0	0.0	1413547.77316	0.0	0.0	168882.00000	89521.45805
7	689223.84228	0.0	0.0	172305.96057	0.0	0.0	118217.40000	0.0

	TAXABLE PROFIT (AFTER PRIOR LOSSES)	INCOME TAX	UNDEP-BALANCE ACCEL-CCA	UNDEP-BALANCE NORMAL CCA	UNAMORTIZED DEBT	CUMULATIVE EXPLORATION	UNDEP-BALANCE PREPRO-DEVELOP	UNDEP-BALANCE DEPLETION
1	0.0	0.0	2267755.10204	0.0	0.0	75656.12245	620612.24490	1054674.48980
2	0.0	0.0	4535510.20408	0.0	0.0	151312.24490	1641224.48980	2109348.97959
3	121977.12404	62208.33326	0.0	0.0	0.0	0.0	1148857.14286	2061940.02151
4	2919142.01134	1488762.42578	0.0	0.0	0.0	0.0	804200.00000	1088892.68440
5	2998113.67904	1529037.97631	0.0	0.0	0.0	0.0	562940.00000	69521.45805
6	3982239.86142	2030942.32932	0.0	0.0	0.0	0.0	394058.00000	0.0
7	398700.48171	203337.24567	0.0	0.0	0.0	0.0	275840.60000	0.0

INTERNAL RATE OF RETURN

PROJECT CASH FLOW

	OPERATING PROFIT	CAPITAL TAX	INCOME TAX	MINING ROYALTY	TOTAL INVESTMENT	WORKING CAPITAL AND SALVAGE VALUE	CASH FLOW
1	0.0	6328.04694	0.0	0.0	3164023.46939	0.0	-3170351.51633
2	0.0	13921.70327	0.0	0.0	3164023.46939	632804.69388	-3810749.86653
3	5659886.33487	13288.89857	62208.33326	1324329.28251	0.0	949207.04082	3310852.77971
4	5659886.33487	10757.67980	1488762.42578	1445756.04088	0.0	0.0	2714610.18841
5	5659886.33487	8226.46102	1529037.97631	1542897.44757	0.0	0.0	2579724.44997
6	5659886.33487	5695.24224	2030942.32932	1620610.57293	0.0	0.0	2002638.19038
7	689223.84228	0.0	203337.24567	12812.26778	0.0	-1582011.73469	2055086.06352

IRR IS 19.7433748

NOTE: 1 THE CALCULATION IS STOPPED IF THE IRR IS LESS THAN ZERO OR GREATER THAN 100%.

PUBLIC CASH FLOW1

	PROJECT CASH FLOW	CAPITAL TAX	INCOME TAX	MINING ROYALTY	CASH FLOW
1	-3170351.51633	6328.04694	0.0	0.0	-3164023.46939
2	-3810749.86653	13921.70327	0.0	0.0	-3796828.16327
3	3310852.77971	13288.89857	62208.33326	1324329.28251	4710679.29405
4	2714610.18841	10757.67980	1488762.42578	1445756.04088	5659886.33487
5	2579724.44997	8226.46102	1529037.97631	1542897.44757	5659886.33487
6	2002638.19038	5695.24224	2030942.32932	1620610.57293	5659886.33487
7	2055086.06352	0.0	203337.24567	12812.26778	2271235.57697

IRR IS 41.504660%

NOTE: 1 THE CALCULATION IS STOPPED IF THE IRR IS LESS THAN ZERO OR GREATER THAN 100%.

2 PUBLIC CASH FLOW1 ASSUMES THAT THE PROJECT WOULD NOT HAVE BEEN UNDERTAKEN BY A PRIVATE COMPANY SO THAT TAXES AND ROYALTIES ARE NOT A COST TO THE PROJECT.

EQUITY CASH FLOW

	PROJECT CASH FLOW	BORROWED CAPITAL	DEBT REPAYMENT	INTEREST ON DEBT	CASH FLOW
1	-3170351.51633	0.0	0.0	0.0	-3170351.51633
2	-3810749.86653	0.0	0.0	0.0	-3810749.86653
3	3310852.77971	0.0	0.0	0.0	3310852.77971
4	2714610.18841	0.0	0.0	0.0	2714610.18841
5	2579724.44997	0.0	0.0	0.0	2579724.44997
6	2002638.19038	0.0	0.0	0.0	2002638.19038
7	2055086.06352	0.0	0.0	0.0	2055086.06352

IRR IS 19.743374%

NOTE: 1 THE CALCULATION IS STOPPED IF THE IRR IS LESS THAN ZERO OR GREATER THAN 100%.

2 EQUITY CASH FLOW IS THAT AFTER ADDING BORROWED CAPITAL AND SUBTRACTING DEBT REPAYMENT AND INTEREST.

3 THE INTEREST RATE IS 8.00%.

VARIABILITY_DATA

500

0.90000	1.10000
0.90000	1.05000
0.80000	1.20000
0.80000	1.05000
0.95000	1.20000
0.95000	1.20000
0.95000	1.20000
0.95000	1.20000
0.95000	1.30000
0.95000	1.10000
0.95000	1.10000

SENSITIVITY ANALYSIS # 1

	PARAMETER CHANGE	IRR CHANGE	RATE OF RETURN
AVERAGE ORE GRADE	-5.0%	-10.37%	17.68732%
RECOVERY RATE	-5.0%	-10.00%	17.76200%
NET VALUE	-5.0%	-10.00%	17.76200%
ORE TONNAGE	-5.0%	-9.76%	17.80841%
PREPRODUCTION EXPLORATION	5.0%	-0.06%	19.71898%
PREPRODUCTION DEVELOPMENT	5.0%	-1.07%	19.52326%
MINE INVESTMENT	5.0%	-0.63%	19.61118%
PROCESSING INVESTMENT	5.0%	-1.11%	19.51626%
SOCIAL CAPITAL	5.0%	-1.11%	19.51570%
MINE OPERATING COSTS	5.0%	-3.02%	19.13789%
PROCESS OPERATING COSTS	5.0%	-1.37%	19.46524%

OPTIMUM RETURN 19.73

SENSITIVITY ANALYSIS # 2

	PARAMETER CHANGE	IRR CHANGE	RATE OF RETURN
AVERAGE ORE GRADE	-10.0%	-21.45%	15.50110%
RECOVERY RATE	-10.0%	-20.66%	15.65730%
NET VALUE	-10.0%	-20.66%	15.65730%
ORE TONNAGE	-10.0%	-20.17%	15.75370%
PREPRODUCTION EXPLORATION	10.0%	-0.16%	19.70334%
PREPRODUCTION DEVELOPMENT	10.0%	-2.12%	19.31595%
MINE INVESTMENT	10.0%	-1.24%	19.48904%
PROCESSING INVESTMENT	10.0%	-2.19%	19.30209%
SOCIAL CAPITAL	10.0%	-2.20%	19.30091%
MINE OPERATING COSTS	10.0%	-6.19%	18.51274%
PROCESS OPERATING COSTS	10.0%	-2.74%	19.19403%

OPTIMUM RETURN 19.73

SENSITIVITY ANALYSIS # 3

	PARAMETER CHANGE	IRR CHANGE	RATE OF RETURN
AVERAGE ORE GRADE	-20.0%	-49.74%	9.90915%
RECOVERY RATE	-20.0%	-47.74%	10.31236%
NET VALUE	-20.0%	-47.74%	10.31236%
ORE TONNAGE	-20.0%	-46.50%	10.55877%
PREPRODUCTION EXPLORATION	20.0%	-0.32%	19.67216%
PREPRODUCTION DEVELOPMENT	20.0%	-4.16%	18.91306%
MINE INVESTMENT	20.0%	-2.46%	19.24866%
PROCESSING INVESTMENT	20.0%	-4.41%	18.86403%
SOCIAL CAPITAL	20.0%	-4.42%	18.86148%
MINE OPERATING COSTS	20.0%	-12.91%	17.18765%
PROCESS OPERATING COSTS	20.0%	-5.57%	18.63468%

OPTIMUM RETURN 19.73

EXPECTED RATE OF RETURN DISTRIBUTION

NUMBER OF SIMULATIONS 500

```
                              |
                              |
                              |
                              |
                              |
                              |
                              |
 7%   OCCURS    0.20%         |*
 8%   OCCURS    0.80%         |*
 9%   OCCURS    1.20%         |*
10%   OCCURS    1.60%         |**
11%   OCCURS    2.40%         |**
12%   OCCURS    5.60%         |******
13%   OCCURS    5.20%         |*****
14%   OCCURS    5.40%         |*****
15%   OCCURS    9.20%         |*********
16%   OCCURS   12.40%         |************
17%   OCCURS   12.20%         |************
18%   OCCURS   14.40%         |**************
19%   OCCURS   10.80%         |***********
20%   OCCURS    7.40%         |*******
21%   OCCURS    5.40%         |*****
22%   OCCURS    3.00%         |***
23%   OCCURS    1.40%         |*
24%   OCCURS    0.80%         |*
25%   OCCURS    0.40%         |*
26%   OCCURS    0.20%         |*
                              |
                              |
                              |
                              |
                              |
```

MEAN RATE OF RETURN 16.741111%

RANDOM NUMBER SEED 17

APPENDIX II

COMPUTER PRINTOUT

Grade-Tonnage Relationship - Log-Normal

Graphs of Functions - Mineral Reserves Only

Financing - 50% Debt Capital

Sensitivity Analysis - No

Probabilistic Analysis - No

Incremental Investment - Yes

INPUT DATA

TWO OPTIONS CARDS

```
0.8948  0.5000  0.0600  0.0800          0.  8.00
     3       1       0       1       0       0
```

COST CARDS

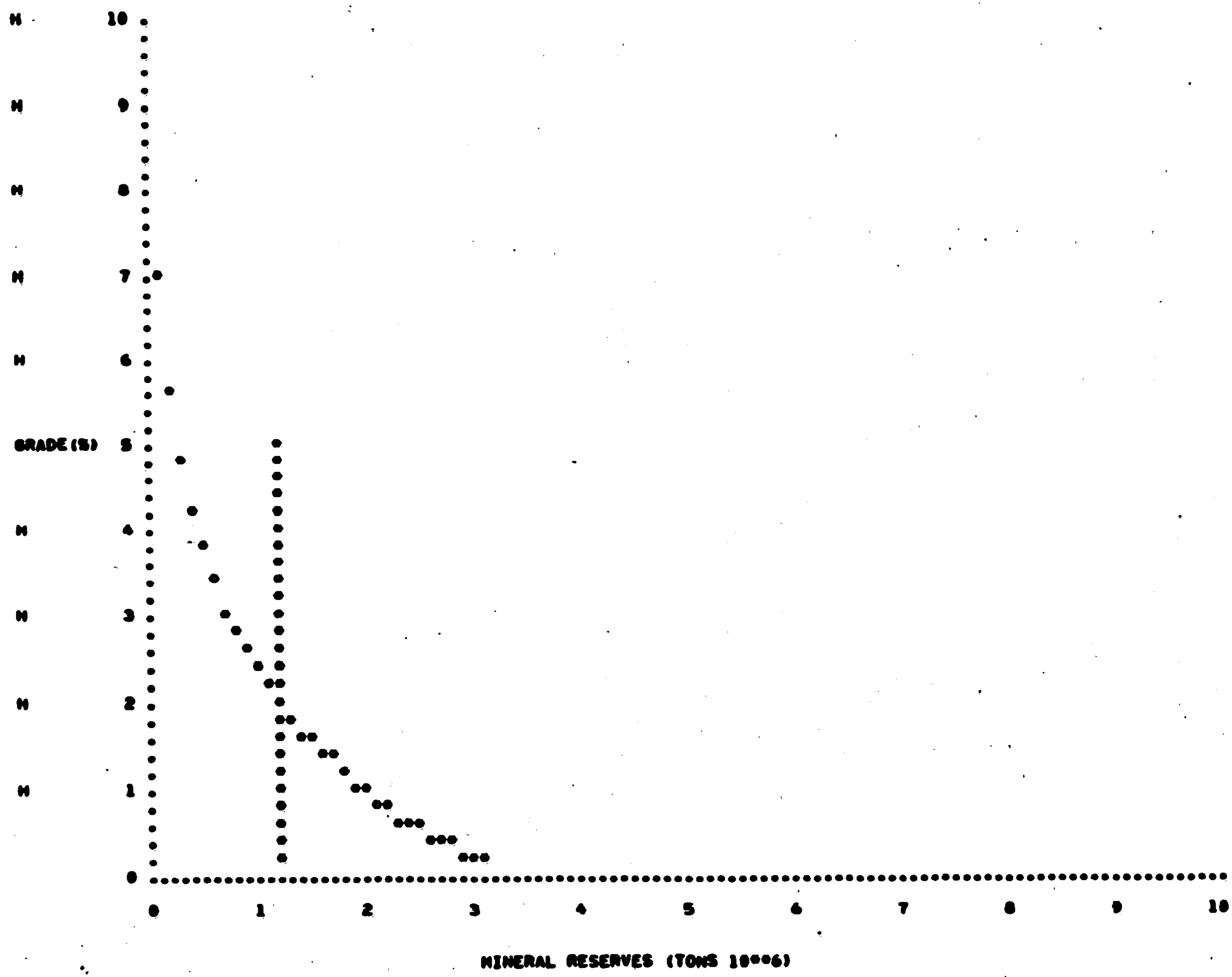
```
 86500.   1000000.   700000.  1100000.  1400000.23.0015.00   87500.
170000.   1900000.  1100000.  2000000.  1900000.18.00 8.00  175000.
340000.   3300000.  1800000.  3600000.  2800000.15.00 3.00  350000.
```

MINERAL RESERVE DATA

```
0.02000      0.0      1200000.00000
```

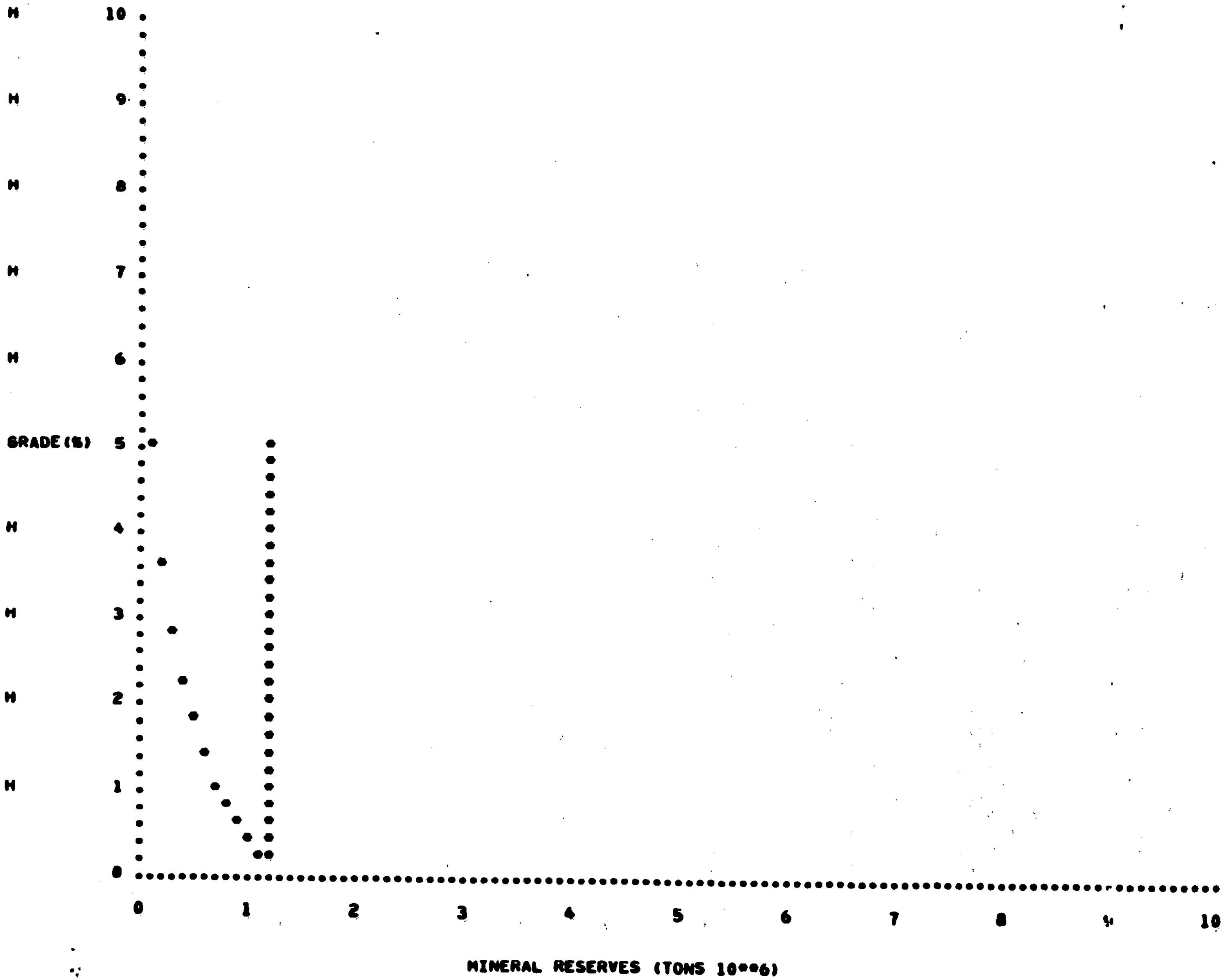
AVERAGE ORE GRADE

Y= 0.29996+(-0.02000)LN(X)



CUTOFF ORE GRADE

Y= 0.27996+(-0.02000)LN(X)



PROJECT ITERATIONS

PREPRODUCTION PERIOD	PRIMARY ORE LIFE	SECONDARY ORE LIFE	TOTAL LIFE	PROJECT CAPACITY	INTERNAL RATE OF RETURN	MARGINAL RATE OF RETURN
2	5	0	7	150000.00	12.10505	0.0
2	6	0	8	150000.00	8.82324	0.0
2	4	0	6	150000.00	15.35750	0.0
2	3	0	5	150000.00	17.08724	0.0
2	2	0	4	150000.00	15.68197	0.0
2	3	0	5	160000.00	16.73973	0.0
2	3	0	5	140000.00	17.35718	0.0
2	3	0	5	130000.00	17.53082	0.0
2	3	0	5	120000.00	17.58370	0.0
2	3	0	5	110000.00	17.48336	0.0
2	4	0	6	120000.00	16.40098	0.0
2	2	0	4	120000.00	15.53953	0.0
2	3	0	5	130000.00	17.53082	0.0
2	3	0	5	110000.00	17.48336	0.0
2	3	0	5	130000.00	17.53082	16.53693
2	3	0	5	140000.00	17.35718	13.84800
2	3	0	5	150000.00	17.08724	11.24692
2	3	0	5	160000.00	16.73973	8.72105
2	3	0	5	170000.00	16.32922	6.25984
2	3	1	6	160000.00	16.65256	8.72105

DETAILED DATA FOR OPTIMUM RETURN

PRODUCTION DATA

	TONS OF ORE	AVERAGE GRADE	CUTOFF GRADE	RECOVERABLE METAL(LBS)	CONCENTRATE VALUE($)
1	0.0	0.0 %	0.0 %	0.0	0.0
2	0.0	0.0 %	0.0 %	0.0	0.0
3	160000.00000	3.832584%	1.832584%	11472717.25255	10265213.76172
4	160000.00000	3.832584%	1.832584%	11472717.25255	10265213.76172
5	160000.00000	3.832584%	1.832584%	11472717.25255	10265213.76172
6	27640.72543	1.776075%	1.720615%	882596.45110	789703.17462

PRIMARY ORE PRODUCTION 480000.0TONS

TOTAL ORE PRODUCTION 507640.7TONS

FINANCIAL DATA

AVERAGE RATE OF RETURN:	16.65256%
MARGINAL RATE OF RETURN:	8.72105%

EXPLORATION COSTS	156144.89796
PREPRODUCTION DEVELOPMENT COSTS	1684489.79592
MINING INVESTMENT	1016122.44898
PROCESSING INVESTMENT	1815102.04082
SOCIAL CAPITAL INVESTMENT	1798979.59184
PREPRODUCTION WORKING CAPITAL	647083.87755
TOTAL	7117922.65306

MINING COSTS PER TON	18.28125
PROCESS COSTS PER TON	8.09375
ADMINISTRATIVE COSTS PER TON	1.31875
TOTAL	27.69375

DEBT-EQUITY RATIO	0.50000
EQUITY CAPITAL	3558961.32653
BORROWED CAPITAL	3558961.32653

ANNUAL CAPITAL INVESTMENT

	PREPRODUCTION EXPLORATION	PREPRODUCTION DEVELOPMENT	MINING INVESTMENT	PROCESSING INVESTMENT	SOCIAL CAPITAL INVESTMENT	WORKING CAP. AND SALVAGE VAL	TOTAL CAPITAL
1	78072.45	842244.90	508061.22	907551.02	899489.80	0.0	3235419.39
2	78072.45	842244.90	508061.22	907551.02	899489.80	647083.88	3882503.27
3	0.0	0.0	0.0	0.0	0.0	970625.82	970625.82
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	-1617709.69	-1617709.69

ROYALTY MINIMIZATION

	PROFIT AFTER EXPLOR	ANNUAL DEPRECIATION	PROCESSING ALLOWANCE	ROYALTY PROFIT	PROFIT BASE (18%)	BASIC ROYALTY	INCREMENTAL ROYALTY	TOTAL ROYALTY
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	419816.30612	0.0	0.0	0.0
3	5834213.76172	1294167.75510	145208.16327	4394837.84335	838032.61224	125704.89184	124480[illegible].83089	1370586.72272
4	5634213.76172	1035334.20408	145208.16327	4653671.39437	670426.08980	100563.91347	1394135.85660	1494699.77007
5	5834213.76172	828267.36327	145208.16327	4860738.23519	536340.87184	80451.13078	1513539.07717	1593990.20795
6	24227.83474	24227.83474	0.0	0.0	429872.69747	0.0	0.0	0.0

	YEARLY TOTAL INVEST	MINING AND SERVICE INVEST	CUMULATIVE PROCESS INVEST	ANNUAL DEPREC RATE	ANNUAL DEPRECIATION	TOTAL UNDEPREC BALANCE	MINING UNDEPREC BALANCE	DISCOUNTED ROYALTY
1	3235419.38776	2327868.36735	907551.02041	0.0	0.0	3235419.38776	2327868.36735	0.0
2	3235419.38776	2327868.36735	1815102.04082	0.0	0.0	6470838.77551	4655736.73469	0.0
3	0.0	0.0	1815102.04082	0.200000000000	1294167.75510	5176671.02041	3724589.38776	1122440.76133
4	0.0	0.0	1815102.04082	0.200000000000	1035334.20408	4141336.81633	2979671.51020	1129971.05395
5	0.0	0.0	1815102.04082	0.200000000000	828267.36327	3313069.45306	2383737.20816	1112385.81293
6	0.0	0.0	1815102.04082	0.007312806169	24227.83474	3288841.61833	2366305.40000	0.0

CAPITAL TAX CALCULATION

	UNAMORTIZED DEBT	EQUITY CAPITAL	ACCUMULATED WORKING CAPITAL	CAPITAL TAX
1	1747126.46939	1617709.69388	0.0	6729.67233
2	3983448.35020	3235419.38776	647083.87755	15731.98323
3	2756412.75687	2426564.54082	1617709.69388	13681.37398
4	1431214.31687	1617709.69388	1617709.69388	9333.26741
5	-0.00000	808854.84694	1617709.69388	4853.12988
6	0.0	0.0	0.0	0.0

INCOME TAX CALCULATION

	GROSS PROFIT AFTER CAPITAL TAX	ACCELERATED CAPITAL COST ALLOWANCE	NORMAL CAPITAL COST ALLOWANCE	RESOURCE ALLOWANCE	INTEREST ON LONG TERM DEBT	EXPLORATION DEDUCTION	PREPROD-DEVELOP ALLOWANCE	DEPLETION ALLOWANCE
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	5820612.38773	4459391.58521	0.0	340305.20063	318675.86802	165763.42367	536476.31020	0.0
4	5824880.49431	456033.06785	0.0	1342211.85661	220513.02055	0.0	375533.41714	857647.28304
5	5829360.63264	0.0	0.0	1457340.15816	114497.14529	0.0	262873.39200	998662.48430
6	24227.83474	0.0	0.0	6056.95868	0.0	0.0	18170.87605	0.0

	TAXABLE PROFIT (AFTER PRIOR LOSSES)	INCOME TAX	UNDEP-BALANCE ACCEL-CCA	UNDEP-BALANCE NORMAL CCA	UNAMORTIZED DEBT	CUMULATIVE EXPLORATION	UNDEP-BALANCE PREPRO-DEVELOP	UNDEP-BALANCE DEPLETION
1	0.0	0.0	2407706.12245	0.0	1747126.46939	81195.34694	875934.69388	1078473.12925
2	0.0	0.0	4915424.65306	0.0	3983448.35020	165763.42367	1788254.36735	2156946.25850
3	-0.00000	0.0	456033.06785	0.0	2756412.75687	0.0	1251778.05714	2156946.25850
4	2550480.27356	1300744.93951	0.0	0.0	1431214.31607	0.0	876244.64000	1299298.97547
5	2995987.45289	1527953.60898	0.0	0.0	-0.00000	0.0	613371.24800	300636.49117
6	0.0	0.0	0.0	0.0	0.0	0.0	595200.37195	300636.49117

INTERNAL RATE OF RETURN

PROJECT CASH FLOW

	OPERATING PROFIT	CAPITAL TAX	INCOME TAX	MINING ROYALTY	TOTAL INVESTMENT	WORKING CAPITAL AND SALVAGE VALUE	CASH FLOW
1	0.0	6729.67233	0.0	0.0	3235419.36776	0.0	-3242149.06008
2	0.0	15731.90323	0.0	0.0	3235419.36776	647083.87755	-3898235.16854
3	5834213.76172	13601.37398	0.0	1370586.72272	0.0	970625.81633	3479399.84868
4	5834213.76172	9333.26741	1300744.93951	1494699.77007	0.0	0.0	3029435.78473
5	5834213.76172	4853.12908	1527953.60098	1593990.20795	0.0	0.0	2707416.82371
6	24227.83474	0.0	0.0	0.0	0.0	-1617709.69388	1641937.52861

IRR IS 16.6525639%

NOTE: 1 THE CALCULATION IS STOPPED IF THE IRR IS LESS THAN ZERO OR GREATER THAN 100%.

PUBLIC CASH FLOW1

	PROJECT CASH FLOW	CAPITAL TAX	INCOME TAX	MINING ROYALTY	CASH FLOW
1	-3242149.06008	6729.67233	0.0	0.0	-3235419.38776
2	-3898235.16854	15731.90323	0.0	0.0	-3682503.26531
3	3479399.84868	13601.37398	0.0	1370586.72272	4863587.94539
4	3029435.78473	9333.26741	1300744.93951	1494699.77007	5834213.76172
5	2787416.82371	4853.12908	1527953.60898	1593990.20795	5834213.76172
6	1641937.52861	0.0	0.0	0.0	1641937.52861

IRR IS 37.032534%

NOTE: 1 THE CALCULATION IS STOPPED IF THE IRR IS LESS THAN ZERO OR GREATER THAN 100%.

2 PUBLIC CASH FLOW1 ASSUMES THAT THE PROJECT WOULD NOT HAVE BEEN UNDERTAKEN BY A PRIVATE COMPANY SO THAT TAXES AND ROYALTIES ARE NOT A COST TO THE PROJECT.

EQUITY CASH FLOW

	PROJECT CASH FLOW	BORROWED CAPITAL	DEBT REPAYMENT	INTEREST ON DEBT	CASH FLOW
1	-3242149.06008	1617709.69388	0.0	0.0	-1624439.36620
2	-3898235.16854	1941251.63265	0.0	0.0	-1956983.53588
3	3479399.84868	0.0	1227035.59334	318675.86802	1933688.38733
4	3029435.78473	0.0	1325198.44080	220513.02055	1483724.32337
5	2707416.82371	0.0	1431214.31607	114497.14529	1161705.36236
6	1641937.52861	0.0	0.0	0.0	1641937.52861

IRR IS 21.432497%

NOTE: 1 THE CALCULATION IS STOPPED IF THE IRR IS LESS THAN ZERO OR GREATER THAN 100%.

2 EQUITY CASH FLOW IS THAT AFTER ADDING BORROWED CAPITAL AND SUBTRACTING DEBT REPAYMENT AND INTEREST.

3 THE INTEREST RATE IS 8.00%.

CHAPTER 4

SOME EXTENSIONS

4.1 Introduction

A computer model capable of determining the optimum size of a project needed to develop a mineral deposit also has applications in the analysis of a variety of related economic problems. This Chapter will suggest some problems the model could aid in solving. Since modifications to the model would be necessary for most tasks, no attempt will be made here to actually demonstrate any of the suggested analysis. This is left for other monographs and perhaps other economists.

The most important information needed for the analyses proposed here is the capital and operating costs data applicable to both the region and the kind of mineral deposit being evaluated. This information could be obtained from two sources. The first source would be producers already in the region or in similar regions who are mining the desired mineral. Such information would have to be updated and modified to reflect current costs and possible changed geographic location. (The assembling of this information is a separate study in itself).

The second source of information would be from a consulting firm which specializes in the evaluation of mining projects of the kind under consideration. The firm would be asked to undertake feasibility studies of a range of project sizes that would mine and process the target mineral in the desired region. The information might be costly initially but could serve as the basis for a variety of economic studies on a region for a considerable period of time.

4.2 Economic Problems for the Model

The problems are discussed in order of increasing difficulty for the model. As presented here, the most difficult problems are those requiring the most modifications to the model. Six kinds of problem are discussed.

4.2.1 Target Grade and Tonnage of a Deposit for a Region

The model is normally provided with data on a mineral deposit to be evaluated. Given the capital and operating costs which would be applicable for a deposit in that region, the optimum rate of production is then calculated. This procedure can be reserved in that if information exists on the costs of mining and processing in a region, it is possible to hypothesize a mineral deposit of some size and grade and then determine if that hypothetical mine is profitable or not. Grade and tonnage can both be adjusted until a profitable deposit is outlined. This procedure can be continued so that a family of profitable deposits is determined, each of different size and grade. The target deposits are those that are most likely to occur in a region based on experience in that region and in regions of a similar kind.

A variation of this analysis would be to determine the size and grade of deposit needed to support investment in a new townsite in a potential mining region. In this instance, a number of deposits could be evaluated together (see 4.2.4 below).

4.2.2 Compare Different Mining and Processing Methods for a Given Project

Projects of different size can frequently employ significantly different mining and processing methods. A possible implication to the model of this is a discontinuity in one or more of the capital and operating cost functions. That is, after a project would reach a given size, there could result a sudden drop in, say, mining costs with the possible introduction of a much more efficient mining method. For the model to handle this properly, the evaluation would have to be undertaken repeatedly using data applicable to the different kind of process or method being evaluated.

A similar kind of analysis to this would be applicable in the evaluation of different kinds of antipollution devices. Some devices could entail a large capital investment but small operating costs while others might entail the reserve. It may well be that separate evaluations for the two possible methods would be the only way of determining which is preferable in terms of economic efficiency.

4.2.3 Evaluate Taxation and Royalty Policy

A completely different area of analysis for the model concerns Government policy with regard to income taxes and royalties. For this kind of analysis, different tax and royalty systems would be used in the evaluation of a given size of mineral deposit. Different rates of tax, different allowable deductions, and different rates for the capital cost allowances could be expected to result in different optimum solutions for the evaluation. A different optimum solution would mean one or more of the following: a different size of project (which means a different rate of extraction and a different level of investment); different amounts of primary and secondary ore; different amounts of tax and royalty revenue; a different total life for the project; and, of course, a different return to the invested capital. For a marginal project, the kinds of tax and royalty systems in effect are critical since a small change in, say, a tax rate can mean the difference between a viable project and an unviable one (ore or no ore).

In order that the model could undertake such an analysis, completely new tax and royalty subroutines would have to be provided and substituted for the old subroutines. This would be relatively easy to do however.

4.2.4 Undertake The Economic Evaluation of a Whole Region

The evaluation of individual deposits in a region may not prove fruitful but the evaluation of a group of deposits together could lead to further development. The procedure here would be to hypothesise a central concentrator doing custom processing for the potential mines being evaluated. As before, a range of concentrator sizes would be used to derive a processing capacity - processing cost function. Each deposit would be evaluated in turn at an assumed processing change. (Mining costs here would include transportation to the concentrator). If total optimum production was different from concentrator capacity, the concentrator size would be changed and all deposits re-evaluated. This procedure would continue till concentrator size matched the total optimum production. Note that deposits not earning the minimum desired rate of return would not be contributing to the total production while the investment in profitable mineral deposits would be incremented till the last increment of investment earned the minimum rate of return. By this means all mining investment would be earning at least the assumed opportunity cost of capital, yet the maximum possible amount of ore would be determined.

An important assumption here is that all concentrate produced could be further processed at the prevailing processing costs (and then sold).

4.2.5 Social Cost - Benefit Analysis

The evaluation undertaken in the previous Chapter and the evaluations proposed above assumed that any divergence between money costs and social costs were of little consequence. This assumption is frequently incorrect. Proper resource management from the Province's point of view should not exclude any significant level of external effects which may result from mining activity.

The determination of social costs and benefits is usually much easier to propose than to carry out, particularly for large projects. For a small project, the divergence between private and social costs may not be significant but for a large project, there is almost certain to be a divergence. This is because of the large amounts of capital, human, and natural resources involved. Since a large project would naturally employ a large number of people, within this number are people who are likely to be otherwise unemployed. Also, such a project would import significant amounts of labor. These consequences can lead to a significant increase in the gross provincial income and tax revenues, yet an evaluation from a private point of view would not include these benefits.

A large project can also generate significant costs and benefits which do not appear in either a public or private accounting procedure. The costs can be in the form of pollution and foregone use of resources in other activities (including recreation). Additional benefits might include improved health, school, and transportation facilities, particularly in less developed parts of the Province.

For the model to handle many of these costs and benefits at its present level of development, shadow prices (costs) would have to be determined and the actual costs and revenues adjusted accordingly. In other cases, proxies could be used for the external effects and the capital and operating costs suitably adjusted. Any other Government objectives might be included by the suitable weighing of some costs and benefits.

4.2.6 Determine the Market Price of a Mineral Deposit

Another application for this model would be to determine the market price for a mineral deposit. In order for the model to do this, it would have to be modified so that it would maximize the present value of a possible project rather than maximize the internal rate of return. The cash flow would be calculated in the same manner but a fixed discount rate would be used, as assigned by the evaluator. The discount rate would be the real opportunity cost of capital for the potential buyer(s) (and would include a risk element). Assuming that the opportunity cost of capital would be the same for the seller and the buyers, the seller would be indifferent between developing the mineral deposit himself or selling it for the calculated value. Note that the present value (if positive) is the economic rent that could be anticipated for the deposit being evaluated. If the province owned the mineral deposit, it could calculate a selling price that would be a substitute for a royalty on production. In this case the present value would be calculated exclusive of any other royalty deduction. Alternately, it could assume a production royalty and sell the deposit for any economic rent calculated with the royalty included.

4.3 Conclusion

The six suggested areas of analysis for which the model may be of use are by no means exhaustive. For one thing, the use of a model such as this is not limited to mineral deposits. Also, other analysts will find applications in their own area of interest that have not been hinted at here.

It is hoped that this model will prove to be as valuable an analytical tool for other economists as the experience in developing it proved to be for the author.

APPENDIX

Comments by Professor B.W. MacKenzie

Professor MacKenzie's comments are presented in the order they were made and are followed by the author's discussion.

1. Professor MacKenzie:

It appears that the estimates used in the model are in constant money terms and that the effects of inflation are not considered. This may result in significant errors for the rate of return and net present value criteria evaluated. Tax considerations over-value and debt financing under-values the criteria evaluated if inflation is present but not considered. Escalation (differential inflation) among the cost and price parameters if it exists also introduces an important source of error. For a complete description of these effects see:

"Treatment of Inflation in Mine Evaluation"
K.C.G. Heath, G.D. Kalcov and G.S. Inns
IMM Transactions, January 1974.

Discussion:

The estimates are in constant money terms as noted. The authors of the article referred to above recommend that "in the early stage of evaluation - of a prospect for a target evaluation, in a hypothetical model prepared for planning purposes - the parameters should not normally be inflated, i.e. the evaluator should work in constant money terms", (P.A 30). The reason for this is that good estimates of inflation are costly and time consuming to obtain, while poor estimates are likely to give results that are less reliable than those obtained by using uninflated parameters. The authors also point out the effects of two possible sources of error - in taxation and project financing - tend to cancel one another (P.A 24). In the case of taxation, accelerated rates of capital recovery (as are applicable here) tend to reduce the effects of inflation since the capital from a profitable project is recovered in the first couple of years of operation. The adverse effects of inflation on borrowed capital can be reduced by using an interest rate that includes an inflationary element. Of course the principal will still be repaid in current dollars.

The model in its present form cannot take into account the effects of differential inflation although it could do so with a relatively minor modification. The problem is to reliably estimate what the amount of the differential would be for a number of years. Of the three areas of concern, the latter would appear to be the most significant.

2. Professor MacKenzie:

The optimization of capacity and cut-off grade variables in the model is based on single point estimates. It is not clear whether these are expected or most-likely estimates. Risk analysis is carried out only after the optimum project has been determined. In my experience, uncertainity has an important effect on the optimization of mining project specifications. Therefore, it is suggested that consideration be given to incorporating risk analysis in the optimization stage of the evaluation process.

Discussion:

The final values for the parameters could be called "most likely" estimates. To incorporate risk into the optimizing part of the model in its present form would require the inclusion of a risk factor in the discount rate and the rate selected as the minimum acceptable (if the latter is different from the discount rate). Doing this would lead to a different optimum solution. The amount of risk to include in the rate(s) is suggested by determining the optimum project without a risk element and doing a probabilistic analysis on that project.

Another possible solution is to do a probabilistic analysis on each project tested during the optimization phase. However, this would be very costly in terms of computer time. It would certainly result in a different optimum (so long as some of the parameters have possible values whose distribution is skewed) than would the use of point estimates and a real discount rate. Also, it would likely result in a slightly different optimum than would be the case by using an inflated discount rate. Only testing would determine if the increased accuracy could be justified in light of the increased costs involved.

3. Professor MacKenzie:

The tonnage-grade functions are assumed to be continuous. This is realistic where there are gradual and continuous grade trends through a deposit. However, often the grades within a deposit are sharply zoned. Also, extraction can only be carried out in terms of discrete mineable units of the deposit. Therefore, an inventory of the tonnage available and the average grade of such tonnage above particular levels of cut-off grade is more realistically an aggregation of discrete mining blocks.

Discussion:

Professor MacKenzie's comment is correct. It implies that the model would have limited use in a final feasibility study. However, I believe that the model is useful for the kinds of analysis discussed in chapter 4 of this report. It will also provide a guide to evaluators on the likely size and cost of a project needed to develop a particular mineral deposit.

4. Professor MacKenzie:

In the model, capital and operating costs are expressed as functions of installed capacity. These costs are also a function of cut-off grade which dictates the degree of selectivity required in the mining operation. The shape of these cost functions should reflect both economies of scale and, beyond some point, diminishing returns as the build-up of capital and manpower begin to force the fixed deposit limits.

Discussion:

The mine operating cost functions referred to would be "typical" for a range of deposit sizes and a particular mining method. The average mining cost declines as the size of mine increases reflecting the usual economies of scale. Diminishing returns can be expected in any mine as rate of mining is increased beyond some normal amount. However, this effect defines an entirely different function than is provided in the model. That is, the function in the model could be considered similar to a long run average cost curve. A short run average cost curve for that size of mine would be needed to show the effect of diminishing returns. At present, the model does have a short run average cost curve of sorts but it only reflects economies of scale. In the ANALYS subroutine, as the optimum value for the mining and concentrating rate is increased or decreased, the average mining and concentrating costs decrease or increase respectively.

5. Professor MacKenzie:

Two factors should be considered in optimizing rate of extraction. The most important (considered in the model) is obviously the overall capacity of extraction and processing equipment which is to be installed. Within an installed system of a specified capacity some degree of over and under capacity operation is possible with a premium cost being incurred with respect to the variable component of operating costs. Thus, the second factor is the degree to which the installed capacity will be utilized over time. While this factor is of lesser importance, it becomes a significant optimization element once the uncertainity dimension is considered.

Discussion:

This point is somewhat related to the previous one. As was pointed out, average operating costs do change as the optimum size is changed in the ANALYS subroutine.

6. Professor MacKenzie:

It seems to me that the description of the model underestimates the importance of variation in the grade mined over mine life. This aspect of the optimisation should embody two decision variables - the sequence of extraction and the cut-off grade. The sequence of extraction of the various mineable units of the deposit (i.e. the order in which they are mined) is usually from highest to lowest grade subject to the technical constraints imposed by the deposit and the mining system. The sequencing variable often has an important effect on optimisation and a high to low grade sequence does not constitute "high-grading". The cut-off grade variable determines how much of the material within each of the mineable units will be extracted. An improved optimum can be achieved if the cut-off grade is allowed to vary over the life of the deposit. For example, if mineral price and operating cost are constant an improvement in the optimisation criteria will be achieved if cut-off grade is initially set somewhat above the fixed cut-off grade optimum and then decreased over the exploitation life down to the point where marginal revenue per unit extracted is equal to marginal operating cost per unit extracted.

Discussion:

The model is able to optimise a project using either two mining sequences. The deposit can be mined with the average grade of annual production at the average grade of the deposit or it can be mined from highest grade to lowest grade. I used the term "high-grading" in this report to refer to the latter case. This term should not be interpreted in any derogatory sense.

I did not include an example in the report of the high-grading sequence simply to keep the report from becoming any larger than it already is. Professor MacKenzie is quite correct in pointing out that a higher rate of return can be achieved by mining the highest grade ore first where this is practical.

7. Professor MacKenzie:

The taxation routine appears to assume that taxation is on an individual project basis. This will under-value the decision criteria in cases where integrated companies with existing sources of income may take their tax allowances earlier and more fully than the time stream of project income.

Discussion:

This comment is correct but it was outside the scope of the study to build any particular kind of corporate model prior to the project - evaluation model. Each firm evaluating a project would likely have a unique income tax situation which could affect the optimum size and profitability of the project from their point of view. The model would have to be modified to reflect any different tax situation than that assumed.

8. Professor MacKenzie:

The types of probability distribution assumed where three point estimates have been made for an uncertain parameter does not appear to be discussed.

Discussion:

The probability distribution is referred to (perhaps too briefly) in Chapter 2 in the description of the ANALYS subroutine. The distributions are assumed to be normal with a split normal distribution used to represent a skewed distribution. Chapter 3 has been amended to clarify this point.

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